BEDFORD BOROUGH COUNCIL

# A Further Assessment of Nitrogen Dioxide in the Bedford Borough

## A Consultation Document

January 2007

- Technical Services Group
- Environmental Health Service
- Pollution Control Section

PRIDE IN BEDFORD

# YOUR AIR QUALITY

**Bedford Borough Council**

## Introduction

Clean air is essential for a good quality of life and progress has been made since the smogs of the 1950s by regulating industry and introducing smoke control areas. However, there are still problems with certain pollutants, particularly from vehicles. In July 1995, the Environment Act 1995 received Royal assent. Part IV of the Act established a new framework for improving air quality, embracing the National Air Quality Strategy, and incorporating health based standards and systems for the management of air quality.

In keeping with the objectives of the Environment Act and as part of a commitment to sustainable development, Bedford Borough Council approved a Local Air Quality Strategy. A corner stone of this Strategy is the Review and Assessment of Bedford's air quality. The objective is to undertake monitoring and evaluation of air quality throughout the borough in a staged process in order to reduce pollution hot spots and integrate air quality into strategic decision making and policies on a local basis. Review and Assessments of local air quality are required every three years and, if necessary, Air Quality Management Areas (AQMA) declared where pollution levels are found likely to exceed national standards. This continual need to review air quality is because of the consequence of changing circumstances including new and expanding industry and increasing vehicular use which could all potentially impact on local air quality.

## Air Quality Review & Assessment (2004-2005)

Two Detailed Assessments carried out as part of the second round of Review and Assessment confirmed that emissions of Nitrogen Dioxide from the traffic within three locations in Bedford (High Street, Prebend Street and the A421 running through the village of Great Barford) were such that the annual mean National Standard for Nitrogen Dioxide was likely to be exceeded by the objective date of 31$^{st}$ December 2005. In addition, it was concluded that the emissions from the Stewartby Brickworks were such that all three National Standards for Sulphur Dioxide were likely to be exceeded by their respective objective dates, the earliest being 31$^{st}$ of December 2004.

In 2005 the Borough Council declared four AQMA's and commenced two Further Assessments with which to inform the two Action Plans that will be needed to bring about the improvements in air quality necessary to ensure the National Standards are met. A Progress Report in 2005 provided further confirmation of the highlighted exceedences and also identified a need to expand the Nitrogen Dioxide passive air quality monitoring resources, particularly for those sites in London Road and Dame Alice Street. A commitment was also made to install new, more accurate, real time air quality monitoring stations in key locations to monitor both Sulphur Dioxide and Nitrogen Dioxide.

**Air Quality Update and Screening Assessment (2006)**

As part of it's continuing obligations under the Environment Act 1995, Bedford Borough Council commenced the third round of Review and Assessment in 2006 with an Update and Screening Assessment. The purpose being to re-examine the local air quality within the whole Borough to establish if there had been any changes since the second round of Review and Assessment which could threaten air quality elsewhere in the Borough other than those areas where AQMA's had been previously declared. This report incorporated the results of the newly expanded passive air quality monitoring resources for Nitrogen Dioxide. It concluded that, as a consequence of emissions from traffic, there may be a need to expand the existing AQMA's on the High Street and Prebend Street, Bedford. In addition, concerns were raised over the air quality on part of Goldington Road and Ampthill Road Bedford where again, emissions from traffic could threaten achievement of the annual mean National Standard for Nitrogen Dioxide.

**Air Quality Further Assessment (2006)**

Bedford Borough Council has now completed two Further Assessments in respect of the air quality situation in the previously declared AQMA's. These in depth studies have been conducted to characterise the sources of pollution so as to enable effective targeting within the Action Plans. The Further Assessment for Nitrogen Dioxide has supplemented information the Borough already had on the need to either designate further AQMA's or expand those already existing. The Further Assessment has outlined areas outside of the AQMA's where the National Standards are being exceeded. The Updating Screening Assessment previously carried out identified the need for two further Detailed Assessments to be completed on Ampthill Road and Goldington Road. Following completion of the Detailed Assessments, Bedford Borough Council will identify if an AQMA needs to be declared for the whole town Centre, or if expansion of the existing areas is adeqaue to encompass the areas where exceedances are identified. Bedford Borough Council therefore proposes to continue to monitor and await the results of the Detailed Assessments to base this decision.

**Moving Forward - Improving Local Air Quality**

At the time of writing Bedford Borough Council is now in the process of finalising the two Action Plans which, when implemented, will work towards achievement of the currently exceeded National Standards for both Nitrogen Dioxide and Sulphur Dioxide. Improving air quality requires a multidisciplinary approach and as such an Air Quality Working Group has been established to oversee the development and progression of these Action Plans.

To inform the Detailed Assessment, Further Assessment and Action Plan processes, the real time air quality monitoring resources are to be expanded further. The Borough Council currently only operates one real time air quality monitoring station measuring Sulphur Dioxide in Stewartby though this has recently been upgraded and modernized to improve the quality of the data obtained. Funding has been secured to install three more stations. These will be placed in the existing AQMA's and will monitor Sulphur Dioxide or Nitrogen

Dioxide as appropriate. In addition, a local company who operates a station in Kempston, is now supplying the Borough Council with their Sulphur Dioxide data. There are also the two stations measuring Sulphur Dioxide operated by the owners of the Brickworks which are based in Stewartby and Kempston Hardwick. Therefore, in total there will be five monitoring stations measuring sulphur Dioxide and two stations measuring Nitrogen Dioxide within the Borough. This is a significant achievement and will ensure a good spread of accurate air quality monitoring data be continually obtained for years to come.

**Our Commitment to You**

Bedford Borough Council's Corporate Plan identifies 6 key priorities to which the Council is fully committed, one of these is to provide a "Clean and Green Borough". As part of this commitment the Council strives for a continuing improvement of air quality within the Borough making it a safe and clean place to live, work, visit and enjoy. With this is mind the Council will use its best endeavours to secure the achievement of the National Standards.

David Logan
Head of Service (Environmental Health, Bedford Borough Council)

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# Further Assessment of Nitrogen Dioxide for the Bedford Borough Council

## (as required by s.84(1) of the Environment Act 1995)

October 2006

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## Executive Summary

Section 84(1) of the Environment Act 1995 requires the Council to undertake the Further Assessment following the designation of its air quality management areas (AQMAs). This Further Assessment of nitrogen dioxide report for the Bedford Borough Council ("the Council") follows the Council's Detailed Assessment and Air Quality Progress reports and thus fulfils this next step of the Local Air Quality Management (LAQM) process.

