

Further Assessment of Air Quality

May 2007

Plymouth City Council
Public Protection Service



Summary

Three air quality management areas were declared in May 2005, one for benzene and two for nitrogen dioxide.

The Environment Act 1995 requires local authorities to undertake a further assessment to ensure that the declaration of the AQMA was correct, to calculate how much of an improvement in air quality is necessary and in addition to other factors to carry out further monitoring.

This report confirms that the aqma's are necessary and the boundary of the aqma's are sufficient. The majority of the NO₂ concentration at each site arises from HGV's and buses and suggestions have been made with regard to the required reductions.

With regard to benzene, stage 2 vapour recovery has now been installed at the petrol station and monitoring is still underway for the forth coming months. However, it is likely that this AQMA will be revoked in the near future.

Strong links have been formed with Plymouth City Council's Transport Department and an Interim Joint Action Plan as part of the Local Transport Plan 2 annual performance review.

Contents

| | |
|--|-----|
| Summary | i |
| Contents | ii |
| List of Tables | iii |
| List of Figures | iii |
| Nomenclature | iv |
| 1.0 Introduction | 1 |
| 1.1 The phased approach to review and assessment | 2 |
| 1.2 The Plymouth Area | 3 |
| 1.3 Aims of the Further Assessment | 4 |
| 1.4 Scope of the report | 5 |
| 1.5 Key findings of the Updating and Screening Assessment and the Detailed Assessment. | 5 |
| 2.0 National Developments | 6 |
| 3.0 New Local Policies And Developments since Declaration of the AQMA | 6 |
| 3.1 Local Transport Plan | 6 |
| 3.2 Local Developments | 6 |
| 4.0 Corroboration of Previous Findings | 7 |
| 4.1 New Monitoring for Nitrogen Dioxide | 7 |
| 4.1.1 Monitoring results from the AUN in Plymouth City Centre. | 7 |
| 4.1.2 Monitoring within the Mutley Plain AQMA | 10 |
| 4.1.3 Monitoring within the Exeter Street AQMA | 14 |
| 4.2 Modelling | 16 |
| 4.2.1 Modelling Mutley Plain AQMA | 17 |
| 4.2.2 Modelling: Exeter Street | 19 |
| 4.3 Validation of modelling | 20 |
| 4.4 New Monitoring for Benzene | 21 |
| 5.0 Source Apportionment and Air Quality Improvements Needed | 27 |
| 6.0 Summary of the Further Assessment | 29 |

Tables

- 1.1 Summary of objectives of the UK Air Quality Strategy
- 1.2 Examples of where the Air Quality objectives should/should not apply
- 4.1 Data for the co-location study at Plymouth AUN site.
- 4.2 Data used to calculate the bias adjustment factor.
- 4.3 Shows the annual mean concentrations for monitoring locations in and around the Mutley AQMA for 2005 and 2006
- 4.4 Shows the results of the chemiluminescent data from Mutley Plain compared to the diffusion tube data.
- 4.5 Table to show the annual mean concentrations for monitoring at locations in and around the Exeter Street AQMA, for 2004 and 2006
- 4.6 Table to show input data for AAQulRE for Mutley Plain
- 4.7 Input data for modelling using AAQulRE for Exeter Street
- 4.8 To show results for validation of AAQulRE, using 2006 actual and modelled predictions.
- 4.9 The Annual averages for benzene monitoring at Exeter Street in 2005 and 2006
- 4.10 Annual average results for the co-location of benzene diffusion tubes and the pumped sampler
- 4.11 Calculation for the bias correction factor for benzene diffusion tube data in 2005
- 4.12 Calculation for the bias correction factor for benzene diffusion tube data in 2006.
- 4.13 Bias adjusted results for Exeter Street benzene diffusion tube results for 2005.
- 4.14 Bias adjusted results for Exeter Street benzene diffusion tube results for 2006
- 5.1 The effect of increased minimum traffic speeds on NO_x emissions and NO₂ concentrations in the Mutley and Exeter Street AQMA's

Figures

- 1.1 Automatic Urban Monitoring Site in Armada Way Plymouth
- 1.2 Local Authorities Surrounding Plymouth.
- 3.1 Ariel Photo of Exeter Street AQMA (red hatch)
- 4.1 Annual mean concentrations at the AUN site in Plymouth.
- 4.2 Trend in bias adjustment factors since 2002
- 4.3 To show locations of the monitoring sites at Mutley Plain.
- 4.4 Results from diffusion tube monitoring at the Mutley Plain shop since 2002
- 4.5 Map to show the monitoring locations in the vicinity of the AQMA for Exeter Street.
- 4.6 Diffusion tube results at Exeter Street Flats
- 4.7 Contour Map to show the predicted concentrations of NO₂ in 2010 within the Mutley Plain AQMA
- 4.8 Contour map to show the predicted concentrations of NO₂ in 2010 within Exeter Street AQMA

- 4.9 Map to show the location of the diffusion tube monitoring and the pumped sampler at Holy Cross School.
- 4.10 Results of Benzene monitoring within the Exeter Street area
- 4.11 Results of the co-location of the benzene pumped sampler and diffusion tube at Holy Cross located on the school door
- 4.12 Results of Benzene monitoring in Plymouth from 2003 to 2005

Nomenclature

| | |
|-------------------|--|
| AQMA | Air quality management area |
| NO ₂ | Nitrogen dioxide |
| PM ₁₀ | Particulate matter of less than 10 microns in size |
| µg/m ³ | micrograms per metre cubed |

1.0: Introduction

The Environment Act was introduced in 1995, and established the statutory provisions for local air quality management for the first time in the UK. This implemented the UK National Air Quality Strategy.

Part IV of the Environment Act 1995 requires each local authority periodically to review air quality in its area. The Air Quality Regulations 1997 were introduced in December 1997 and later revised in January 2000. In addition to the objectives set out in the Air Quality Regulations 2000, and the Air Quality (Amendment) Regulations 2002 ('the Regulations'), the EU has set limit values in respect of nitrogen dioxide and benzene, to be achieved by 2010, as well as indicative limit values for PM₁₀, also to be achieved by 2010. Local authorities have to consider the present quality of the air in their district and that for future years. It is necessary to assess which pollutants, if any, will exceed the prescribed objectives (Table 1.1).

Table 1.1: Summary of objectives of the UK Air Quality Strategy

| Pollutant | Objective | Measured as | To be achieved by | |
|------------------------------------|--|---|-------------------|------------------|
| Benzene | 5 µg/m ³ | Annual Mean | 31 December 2010 | |
| 1,3-Butadiene | 2.25 µg/m ³ (1 ppb) | Running Annual Mean | 31 December 2003 | |
| Carbon monoxide | 10 mg/m ³ (10 ppm) | Running 8 Hour Mean | 31 December 2003 | |
| Lead | 0.5 µg/m ³ | Annual Mean | 31 December 2004 | |
| | 0.25 µg/m ³ | Annual Mean | 31 December 2008 | |
| Nitrogen dioxide* | 200 µg/m ³ (105 ppb) | more 1 Hour Mean | 31 December 2005 | |
| | Not to be exceeded more than 18 times per year | 40 µg/m ³ (21 ppb) | Annual Mean | 31 December 2005 |
| Particles (PM₁₀) | 50 µg/m ³ | more 24 Hour Mean | 31 December 2004 | |
| | Not to be exceeded more than 35 times per year | 40 µg/m ³ | Annual Mean | 31 December 2004 |
| | 266 µg/m ³ (100 ppb) | Not to be exceeded more than 15 Minute Mean | | 31 December 2005 |
| Sulphur dioxide | 350 µg/m ³ (132 ppb) | Not to be exceeded more than 1 Hour Mean | 31 December 2004 | |
| | 125 µg/m ³ (47 ppb) | Not to be exceeded more than 24 Hour Mean | 31 December 2004 | |

Notes:
 µg/m³ - micrograms per cubic metre
 mg/m³ - milligrams per cubic metre
 Ppb – parts per billion
 Ppm – parts per million
 * The objectives for nitrogen dioxide are provisional

1.1: The phased approach to review and assessment.

Review and assessment is a long-term, ongoing process, structured as a series of ‘rounds’. Local authorities in England, Scotland and Wales have now completed the first round of Review and assessment and the second round is currently underway.

Where the updating and screening process identifies a risk that an air quality objective may be exceeded at a location with relevant public exposure (Table 1.2) the authority will be required to undertake a detailed assessment. The aim of the detailed assessment should be to identify with reasonable certainty whether or not a likely exceedence will occur. An Air Quality Management Area (AQMA) should not be declared unless a detailed assessment has been completed.

Table 1.2 Examples of where the Air Quality Objectives should/should not apply.

| Averaging Period | Objectives should apply at: | Objectives should generally not apply at: |
|-------------------------------------|--|---|
| Annual mean | All locations where members of the public might be regularly exposed. Building facades of residential properties, schools, hospitals, libraries etc. | Building facades of offices or other places of work where members of the public do not have regular access. Gardens of residential properties. Kerbside sites (as opposed to locations at the building facade), or any other location where public exposure is expected to be short term. |
| 24-hour mean and 8-hour mean | All locations where the annual mean objective would apply. Gardens of residential properties | Kerbside sites (as opposed to locations at the building facade), or any other location where public exposure is expected to be short term. |
| 1-hour mean | All locations where the annual mean and 24 and 8-hour mean objectives apply. Kerbside sites (e.g. pavements of busy shopping streets) Those parts of car parks, bus stations and railway stations etc. which are not fully enclosed, where the public might reasonably be expected to spend 1-hour or more. Any outdoor locations to which the public might reasonably be expected to spend 1-hour or longer. | Kerbside sites where the public would not be expected to have regular access. |
| 15-min mean | All locations where members of the public might reasonably be exposed for a period of 15 minutes or longer | |

1.2: The Plymouth Area

Plymouth has a population of just under 250,000 and is the largest city in the South West. As well as being a prime tourist area, it is also a large Naval port. The bulk of the city lies on a peninsula of land between two rivers, the Tamar to the west and the Plym to the east. The city is bounded to the north by Dartmoor and is surrounded by smaller conurbation's, housing many of the employees for the city.

Plymouth City Council has carried out air quality monitoring in some form since the 1960s. At this time only smoke and sulphur dioxide monitoring was undertaken as part of the national network. However, continuous analysers to monitor for sulphur dioxide, oxides of nitrogen and ozone were installed in 1992. In 1997, the site became part of the Automatic Urban Network (AUN) (Figure 1.1) and DEFRA added more equipment to the network in the form of a carbon monoxide analyser and a TEOM particulate monitor. In 2002, a pumped benzene diffusion tube sampler was added to the suite of equipment. The site is situated in Armada Way.

Figure 1.1: Automatic Urban Monitoring Site in Armada Way, Plymouth



Information from this network is now available on the internet at www.airquality.co.uk. The site is regarded as an urban background monitoring station, and LAQM.TG(03) specifies this site as an urban location distanced from sources and therefore broadly representative of city-wide background conditions such as urban residential areas.

Quality Assurance and Quality Control (QA/QC) measures are detailed in Appendix 1 for both the AUN site and diffusion tube monitoring.

The surrounding local authorities have smaller populations but are much larger in geographical areas. The neighbouring local authorities include the South Hams to the East, and in Cornwall, Caradon to the West, as shown in Figure 1.2.

Figure 1.2 Local Authorities Surrounding Plymouth.



Regular meetings take place between representatives from each of the local authorities within Devon to discuss issues that affected neighbouring authorities, with regard to air quality, including new or substantially changed industrial processes.

1.3 Aims of the Further Assessment

Section 84(1) of the Environment Act 1995 requires local authorities to undertake a further assessment, where the local authority has designated an Air Quality Management Area (AQMA); this is now termed the Further Assessment (previously known as “Stage 4 Assessment”).

The above requirement is undertaken to supplement the information local authorities have on their AQMAs. The Department of Environment, Food and Rural Affairs (DEFRA) produced guidance on undertaking the “Stage 4 Assessment” (DEFRA, 2001). The Stage 4 guidance note explains that a Further Assessment report allow authorities to:-

- allow their original assessment of air quality to be compared against the prescribed objectives, and thus to ensure that they were right to designate the AQMA in the first place.
- calculate more accurately how much of an improvement in air quality would be needed to deliver air quality objectives within the AQMA.

- refine the knowledge of the sources of pollution so that air quality action plans can be properly targeted.
- take account of national policy developments, which may come to light after the AQMA declaration
- take account as far as possible of any local policy developments which are likely to affect air quality by the relevant date, and which were not fully factored into earlier calculations.
- carry out real-time monitoring where this has not been done previously
- carry out further monitoring in problem areas to check earlier findings.
- corroborate other assumptions on which the designation of the AQMA has been based, and to check that the original designation is still valid, and does not need amending in any way
- respond to any comments made by statutory consultees in respect of authorities' previous reports, particularly where these have highlighted that insufficient attention has been paid to, for example, the validation of modelled data.

1.4 Scope of the report

This report was produced by Plymouth City Council's Environmental Protection Unit to set out the findings of the further assessment of local air quality as carried out by the authority. It was produced to satisfy the local authority's obligations under Part IV of the Environmental Act 1995.

There are three AQMAs that will be studied within this report, two for NO₂, Exeter Street and Mutley Plain, and the third AQMA is for benzene, which is due to the close proximity of a petrol station to student accommodation and a primary school.

1.5 Key Findings of the Updating and Screening Assessment and the Detailed Assessment.

The USA for Plymouth City Council concluded that the objectives for carbon monoxide, lead, 1, 3-butadiene and sulphur dioxide are likely to be achieved across the City and thus no further action was required. The USA did, however, identify likely exceedences of the annual mean nitrogen dioxide objective within a number of areas within Plymouth. A detailed assessment was carried out for each area and it was concluded that there was a likelihood that the objective for nitrogen dioxide would be exceeded at two locations within Plymouth. As a result it was decided that AQMAs would be declared for both Exeter Street and Mutley Plain for nitrogen dioxide.

The USA also identified a potential exceedence of the objective for benzene, which was due to the proximity of a petrol station to residential accommodation and a school. A detailed assessment was undertaken and the conclusion was that, Plymouth City Council were satisfied of the likelihood of the 2010 objective of 5µg/m³ not being met, as there were no plans to install Stage 2 vapour recovery to the petrol station. An AQMA was declared.

2 National Developments

A new National Air Quality Strategy has been prepared and the draft copy is in the consultation stage. Also an update of the technical guidance (LAQM.TG03) was produced to cover the Updating and Screening Process checklists at the beginning of last year. These proposed developments have not affected the preparation of this report.

3 New Local Policies and Developments since Declaration of the AQMA.

3.1 Local Transport Plan (LTP)

Plymouth City Council has produced a Local Transport Plan (LTP). This document was produced prior to the Further Assessment report. Included within the LTP is the Interim Air Quality Action Plan, which can be viewed at

<http://www.plymouth.gov.uk/homepage/transportandstreets/transportplanning/proltp/proltpinterim.htm>.

3.2 Local Developments

There has been no significant development within the Mutley Plain AQMA since it was declared. However there has been considerable development within the Exeter Street AQMA. The development includes high-rise offices, a residential block and a hotel. A plan to show these developments is shown in Figure 3.1. A large shopping complex has also been developed just outside the AQMA incorporating a car park for 1270 vehicles. The complex was opened in October 2006 and it included a realignment of the road layout, with the replacement of a roundabout with a traffic light junction, which has affected the flow and volume of traffic. This became fully operational in December 2006. The affect that this re-alignment of the road layout has not been assessed fully yet but monitoring is continuing to determine the impact, if any, on the AQMA.

Figure 3.1 Aerial Photo of Exeter Street AQMA (red hatch) with new developments highlighted in pink.



There are other major developments in neighbouring authorities planned that will have a significant impact on the volume of traffic entering the authority. The site previously occupied by Blue Circle cement, as Plymstock Quarry is still being considered by the local planning authority as a site for mixed use development including 1500 dwellings with some commercial and employment use, including a school, health and leisure uses. This is located directly adjacent to the current landfill site which is due to cease operation in 2007. The major road link from this site will lead traffic to the major link road which will follow a route in to the city centre via the current AQMA for Exeter Street. This is still in the outline planning development stage and transport details are expected to be provided as part of any application.

A larger scale development is currently planned within the neighbouring council, South Hams, which includes the proposal for a new town, with 4500 new dwellings, in addition to 3 primary schools, one secondary school, a bus depot, park and ride sites and various employment land. This site is planned for occupation by 2016 and as such is only in the very initial stages of proposals. There are two transport links planned for this development, one connecting directly with the A38, outside the Plymouth boundary, which has no current air quality concerns due to lack of public exposure in a relevant location and the second connection through Plymstock. However, this site will have a requirement for a high quality public transport link, to be in place prior to the first homes being occupied.

These developments will be assessed as they happen.

4 Corroboration of Previous Findings

4.1 New Monitoring for Nitrogen Dioxide.

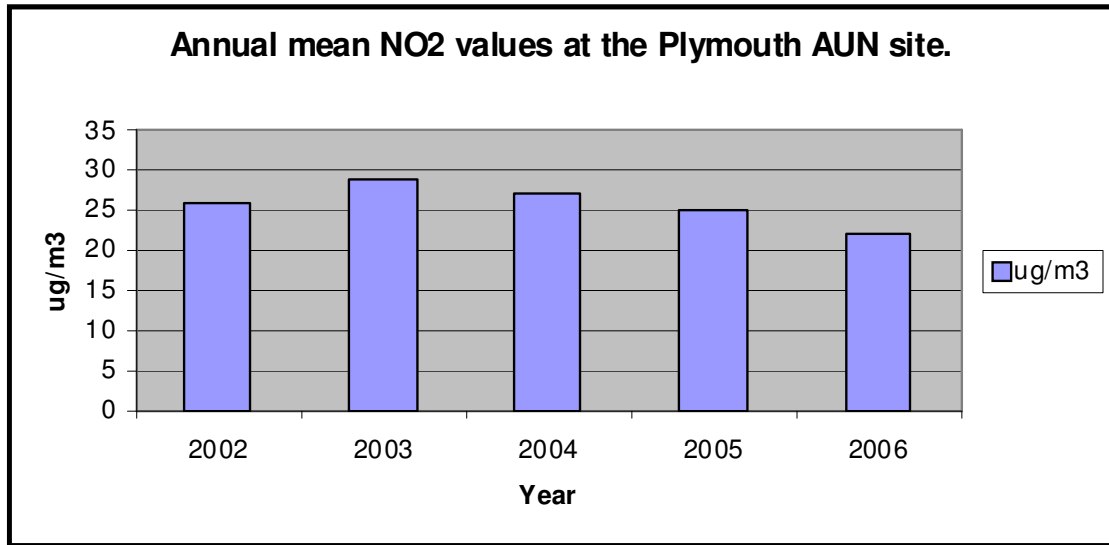
4.1.1 Monitoring results from the AUN in Plymouth City Centre.

Plymouth is part of the national Air Quality Monitoring Network and data has been collected from the AUN, located at an urban background site located in Plymouth City Centre. The data is ratified every 6 months, by Netcen. Only ratified data is used in this report.

QA/QC procedures for both the AUN site and diffusion tube monitoring are detailed in Appendix 1.

Annual mean concentrations for the past few years monitoring at the AUN site in Plymouth are shown in Figure 4.1.

Figure 4.1 Annual mean concentrations at the AUN site in Plymouth.



As Plymouth is part of the national air quality monitoring network, with an AUN site at an urban background location, it has been possible to conduct a co-location exercise, using triplicate diffusion tubes to obtain a relevant bias adjustment factor.

The diffusion tubes have been supplied and analysed by Gradko, using the 20% TEA in water preparation method. QA/QC details are provided in Appendix 1.

Data from the AUN site is ratified by NETCEN on a six monthly basis. The bias adjustment factor has been calculated following Box 6.4 in the Technical Guidance document LAQM.TG(03). The data for the co-location study is shown in Table 4.1.

All the data used has been ratified and there are no periods of less than 90% data capture for 2005, however due to a problem with the roof the inlet manifold became crushed and a number of months worth data were lost from the continuous analyser at the Plymouth AUN site during 2006. Due to the fact that there was not a full year of monitoring, it has been decided that the national bias adjustment factor will be used for 2006, as it presents the worst case scenario. The bias factor for 2005 is 0.86, which will provide lower results. This is a bias adjustment factor of 0.98.

Table 4.1: 2005 data for the co-location study at Plymouth AUN site. All results in $\mu\text{g}/\text{m}^3$.

| Date Out | Date in | AUN1 | AUN2 | AUN3 | Average AUN | AUN Chem |
|------------|------------|-------|-------|-------|-------------|----------|
| 21/12/2004 | 18/01/2005 | 24.73 | 25.38 | 24.18 | 24.76 | 24.96 |
| 18/01/2005 | 15/02/2005 | 30.78 | 30.62 | | 30.70 | 24.57 |
| 15/02/2005 | 15/03/2005 | 33.02 | 33.67 | 42.55 | 36.41 | 31.86 |
| 15/03/2005 | 12/04/2005 | 35.29 | 35.66 | 34.62 | 35.19 | 24.58 |
| 12/04/2005 | 10/05/2005 | 26.41 | 30.19 | 29.7 | 28.77 | 21.96 |
| 10/05/2005 | 07/06/2005 | 29.48 | 30.81 | 29.36 | 29.88 | 22.41 |
| 07/06/2005 | 05/07/2005 | 26.32 | 27.5 | 23.85 | 25.89 | 19.51 |
| 05/07/2005 | 02/08/2005 | 26.12 | 26.29 | 23.04 | 25.15 | 18.96 |
| 02/08/2005 | 30/08/2005 | 18.51 | 18.51 | 21.53 | 19.52 | 18.03 |
| 30/08/2005 | 27/09/2005 | 31.35 | 19.4 | 32.08 | 27.61 | 26.17 |
| 27/09/2005 | 25/10/2005 | 28.84 | 25.91 | 28.27 | 27.67 | 27.46 |
| 25/10/2005 | 22/11/2005 | 34.07 | 33.62 | 35.08 | 34.26 | 28.00 |
| 22/11/2005 | 20/12/2005 | 36.34 | 30.46 | 35.1 | 33.97 | 36.48 |

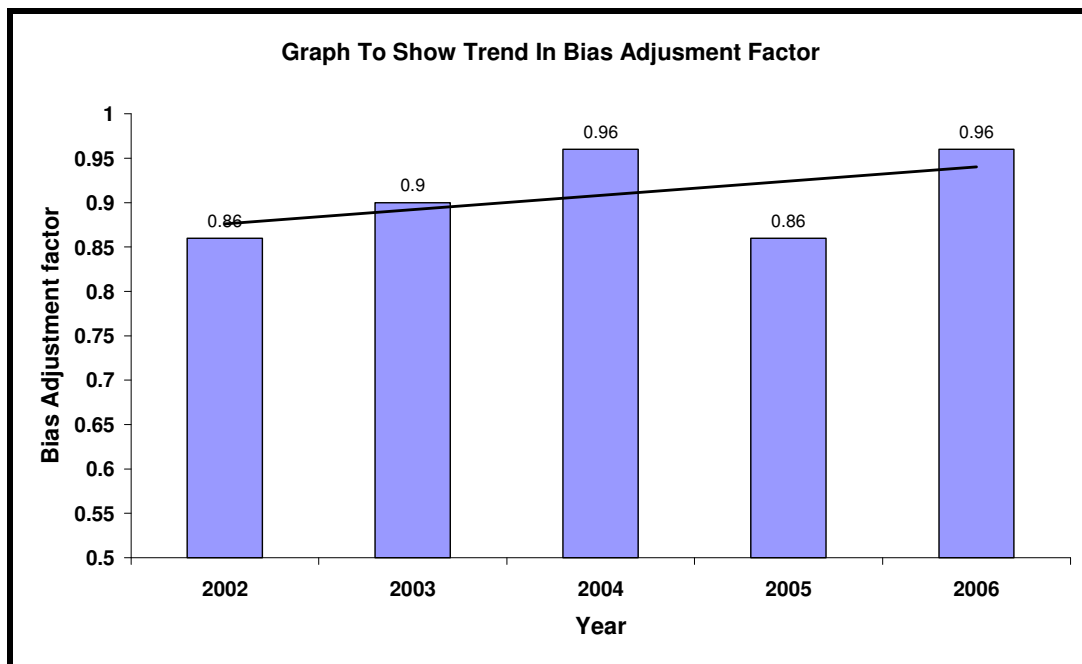
Using the data from Table 4.1 the bias adjustment factor can be calculated. The data for this is shown in Table 4.2.

Table 4.2: Data used to calculate the bias adjustment factor.

| | Dm | Cm | Bias Adjustment factor for 2005 |
|---|-------|-------|---------------------------------|
| All ratified data and no periods of less than 90% data capture. | 29.21 | 25.00 | 0.86 |

Therefore the bias adjustment factor for 2005 is 0.86. The bias adjustment factors since 2002 are shown in Figure 4.2. This bias adjustment factor will be used with all of the 2005 diffusion tube data.

Figure 4.2 Trend in bias adjustment factors since 2002.



4.1.2 Monitoring within the Mutley Plain AQMA.

The table below shows the summary of the checklist approach for nitrogen dioxide for the Further Assessment. To comply with the requirements of the further assessment, the following criteria have to be met, which are taken from the checklist provided by the helpdesk.

Monitoring

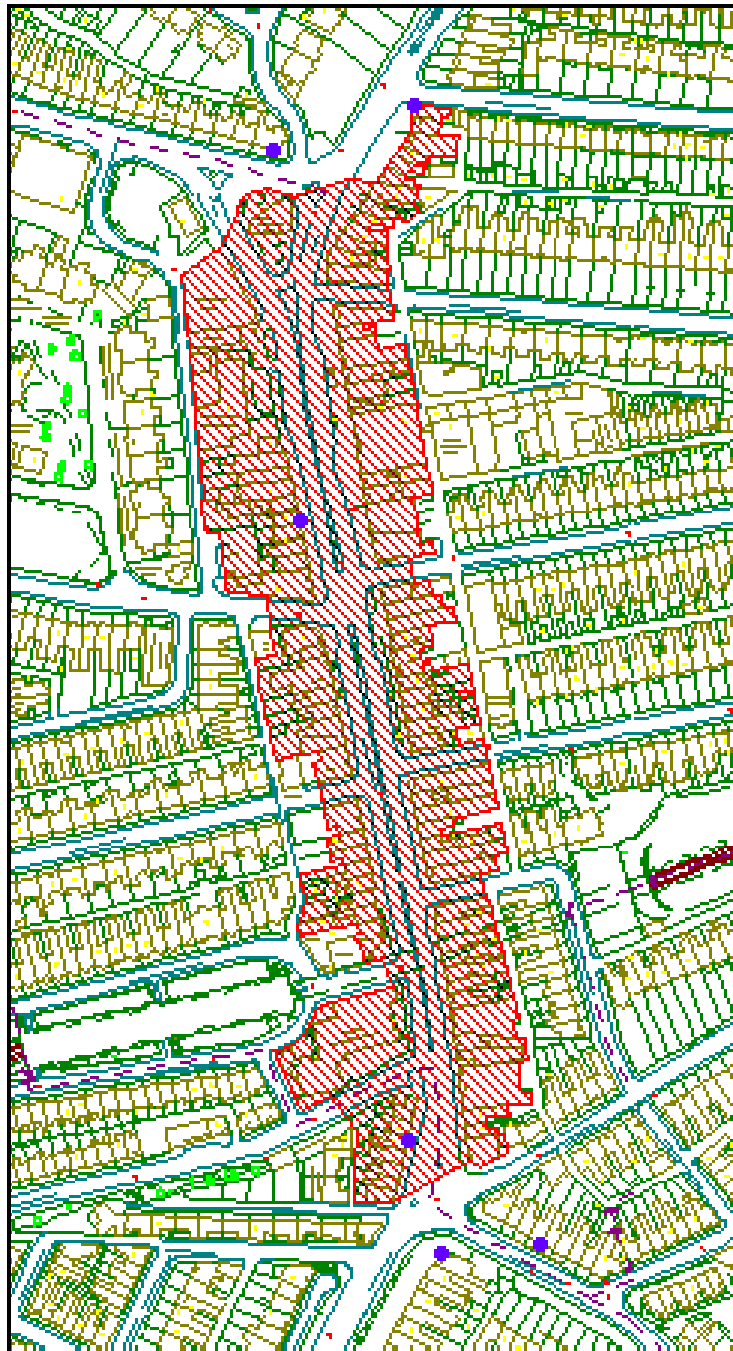
- Has further monitoring been undertaken?
- Is the 'totality' of the monitoring effort sufficient?
- Has monitoring confirmed 2005 exceedances?
- Has sufficient detail of QA/QC procedures been provided?
- Has monitoring amended the conclusions of Stage 3?

Plymouth City Council operates a real-time chemiluminescent analyser on Mutley Plain, with further monitoring being carried out using diffusion tubes at a number of locations both within and on the periphery of the AQMA.

The locations of the monitoring sites within the Mutley Plain AQMA are shown in Figure 4.3.

The mean results for the diffusion tubes are shown in table 4.3.

Figure 4.3 to show locations of the monitoring sites at Mutley Plain.



Diffusion Tube Monitoring

Table 4.3 shows the annual mean concentrations for monitoring locations in and around the Mutley Plain AQMA, for 2005 and 2006 and the predictions for 2010, using Box 6.6 of LAQM.TG(03).

| 2005 | Mean Average 2005 | Bias Adjustment 0.86 | Prediction 2010 |
|-----------------------------|----------------------|-------------------------|--------------------|
| Mutley Plain (shop) | 51.17 | 44.01 | 36.21 |
| Hyde Park Rd (surgery) | 34.25 | 29.46 | 24.24 |
| Mutley Plain (Hair Salon) | 49.37 | 42.46 | 34.94 |
| Connells (Manamead Rd) | 38.41 | 33.03 | 27.18 |
| 14a Mutley plain | 47.41 | 40.77 | 33.55 |
| 140 Mutley Plain/North Hill | 35.94 | 30.91 | 25.43 |
| 24 - Greenbank Road | 35.68 | 30.68 | 25.25 |

| 2006 | Mean Average 2006 | Bias Adjusted 0.98 | Estimated 2010 | Periods Monitored |
|--------------------------------------|-------------------------|-----------------------|-------------------|----------------------|
| 64 Mutley Plain | 49.50 | 48.51 | 42 | 11 |
| 2 Hyde Park Rd | 35.10 | 34.40 | 29.78 | 13 |
| 22 Mutley Plain | 48.63 | 47.66 | 41.26 | 9 |
| Connells (Manamead Rd) | 35.17 | 34.47 | 29.84 | 13 |
| 14a Mutley plain | 46.57 | 45.64 | 39.51 | 11 |
| 140 North Hill | 31.90 | 31.26 | 27.06 | 11 |
| 6 Alexandra Place, Greenbank Road | 37.57 | 36.82 | 31.88 | 12 |

Continuous Monitoring

Due to the fact that the tubes are in prominent positions and are located in an area of numerous pubs and clubs, a number have been stolen or removed. The tubes are placed in the most unobtrusive locations possible to avoid these losses as much as possible

The real-time analyser was located on the second floor of a retail unit, with the sample tube being at first floor level. The results shown in table 4.4 for the chemiluminescent analyser on Mutley Plain indicate that the level is much lower than that of the diffusion tube. Unfortunately due to initial complications and misinformation from the suppliers, incorrect procedures for the calibration were followed. This has resulted in the fact that we have not had the correct information to ratify the data. These problems have now been corrected and the current data collection and calibration procedures are giving much more accurate results.

Table 4.4 shows the results of the chemiluminescent monitoring data from Mutley Plain compared to the diffusion tube data.

Mutley Analyser

| Year | Mean in ug/m3 | 1 hour mean exceedences | Diffusion Tube | Diffusion Tube Bias adjusted |
|------|------------------|----------------------------|-------------------|---------------------------------|
| 2005 | 38.5 | 0 | 51.17 | 44.01 |

The graph in Figure 4.4 shows the bias adjusted results for the diffusion tube located at the Mutley Plain Shop for the past few years.

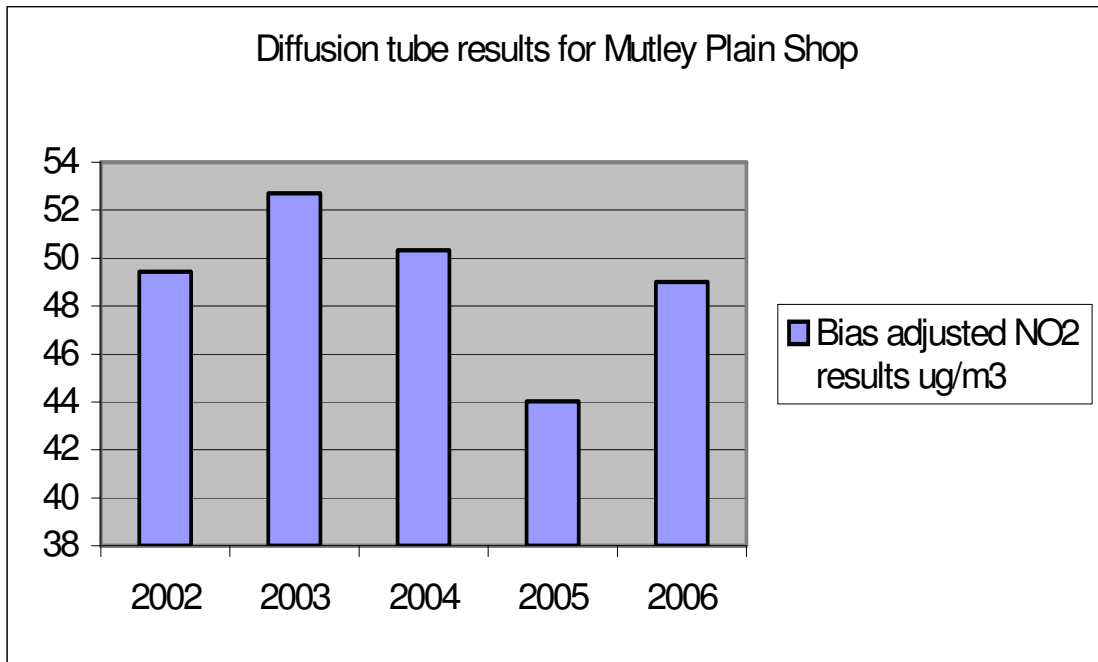


Figure 4.4 Results from diffusion tube monitoring at the Mutley Plain Shop since 2002.

There appears to be a dip in 2005, which may have been due to the fact that major road works were being carried and much of the traffic was diverted to other routes for a large proportion of the year.

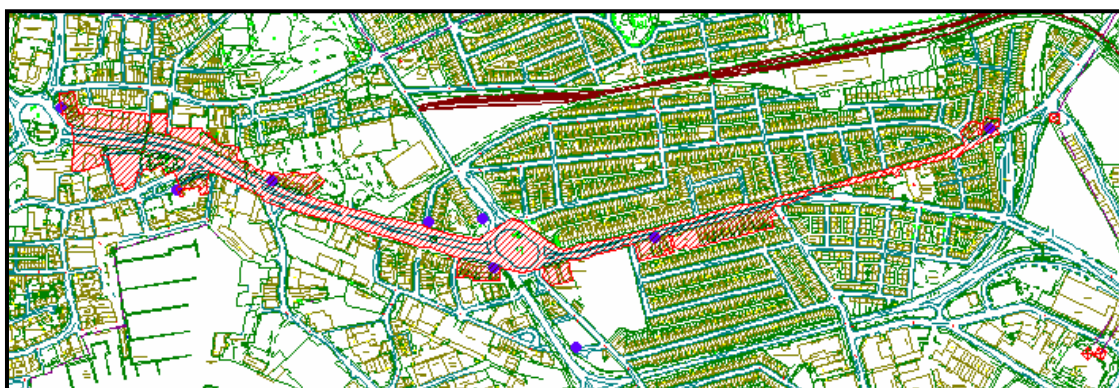
Conclusions

Further monitoring has been carried out and is continuing, using both diffusion tubes and a chemiluminescence analyser. The monitoring shows exceedances of the 2005 objective. The results of the further monitoring have not amended the conclusions of the detailed assessment and it is predicted that only some of the locations will meet the 2010 objective.

4.1.3 Exeter Street AQMA

The Exeter Street AQMA is monitored using only diffusion tubes at the current time. The locations of these tubes are shown in Figure 4.5 DEFRA funding has been given for continuous monitoring which is due to commence in 2007 to give more detailed and accurate results, including analysing the one hour objective.

Figure 4.5 Map to show the monitoring location in the vicinity of the AQMA for Exeter Street.



The results for the monitoring using diffusion tubes can be seen in Table 4.5, and the highlighted boxes indicate an exceedence of the relevant air quality objective for NO₂.

Table 4.5 Table to show the annual mean concentrations for monitoring at locations in and around the Exeter Street AQMA, for 2005 and 2006 and the predictions for 2010 using box 6.6 of LAQM.TG (03).