The earlier Detailed Assessment report produced by the Council identified areas within the Council's area where the annual mean nitrogen dioxide concentrations were predicted to exceed government objectives. Public exposure was identified in these areas and the Council consequently designated three AQMAs (two in the town centre of Bedford and one in Great Barford).

New modelling predictions have been made in this report for the Bedford town centre, and these incorporate a series of improvements over and above that undertaken previously. These improvements include both improved modelling methods and treatment of emissions. This report also incorporates further monitoring undertaken in the Council's area.

The revised modelling predictions confirm the earlier findings that the annual mean nitrogen dioxide objective will be exceeded in parts of the Bedford town centre (including the two AQMAs, as well as along adjoining roads).

Further modelling of the Great Barford AQMA has not been undertaken, since this area has greatly changed as a result of the A421 Great Barford Bypass scheme. This new road opened on the 24$^{th}$ August 2006, connecting the Bedford southern bypass with the A1 near St. Neots and therefore bypassing the AQMA in Great Barford. Following the opening of the new road, the Council proposes to continue monitoring at its existing sites in Great Barford for at least the next 12 months. This will permit sufficient time to assess whether or not there has been a reduction in concentrations below AQS objective. On the assumption that concentrations do reduce sufficiently, the Council will revoke the designation of the AQMA in accordance with the government's policy guidance.

This report follows the guidance produced by the Department of Environment, Food and Rural Affairs (DEFRA) and this allows the Council to refine the knowledge of the sources of pollution so that air quality action plans can be properly targeted. This has been undertaken using further modelling predictions.

The report investigates the sources of pollution where the AQS objective for nitrogen dioxide is exceeded within the Council's town centre AQMAs. To do this a number of locations have been chosen to help understand the source contribution of oxides of nitrogen, ($NO_x$). This assessment is for $NO_x$ rather than nitrogen dioxide because the latter is mostly a secondary pollutant formed as a result of complicated atmospheric chemistry from oxides of nitrogen.

The results confirm the importance of road traffic to air quality and based on the median result at the locations investigated, 25% of the total contribution is derived from background sources of $NO_x$ and 75% from road transport.

Additional modelling was undertaken in roads adjoining the town centre AQMAs and this confirmed the results of monitoring, which showed that concentrations of $NO_2$ exceeded the annual mean objective in these areas.

The Council is recommended to undertake the following actions, in respect of the findings for the statutory objectives relating to annual mean nitrogen dioxide:

1) Retain its existing AQMAs and undertake consultation on the findings arising from this report with the statutory and other consultees as required.

2) Amend its existing town centre AQMAs, or alternatively to declare new AQMAs to incorporate those areas of the town centre where the newly identified relevant exposure arises and where the annual mean objective for $NO_2$ is exceeded.

3) Use the results of the source apportionment work in this report to identify potential actions that will enable the Council to work towards improving air quality.

4) Provide a high quality continuous $NO_2$ analysing capability in the town centre AQMAs to improve its current monitoring capability and further inform the findings of this report.

5) For the Great Barford AQMA, to maintain the current $NO_2$ monitoring capability for at least the next 12 months to assess the extent of the likely air quality improvements arising as a result of the recently opened A421 Bypass.

6) If the above findings for the Great Barford AQMA indicate that the annual mean $NO_2$ objective is no longer exceeded, prepare a Detailed Assessment with a view to revoking the AQMA.

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# 1 Introduction to the further assessment of air quality

## 1.1 Overview

This report provides the further assessment of air quality for the Bedford Borough Council ("the Council"). This forms part of the Council's duties under Local Air Quality Management (LAQM) process of the Environment Act 1995.

The report includes revised modelling studies of the Council's Air Quality Management Areas (AQMAs) for nitrogen dioxide ($NO_2$) in the Bedford town centre, plus adjacent areas. Source apportionment of the pollution sources has also been undertaken. Thus the report fulfils this step of the Local Air Quality Management (LAQM) process.

The Council also designated an AQMA along the A421 running through the centre of Great Barford (see section 1.3 below) and designated an AQMA for sulphur dioxide (please note this is the subject of a separate Further Assessment report).

## 1.2 Background

Local air quality management forms a key part of the Government's strategies to achieve the air quality objectives under the Air Quality (England) Regulations 2000 and 2002. As part of its duties the Council completed its Updating and Screening Assessment of the seven LAQM pollutants and concluded that a Detailed Assessment was necessary in parts of the town centre of Bedford and in Great Barford.

The results of the Detailed Assessment of $NO_2$ identified a risk of the annual mean objective (see Table 1) being exceeded after 2005 in the Council's area in the town centre of Bedford at Prebend Street and the High Street and also along the A421 through Great Barford. As a result the Council designated two AQMAs in part of the Bedford town centre and a separate AQMA along the A421 in Great Barford. (Figure 1, Figure 2 and Figure 3 below).

**Table 1** Air quality objective relevant to this Further Assessment

| | Concentration | Measured as | Date to be achieved by |
|---|---|---|---|
| Nitrogen dioxide ($NO_2$) | 40 µg $m^{-3}$ | Annual mean | 31-Dec-05 |