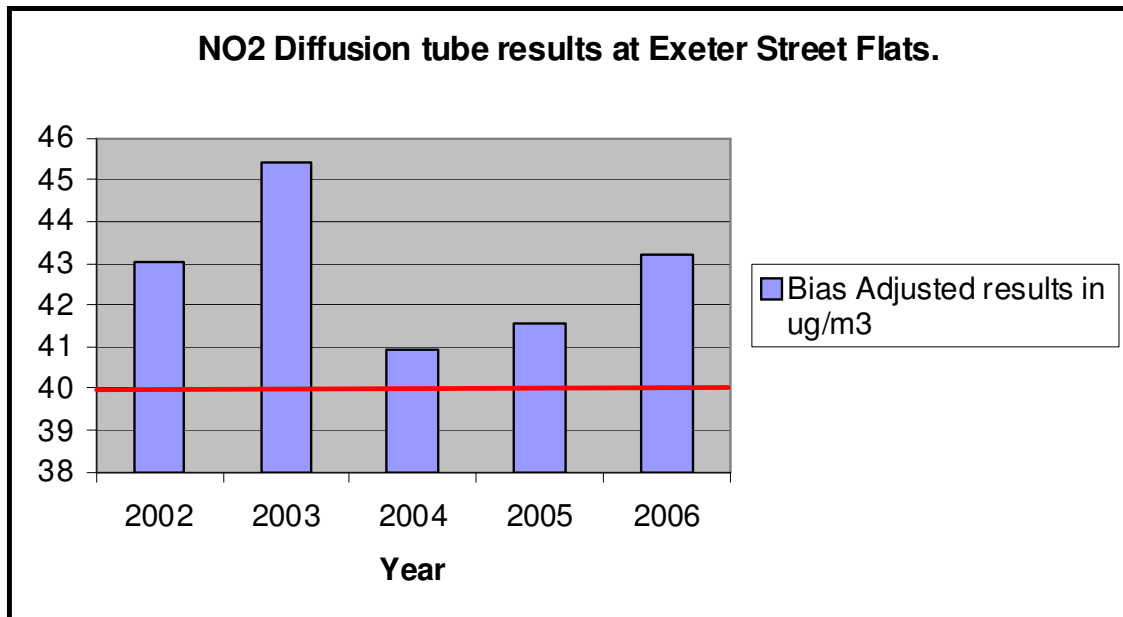
| 2005 | Mean Average | Bias adjusted 0.86 | Prediction 2010 |
|--------------------------------|--------------|--------------------|-----------------|
| Charles Cross | 42.22 | 36.31 | 23.77 |
| Mariners Court | 36.40 | 31.31 | 20.50 |
| Exeter Street (flats) | 48.35 | 41.58 | 27.22 |
| St Judes Road | 35.47 | 30.51 | 19.97 |
| Greenbank Road | 35.68 | 30.68 | 20.09 |
| 11 Tothill Road | 33.17 | 28.53 | 18.68 |
| 212a Exeter Street | 41.03 | 35.29 | 23.10 |
| 5 - Embankment Rd (House) | 41.81 | 35.96 | 23.54 |
| 6 - Embankment Rd (Portakabin) | 30.24 | 26.01 | 17.03 |
| 22 - 44 Embankment Road | 48.98 | 42.13 | 27.58 |
| 21 - Cattedown Road | 37.13 | 31.93 | 20.91 |

| 2006 | Mean Average | Bias Adjusted 0.98 | Estimated 2010 | Periods Monitored. |
|---------------------------------|--------------|-----------------------|----------------|-----------------------|
| Charles Cross | 45.12 | 44.22 | 38.28 | 12 |
| Mariners Court | 31.91 | 31.27 | 27.07 | 10 |
| Exeter Street (flats 103 - 111) | 44.08 | 43.20 | 37.4 | 9 |
| St Judes Road | 35.73 | 35.02 | 30.32 | 11 |
| 48 Embankment Road | 43.96 | 43.08 | 37.3 | 9 |
| 211 Embankment Road | 49.62 | 48.63 | 42.1 | 13 |
| 11 Tothill Road | 33.92 | 33.24 | 28.78 | 13 |
| 212a Exeter Street | 39.86 | 39.06 | 33.82 | 12 |

The diffusion tubes are deployed every four weeks and some of the tubes were stolen or removed hence the varying periods monitored. Only one site is predicted to exceed the 2010 objective for NO₂ but a number of sites exceeded the 2005 objective.

The graph in Figure 4.6 on the following page shows the annual mean results since 2002 for diffusion tube monitoring at Exeter Street Flats.

Figure 4.6 Diffusion tube results at Exeter Street Flats



There is currently no continuous analyser located on Exeter Street and therefore it is not possible to know if there have been any exceedences of the 1 hour objective. However, since there have not been any exceedences in other parts of Plymouth it is unlikely that there would have been any within the Exeter Street AQMA. A continuous analyser and PM₁₀ monitor are being installed on Exeter Street in August 2007, partly funded by DEFRA.

Conclusions

Further monitoring has been carried out and is continuing, using diffusion tubes. The monitoring shows exceedances of the 2005 objective at a number of sites within the AQMA, with one site predicted to exceed the 2010 objective. The results of the further monitoring have not amended the conclusions of the Detailed Assessment, and the declaration of the AQMA is justified. Also a prediction at one of the locations is breaching the 2010 objective.

4.2 Modelling

Modelling has been carried out using the AAQuIRE 6.1.1 modelling package produced by Faber and Maunsell. AAQuIRE uses dispersion algorithms based on the CALINE 4 system for modelling road traffic. The model has been widely validated and used throughout the world (AAQuIRE manual 200:2003). The version of AAQuIRE used incorporated the latest emissions factors database for the UK. Plymouth Airport meteorological data used was from Plymouth Airport meteorological station.

The CALINE 4 model used incorporates default factors for the conversion of NO_x to NO₂ and these default factors were used in the modelling exercises.

In addition to the integral model data, further data relating to vehicle composition, speed, geographical factors and background NO₂ concentrations were input to the model and are shown in tables below. Vehicle counts were based on data provided by the Transport Department from 2005.

The total vehicle counts for future years were extrapolated forward using an estimated total traffic growth rate of 1% per year. It is likely to be an overestimate for years beyond this as national data show traffic growth slowing (DETR, 1999), but is useful for providing worst-case scenario.

The proportion of HGVs for each road has been taken from the Automatic Traffic Count data which is taken from traffic monitoring data obtained for each relevant site. This data is provided by the transport department.

AAQuIRE requires a further breakdown of vehicle categories according to whether engines are petrol or diesel, and, if petrol, fitted with a catalyst or not. Proportions of hot and cold engines were estimated – assuming a worst-case situation with a large number of cold engines. Average speed data was provided by the Transport department,

Data relating to the road dimensions were obtained by measuring road width on the Geographical Processing System (GGP) used by Plymouth City Council. The right and the left mix widths of the road were designated as zero which indicates no significant dispersion of pollutants.

The background concentration of NO_x was obtained from the estimated background air pollution maps for 2004 and projections for other years provided on the Air Quality Archive website.

4.2.1 Modelling: Mutley Plain AQMA

The input data for modelling of the AQMA at Mutley Plain is shown in table 4.6 on the following page.

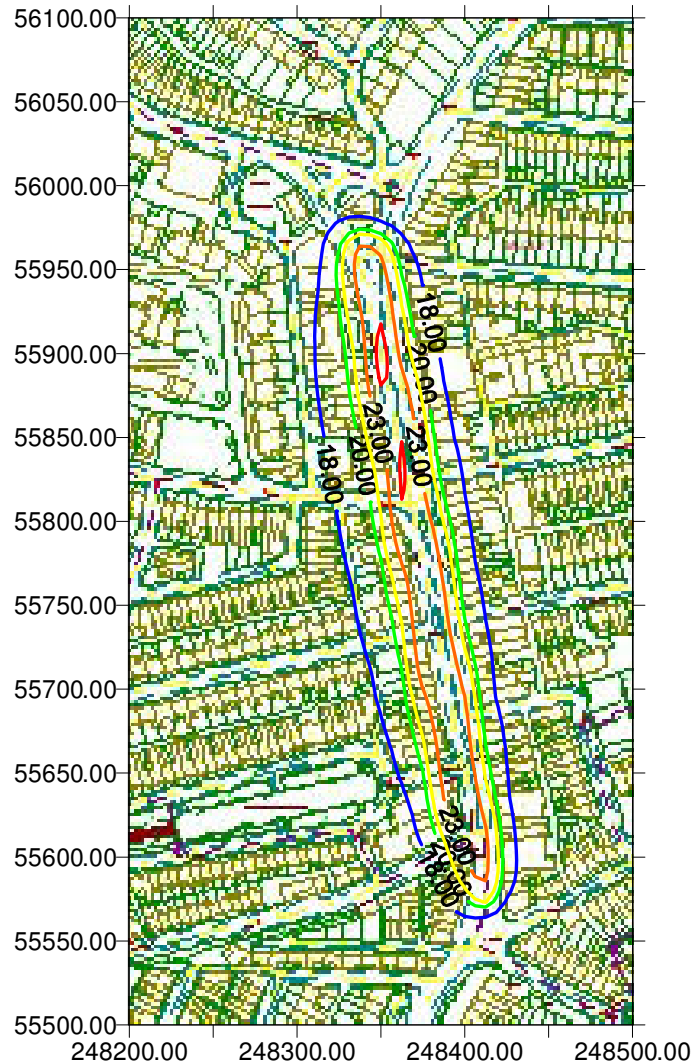
Table 4.6

| Data Input | Mutley Plain |
|---|------------------------------------|
| Surface roughness | Large town/city |
| Class | 1 |
| Area modelled: SW grid point | 248200, 55500 |
| Area modelled: NE grid point | 248500, 56100 |
| Grid space | 15 |
| Receptor height | 1.5 |
| Year | 2010 |
| Road coordinates | 248413 55571 to 248341 55969 |
| Vehicles per hour | 2099 |
| %HDV | 5.6 |
| Average speed km/hr | 21.3 |
| Road height | 0 |
| Road width (m) | 16.81 |
| Road type | 1 (flat) |
| Left mix width | 0 |
| Right mix width | 0 |
| % LDV petrol cold | 4 |
| % LDV petrol hot | 6 |
| % LDV petrol cold catalyst | 25 |
| % LDV petrol hot catalyst | 40 |
| % LDV diesel cold | 5 |
| % LDV diesel hot | 20 |
| % HGV cold | 30 |
| % HGV hot | 70 |
| Background conc. NO _x (µg/m ³) | 19.5 µg/m ³ (from maps) |
| Default NO _x /NO ₂ ratios applied | Yes |
| Met Data | Plymouth |

Results of Modelling using AAQuIRE for Mutley Plain

The contour map to show the concentrations of NO₂ within Mutley Plain AQMA is shown in figure 4.7 on the following page. This depicts the predictions for 2010.

Figure 4.7 Contour map to show the predicted concentrations of NO₂ in 2010 within Mutley Plain AQMA.



The modelling results obtained using AAQuIRE, predict that the concentrations of NO₂ in 2010 within the Mutley Plain AQMA will be below the 40µg/m³ objective, with the highest recorded concentration for 2010 being 25.5 µg/m³. Some work has been carried out to try and validate the model which is shown in section 4.3. This confirms that the model is underestimating the results, which it appears to do for busier roads. The model was validated against data for 2006 for both modelled and actual results.

4.2.2 Modelling: Exeter Street

Modelling has been carried out using AAQuIRE as detailed above. The input data for Exeter Street is shown in Table 4.7.

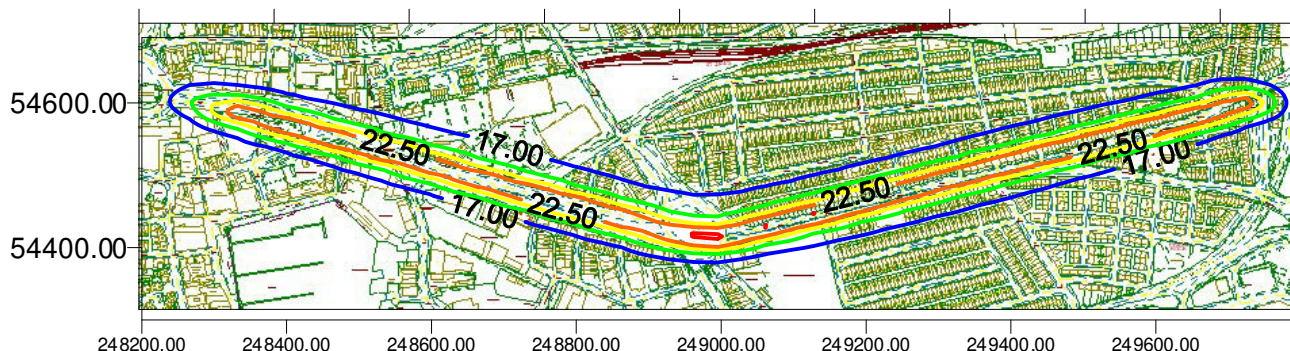
Table 4.7 to show the input data for modelling using AAQuIRE.

| Data Input | Exeter Street |
|---|--|
| Surface roughness | Large town/city |
| Class | 1 |
| Area modelled: SW grid point | 248200 54300 |
| Area modelled: NE grid point | 249800 54700 |
| Grid space | 15 |
| Receptor height | 1.5 |
| Year | 2010 |
| Road coordinates | 248268 54602 to 248971 54405 248971 54405 to 249758 54608 |
| Vehicles per hour | 3887 |
| %HDV | 5.6 |
| Average speed km/hr | 24.7 |
| Road height | 0 |
| Road width | 25 |
| Road type | 1 (flat) |
| Left mix width | 0 |
| Right mix width | 0 |
| % LDV petrol cold | 4 |
| % LDV petrol hot | 6 |
| % LDV petrol cold catalyst | 25 |
| % LDV petrol hot catalyst | 40 |
| % LDV diesel cold | 5 |
| % LDV diesel hot | 20 |
| % HGV cold | 30 |
| % HGV hot | 70 |
| Background conc. NO _x (µg/m ³) | 17.3 µg/m ³ (from maps) |
| Default NO _x /NO ₂ ratios applied | Yes |
| Met Data | Plymouth |

Results of modelling using AAQuIRE for Exeter Street.

The contour map to show the concentrations of NO₂ for 2010 within the Exeter Street AQMA is shown in figure 4.8

Figure 4.8 Contour map to show the predicted concentrations of NO in 2010 within Exeter Street AQMA.



The modelling results using AAQuIRE, predict that the concentrations of NO₂ in 2010 within the Exeter Street AQMA will be below the 40µg/m³ objective, with the highest recorded concentration for 2010 being 24.5µg/m³. Some work has been carried out to try and validate the model which is shown in section 4.3. This confirms that the model is underestimating the results, which it appears to do for busier roads. The model was validated against data for 2006 for both modelled and actual result

4.3 Validation of modelling.

For model validation, all of the areas were examined to ensure that the results from the diffusion tubes followed a consistent trend. Each area was then modelled using AAQuIRE, for data from 2006, and the modelled results were compared to both the actual mean value from the tubes and for the bias adjusted means for each area. The results can be seen in Table 4.8 below.

Table 4.8 Results for validation of AAQuIRE, using 2006 actual data and modelled predictions.

| | Exeter Street (flats) | Mutley Plain (shop) |
|--|-----------------------|---------------------|
| Diffusion Tube mean | 44.08 | 50.51 |
| Bias adjusted tube mean. | 43.20 | 49.50 |
| Modelled result for 2006 | 27.0 | 26.5 |
| Forecast for 2010 using Box 6.6 | 37.4 | 42.86 |
| Modelled Results 2010 | 25.5 | 24.5 |

These results tend to indicate that AAQURE is underestimating the concentrations of NO₂ significantly. This has been true previously for busy and congested routes within Plymouth.

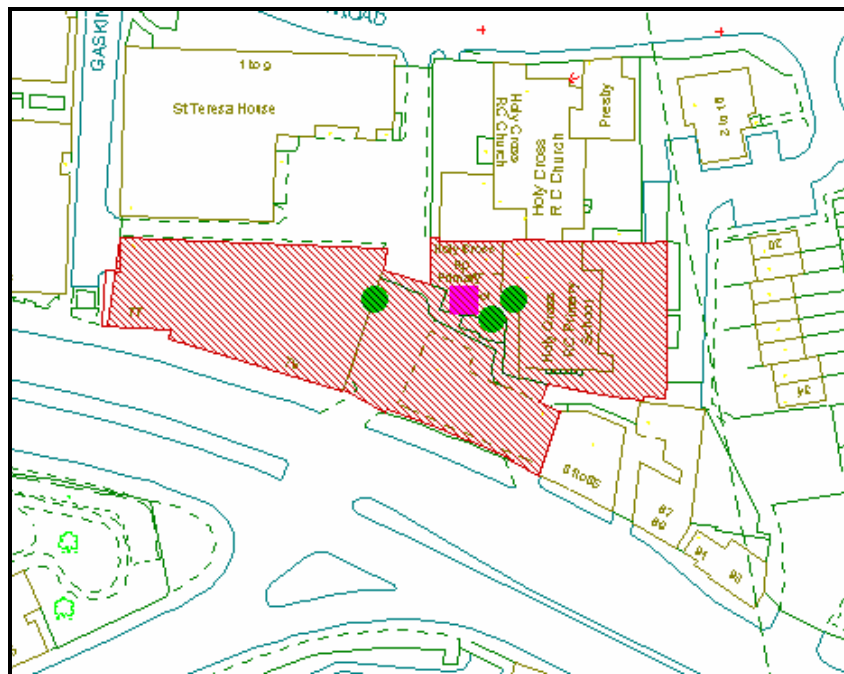
4.4 New Monitoring for Benzene.

Monitoring data within Exeter Street AQMA for Benzene.

An AQMA for benzene was declared on 25th May 2005, due to the fact that there was a school and student accommodation located within 10m of petrol pumps and monitoring had indicated an exceedance of the 2010 objective of 5µg/m³.