**Figure 1** Bedford AQMA No. 2 in Prebend Street, Bedford

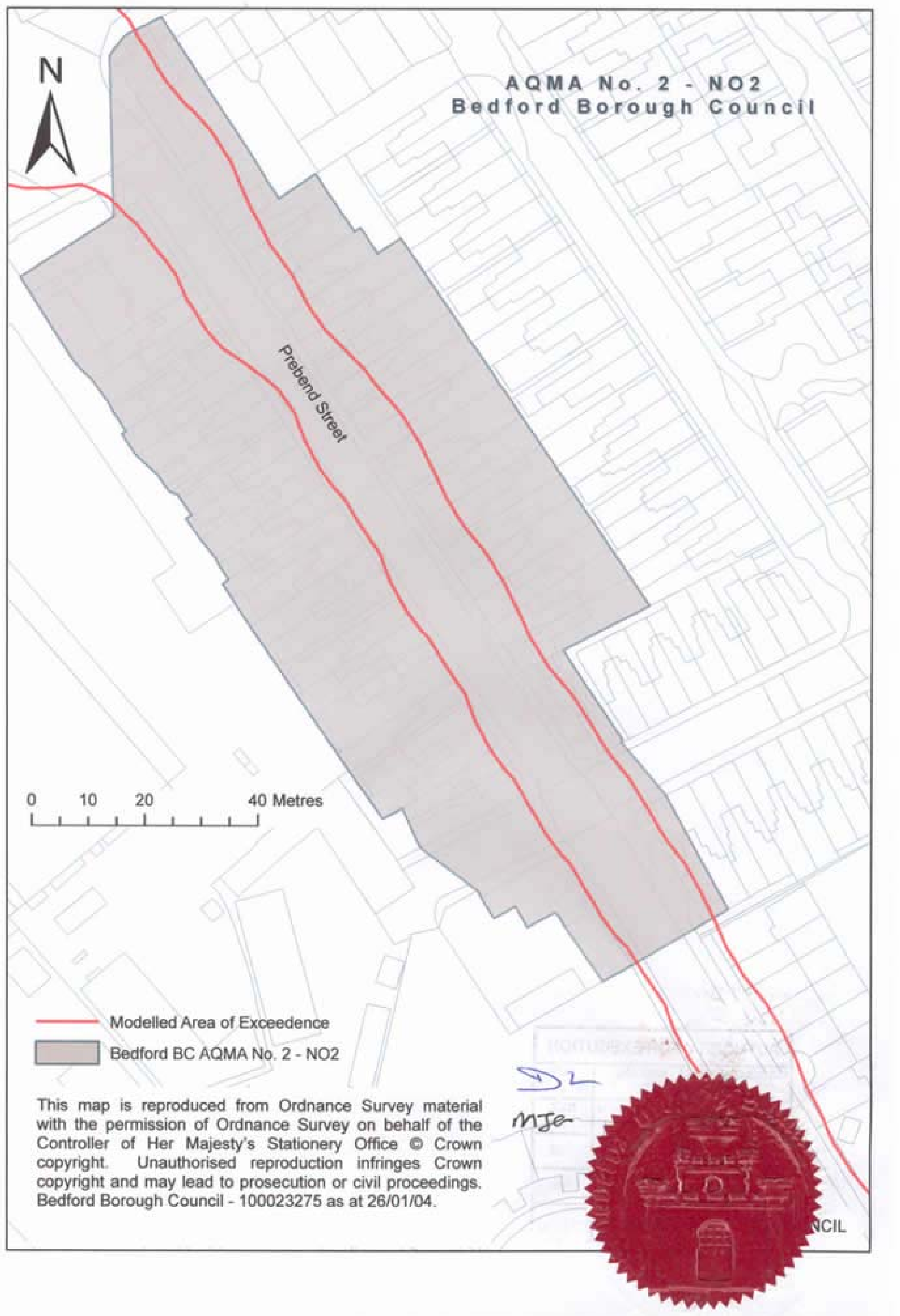
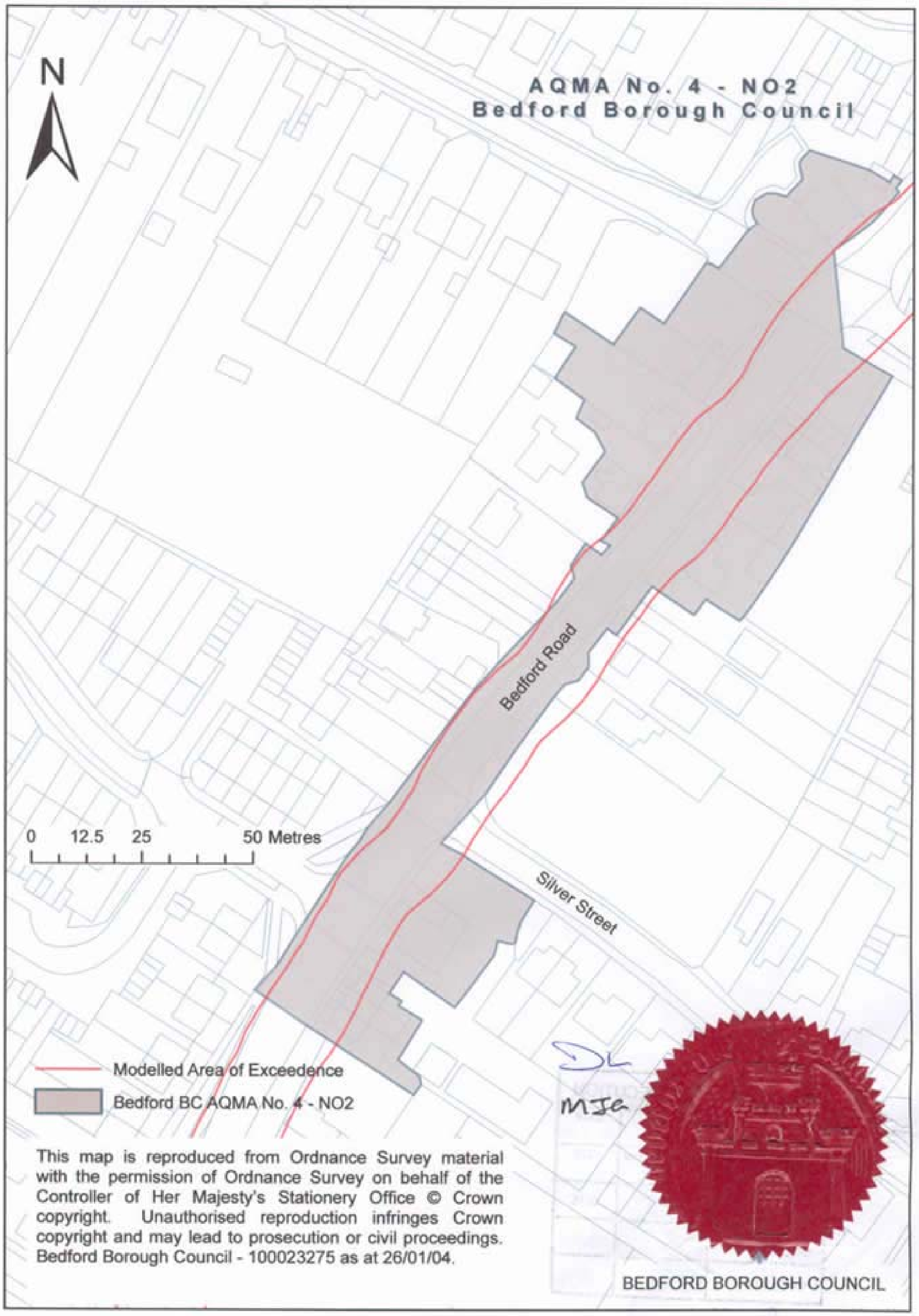


**Figure 2** Bedford AQMA No. 3 in High Street, Bedford

**Figure 3** Bedford AQMA No. 4 in Great Barford



### 1.3 Great Barford AQMA

At the time of the designation of the Great Barford AQMA, the proposal for the A421 Great Barford Bypass scheme was well underway. The Environmental Impact Assessment produced for the road demonstrated that there would be a significant reduction in pollutant concentrations with the proposed Bypass in place (see http://www.highways.gov.uk/roads/projects/4617.aspx). Construction has taken place over the past two years and the Bypass has recently opened to traffic (on the 24th August 2006). It is a dual carriageway, which is 4.8 miles long connecting the Bedford southern bypass with the A1 near St. Neots.