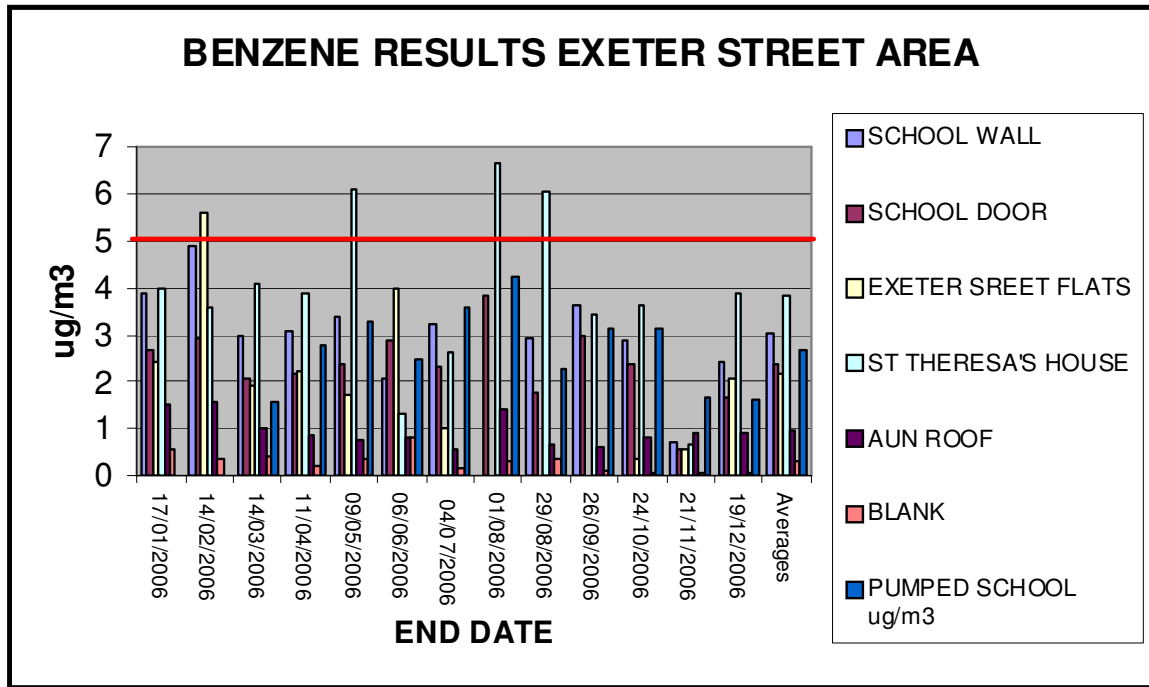
Further monitoring has been carried out within the AQMA on Exeter Street. Firstly diffusion tube monitoring has been carried out at a number of sites around the school grounds, and at the newly constructed student residence at St Theresa's House, directly adjacent to the petrol station. Also a continuous pumped analyser has been installed at the school, with the inlet tube located close to one of the current diffusion tube locations. Figure 4.9 shows the location of the monitoring.

Figure 4.9: Map to show the location of the diffusion tube monitoring and the pumped sampler at Holy Cross School. (Green dots represent diffusion tubes, and the pink square is the pumped sampler.)



The results of the monitoring carried out on Exeter Street are shown in Figure 4.10. The annual averages of these results are shown in table 4.9.

Figure 4.10 Results of Benzene monitoring within the Exeter Street area



It can be seen that St Theresa's House has exceeded on a monthly basis a number of times, but when this is taken on an annual average, the results are below the annual mean figure.

Table 4.9: The annual averages for benzene monitoring at Exeter Street in 2005 and 2006.

| LOCATION | 2005 in ug/m ³ | 2006 in ug/m ³ |
|---------------------------------|---------------------------|---------------------------|
| SCHOOL WALL | 3.06 | 3.01 |
| SCHOOL DOOR | 2.00 | 2.35 |
| EXETER STREET FLATS | 1.41 | 2.18 |
| ST THERESA'S HOUSE | 4.35 | 3.84 |
| BLANK | 0.27 | 0.31 |
| PUMPED SCHOOL ug/m ³ | 2.84 | 2.70 |

From the results it can be seen that there is a marked difference in the values between the pumped sampler and the co-located diffusion tube. This was also noted from the results at the AUN site in Plymouth city centre. The results for these two co-location studies are shown in Figure 4.11 and table 4.10.

As can be seen in table 4.9, the diffusion tube monitoring result at St Theresa's House (student accommodation) has reduced significantly over 2006.

There has been a considerable amount of building work in this area that is likely to have changed or restricted the air flow in Exeter Street itself. In addition, Exeter Street flats have increased over 2006, which is an opposite location away from the petrol station. This can only be explained by traffic flows along Exeter Street.

Figure 4.11 Results from co-location of the benzene pumped sampler and diffusion tube at Holy Cross School located on the school door.

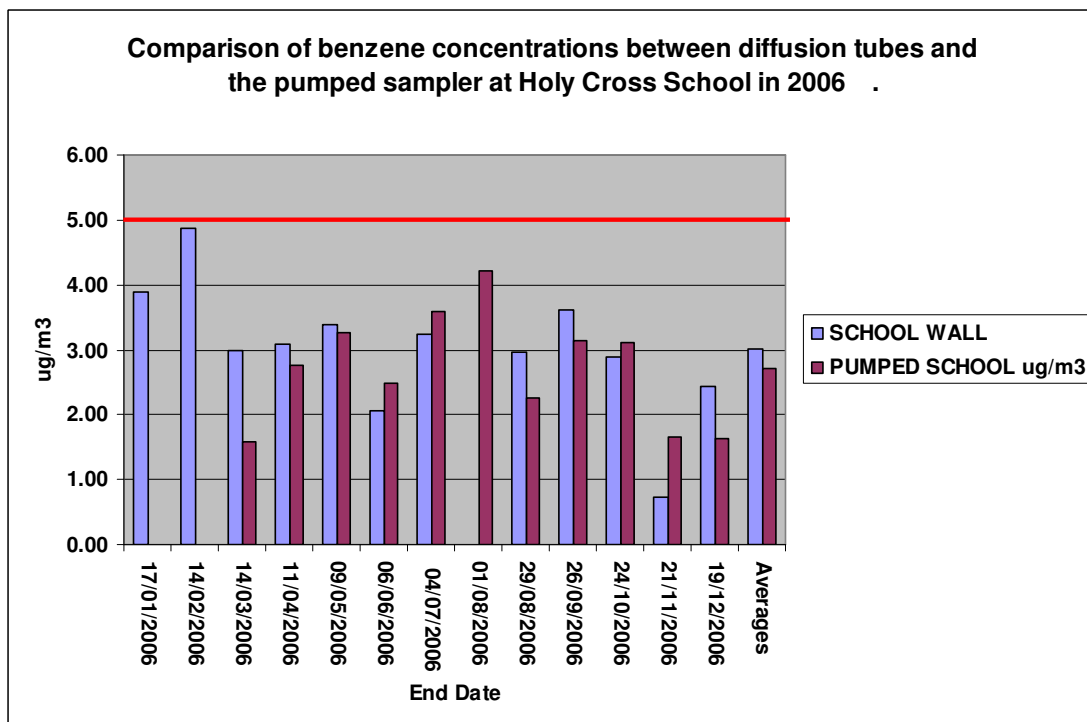
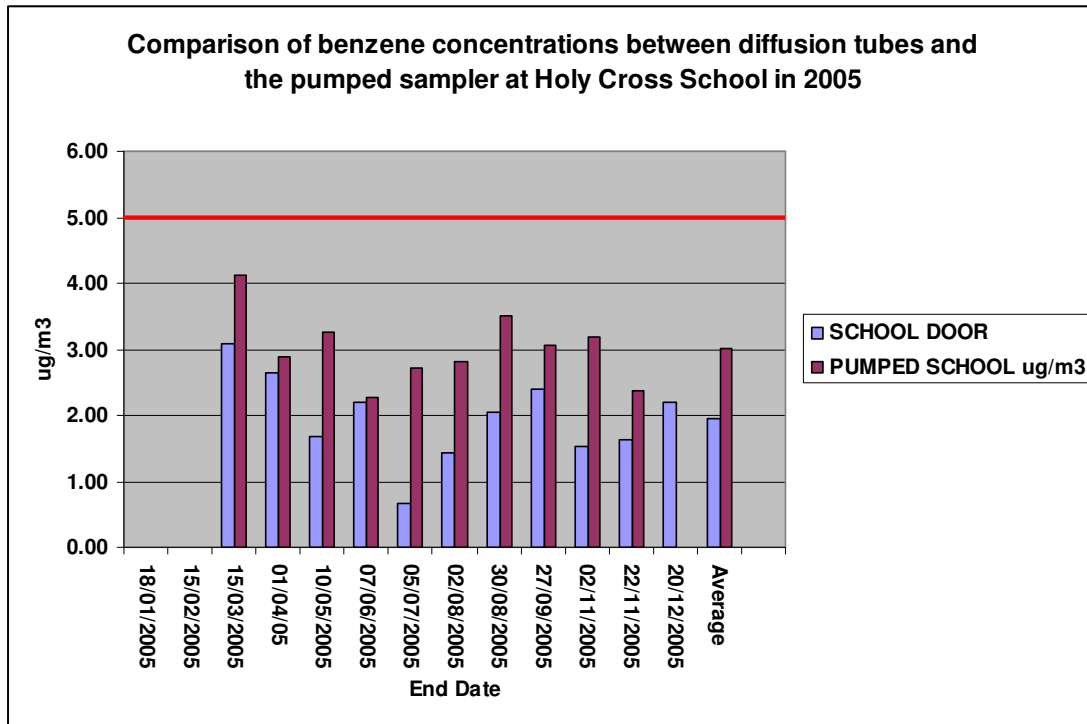


Table 4.10 Annual average results for the co-location of benzene diffusion tubes and the pumped sampler.

| 2005 | Diffusion Tube | Pumped Sampler |
|---------------------------------|----------------|----------------|
| AUN Site | 0.75 | 1.09 |
| Holy Cross School (School Door) | 2.00 | 2.84 |

| 2006 | Diffusion Tube | Pumped Sampler |
|---------------------------------|----------------|----------------|
| AUN Site | 0.67 | 0.92 |
| Holy Cross School (School door) | 2.35 | 2.70 |

The annual average results for the two co-location studies are shown in table 4.10. From the results it can be seen that the average result for the diffusion tube is much lower than that of the pumped sampler. A bias correction factor can therefore be calculated. The same approach as calculating a nitrogen dioxide bias correction factor from Box 6.4 in LAQM.TG (03) was used. The calculation and results are shown in Table 3.5.

Table 4.11: Calculation for the bias correction factor for benzene diffusion tube data in 2005.

| |
|--|
| <p>Bias Adjustment</p> <p>A bias adjustment factor is calculated as follows.</p> <p>$A = C_m/D_m$</p> <p>C_m = Annual mean sampler concentration.</p> <p>D_m = Annual mean diffusion tube concentration.</p> <p>AUN site bias adjustment.</p> <p>$C_m = 1.09$</p> <p>$D_m = 0.75$</p> <p>$A = 1.09/0.75$</p> <p>$A = 1.45$</p> <p>This means the tubes under read by 31.2%</p> <p>School bias adjustment</p> <p>$C_m = 2.84$</p> <p>$D_m = 2.00$</p> <p>$A = 2.84/2.00$</p> <p>$A = 1.42$</p> <p>This means the tubes under read by 29.6%</p> <p>An average of these two bias adjustment factors is 30.4%</p> |
|--|

The bias adjustment correction factor for 2005 is 1.435, which means that the benzene diffusion tubes under read by 30.4%. Since this figure seemed high the matter was discussed with David Butterfield from NPL and he confirmed that this factor was correct. Derby Council have carried out a survey for the last 18 months and have found the same, that the tubes under read the pumped sampler by around 30%. Table 4.13 shows the annual average results and the corrected results using the bias adjustment factor. When the bias adjustment factor is applied to the 2005 data it indicates that the 2010 objective has been exceeded at St Theresa's House.

Table 4.12: Calculation for the bias correction factor for benzene diffusion tube data in 2006.

| |
|---|
| <p>Bias Adjustment</p> <p>A bias adjustment factor is calculated as follows.</p> <p>$A = C_m/D_m$</p> <p>C_m = Annual mean sampler concentration.</p> <p>D_m = Annual mean diffusion tube concentration.</p> <p>School bias adjustment</p> <p>$C_m = 2.70$</p> <p>$D_m = 2.35$</p> <p>$A = 2.70/2.35$</p> <p>$A = 1.15$</p> <p>This means the tubes under read by 12.9%</p> |
|---|

The bias adjustment correction factor for 2006 is 1.15, which means that the benzene diffusion tubes under read by 12.9 %.

Table 4.13 Bias adjusted results for Exeter Street benzene diffusion tube results for 2005.

| .Location | Mean in $\mu\text{g}/\text{m}^3$ | Bias Adjusted |
|-------------------------------|--|----------------------|
| SCHOOL WALL | 3.06 | 4.00 |
| SCHOOL DOOR (Co-located tube) | 2.00 | 2.61 |
| EXETER STREET FLATS | 1.41 | 1.84 |
| ST THERESA'S HOUSE | 4.35 | 5.67 |
| BLANK | 0.27 | 0.35 |

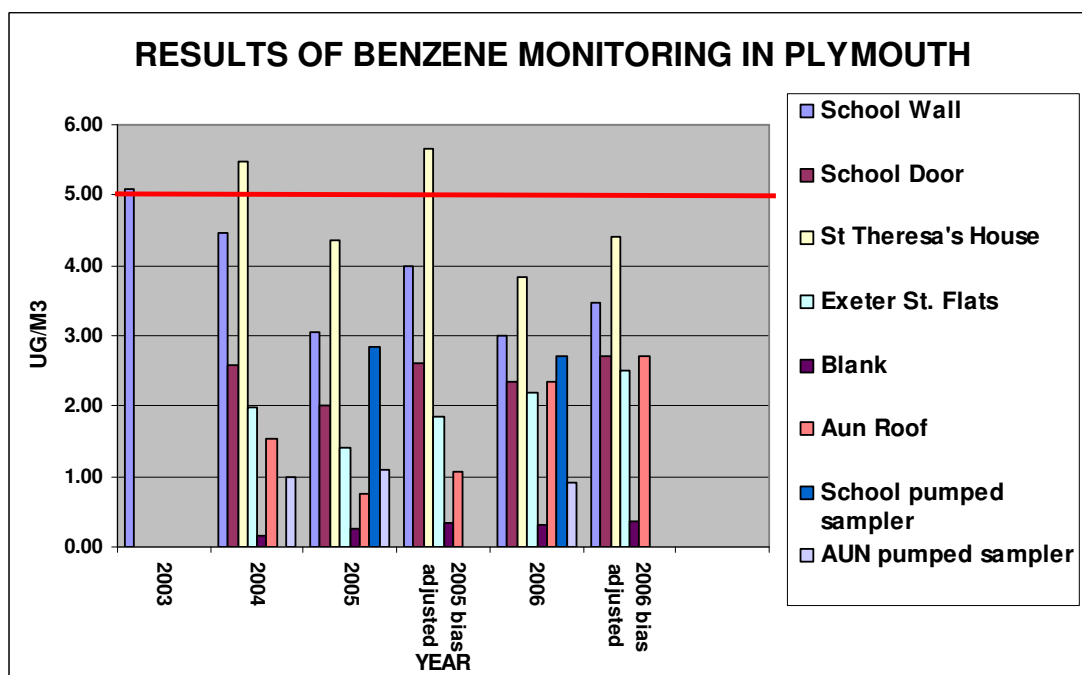
Table 4.14 Bias adjusted results for Exeter Street benzene diffusion tube results for 2006

| Location | Mean in $\mu\text{g}/\text{m}^3$ | Bias Adjusted |
|---------------------|----------------------------------|---------------|
| SCHOOL WALL | 3.01 | 3.46 |
| SCHOOL DOOR | 2.35 | 2.7 |
| EXETER STREET FLATS | 2.18 | 2.51 |
| ST THERESA'S HOUSE | 3.84 | 4.42 |
| BLANK | 0.31 | 0.36 |

These results show that when bias adjusted, there are no exceedences of the 2010 objective.

To show a yearly trend, the annual averages for the last few years are shown in Figure 4.12

Figure 4.12



After examining the results over the last few years it indicates that St Theresa's House (student accommodation) has been above the 2010 objectives in 3 of the 4 years.

Conclusions

These results when corrected show that there is an exceedence of the 2010 benzene objective, and thus confirm the declaration for the AQMA for benzene.

Further Developments

The petrol filling station on Exeter Street has been fitted with Stage II Vapour Recovery in January 2007. This should significantly reduce the benzene concentration and hence in the near future it should be possible to revoke the AQMA for benzene. However to make sure that the levels have dropped significantly monitoring will continue for a further year.

5.0 Source Apportionment and Air Quality Improvements Needed

In order to develop an appropriate action plan it is necessary to identify the sources contributing to the objective exceedences. The information presented here is a summary of the results of the findings of the source apportionment report carried out by the Centre for Energy and the Environment on behalf of Plymouth City Council. Appendix 2 shows the full report.

Analysis of the traffic data for the two AQMAs has enabled the NO_x emissions to be apportioned between type of vehicle, direction of travel and speed. In both locations, although cars account for over 90% of traffic throughput, they only account for about 45% of total vehicle NO_x arisings. Conversely, heavy goods vehicles account for 4 to 6% of vehicle throughput but give rise to 32% of total NO_x emissions on Exeter Street and 27% at Mutley Plain. Public service vehicles similarly account for low percentages of throughput (below 2.5%), but up to 24% of total emissions. Emissions from heavy vehicles increase greatly at low speeds.

Slow moving traffic and congestion can greatly increase NO_x emissions, and in all cases, the slowest vehicles contribute disproportionately to emissions. The effect of increasing minimum traffic speeds (e.g. by implementing measures to ease congestion) is predicted to be the greatest in the Mutley Plain AQMA, where ensuring that all vehicles travel at a minimum speed of 23.5 mph would reduce NO_x emissions by 11.5% and annual average NO₂ concentrations by 5.8%. On Exeter Street a 5.4% reduction in NO_x emissions and a 2.6% reduction in the annual average NO₂ concentration are predicted. Table 5.1 shows the effect of increased minimum traffic speeds on NO_x emissions and NO₂ concentrations in the Mutley and Exeter Street AQMAs. However, none of these reductions would alone be sufficient to enable the NO₂ objective to be met.

Table 5.1 The effect of increased minimum traffic speeds on NO_x emissions and NO₂ concentrations in the Mutley and Exeter Street AQMAs.**Exeter Street**

| Road | Scenario | Average Emission Rate (g/km/s) | % Reduction | Annual Average Concentration (µgm ⁻³) | % Reduction |
|-----------------|--------------------|--------------------------------|-------------|---|-------------|
| | All Vehicles >23.5 | 0.32 | 5.36 | 40.5 | 2.64 |
| Exeter Street | HGVs > 23.5 mph | 0.34 | 0.17 | 41.6 | 0.08 |
| | Buses > 23.5 mph | 0.34 | 0.10 | 41.6 | 0.05 |
| | HGVs and Buses | 0.34 | 0.26 | 41.5 | 0.13 |
| | All Vehicles >23.5 | 0.43 | 2.34 | 41.6 | 1.18 |
| Embankment Road | HGVs > 23.5 mph | 0.44 | 0.11 | 42.1 | 0.06 |
| | Buses > 23.5 mph | 0.44 | 0.02 | 42.1 | 0.01 |
| | HGVs and Buses | 0.44 | 0.14 | 42.1 | 0.07 |

Mutley Plain

| Scenario | Average Emission Rate (g/km/s) | % Reduction | Annual Average Concentration (µgm ⁻³) | % Reduction |
|--------------------|--------------------------------|-------------|---|-------------|
| All Vehicles >23.5 | 0.19 | 11.55 | 41.4 | 5.82 |
| HGVs > 23.5 mph | 0.22 | 0.29 | 43.9 | 0.14 |
| Buses > 23.5 mph | 0.22 | 0.29 | 43.9 | 0.14 |
| HGVs and Buses | 0.22 | 0.59 | 43.9 | 0.29 |

On Mutley Plain, the importance of idling buses was assessed (there are multiple bus stops along the length of the road). It has been estimated that a single bus idling continually would give rise to similar NO_x emissions as that calculated for all the buses passing through this AQMA (and the latter account for 24% of emissions from mobile vehicles.) Given that there are 664 recorded bus movements through the AQMA (excluding minibuses) and appear to be 866 timetable movements, it is likely that idling buses make a significant contribution to total emissions. Previous research by the Centre indicated that if a bus idles for more than 6.6 minutes, emissions would be reduced by switching off and re-starting the engine.

The reduction in HGVs, buses, or HGVs and buses that would be required to reduce the annual average NO₂ concentration to meet the objective was also estimated. On Exeter Street, a 25% reduction in HGVs and a 48% reduction in buses was found to be necessary. On Embankment Road, the required percentage reduction in HGVs was similar, but the objective could not be met by reducing the flow of buses alone. On Mutley Plain, a 69% reduction in HGV flow or a 77% reduction in bus flow would be necessary.

Finally, the effect of removing HGVs, either totally or during peak hours only was gauged. On all of the roads, the former was predicted to enable the objectives to be met, but the latter was not. Reductions of less than 100% (e.g. due to local deliveries being allowed) would have a proportionate effect between the figures estimated for the flows "as is" and those with all HGV's removed.

The objectives of the source apportionment analysis are to help inform decisions on appropriate measures that may be adopted in the subsequent air quality action plan and in future Local Transport Plans. The principal findings are that measures to control heavy vehicles could easily be as significant as actions taken to control cars, even though they form a far smaller proportion of vehicle throughput, and that measures taken to enable traffic to flow more freely could also have a significant benefit.

6.0 Summary of Further Assessment Nitrogen Dioxide.

The results of the Further Assessment confirm that Plymouth City Council was correct in its decision to declare two AQMAs for nitrogen dioxide. The monitoring around the boundaries of the AQMAs suggests the the extent of the area declared is sufficient for both Mutley Plain and Exeter Street.

The source apportionment shows that the majority of the problem arises from buses and HGV's. The percentage reduction in HGV's and buses that would be required to reduce the annual average NO₂ to meet the objective was estimated, on Exeter street, a 25% reduction in HGVs and a 48% reduction in buses was found to be necessary to obtain the objective. On Mutley Plain, a 69% reduction in HGV flow or a 77% reduction in bus flow would be necessary to achieve the objective.

Monitoring will continue and continuous analysers will be installed within the AQMA's to enable the extent and validity of the declarations to be assessed on an ongoing basis.

Benzene

The result of the Further Assessment for benzene confirms that Plymouth City Council was correct in the declaration of the AQMA for benzene. The monitoring indicates that the extent of the declared area is sufficient. The fact that Stage II vapour recovery has been installed indicates that the AQMA is likely to be revoked in the near future. However monitoring will continue in 2007 to assess the effectiveness of the system and to ensure that the levels have reduced sufficiently.

Future Developments

Strong links have been made with the Transport department to produce the formal action plan. An interim action plan has been written and forms a chapter in the Local Transport Plan. New developments are being assessed as to their suitability with regard to air quality, and comments and conditions are being made accordingly.

Appendix 1: Quality Assurance and Control Measures

Nitrogen Dioxide Diffusion Tubes

Where NO₂ is monitored using diffusion tubes, the standard method recommended by NETCEN and the analytical laboratory undertaking analysis (Gradko) is followed. Gradko are a fully accredited establishment and supply tubes to many local authorities.

NO₂ diffusion tubes are clear plastic tubes, with one open end and a closed end containing a NO₂ absorbing chemical matrix (triethanoamine). The type of tubes used are 20% TEA in water. The open end is sealed with a plastic cap before it is transported to the monitoring location. At the site the cap is removed and the tube is mounted vertically with the open end at the bottom.

The interval between preparation and deployment is kept to a minimum. During storage the tubes are kept in a sealed plastic bag in the refrigerator. A blank tube is sent which remains in the sealed bag during the monitoring period and is returned with the rest of the tubes to the laboratory for analysis.

Monitoring sites were identified upon relevant exposure or those that were considered to be representative of a relevant exposure location. The tubes were mounted mostly on drainpipes. Ideally, the tubes should be mounted on to spacer blocks and not attached directly to any surface. Tubes, however, are prone to theft and are, therefore, attached using strong tape above head height. The tubes are exposed for a period of four weeks and the exposure time noted in hours.

Quality assurance is given by participation in the Working Sampling Proficiency Programme (WASP). These tests provide a regular independent check on the calibration. Gradko also participate in the Field Intercomparison Tube Survey carried out by NETCEN where diffusion tubes are co-located against an AUN site. This gives a bias adjustment factor A of 0.82±0.1. When this is compared to the bias adjustment factor calculated using the co-location study at Plymouth AUN site a good correlation is found.

The analytical lab used was Gradko International Ltd., St Martins House, 77 Wales Street, Winchester, Hampshire SO23 0RH.

Benzene Diffusion Tubes

Benzene diffusion tubes are supplied by Gradko. Analysis is carried out using gas chromatography/ Thermal desorption techniques. Standard solutions are prepared covering the concentration range 10-2000ng and there is an uptake rate of 1.28ng per ppm per minute.

The exposed tubes are thermally desorped and the vapour phase transferred to a gas chromatography system. Calibration determinations are made for every batch of tubes analysed.



**SOURCE APPORTIONMENT FOR
PLYMOUTH'S AIR QUALITY
MANAGEMENT AREAS**

T.A. Mitchell BSc

Internal Document 456

September 2006

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MANAGEMENT SUMMARY

Local authorities periodically review air quality in their area with reference to the objectives given in the National Air Quality Strategy. The third round Updating and Screening Assessment for Plymouth, conducted in 2006^[1], concluded that on the basis of ongoing monitoring, nitrogen dioxide (NO₂) exposure in the existing Mutley Plain and Exeter Street Air Quality Management Areas (AQMA) remain in excess of the annual mean objective of 40 µg m⁻³. These AQMA were declared in May 2005, along with an AQMA for Benzene exposure in Exeter Street.

Once an AQMA has been declared, there is a need to develop an action plan to alleviate the problem. In order to predict the effectiveness of particular strategies, it is necessary to apportion the pollution more accurately between different sources. For road traffic, this will involve an examination of the contribution made by different categories of vehicle and specific directional flows, as well as an examination of the sensitivity of pollution arisings to factors such as traffic speed and congestion. This report contains the results of the source apportionment exercise for the two NO₂ AQMA in Plymouth. The source of the Benzene exposure in Exeter Street has already been clearly identified (petrol pumps in close proximity to a school and student accommodation); this has already been documented in detail in the 2006 Updating and Screening Assessment and has not been considered further in this report.

Analyses of traffic data for the two AQMA in Plymouth have enabled the NO_x emissions to be apportioned between type of vehicle, direction of travel and speed. In both locations, although cars account for over 90% of traffic throughput, they only account for about 45% of total vehicle NO_x arisings. Conversely, heavy goods vehicles account for 4 to 6% of vehicle throughput but give rise to 32% of total NO_x emissions on Exeter Street and 27% at Mutley Plain. Public service vehicles similarly account for low percentages of throughput (below 2.5%), but up to 24% of total emissions. Emissions from heavy vehicles increase greatly at low speeds.

Slow moving traffic and congestion can increase NO_x emissions significantly, and in all cases, the slowest vehicles contribute disproportionately to emissions. The effect of increasing minimum traffic speeds (e.g. by implementing measures to ease congestion) is predicted to be greatest in the Mutley Plain AQMA, where ensuring that all vehicles travel at a minimum speed of 23.5 mph would reduce NO_x emissions by 11.5% and annual average NO₂ concentrations by 5.8%. On Exeter Street, a 5.4% reduction in NO_x emissions and a 2.6% reduction in the annual average NO₂ concentration are predicted. However, none of these reductions would alone be sufficient to enable the NO₂ objective to be met.

On Mutley Plain, the importance of idling buses was assessed (there are multiple bus stops along the length of the road). It has been estimated that a single bus idling continually would give rise to similar NO_x emissions as that calculated for all of the buses passing through this AQMA (and the latter account for 24% of emissions from mobile vehicles). Given that there are 664 recorded bus movements through the AQMA (excluding minibuses) and appear to be 866 timetabled movements, it is likely that idling buses make a significant contribution to total emissions. Previous research by the Centre indicated that if a bus idles for more than 6.6 minutes, emissions would be reduced by switching off and re-starting the engine.

The reduction in HGVs, buses, or HGVs and buses that would be required to reduce the annual average NO₂ concentration to meet the objective was also estimated. On Exeter Street, a 25% reduction in HGVs and a 48% reduction in buses was found to be necessary. On Embankment Road, the required percentage reduction in HGVs was similar, but the objective could not be met by reducing the flow of buses alone. On Mutley Plain, a 69% reduction in HGV flow or a 77% reduction in bus flow would be necessary.

Finally, the effect of removing HGVs, either totally or during peak hours only, was gauged. On all of the roads, the former was predicted to enable the objective to be met, but the latter was not. Reductions of less than 100% (e.g. due to local deliveries being allowed) would have a proportionate effect between the figures estimated for the flows "as is" and those with all HGVs removed.

The objectives of the source apportionment analysis are to help inform decisions on appropriate measures that may be adopted in the subsequent air quality action plan and in future Local Transport Plans. The principal findings are that measures to control heavy vehicles could easily be as significant as actions taken to control cars, even though they form a far smaller proportion of vehicle throughput, and that measures taken to enable traffic to flow more freely could also have a significant benefit.

Introduction

Local authorities periodically review air quality in their area with reference to the objectives given in the National Air Quality Strategy. The third round Updating and Screening Assessment for Plymouth, conducted in 2006^[1], concluded that on the basis of ongoing monitoring, nitrogen dioxide (NO₂) exposure in the existing Mutley Plain and Exeter Street Air Quality Management Areas (AQMA) remain in excess of the annual mean objective of 40 µg m⁻³. These AQMA were declared in May 2005, along with an AQMA for Benzene exposure in Exeter Street.

Once an AQMA has been declared, there is a need to develop an action plan that will allow the problem to be alleviated. In order to assess the effectiveness of particular strategies, it is necessary to apportion the pollution more accurately between different sources. For road traffic, this will involve an examination of the contribution made by different categories of vehicle and specific directional flows, as well as an examination of the sensitivity of pollution arising to factors such as traffic speed and congestion. This report contains the results of the source apportionment exercise for the two NO₂ AQMA in Plymouth. The source of the Benzene exposure in Exeter Street has already been clearly identified (petrol pumps in close proximity to a school and student accommodation); this has already been documented in detail in the 2006 Updating and Screening Assessment and has not been considered further in this report.

The basis of the source apportionment study is traffic data supplied by Plymouth City Council for three locations: Mutley Plain, Exeter Street and Embankment Road (the latter being the eastern end of the Exeter Street AQMA). In each case, traffic flow is categorised by speed, type of vehicle and time of day. On Exeter Street and Embankment Road, the statistics are available separately for each direction of travel. The emission rates of nitrogen oxides (NO_x) implicit in these data have been calculated using the emission factors and average national fleet compositions (in terms of pollution control standard and fuel type) from the National Atmospheric Emissions Inventory spreadsheets^{[2], [3]}. It was initially hoped that data on the technologies of buses operating in the AQMA could be obtained and used, but since data were not forthcoming from the two major operators, Plymouth Citybus and First Devon and Cornwall, the national split of technologies has been assumed, as for other types of vehicle. At the request of Plymouth City Council, various scenarios have been examined to determine the sensitivity of emission rates to changes in vehicle speed and the restriction of goods vehicles and buses. The effect of these changes on NO₂ concentrations has also been estimated. This modelling will be useful in formulating a Further Assessment and informing suitable measures for incorporation into Air Quality Action Plans and Local transport Plans for the two AQMA.

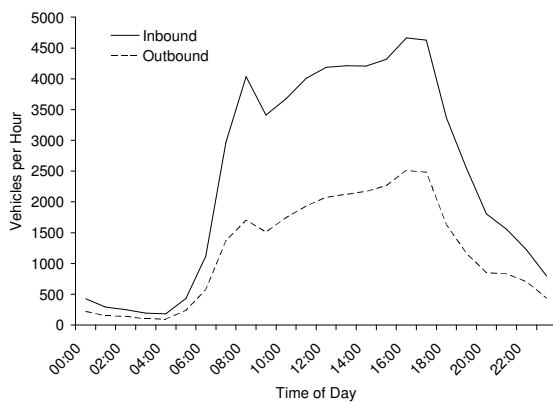
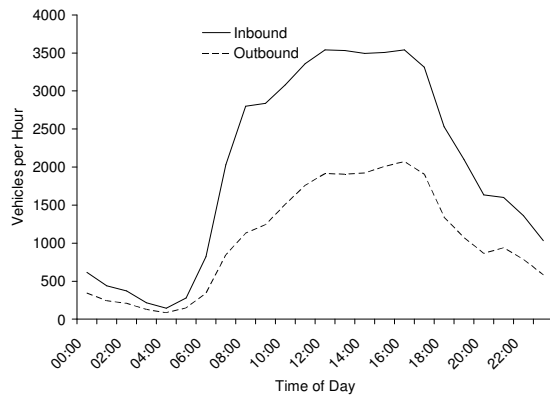
Exeter Street AQMA

The Exeter Street AQMA includes Exeter Street and part of Embankment Road, which together form part of the A374 which links Plymouth city centre with the A38 primary route to the north-east of the city. The sections of road within the AQMA are busy dual carriageways, lined on each side with a mixture of residential, retail and commercial buildings. There are bus lanes along much of the length of Exeter Street, in addition to two lanes in each direction available to all types of vehicle.

Examination of the traffic data supplied for 2005 show that on Exeter Street there is about 10% more outbound traffic than inbound traffic, and that inbound traffic exceeds outbound traffic in the morning peak hours only (06:00 to 10:00) (Figure 1a). Average daily throughput on Exeter Street is 48182 vehicles. The average speed of inbound vehicles is 22 mph and that of outbound vehicles is 26 mph.

On Embankment Road, flow is greater (58496 vehicles per day) with about 1.5% more inbound traffic than outbound traffic. Inbound traffic dominates from 06:00 to noon, with a pronounced peak between 08:00 and 09:00 (Figure 1b). The average speed of inbound vehicles is 41 mph and of outbound vehicles is 33 mph. The higher speeds suggest that this

count may be located along the more free-flowing section of road to the north-east of the Exeter Street AQMA.

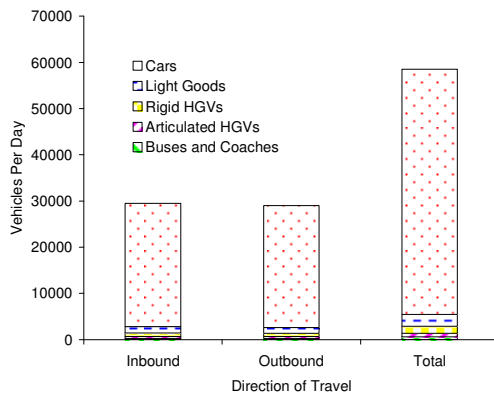
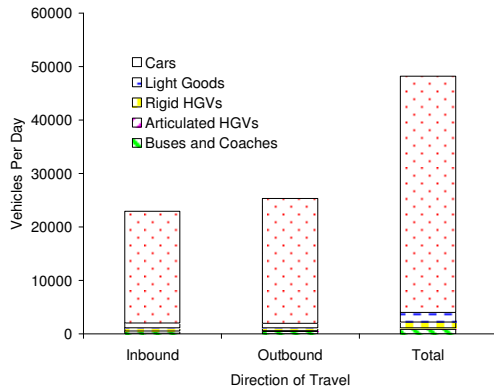


(a) Exeter Street

(b) Embankment Road

Figure 1. Flows by time of day on Exeter Street and Embankment Road.

Figure 2 shows the flow of vehicles by type in terms of daily totals on the two roads. It can be seen that in both cases cars account for just over 90% of total vehicle throughput. However, as will be shown later, other vehicle types can make a significant contribution to total NO_x emissions since their emission factors are higher.



(a) Exeter Street

(b) Embankment Road

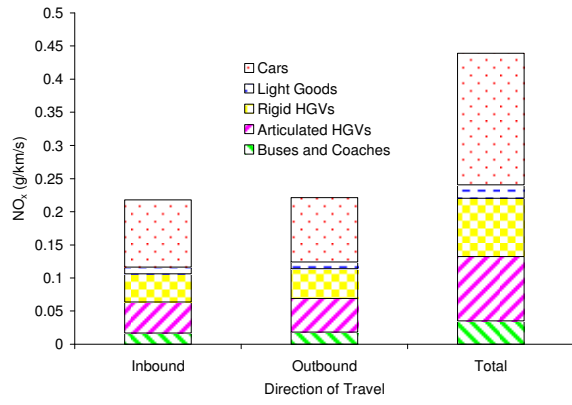
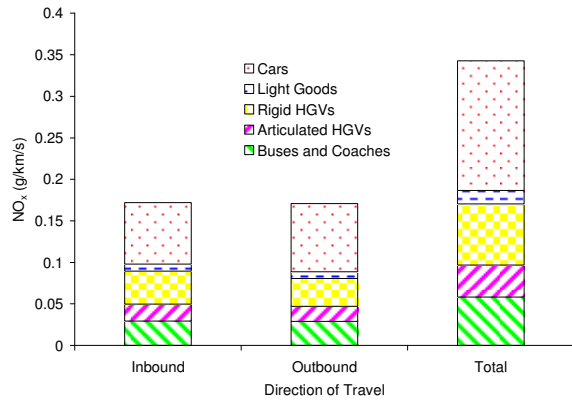
Figure 2. Flows by type of vehicle and direction of travel on Exeter Street and Embankment Road.

The road traffic emissions that lead to the formation of nitrogen dioxide (NO₂) primarily occur as nitric oxide (NO), with about 10% arising directly as NO₂ [4]. NO and NO₂ are collectively known as nitrogen oxides (NO_x). In simplified terms, the NO component of the emissions reacts with ozone (O₃) to form NO₂ (the reality is more complicated due to the photolytic decomposition of NO₂ to form NO and O₃). The aim in source apportionment is to attribute the pollution arising to specific sources, hence this is largely done in terms of NO_x emissions. NO_x emissions rates for different categories of vehicle, fuel type and emissions technology and the national split between fuel type and emissions technology within each vehicle category are available from the National Atmospheric Emissions Inventory spreadsheets [2], [3]. The emissions data are given in the units grams per kilometre travelled, and are dependent upon the speed of the traffic. The figures are in terms of “NO_x as NO₂”, i.e. assuming all NO_x to be in the form of NO₂.