Following the opening of the new road, the Council proposes to continue monitoring at its existing sites in Great Barford for at least the next 12 months. This will permit sufficient time to assess whether or not there has been a reduction in concentrations below AQS objective. On the assumption that concentrations do reduce sufficiently, the Council will revoke the designation of the AQMA in accordance with the government's policy guidance.

# 2 Air Pollution Measurements in the Bedford town centre area

## 2.1 Diffusion tube measurements in the Bedford AQMAs

The Council monitors $NO_2$ using diffusion tubes across the Borough and this chapter provides an update of the results of the monitoring in the AQMAs. The monitoring is undertaken using diffusion tubes supplied and analysed by Gradko. The method of preparation is 50% TEA in acetone.

The sites shown in Figure 4 are the sites located in and adjacent to the two Bedford town centre AQMAs (for specific details see Appendix F). The figure shows the 14 locations in the town centre near to the AQMAs, and of these, all but 3 commenced late in 2004. The new monitoring sites are all sited close to the façade of existing properties representing relevant exposure.

**Figure 4** Bedford town centre diffusion tube sites


The Council is also looking to install two continuous analysers in the Bedford town centre AQMAs and will in due course undertake a local co-location study once the sites have been established. In lieu of this, appropriate correction factors for 2002 to 2005 (to allow for bias) have been derived from the latest default factor spreadsheet (March 2006) from DEFRA’s helpdesk. These factors are derived from series of co-location studies undertaken elsewhere and are as follows:

| Year | Bias factor |
|---|---|
| 2002 | 1.27 |
| 2003 | 1.11 |
| 2004 | 1.1 |
| 2005 | 1.18 |

The factors indicate that the diffusion tube measurements are under reading for all years, compared to continuous measurements. The results presented in Table 2 are the bias adjusted results. It should be noted that results for the sites with less than 75% data capture are marked using italics.

**Table 2** Diffusion tube monitoring in Bedford town centre (2002 to 2005) (µg $m^{-3}$)

| Code | Type | 2002 | 2003 | 2004 | 2005 | Estimated 2010 |
|---|---|---|---|---|---|---|
| BF06 | K (AQMA) | 41.6 | 46 | **44.6** | **45.5** | 38.2 |
| BF25 | K (AQMA) | 34.6 | 46.8 | **41.5** | 39.8 | 33.5 |
| BF30 | K | 43.1 | 59.9 | **50.4** | **60.5** | 50.9 |
| BF37 | R (AQMA) | n.o | n.o | *54.1* | **61.1** | 51.4 |
| BF38 | R (AQMA) | n.o | n.o | *43.4* | **52.2** | 43.9 |
| BF40 | K (AQMA) | n.o | n.o | *59.9* | **57.7** | 48.5 |
| BF41 | R (AQMA) | n.o | n.o | *51.5* | **56.2** | 47.2 |
| BF42 | R (AQMA) | n.o | n.o | *49.9* | **63.6** | 53.5 |
| BF43 | R | n.o | n.o | *50.4* | **53.5** | 45 |
| BF45 | R (AQMA) | n.o | n.o | *48.8* | **52.2** | 43.9 |
| BF46 | R | n.o | n.o | *36.4* | **46.4** | 39 |
| BF48 | R (AQMA) | n.o | n.o | *54.1* | **62.9** | 52.9 |
| BF50 | R | n.o | n.o | *33.1* | 35.3 | 29.7 |
| BF53 | R | n.o | n.o | *49* | **52.3** | 44 |

(Note – n.o indicates that site was not open; bold indicates exceeds objective; italics indicates < 75% data capture)

The 2005 results and estimated 2010 predictions for the sites are also presented in Table 2. The sites within the Council's AQMAs are also indicated. Of the sites that were in existence prior to 2004 and exceeded the annual mean objective in 2005, both BF06 and BF25 are in the AQMAs.

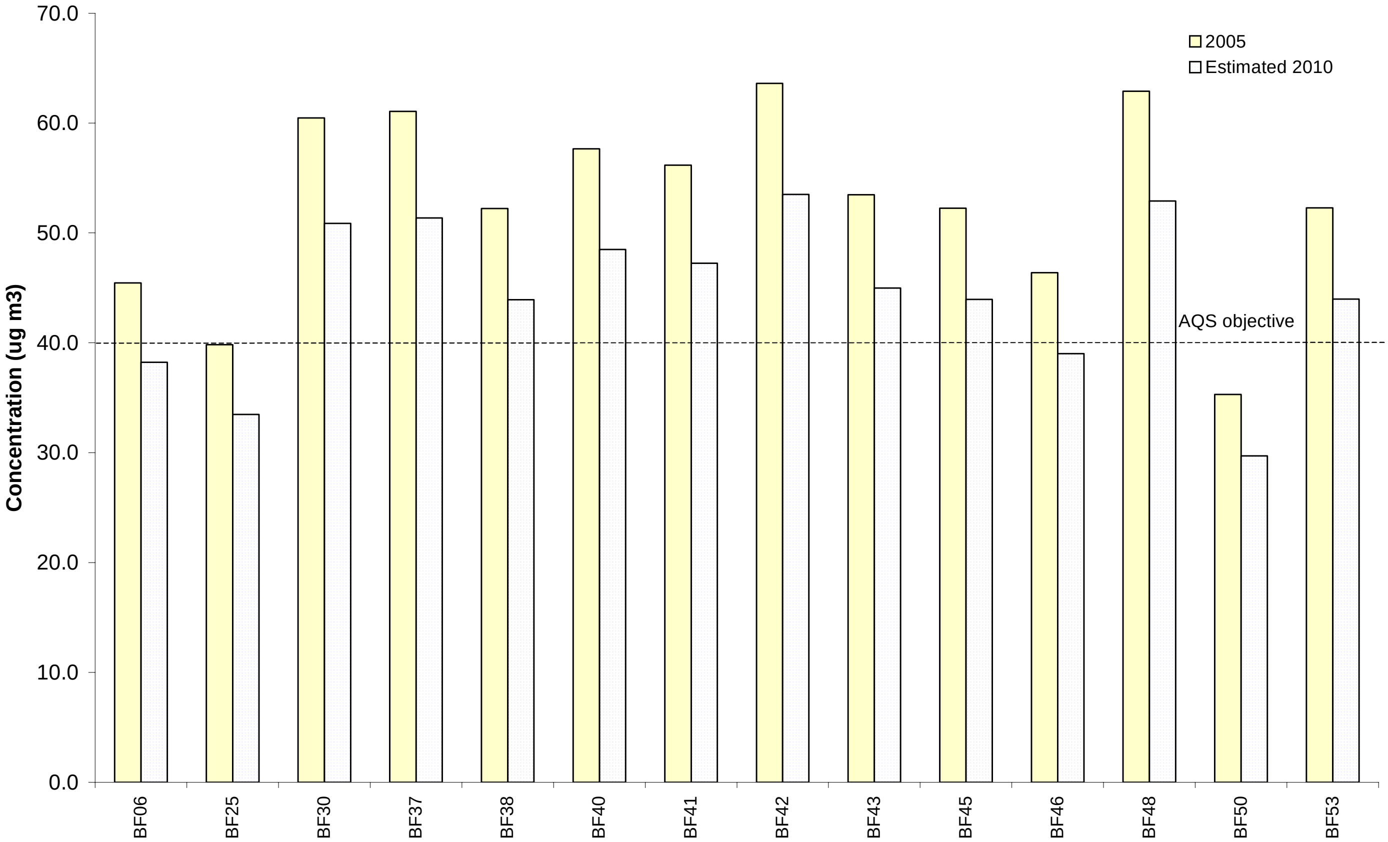
The 2005 monitoring also revealed that the new sites exceeded the objective (BF37, 38, 40, 41, 42, 43, 45, 46, 48 and 53).

As reported in the Council's 2006 Updating and Screening Assessment Report, some of locations near to the AQMAs also exceeded the objective, including sites in River Street (BF30), The Broadway (BF40), Shakespeare Road (BF43), Ashburnham Road (BF46) and Dame Alice Street (BF53). Hence these sites are investigated in this Further Assessment of its AQMAs with a view to amending the AQMA.

The only sites that did not exceed the objective in 2005 were BF 25 (which just met the objective) and BF50 in Tavistock Street.

Estimates based on the predicted reductions in the LAQM TG03 technical guidance are also included for 2010. This date is when the EU Limit value for $NO_2$ should be met. Using these factors, these predictions indicate although there will be a reduction in concentrations it will not be sufficient for all the sites to meet the 40 µg $m^{-3}$ annual mean standard.

**Figure 5** Bias corrected diffusion tube monitoring results in and close to Bedford town centre AQMAs (2005)



# 3 Predictions of Nitrogen Dioxide ($NO_2$) for the Bedford town centre AQMAs

## 3.1 Outline of modelling developments

The Further Assessment incorporates:

- Major roads on an exact geographic basis Ordnance Survey (OS), to allow an improved assessment of exposure;
- Predictions plotted on OS base maps;
- Incorporation of a direct $NO_2$ component;
- A best estimate of model uncertainty, using Monte Carlo techniques;

A detailed explanation of the methods used, including the developments undertaken is given in the appendices.

The model has been empirically developed for urban areas and has been widely validated against a range of continuous monitoring sites in London and the southeast. Details of the model validation are given in Appendix C.

Revised traffic data are used for the modelling; these were obtained from the Department for Transport Rotating Census and are based upon the recent traffic count sites for the road links. Traffic information details are given in Appendix D.

## 3.2 Annual mean $NO_2$ ($\mu g\ m^{-3}$) in 2005

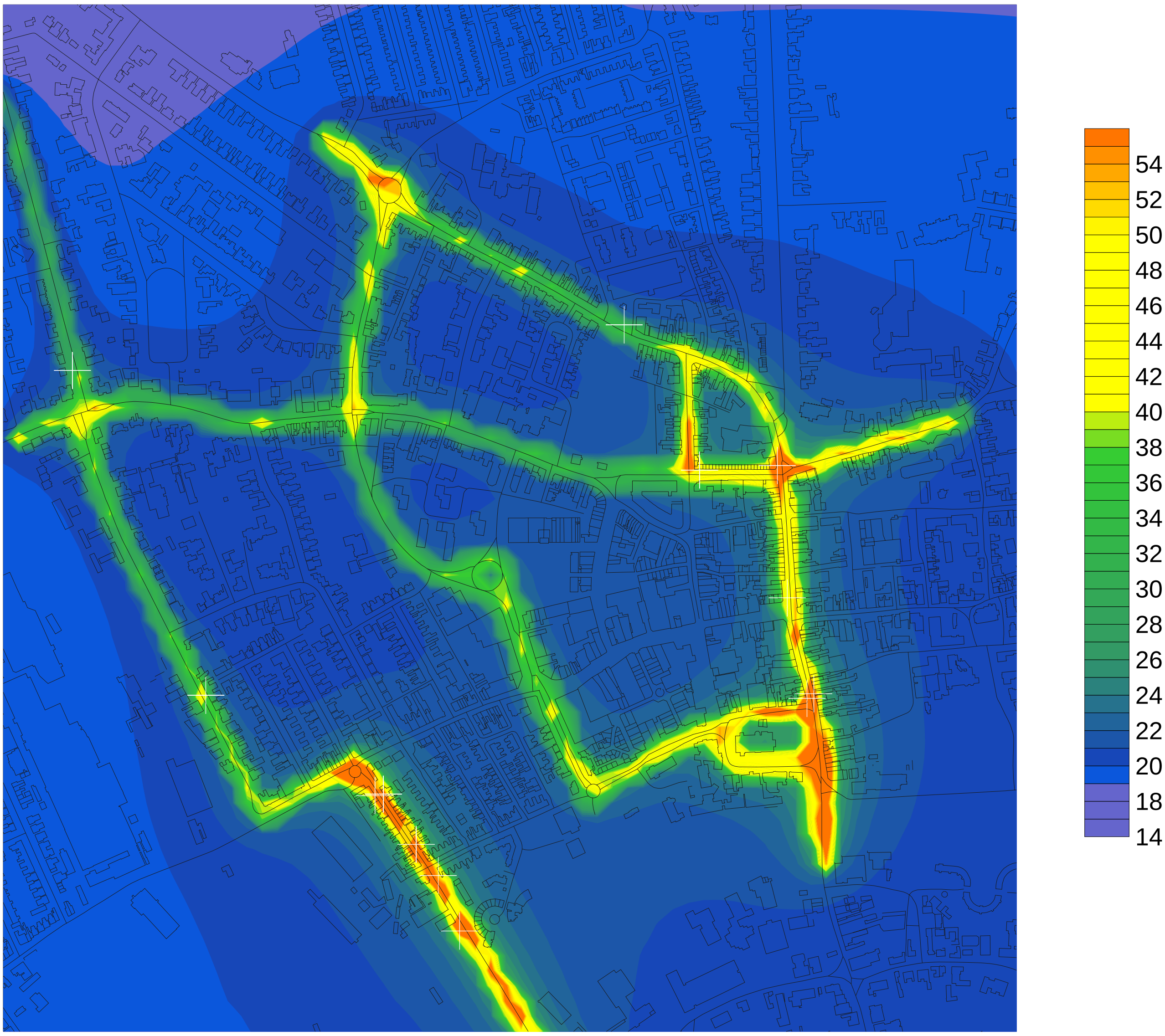
The predicted concentrations of the annual mean $NO_2$ for the corrected 2005 base case are shown in Figure 6. Only areas coloured yellow to red exceed the air quality objective.