The Centre for Energy and the Environment has written software to process these data and enable the NO_x (as NO₂) emissions rate to be calculated for a particular stretch of road given information on the throughput of different types of vehicle. Considering the flow characteristics on Exeter Street and Embankment Road, and assuming the national fleet composition for the year 2006 within each broad category of vehicle has yielded the NO_x emission rates shown in Figures 3 to 6 and tabulated in Appendices 1 and 2. When interpreting the vehicle categories in the traffic data, the assumptions outlined in Table 1 have been made.

Table 1. Interpretation of vehicle categories.

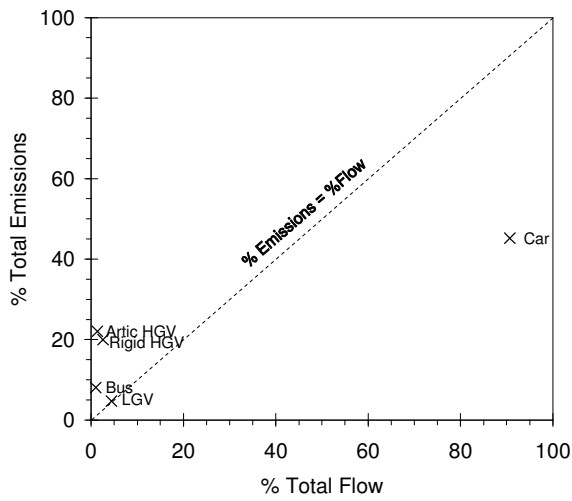
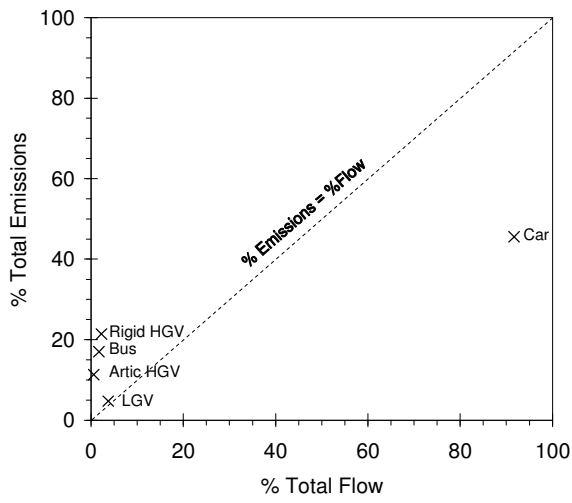
| Traffic Data Vehicle Category | NAEI Vehicle Category Assumed |
|--|---------------------------------|
| Car, Car and Trailer, Light Van | Car |
| Heavy Van, Minibus | Light Goods Vehicle |
| Rigid Lorry | Rigid Heavy Goods Vehicle |
| Rigid Lorry and Trailer, Articulated HGV | Articulated Heavy Goods Vehicle |
| Bus, Coach | Bus |



(a) Exeter Street

(b) Embankment Road

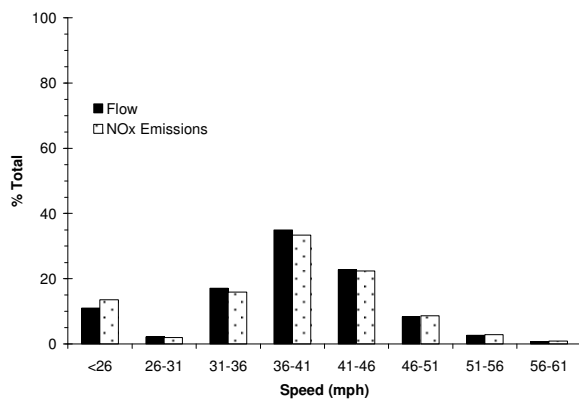
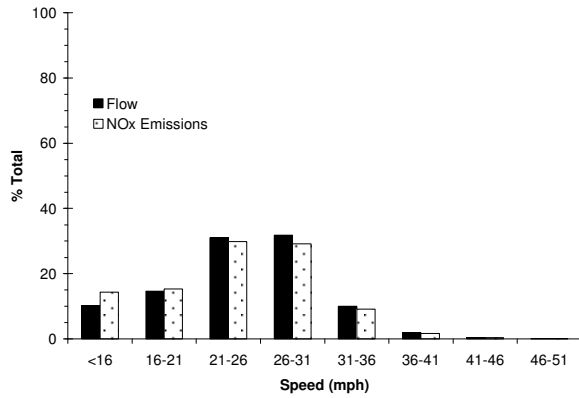
Figure 3. NO_x Emissions by type of vehicle and direction of travel on Exeter Street and Embankment Road.



(a) Exeter Street

(b) Embankment Road

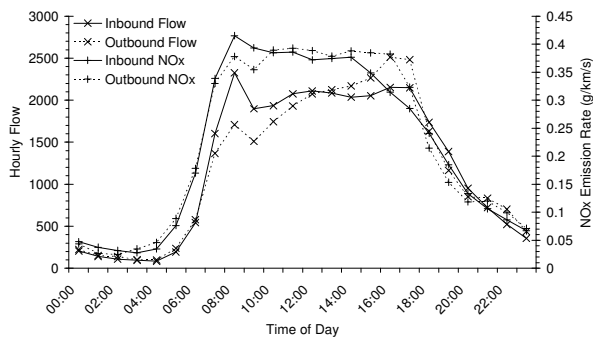
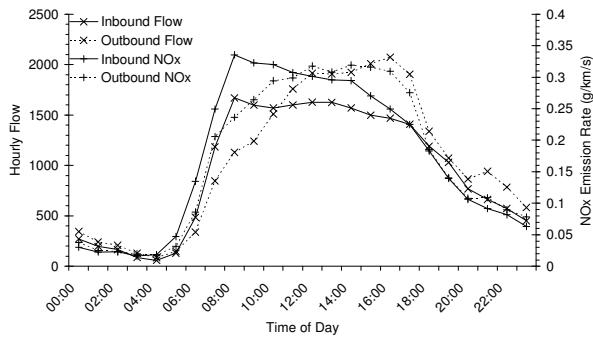
Figure 4. Correlation of NO_x Emissions with flows by type of vehicle on Exeter Street and Embankment Road.



(a) Exeter Street

(b) Embankment Road

Figure 5. NO_x Emissions by vehicle speed on Exeter Street and Embankment Road.



(a) Exeter Street

(b) Embankment Road

Figure 6. NO_x Emissions and vehicle flows by time of day on Exeter Street and Embankment Road.

It is evident from Figures 2 and 3 that the emissions of NO_x from HGVs and buses are disproportionately large compared to their share of total vehicle throughput (the higher emissions rate per kilometre for heavy vehicles is evident in Figure 7). Figure 4 illustrates this more clearly by correlating the percentage contribution to NO_x emissions with the percentage contribution to total throughput for each type of vehicle. The implications of this are that measures taken to reduce emissions from heavy vehicles could be just as effective at reducing overall emissions from the road as measures taken to control emissions from cars.

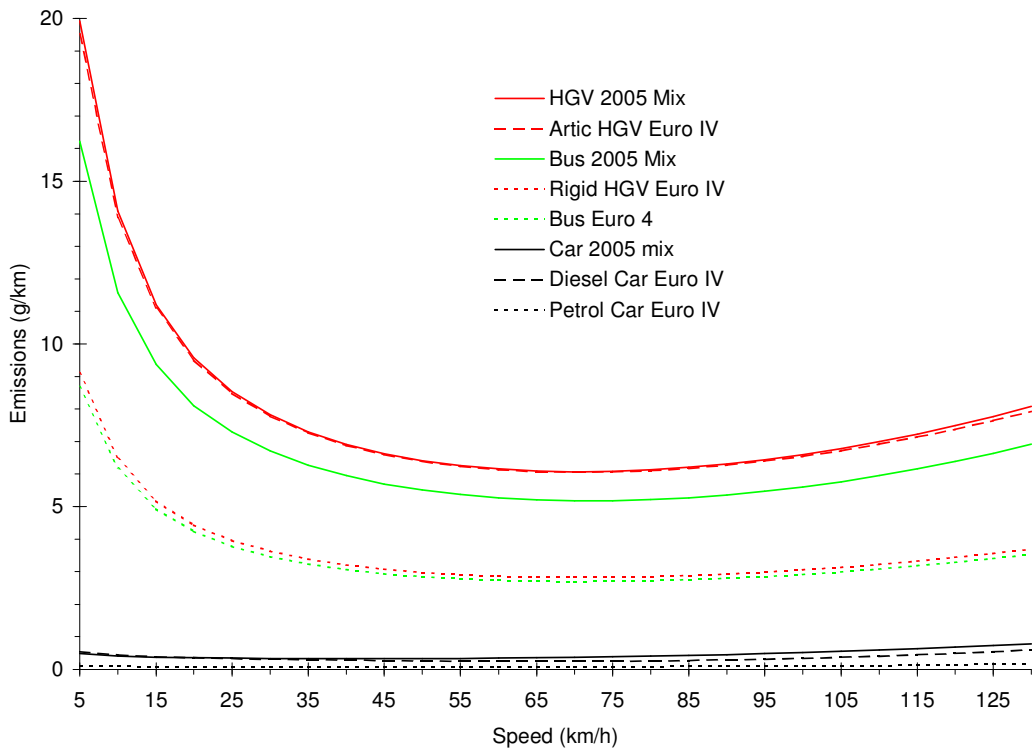


Figure 7. Comparison of emission factors for different types of vehicle, both for the 2005 national vehicle age and technology mix, and for vehicles meeting the 2006 emissions standard (for users of monochrome versions of this document: the legend order is commensurate with emissions, from greatest to lowest) ^{[2], [3]}.

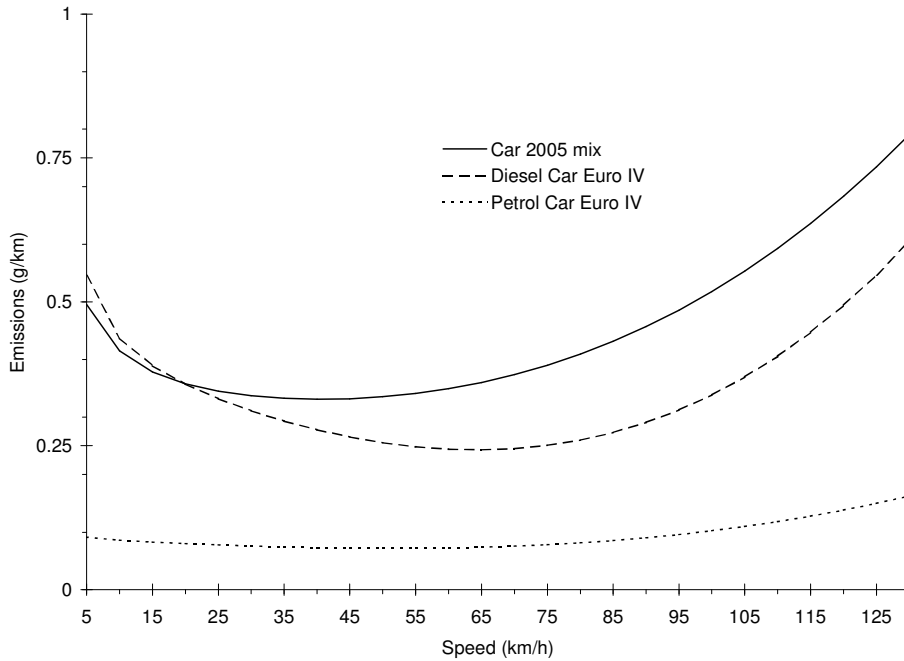
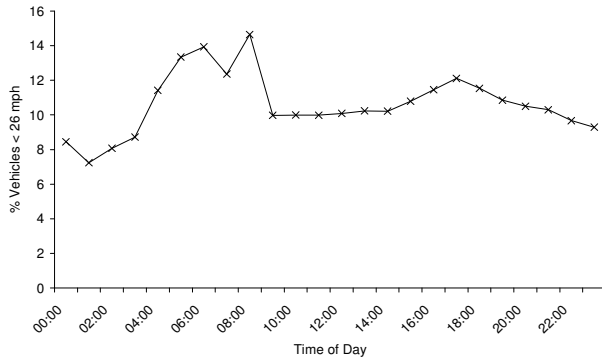
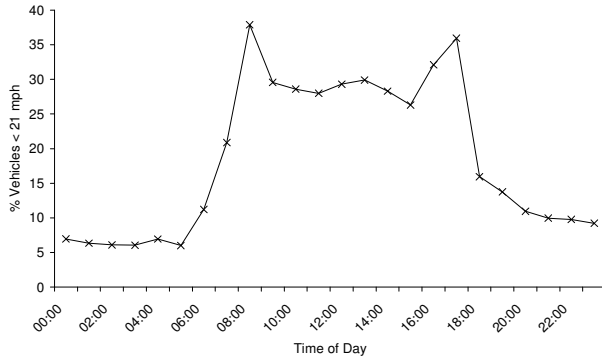


Figure 8. Comparison of emission factors for cars, both for the 2005 national vehicle age and technology mix, and for vehicles meeting the 2006 emissions standard^{[2], [3]}.

Emissions factors per vehicle-kilometre fall with increased road speed, up to an optimum point after which they start to increase (Figures 7 and 8). Figure 5 compares the percentage of total flow in each band of vehicle speeds with the percentage of NO_x pollution attributable to vehicles travelling in each speed band. It is evident that vehicles travelling less than about 20 miles per hour (32 km/h) account for slightly larger percentage of total pollution arisings than their percentage contribution to total vehicle flow. The effect of increasing the minimum vehicle speed is considered later in this section.

Figure 6 compares the hourly average flow rate and NO_x emissions rate, for each direction of flow on the two roads. As would be expected, the magnitude of emissions generally follows the trends in flow rate. The subtle differences are attributable to changes in traffic speed and the vehicle mix at different times of day. The AM peak hour pollution increases out of proportion to the flow rate principally because of the increase in slow-moving vehicles (Figure 9).



(a) Exeter Street

(b) Embankment Road

Figure 9. Percentage of slow vehicles by time of day on Exeter Street and Embankment Road.

A number of scenarios have been modelled to quantify the effects of various possible pollution reduction measures in the Exeter Street AQMA. These include increasing minimum vehicle speeds and reducing the throughput of heavy goods vehicles and buses. In addition to the prediction of NO_x emission rates for each scenario, it was felt valuable to estimate the effect on NO₂ concentrations. This could be achieved in two ways: using dispersion modelling software or by means of simple empirical relationships. Both are subject to a high margin of uncertainty, and the approach taken was to use the empirical relationships employed in the Design Manual for Roads and Bridges (DMRB) spreadsheet calculator of local air quality^[5].

The methodology^[6] uses a dispersion function to estimate the NO_x concentration at a specified distance from the road from the daily NO_x emission rate per kilometre on the road. A calibration adjustment¹ is then applied, followed by a function that converts the NO_x concentration into an NO₂ concentration. This requires the background concentrations of NO_x and NO₂ to be known. These values have been taken from the tabulated background pollution concentrations available from the Local Air Quality Management website^[7], and are shown in Table 2.

The above methodology was verified by predicting NO₂ concentrations for 2005 from the NO_x emissions implicit in the supplied traffic data, and comparing these to the concentrations monitored in the AQMAs using diffusion tubes (Table 2). This process showed that an adjustment factor needed to be applied to correctly predict the monitored NO₂ concentrations. A multiplicative factor to be applied to the predicted NO₂ contribution from the road traffic was derived for each location (Table 2), and has been used when estimating the effect of the various scenarios outlined below on NO₂ concentrations. It is not surprising that such a factor was needed, given that the Local Air Quality Management technical guidance^[8] states that the road component of NO₂ should be doubled to take into account the presence of a street canyon, and the roads under consideration are lined with buildings. Also, when estimating emissions, traffic in the lowest speed category has been assumed to travel at half of the maximum speed for this category; additionally stationary traffic may reduce the average speed for this category (emissions rates are not available in the NAEI for emissions from stationary vehicles^[9]).

Table 2. Parameters used to estimate NO₂ concentrations in the Exeter Street AQMA.

| Location | Background NO _x Concentration for 2005 (µg m ⁻³) | Background NO ₂ Concentration for 2005 (µg m ⁻³) | Highest Monitored Annual Average NO ₂ Concentration for 2005 ² (µg m ⁻³) | NO ₂ Road Contribution Multiplicative Adjustment |
|-----------------|---|---|--|---|
| Exeter Street | 22.0 | 17.4 | 41.58 | 2.84 |
| Embankment Road | 22.1 | 16.5 | 42.13 | 2.67 |

The first scenario considered was to determine the effect of increasing the speed of the slowest-moving vehicles: for Exeter Street the speed of those travelling at 21 mph or less was increased to 23.5 mph, and for Embankment Road the speed of those travelling at 26 mph or less was increased from the 13 mph assumed previously to 23.5 mph. The predicted effects are shown in Table 3: a small reduction in both NO_x emissions and NO₂ concentrations is predicted. A similar analysis was carried out, but applied to HGVs or buses only, or both HGVs and buses (Table 3). It should be noted that speed data were not available separately for different vehicles types; it is likely that the heavier vehicles will travel more slowly (particularly for buses since they stop to pick up and set down passengers) and therefore the predictions will be conservative. The effects of increasing the minimum speeds of HGVs and buses alone is predicted to be negligible.

Table 3. Effect of increased minimum traffic speeds on NO_x emissions and NO₂ concentrations in the Exeter Street AQMA.

| Road | Scenario | NO _x | | NO ₂ | |
|---------------|---------------------------|--------------------------------|-------------|--|-------------|
| | | Average Emission Rate (g/km/s) | % Reduction | Annual Average Concentration (µg m ⁻³) | % Reduction |
| Exeter Street | All Vehicles > 23.5 mph | 0.32 | 5.36 | 40.5 | 2.64 |
| | HGVs > 23.5 mph | 0.34 | 0.17 | 41.6 | 0.08 |
| | Buses > 23.5 mph | 0.34 | 0.10 | 41.6 | 0.05 |
| | HGVs and Buses > 23.5 mph | 0.34 | 0.26 | 41.5 | 0.13 |

¹ This adjustment was found necessary by the developers of the DMRB methodology to correctly predict monitored NO_x concentrations.

² Bias adjusted using factor of 0.86 derived from Plymouth AUN co-location study^[1].

Further Assessment of Air Quality May 2007

| | | | | | |
|--------------------|---------------------------|------|------|------|------|
| Embankment Road | All Vehicles > 23.5 mph | 0.43 | 2.34 | 41.6 | 1.18 |
| | HGVs > 23.5 mph | 0.44 | 0.11 | 42.1 | 0.06 |
| | Buses > 23.5 mph | 0.44 | 0.02 | 42.1 | 0.01 |
| | HGVs and Buses > 23.5 mph | 0.44 | 0.14 | 42.1 | 0.07 |

The percentage reduction in HGVs, buses, or HGVs and buses required to meet the $40 \mu\text{g m}^{-3}$ annual average NO_2 air quality objective has been estimated, giving the figures shown in Table 4. It can be seen that reducing HGV flows by about one-quarter is predicted to enable the objective to be met. A reduction of about 50% would be required on Exeter Street to effect the same change from buses only, and would not be achievable on Embankment Road.

Table 4. Percentage reduction in HGVs or buses required to meet the annual average objective for NO₂.

| Road | Scenario | % Reduction Required |
|-----------------|--------------------------|----------------------|
| Exeter Street | HGV Flow Reduced | 24.7 |
| | Bus Flow Reduced | 48.0 |
| | HGV and Bus Flow Reduced | 16.3 |
| Embankment Road | HGV Flow Reduced | 24.5 |
| | Bus Flow Reduced | Not Achievable |
| | HGV and Bus Flow Reduced | 20.6 |

The final scenarios considered were the effects of removing all HGVs, or HGVs during peak hours only (08:00 to 09:15 and 16:00 to 18:15), on NO₂ concentrations. On Exeter Street, removing all HGVs is predicted to reduce the annual average NO₂ concentration to 39.4 µg/m³ (meeting the objective) and removing HGVs during peak hours (which account for 20.1% of HGV flow) is predicted to give 40.3 µg/m³ (falling short of the objective). On Embankment Road, removing all HGVs is predicted to reduce the annual average NO₂ concentration to 33.0 µg/m³ (meeting the objective) and removing HGVs during peak hours (which account for 18.8% of HGV flow) is predicted to give 40.5 µg/m³ (falling short of the objective). It should be noted that measures that reduce vehicle flows will also tend to ease congestion, raising vehicle speeds and further reducing emissions.

Mutley Plain AQMA

The Mutley Plain AQMA encompasses a busy two-lane suburban dual carriageway, which forms part of the B3250. The road is lined on both sides by shops. There are several bus lay-bys, and a large number of bus routes use the road.

Examination of the traffic data supplied for 2005 show that the average daily throughput is 29171 vehicles (total for both directions). The average speed is 20 mph. The profile of the traffic flow is shown in Figure 10.

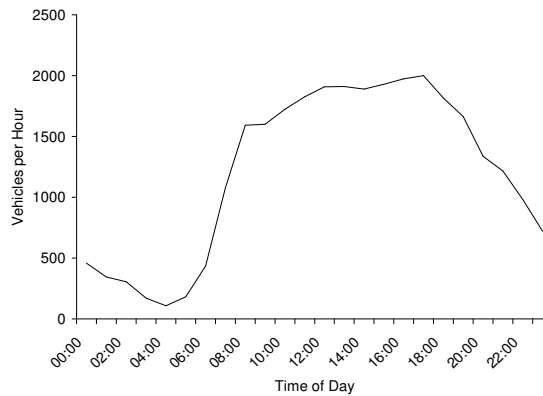


Figure 10. Flows by time of day at Mutley Plain.

Figure 11 shows the flow of vehicles by type in terms of daily totals on the road. Cars account for 93% of total vehicle throughput. However, other vehicle types can make a significant contribution to total NO_x emissions since their emission factors are higher.

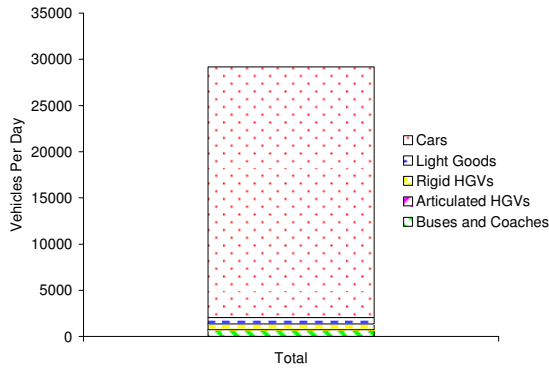


Figure 11. Flows by type of vehicle at Mutley Plain.

Considering the flow characteristics on Mutley Plain provided by the traffic data, and assuming the national fleet composition for the year 2006 within each broad category of vehicle has yielded the NO_x emission rates shown in Figures 12 to 15 and Appendix 3. The estimates were made using the same methodology as described for the Exeter Street AQMA.

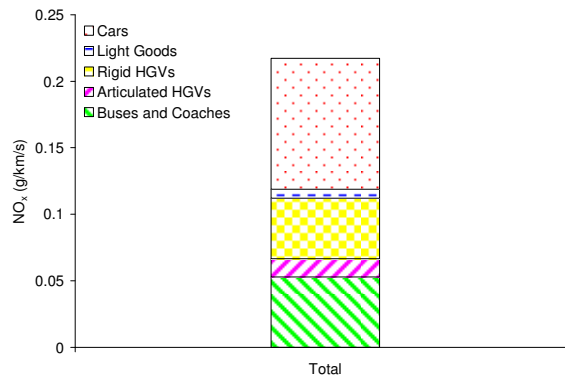


Figure 12. NO_x emissions by vehicle category on Mutley Plain.

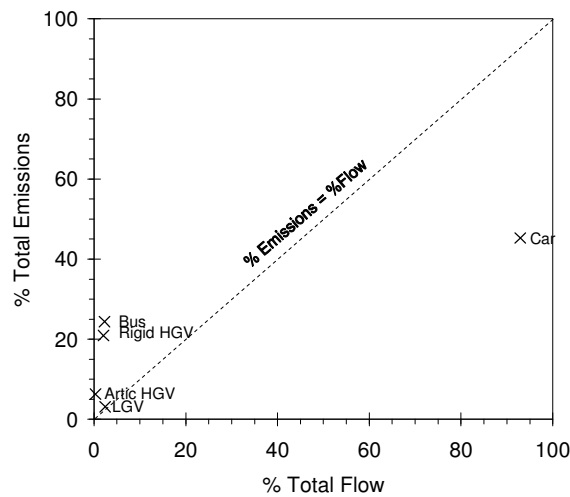


Figure 13. Correlation of NO_x Emissions with flows by type of vehicle on Mutley Plain.

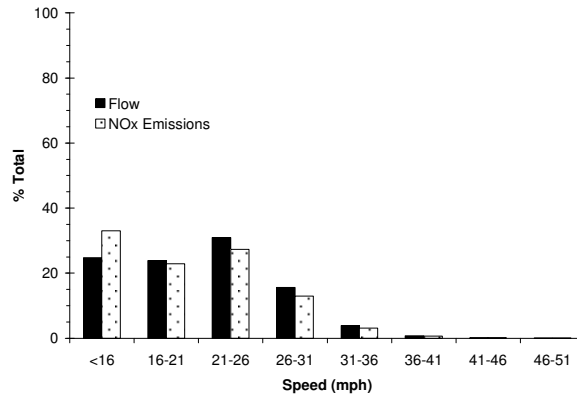


Figure 14. NO_x Emissions by vehicle speed on Mutley Plain.

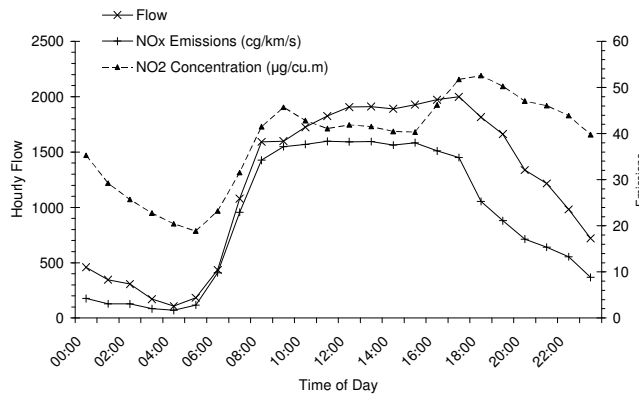


Figure 15. NO_x Emissions, NO₂ concentrations and vehicles flows by time of day on Mutley Plain.

As in the Exeter Street AQMA, it is evident from Figures 11 and 12 that the emissions of NO_x from HGVs and buses are disproportionately large compared to their share of total vehicle throughput (the higher emissions rate per kilometre for heavy vehicles is evident in Figure 7). Emissions from buses are particularly significant, accounting for 24% of emissions compared to 2.3% of traffic throughput. Figure 13 compares the percentage contribution to NO_x emissions with the percentage contribution to total throughput for each type of vehicle. The implications of the above are that measures taken to reduce emissions from heavy vehicles could be just as effective at reducing overall emissions from the road as measures taken to control emissions from cars.

Emissions factors per vehicle-kilometre fall with increased road speed, up to an optimum point after which they start to increase (Figures 7 and 8). Figure 14 compares the percentage of total flow in each band of vehicle speeds with the percentage of NO_x pollution attributable to vehicles travelling in each speed band. It is evident that vehicles travelling less than about 16 miles per hour (26 km/h) account for a disproportionately large percentage of total pollution arising. The effect of increasing the minimum vehicle speed is considered later in this section.

Figure 15 compares the hourly average flow rate and the predicted NO_x emissions rate for the road, and also shows the hourly average NO₂ concentration based on data obtained from the Mutley Plain chemiluminescent analyser between 1st January 2006 and 4th August 2006 (reliable data are not available for much of 2005 owing to commissioning problems^[1]). As would be expected, the magnitude of NO_x emissions generally follows the trends in flow rate. The subtle differences are attributable to changes in traffic speed and the vehicle mix at different times of day. The morning peak hour pollution increases disproportionately to the flow rate owing in part to the increase in slow-moving vehicles (Figure 16).

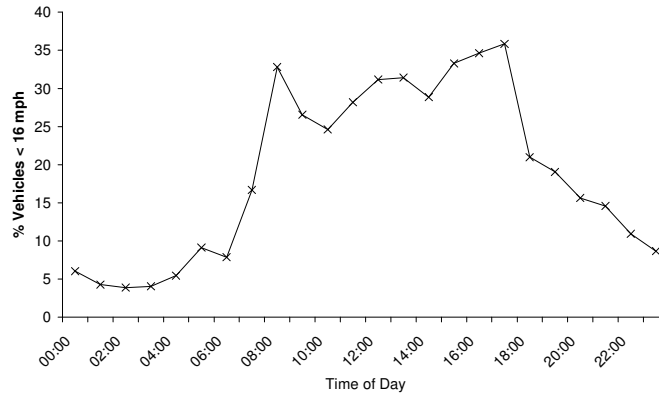


Figure 16. Percentage of slow vehicles by time of day on Mutley Plain.

The NO_2 time trace in Figure 15 generally follows the trend in NO_x arisings, but with some time lag evident. This may arise due to NO_2 being predominantly a secondary pollutant, formed when nitric oxide reacts with ozone. Diurnal availability of tropospheric ozone concentrations may also be a factor; Figure 17 shows that the progressive rise in the NO_2 concentration throughout the day-time may be linked to the availability of ozone. The pronounced peak in NO_2 concentrations between 21:00 and 23:00 that was evident in previously reported data ^[10] is not evident.

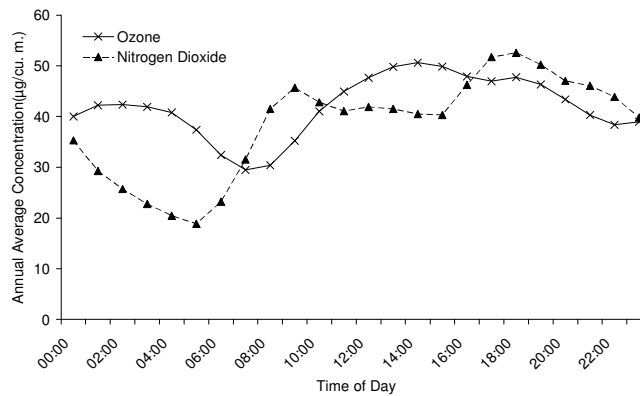


Figure 17. Ozone concentrations at Plymouth's Automatic Urban Network (AUN) monitoring site, averaged by time of day, compared to NO_2 concentrations at Mutley Plain.

A number of scenarios have been modelled to quantify the effects of various possible pollution reduction measures in the Mutley Plain AQMA. These include increasing minimum vehicle speeds and reducing the throughput of heavy goods vehicles and buses. In addition to the prediction of NO_x emission rates for each scenario, it was felt valuable to estimate the effect on NO_2 concentrations; this has been achieved using the methodology already outlined above in the section on the Exeter Street AQMA. The background pollution concentrations, monitored NO_2 concentrations and the derived multiplicative adjustment for the road contribution to NO_2 concentrations are shown in Table 5. Again, the need for such a factor is not surprising, given that the Local Air Quality Management technical guidance ^[8] states that the road component of NO_2 should be doubled to take into account the presence of a street canyon, and the roads under consideration are lined with buildings. Also, when estimating emissions, traffic in the lowest speed category has been assumed to travel at half of the maximum speed for this category; additionally stationary traffic may reduce the average speed for this category (emissions rates are not available in the NAEI for emissions from stationary vehicles ^[9]).

Table 5. Parameters used to estimate NO_2 concentrations in the Mutley Plain AQMA.

| Background NO_x | Background NO_2 | Highest Monitored | NO_2 Road |
|--------------------------|--------------------------|-------------------|--------------------|
|--------------------------|--------------------------|-------------------|--------------------|

| Concentration for 2005 ($\mu\text{g m}^{-3}$) | Concentration for 2005 ($\mu\text{g m}^{-3}$) | Annual Average NO ₂ Concentration for 2005 ($\mu\text{g m}^{-3}$) ³ | Contribution Multiplicative Adjustment |
|--|--|---|--|
| 24.6 | 18.6 | 44.01 | 3.45 |

The first scenario considered was to determine the effect of increasing the speed of the slowest-moving vehicles: the speed of those travelling at 21 mph or less was increased to 23.5 mph. The predicted effects are shown in Table 6: a modest reduction in both NO_x emissions and NO₂ concentrations is predicted, the effect being greater than that in the Exeter Street AQMA where there is a smaller proportion of slow-moving traffic. A similar analysis was carried out, but applied to HGVs or buses only, or both HGVs and buses (Table 6). It should be noted that speed data were not available separately for different vehicles types; it is likely that the heavier vehicles will travel more slowly (particularly for buses since they stop to pick up and set down passengers) and therefore the predictions will be conservative. The effects of increasing the minimum speeds of HGVs and PSVs alone is predicted to be negligible.

Table 6. Effect of increased minimum traffic speeds on NO_x emissions and NO₂ concentrations in the Mutley Plain AQMA.

| Scenario | NO _x | | NO ₂ | |
|---------------------------|--------------------------------------|-------------|--|-------------|
| | Average Emission Rate (g/km/s) | % Reduction | Annual Average Concentration ($\mu\text{g m}^{-3}$) | % Reduction |
| All Vehicles > 23.5 mph | 0.19 | 11.55 | 41.4 | 5.82 |
| HGVs > 23.5 mph | 0.22 | 0.29 | 43.9 | 0.14 |
| Buses > 23.5 mph | 0.22 | 0.29 | 43.9 | 0.14 |
| HGVs and Buses > 23.5 mph | 0.22 | 0.59 | 43.9 | 0.29 |

There are multiple bus stops and lay-bys along the length of Mutley Plain, and quantification of the relative effect of idling buses compared to buses travelling through the AQMA was required (the additional emissions from idling vehicles are not included in the NO_x emission rates estimated elsewhere in this report). The emissions rate from buses passing through the Mutley Plain AQMA averages 0.053 g/km/s, compared to an approximate equivalent emissions rate⁴ of 0.022 g/s for a single idling bus. Given that the length of road in the Mutley Plain AQMA is 0.44 km, this implies that the total NO_x emissions rate from buses passing through the AQMA is 0.023 g/s and hence there would have to be, on average, one bus idling continually within the AQMA for its emissions to equal those from the non-stationary buses. The traffic data show that 665 buses pass through the AQMA per day (excluding minibuses, which are categorised with heavy vans in the traffic data, Table 1), each of these would have to stop for 2 minutes and 10 seconds to be equivalent to one bus idling continually. Not all of these buses will be on local timetabled services (an analysis of timetables shows that there are 866 bus movements per day through Mutley Plain, some of which may be minibuses). The analysis shows that emissions from idling buses are likely to be a significant minority of total emissions within the AQMA.

A previous report by the Centre for Energy and the Environment^[11] showed that the emissions penalty associated with re-starting a bus engine from cold is equivalent to emissions from 6.6 minutes of idling, and hence longer periods of idling should be discouraged.

The percentage reduction in HGVs, buses, or HGVs and buses required to meet the 40 $\mu\text{g m}^{-3}$ annual average NO₂ air quality objective has been estimated, giving the figures shown in Table 7. It can be seen that reducing HGV flows by about 70% is predicted to enable the objective to be met. A reduction of about 77% would be required to effect the same change from buses only.

³ Bias adjusted using factor of 0.86 derived from Plymouth AUN co-location study^[1].

⁴ As outlined in reference 9, in the absence of NAEI data for idling vehicles, an idling emissions rate has been approximated by assuming a speed of 5 km/h.

Table 7. Percentage reduction in HGVs or buses required to meet the annual average objective for NO_2 .

| Scenario | % Reduction Required |
|--------------------------|----------------------|
| HGV Flow Reduced | 68.9 |
| Bus Flow Reduced | 77.2 |
| HGV and Bus Flow Reduced | 36.4 |

The final scenarios considered were the effects of removing all HGVs, or HGVs during peak hours only (08:00 to 09:15 and 16:00 to 18:15), on NO_2 concentrations. Removing all HGVs is predicted to reduce the annual average NO_2 concentration to $38.1 \mu\text{g}/\text{m}^3$ (meeting the objective) and removing HGVs during peak hours (which account for 20.7% of HGV flow) is predicted to give $42.8 \mu\text{g}/\text{m}^3$ (falling short of the objective). It should be noted that measures that reduce vehicle flows will also tend to ease congestion, raising vehicle speeds and further reducing emissions.

Conclusions

Analyses of traffic data for the two AQMAs in Plymouth, have enabled the NO_x emissions to be apportioned between type of vehicle, direction of travel and speed. In both locations, although cars account for over 90% of traffic throughput, they only account for about 45% of total vehicle NO_x arisings. Conversely, heavy goods vehicles account for 4 to 6% of vehicle throughput but give rise to 32% of total NO_x emissions on Exeter Street and 27% at Mutley Plain. Public service vehicles similarly account for low percentages of throughput (below 2.5%), but up to 24% of total emissions. Emissions from heavy vehicles increase greatly at low speeds.

Slow moving traffic and congestion can increase NO_x emissions significantly, and in all cases, the slowest vehicles contribute disproportionately to emissions. The effect of increasing minimum traffic speeds (e.g. by implementing measures to ease congestion) is predicted to be greatest in the Mutley Plain AQMA, where ensuring that all vehicles travel at a minimum speed of 23.5 mph would reduce NO_x emissions by 11.5% and annual average NO_2 concentrations by 5.8%. On Exeter Street, a 5.4% reduction in NO_x emissions and a 2.6% reduction in the annual average NO_2 concentration are predicted. However, none of these reductions would alone be sufficient to enable the NO_2 objective to be met.