The locations of the major roads are modelled to a high degree of accuracy and in this case it is within 1m. This enables the concentration contours to be plotted with OS Landline data[1], which gives details of individual houses and allows easy estimation of the exposure of the local population to concentrations above the AQS objective. The pollution contours also show the rapid fall off in concentration to the background from the road.

The predictions confirm that the air quality objective is exceeded in the AQMAs and in other nearby areas close to the centre of roads and close to junctions.

[1] Note – Reproduction from/based upon the Ordnance Survey Mapping with the permission of the Controller of Her Majesty's Stationery Office © Crown Copyright. Unauthorised reproduction infringes Crown Copyright and may lead to prosecution or civil proceedings. Bedford Borough Council Licence No. LA100023275.

**Figure 6** Modelled annual mean $NO_2$ in Bedford AQMA 2005 (µg $m^{-3}$)




(Note – the white crosses mark Bedford B.C diffusion tube monitoring sites)

### 3.3 Comparison with monitored results

The bias adjusted monitored results for the sites were given in the previous chapter. The 2005 results in the AQMA are compared below to the predicted results at the same sites using the verified 2005 base model. For details of the model verification and the correction factor used see Appendix C.

**Table 3** Bias adjusted monitored and modelled annual mean $NO_2$ concentrations (µg $m^{-3}$)

| Site | Reference | Modelled | Bias adjusted |
|---|---|---|---|
| Ashburnham Road | BF46 | 40.4 | 46.4 |
| Prebend Street | BF48 | 51.6 | 62.9 |
| Prebend Street | BF25 | 61.6 | 39.8 |
| Prebend Street | BF42 | 66.9 | 63.6 |
| Prebend Street | BF38 | 51 | 52.2 |
| Prebend Street | BF45 | 64.4 | 52.2 |
| High Street | BF37 | 64.1 | 61.1 |
| High Street | BF41 | 62.6 | 56.2 |
| High Street | BF06 | 44.2 | 45.5 |
| The Broadway | BF40 | 64.2 | 57.7 |
| Dame Alice Street | BF53 | 47.9 | 52.3 |
| Tavistock Street | BF50 | 31.3 | 35.3 |
| Shakespeare Road | BF46 | 31.5 | 53.5 |

This comparison indicates an overall reasonable agreement, whilst recognising the limitations of both the monitoring and modelling. Some sites in Prebend Street (BF42 and BF38) have a very good agreement, as do BF37 and BF06 in the High Street. The modelled results for the BF25 site in Prebend Street greatly over predicts the monitored result. It should however be noted that this monitored result is much lower than the other monitored results in Prebend Street. The modelled predictions also under predict the monitored results for Ashburnham Road, Dame Alice Street and Tavistock Street. The Broadway site however is over predicted. Shakespeare Road is also greatly under predicted.

### 3.4 Commentary on Bedford AQMA modelling

It is important to recognise that the Bedford AQMA comprises both narrow and highly congested streets that are bounded by buildings on both sides of the road. Such conditions can limit the dispersion of pollution and can lead to locally high concentrations. Prebend Street (shown on the front cover of the report) provides a good example. The photograph was taken mid morning after the morning rush hour and despite this there is still evidence of congestion in the street. This is understood to be typical of conditions during the day along this street. Similarly the High Street, which is a one-way street flowing southward, is also frequently congested.

A reason for this is that the river Ouse flows through the centre of Bedford, acting as a barrier to road traffic. The two bridges; Town Bridge and County Bridge, which lead directly to the High Street and Prebend Street and hence these roads are main routes in and through the Bedford town centre.

As a result of the constricted conditions, the average speed of vehicles is low; with stop start driving during busy congested periods. A combination of these factors leads to higher emissions and consequently higher pollution. Both Prebend Street and the High Street provide examples of this situation in Bedford and as a consequence have the highest monitored $NO_2$ concentrations.

These conditions are challenging to model using dispersion models. This is partly because of the situation as already described, but also because there is a very steep concentration gradient from roads to the background. This means that concentrations can change markedly over the distance of a few metres. This also partly explains why the model predicts some sites better than others.

Despite these limitations it is considered that the modelling in the report provides a reasonable approximation of the Bedford town centre, compared to the bias adjusted monitoring results.

# 4 Source Apportionment for $NO_X$ in the Bedford AQMAs

## 4.1 Methodology

To better understand the air quality improvement needed to achieve the AQS objectives, it is necessary to determine the individual source emissions that contribute to the overall predicted pollution concentration. Both pollutant emissions, location and atmospheric processes, including meteorology, determine the pollution concentration in any given area.

The pollutant under investigation in this stage of the LAQM process, i.e. $NO_2$, further complicates the understanding of source apportionment. For $NO_2$, the contribution that the different sources make to the predicted concentrations can only be understood by examining the contribution of $NO_x$ sources as the primary emission. This reflects the fact that the relationship between $NO_2$ and $NO_x$ is non-linear and determined by photochemistry that is highly location dependent. The modelling undertaken to derive the predictions of $NO_2$ reflect this aspect and this is explored more fully in the model description given in Appendix A. The uncertainty associated with the modelling undertaken is explained in Appendix E.

The source apportionment methodology used here is based on determining the source apportionment for individual categories of the vehicle fleet, which of course recognises the major influence of road transport (as the dominant local source). The categories are Cars (i.e. all diesel and petrol cars, including taxis); Buses (i.e. all buses and coaches); HGVs (i.e. all rigid and articulated vehicles > 3.5 tonnes) and LGVs (including petrol and diesel vans, etc). Each category also includes within it all Euro and pre-Euro classifications.