It has been estimated that a single bus idling continually on Mutley Plain would give rise to similar NO_x emissions as that calculated for all of the buses passing through the Mutley Plain AQMA (and the latter account for 24% of emissions from mobile vehicles). Given that there are 664 recorded bus movements through the AQMA (excluding minibuses) and appear to be 866 timetabled movements, it is likely that idling buses make a significant contribution to total emissions. Previous research by the Centre indicated that if a bus idles for more than 6.6 minutes, emissions would be reduced if the engine was switched off and re-started.

On Exeter Street, a 25% reduction in HGVs and a 48% reduction in buses was found to be necessary to reduce the annual average NO_2 concentration to meet the objective. On Embankment Road, the required percentage reduction in HGVs was similar, but the objective could not be met by reducing the flow of buses alone. On Mutley Plain, a 69% reduction in HGV flow or a 77% reduction in bus flow would be necessary.

Finally, the effect of removing HGVs, either totally or during peak hours only, was gauged. On all of the roads, a total ban on HGVs was predicted to enable the objective to be met, but a peak hour HGV ban was not. Reductions of less than 100% (e.g. due to local deliveries being allowed) would have a proportionate effect between the figures estimated for the flows "as is" and those with all HGVs removed.

The objectives of the source apportionment analysis are to help inform decisions on appropriate measures that may be adopted in the subsequent air quality action plan and in future Local Transport Plans. The principal findings are that measures to control heavy vehicles could easily be as significant as actions taken to control cars, even though they form a far smaller proportion of vehicle throughput, and that measures taken to enable traffic to flow more freely could also have a significant benefit.

REFERENCES

- 1 **Updating and Screening Assessment 2006.** Plymouth City Council.
- 2 **National Atmospheric Emissions Inventory Vehicle Speed Emission Factors Spreadsheet (Version 02/3)**
(http://www.naei.org.uk/other/vehicle_emissions_v8.xls).
- 3 **National Atmospheric Emissions Inventory UK Vehicle Fleet Composition Projections 2002 (Version 1/2)**
(http://www.naei.org.uk/other/uk_fleet_composition_projections_v2.xls).
- 4 **Nitrogen Dioxide in the United Kingdom.** DEFRA Air Quality Expert Group. (<http://www.defra.gov.uk/environment/airquality/aeqg/mitrogen-dioxide/index.htm>).
- 5 **Design Manual for Roads and Bridges Air Quality Spreadsheet version 1.02**
(http://www.highways.gov.uk/business/documents/dmrb_screening_method.zip).
- 6 **Method for Using the Output from the Casella Stanger EFT in the Local Air Quality Assessment and Regional Impact Assessment Applications of DMRB Screening Method Version 1.02.** Transport Research Laboratory Report PA/SE/4032/03. P.G. Boulter. 2003: TRL Limited.
- 7 **Estimated Background Air Pollution Maps for 2004 and Projections for Other Years, issued 2006: Data for Plymouth**
(http://www.airquality.co.uk/archive/laqm/tools/197_2004.csv).
- 8 **Part IV of the Environment Act 1995: Local Air Quality Management. Technical Guidance. LAQM.TG(03).** London: Department for Environment, Food and Rural Affairs.
- 9 **National Atmospheric Emissions Inventory Road Transport FAQs**
(http://www.naei.org.uk/emissions/kb.php?action=showpost&question_id=145).
- 10 **Plymouth City Council Local Transport Plan 2006 – 2011. Figure 9.9.**
(http://www.plymouth.gov.uk/09_ltp_chapter9_2703x2.pdf).
- 11 **Alternative Strategies for Minibus Operation: Switch-Off vs. Idle at Bus Stops.** T.A. Mitchell 2000: South West Energy and Environment Group Briefing Paper 55.

APPENDIX 1: MODELLING RESULTS FOR EXETER STREETTable 8. *NO_x emission rates for Exeter Street inbound.*

| Time | NO _x Emissions rate (g/km/s) | | | | |
|-------------|---|-------------|-----------|-----------|----------|
| | Car | Light Goods | HGV Rigid | HGV Artic | Bus |
| 00:00-01:00 | 0.022001 | 0.000829 | 0.002942 | 0.003053 | 0.001535 |
| 01:00-02:00 | 0.015958 | 0.000617 | 0.002927 | 0.003037 | 0 |
| 02:00-03:00 | 0.01315 | 0.000614 | 0.004375 | 0.003027 | 0.00152 |
| 03:00-04:00 | 0.006723 | 0.000608 | 0.002885 | 0.005989 | 0 |
| 04:00-05:00 | 0.00412 | 0.00081 | 0.004344 | 0.009015 | 0 |
| 05:00-06:00 | 0.008905 | 0.001217 | 0.013032 | 0.021037 | 0.003018 |
| 06:00-07:00 | 0.033812 | 0.006296 | 0.0395 | 0.028373 | 0.026913 |
| 07:00-08:00 | 0.087694 | 0.014036 | 0.074885 | 0.036362 | 0.036503 |
| 08:00-09:00 | 0.130534 | 0.019365 | 0.088275 | 0.041935 | 0.055215 |
| 09:00-10:00 | 0.12181 | 0.019207 | 0.090067 | 0.039509 | 0.052144 |
| 10:00-11:00 | 0.119774 | 0.018121 | 0.086641 | 0.039527 | 0.055774 |
| 11:00-12:00 | 0.123947 | 0.017087 | 0.082515 | 0.032764 | 0.051013 |
| 12:00-13:00 | 0.127583 | 0.015312 | 0.072366 | 0.032938 | 0.053103 |
| 13:00-14:00 | 0.127671 | 0.015302 | 0.068795 | 0.032918 | 0.05124 |
| 14:00-15:00 | 0.121645 | 0.015875 | 0.074445 | 0.028722 | 0.053927 |
| 15:00-16:00 | 0.115744 | 0.015054 | 0.064169 | 0.024516 | 0.050895 |
| 16:00-17:00 | 0.115003 | 0.012363 | 0.048772 | 0.024417 | 0.04894 |
| 17:00-18:00 | 0.111588 | 0.009021 | 0.035049 | 0.02077 | 0.04858 |
| 18:00-19:00 | 0.093963 | 0.005835 | 0.030154 | 0.016464 | 0.036375 |
| 19:00-20:00 | 0.082153 | 0.004505 | 0.018714 | 0.012943 | 0.021134 |
| 20:00-21:00 | 0.060991 | 0.002972 | 0.015269 | 0.009506 | 0.01752 |
| 21:00-22:00 | 0.052783 | 0.002548 | 0.012253 | 0.009535 | 0.014375 |
| 22:00-23:00 | 0.045501 | 0.001902 | 0.010611 | 0.009437 | 0.014231 |
| 23:00-00:00 | 0.035879 | 0.00126 | 0.009007 | 0.006231 | 0.010963 |

Table 9. *NO_x emission rates for Exeter Street outbound.*

| Time | NO _x Emissions rate (g/km/s) | | | | |
|-------------|---|-------------|-----------|-----------|----------|
| | Car | Light Goods | HGV Rigid | HGV Artic | Bus |
| 00:00-01:00 | 0.027997 | 0.001018 | 0.002899 | 0.003008 | 0.003022 |
| 01:00-02:00 | 0.019784 | 0.000808 | 0.001439 | 0.002986 | 0 |
| 02:00-03:00 | 0.01714 | 0.000602 | 0.002865 | 0.002973 | 0 |
| 03:00-04:00 | 0.010158 | 0.000601 | 0.004287 | 0.002966 | 0.001488 |
| 04:00-05:00 | 0.006601 | 0.000603 | 0.004315 | 0.00597 | 0 |
| 05:00-06:00 | 0.011115 | 0.001412 | 0.007184 | 0.008946 | 0.002994 |
| 06:00-07:00 | 0.023888 | 0.004458 | 0.021688 | 0.021005 | 0.015065 |
| 07:00-08:00 | 0.060439 | 0.012014 | 0.049934 | 0.043956 | 0.039369 |
| 08:00-09:00 | 0.083148 | 0.014428 | 0.064862 | 0.035245 | 0.038549 |
| 09:00-10:00 | 0.090094 | 0.017105 | 0.073173 | 0.037957 | 0.046019 |
| 10:00-11:00 | 0.111852 | 0.018232 | 0.075017 | 0.03812 | 0.051007 |
| 11:00-12:00 | 0.133339 | 0.017155 | 0.075886 | 0.028344 | 0.044269 |
| 12:00-13:00 | 0.147458 | 0.0156 | 0.074237 | 0.028881 | 0.051519 |
| 13:00-14:00 | 0.147755 | 0.015232 | 0.067128 | 0.02915 | 0.048734 |
| 14:00-15:00 | 0.148658 | 0.015469 | 0.072035 | 0.02924 | 0.053771 |
| 15:00-16:00 | 0.156746 | 0.01553 | 0.064763 | 0.026216 | 0.05258 |
| 16:00-17:00 | 0.167014 | 0.012455 | 0.049051 | 0.024553 | 0.056154 |
| 17:00-18:00 | 0.157661 | 0.008222 | 0.02849 | 0.022148 | 0.058977 |
| 18:00-19:00 | 0.106018 | 0.005579 | 0.023781 | 0.009253 | 0.040267 |
| 19:00-20:00 | 0.085572 | 0.003895 | 0.01609 | 0.009107 | 0.025921 |
| 20:00-21:00 | 0.069396 | 0.002661 | 0.010201 | 0.006049 | 0.019751 |
| 21:00-22:00 | 0.075912 | 0.002873 | 0.007284 | 0.009071 | 0.013674 |
| 22:00-23:00 | 0.063671 | 0.00185 | 0.005857 | 0.006078 | 0.012214 |
| 23:00-00:00 | 0.046532 | 0.00164 | 0.007309 | 0.006067 | 0.016763 |

APPENDIX 2: MODELLING RESULTS FOR EMBANKMENT ROADTable 10. NO_x emission rates for Embankment Road inbound.

| Time | NO _x Emissions rate (g/km/s) | | | | Bus |
|-------------|---|-------------|-----------|-----------|----------|
| | Car | Light Goods | HGV Rigid | HGV Artic | |
| 00:00-01:00 | 0.017354 | 0.001123 | 0.00667 | 0.019365 | 0.002762 |
| 01:00-02:00 | 0.011858 | 0.000941 | 0.009351 | 0.013848 | 0.001382 |
| 02:00-03:00 | 0.00897 | 0.000948 | 0.009369 | 0.011097 | 0.001384 |
| 03:00-04:00 | 0.007781 | 0.000754 | 0.008016 | 0.011079 | 0 |
| 04:00-05:00 | 0.006013 | 0.001119 | 0.010657 | 0.016576 | 0 |
| 05:00-06:00 | 0.014172 | 0.002239 | 0.021311 | 0.035908 | 0.002757 |
| 06:00-07:00 | 0.042381 | 0.005028 | 0.050609 | 0.066282 | 0.005513 |
| 07:00-08:00 | 0.127854 | 0.019816 | 0.086436 | 0.085504 | 0.019276 |
| 08:00-09:00 | 0.187163 | 0.023349 | 0.092806 | 0.079279 | 0.032536 |
| 09:00-10:00 | 0.15022 | 0.021306 | 0.10135 | 0.091291 | 0.029011 |
| 10:00-11:00 | 0.154984 | 0.019252 | 0.089212 | 0.085629 | 0.035864 |
| 11:00-12:00 | 0.168616 | 0.018709 | 0.090637 | 0.077422 | 0.030379 |
| 12:00-13:00 | 0.173354 | 0.017794 | 0.081364 | 0.069175 | 0.030399 |
| 13:00-14:00 | 0.171295 | 0.017801 | 0.078725 | 0.077503 | 0.029027 |
| 14:00-15:00 | 0.16641 | 0.018349 | 0.085316 | 0.077428 | 0.028997 |
| 15:00-16:00 | 0.170122 | 0.017971 | 0.069235 | 0.06076 | 0.030338 |
| 16:00-17:00 | 0.181304 | 0.017255 | 0.049304 | 0.035935 | 0.030369 |
| 17:00-18:00 | 0.183732 | 0.013767 | 0.025385 | 0.030487 | 0.031839 |
| 18:00-19:00 | 0.150124 | 0.009684 | 0.02273 | 0.033282 | 0.02493 |
| 19:00-20:00 | 0.121782 | 0.006697 | 0.011996 | 0.033177 | 0.011044 |
| 20:00-21:00 | 0.083813 | 0.004286 | 0.006666 | 0.027653 | 0.011046 |
| 21:00-22:00 | 0.062829 | 0.003539 | 0.006667 | 0.024892 | 0.008287 |
| 22:00-23:00 | 0.044899 | 0.002797 | 0.005338 | 0.024913 | 0.008294 |
| 23:00-00:00 | 0.030523 | 0.001868 | 0.004002 | 0.0249 | 0.005526 |

Table 11. NO_x emission rates for Embankment Road outbound.

| Time | NO _x Emissions rate (g/km/s) | | | | Bus |
|-------------|---|-------------|-----------|-----------|----------|
| | Car | Light Goods | HGV Rigid | HGV Artic | |
| 00:00-01:00 | 0.018466 | 0.001169 | 0.004329 | 0.017959 | 0.001496 |
| 01:00-02:00 | 0.012557 | 0.000967 | 0.00428 | 0.008878 | 0 |
| 02:00-03:00 | 0.011873 | 0.000966 | 0.005706 | 0.005918 | 0 |
| 03:00-04:00 | 0.007164 | 0.001169 | 0.018778 | 0.005992 | 0.001496 |
| 04:00-05:00 | 0.006796 | 0.001384 | 0.00886 | 0.027567 | 0.001531 |
| 05:00-06:00 | 0.017063 | 0.002988 | 0.025416 | 0.040312 | 0.003099 |
| 06:00-07:00 | 0.042948 | 0.008038 | 0.04089 | 0.072244 | 0.014126 |
| 07:00-08:00 | 0.104524 | 0.017895 | 0.083307 | 0.09111 | 0.032973 |
| 08:00-09:00 | 0.130993 | 0.02286 | 0.100731 | 0.094974 | 0.028487 |
| 09:00-10:00 | 0.11347 | 0.021657 | 0.096393 | 0.092291 | 0.03076 |
| 10:00-11:00 | 0.133345 | 0.020634 | 0.100474 | 0.098088 | 0.036784 |
| 11:00-12:00 | 0.150462 | 0.019814 | 0.101719 | 0.091749 | 0.029055 |
| 12:00-13:00 | 0.164621 | 0.018203 | 0.088258 | 0.085446 | 0.032044 |
| 13:00-14:00 | 0.169698 | 0.018008 | 0.08236 | 0.076278 | 0.032039 |
| 14:00-15:00 | 0.172959 | 0.018396 | 0.08668 | 0.076198 | 0.033531 |
| 15:00-16:00 | 0.181804 | 0.018842 | 0.078215 | 0.067354 | 0.038273 |
| 16:00-17:00 | 0.205054 | 0.018101 | 0.060739 | 0.06454 | 0.033812 |
| 17:00-18:00 | 0.207139 | 0.013568 | 0.026796 | 0.043236 | 0.032432 |
| 18:00-19:00 | 0.137525 | 0.007981 | 0.016414 | 0.034049 | 0.018569 |
| 19:00-20:00 | 0.098991 | 0.005194 | 0.011963 | 0.027918 | 0.009303 |
| 20:00-21:00 | 0.072283 | 0.003382 | 0.010399 | 0.024652 | 0.007702 |
| 21:00-22:00 | 0.070264 | 0.003163 | 0.013205 | 0.027394 | 0.006087 |
| 22:00-23:00 | 0.059509 | 0.002356 | 0.008705 | 0.021069 | 0.007524 |
| 23:00-00:00 | 0.036812 | 0.001568 | 0.005799 | 0.018045 | 0.00902 |

APPENDIX 3: MODELLING RESULTS FOR MUTLEY PLAIN*Table 12. NO_x emission rates for Mutley Plain.*

| Time | NO _x Emissions rate (g/km/s) | | | | Bus |
|-------------|---|-------------|-----------|-----------|----------|
| | Car | Light Goods | HGV Rigid | HGV Artic | |
| 00:00-01:00 | 0.038103 | 0.001061 | 0.003112 | 0 | 0 |
| 01:00-02:00 | 0.028768 | 0.000628 | 0.001521 | 0 | 0 |
| 02:00-03:00 | 0.02534 | 0.000624 | 0.003015 | 0 | 0.00157 |
| 03:00-04:00 | 0.013926 | 0.000412 | 0.004485 | 0 | 0.001556 |
| 04:00-05:00 | 0.008382 | 0.000828 | 0.006056 | 0 | 0.001575 |
| 05:00-06:00 | 0.014374 | 0.001455 | 0.009282 | 0.003209 | 0 |
| 06:00-07:00 | 0.031695 | 0.004848 | 0.034258 | 0.006461 | 0.02106 |
| 07:00-08:00 | 0.082033 | 0.010323 | 0.062844 | 0.010567 | 0.063454 |
| 08:00-09:00 | 0.127289 | 0.012203 | 0.080243 | 0.027717 | 0.094759 |
| 09:00-10:00 | 0.124342 | 0.01275 | 0.106824 | 0.022907 | 0.104852 |
| 10:00-11:00 | 0.134932 | 0.01297 | 0.109607 | 0.022722 | 0.096493 |
| 11:00-12:00 | 0.144989 | 0.013307 | 0.100979 | 0.023256 | 0.100613 |
| 12:00-13:00 | 0.153838 | 0.012693 | 0.087573 | 0.02762 | 0.100379 |
| 13:00-14:00 | 0.154431 | 0.012463 | 0.085756 | 0.027647 | 0.102443 |
| 14:00-15:00 | 0.151907 | 0.012626 | 0.086299 | 0.023332 | 0.10092 |
| 15:00-16:00 | 0.156674 | 0.012959 | 0.075062 | 0.03191 | 0.10341 |
| 16:00-17:00 | 0.162697 | 0.011133 | 0.056237 | 0.032149 | 0.100149 |
| 17:00-18:00 | 0.166819 | 0.00952 | 0.048748 | 0.036366 | 0.086575 |
| 18:00-19:00 | 0.150238 | 0.006083 | 0.030261 | 0.007381 | 0.059056 |
| 19:00-20:00 | 0.138511 | 0.004258 | 0.024572 | 0.007279 | 0.036414 |
| 20:00-21:00 | 0.110683 | 0.002885 | 0.023947 | 0.003547 | 0.030196 |
| 21:00-22:00 | 0.100551 | 0.002659 | 0.020398 | 0.003525 | 0.026487 |
| 22:00-23:00 | 0.080176 | 0.001968 | 0.018113 | 0.006831 | 0.025686 |
| 23:00-00:00 | 0.059152 | 0.001294 | 0.011234 | 0.003329 | 0.01336 |