In all instances the determination of the influences of the different sources is undertaken by modelling sources independently of one another and establishing the predicted concentration at a given point. This is necessary since the influence of the different sources varies between locations due to their proximity to the sources; hence the apportionment is location dependent.

A series of specific point locations were selected for investigation to provide a representative understanding. The locations chosen are the diffusion site locations in the town centre, including the AQMAs.

## 4.2 Annual mean $NO_2$ at identified locations within the Council's area

The understanding of $NO_x$ is based on the 2005 base predictions. The method for calculating the emissions incorporates the many different categories in the vehicle fleet using the road, however for the purposes of understanding source contributions more straightforwardly the following grouping has been applied to the sources:

- HGVs
- LGVs (both petrol and diesel)
- Cars (including all cars, taxis and motorcycles)
- Buses and coaches

A series of model runs for the base case were undertaken for each of the categories described above. The background was determined from the revised background predictions provided by DEFRA (www.airquality.co.uk). (See Figure 4 for the locations of the diffusion tubes sites).

The results in terms of relative contributions of $NO_x$ for these sites are shown in Table 4

**Table 4** Predicted relative $NO_x$ contributions (%) for the different sources

| Location | Ref | Buses | Cars | HGVs | LGVs | Background |
|---|---|---|---|---|---|---|
| Ashburnham Road | BF46 | 11.7 | 26.3 | 23.1 | 5.9 | 33 |
| Prebend Street | BF48 | 9 | 25.2 | 34.4 | 6.5 | 24.9 |
| Prebend Street | BF25 | 9.5 | 26.8 | 36.7 | 6.9 | 20.1 |
| Prebend Street | BF42 | 9.6 | 27.3 | 37.8 | 7.1 | 18.3 |
| Prebend Street | BF38 | 8.7 | 24.8 | 34.4 | 6.4 | 25.7 |
| Prebend Street | BF45 | 9.4 | 27 | 37.5 | 7 | 19.2 |
| High Street | BF37 | 10.4 | 25.2 | 38 | 7.2 | 19.2 |
| High Street | BF41 | 10.3 | 25.1 | 37.8 | 7.1 | 19.7 |
| High Street | BF06 | 8.7 | 22 | 33.1 | 5.9 | 30.3 |
| The Broadway | BF40 | 7.5 | 24.5 | 41.8 | 7.4 | 18.8 |
| Dame Alice Street | BF53 | 9.4 | 20.3 | 37.4 | 5.8 | 27.1 |
| Tavistock Street | BF50 | 3.2 | 17.8 | 25.8 | 6.3 | 47 |
| Shakespeare Rd | BF43 | 5.7 | 24.9 | 18.8 | 6.8 | 43.8 |

The results show the varying contributions between the different sources, which relate to the location itself, especially proximity to kerbside and to the varying traffic activity (types, numbers and speeds of vehicles). As a consequence of this, the background contribution varies between the locations examined, with the smallest proportion at the most polluted site, i.e. BF42 in Prebend Street, which is approximately 18%. The Tavistock Street location (BF50) has a lower measured pollution concentration and hence has the highest background proportion of 47%. For the other sites the background contribution of NOx is between 19 and 33%. The background contribution comprises $NO_x$ arising from other non-road vehicle emission sources, including domestic/ commercial (including heating and lighting) and industrial sources, plus other roads in the area and rural sources.

The HGVs category provides the largest individual contribution of the road vehicle categories at most locations examined, apart from Ashburnham Road, where Cars make the greater contribution. For the Broadway, this contribution reaches almost half the total. Overall for all locations the contribution from HGVs is approximately 30%.

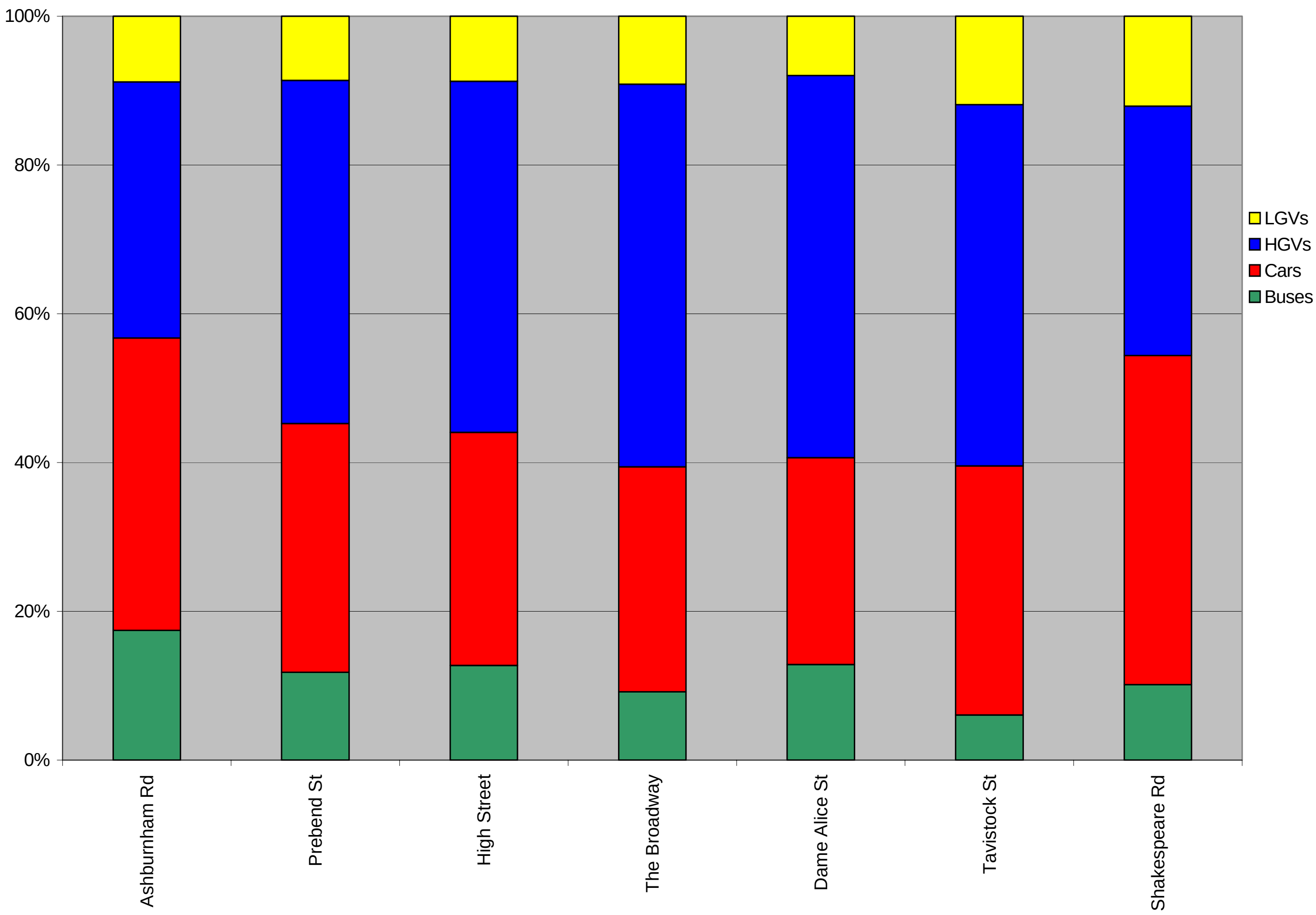
For each of the sites the smallest individual contribution relates to LGVs, which total around 5-7% of the total contribution of $NO_x$ at each site.

The contribution from buses is more than that for LGVs at all sites, and is around 10%, other than at Tavistock Street and Shakespeare Road, which are around 5% or less. The Buses contribution also exceeds that of LGVs at all locations.

The contribution from Cars exceeds that of both Buses and LGVs combined for all locations.  Overall for all locations the contribution is approximately 24%.

The contribution of the road vehicles only to the individual locations is also shown in below. In this instance the road vehicle contributions only are counted and therefore the percentages indicated are relative to this total rather than those in the earlier table. Average values are shown for the Prebend Street and High Street locations.

**Figure 7** Source contribution (excluding background sources)



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# 5 Scenario modelling of Bedford AQMA

## 5.1 Scenario selection

The Council having declared an AQMA is required to produce an action plan following the production of its Further Assessment report. The purpose of the action plan is to allow the Council to work towards the statutory air quality objectives that have been identified as being likely to be exceeded and where members of the public are exposed.

To test the effectiveness of possible measures to improve air quality within the AQMAs, a series of scenario tests have been considered. These reflect the fact that road transport is the main source of emissions (as discussed above). The tests build upon the modelling undertaken earlier, including the source apportionment work.

The scenarios tested reflect that there are likely to be changes over time; both in terms of changes to vehicle flows and an increased uptake of newer less polluting vehicles replacing older vehicles.

The scenarios tested are:

2) 2010 base – with no vehicle growth for Bedford from 2005 until 2010.

3) 2010 plus 10% growth – in this scenario there is 10% vehicle growth above that of the scenario referred to above. The growth is assumed to be equal across all vehicle categories.

4) 2005 base with a 10% reduction in traffic – in this scenario an equal reduction of 10% is assumed across all vehicle categories.

For the future scenarios, the vehicle stock rollover i.e. the replacement of older vehicles by newer vehicles is assumed to be in line with the changes predicted nationally. The vehicle speeds are also assumed to be unchanged for each scenario.

## 5.2 Results of scenario testing

The results of the modelling for the scenario tests undertaken are given in the following table. The results provided are the predicted $NO_2$ concentrations at the selected sites used earlier in the revised modelling chapter (Chapter 3). The modelled results for the 2005 base year are also included for comparison purposes.

**Table 5** Predicted annual mean concentrations of $NO_2$ ($\mu g\ m^{-3}$) at the identified locations

| Site | Ref | 2005 reduced traffic | 2010 base | 2010 plus vehicle growth | 2005 base |
|---|---|---|---|---|---|
| Ashburnham Road | BF46 | 38.3 | 31.9 | 33.3 | 40.4 |
| Prebend Street | BF48 | 48.5 | 39.6 | 41.7 | 51.6 |
| Prebend Street | BF25 | 57.5 | 46.5 | 49.2 | 61.6 |
| Prebend Street | BF42 | 62.4 | 50.2 | 53.3 | 66.9 |
| Prebend Street | BF38 | 47.9 | 39.1 | 41.1 | 51 |
| Prebend Street | BF45 | 60.1 | 48.5 | 51.4 | 64.4 |
| High Street | BF37 | 59.8 | 48.2 | 51.1 | 64.1 |
| High Street | BF41 | 58.5 | 47.2 | 50.0 | 62.6 |
| High Street | BF06 | 41.8 | 34.4 | 36.0 | 44.2 |
| The Broadway | BF40 | 59.9 | 48.1 | 51.1 | 64.2 |
| Dame Alice Street | BF53 | 45.1 | 36.9 | 38.8 | 47.9 |
| Tavistock Street | BF50 | 30.1 | 25.6 | 26.4 | 31.3 |
| Shakespeare Rd | BF43 | 30.2 | 25.8 | 26.7 | 31.5 |

The results indicate that for all locations and scenarios tested, the annual mean concentrations reduce of $NO_2$ will reduce. This reduction reflects both the changes to vehicle flows and stock, plus for the 2010 scenarios, the predicted reduction in background concentrations in the area.

The 2010 base scenario indicates the greatest reduction in concentrations from that of the 2005 base case prediction. Additional sites predicted to meet the 2005 annual mean air quality objective for $NO_2$ include: BF 46 in Ashburnham Road, BF38 and BF 48 in Prebend Street, BF06 in the High Street and BF53 in Dame Alice Street. Despite these reductions, concentrations are still predicted to exceed the objective at other locations in the High Street, Prebend Street and the Broadway.

The 2010 with 10% additional vehicle growth scenario results in higher predicted concentrations than the 2010 base scenario, by up to 3.1 $\mu g\ m^{-3}$. Additionally the BF48 in Prebend Street is predicted to exceed the objective with this scenario.

The scenario with least improvement of those tested is that for 2005 with a reduction of vehicles of 10% on the Bedford town centre roads, based on 2005 traffic flows and vehicle stock. This scenario indicates a reduction of up to 4.5 $\mu g\ m^{-3}$ from the 2005 base case at the most polluted location, i.e. BF42 in Prebend Street. This reduction in concentrations is however insufficient for any location to meet the AQS objective, apart from BF46 in Ashburnham Road.

### 5.3 Commentary on scenarios investigated

There are a number of important points to note about the scenarios and the predicted results. First as reported earlier, the Bedford AQMA is very challenging to model in view of the constricted and congested roads. The base case modelling also showed some variation from the bias adjusted diffusion tube results and hence it reasonable to accept that there will be similar variation between the scenario predictions and those monitored.

The relationship between $NO_x$ and $NO_2$ is one of a number of critical factors relevant to understanding the outcomes from the scenario tests undertaken. This relationship, which is location dependent, provides the understanding between the photochemical processes that lead to the formation of $NO_2$ from $NO_x$. This relationship is non linear which means that a reduction of the primary emission (i.e. $NO_x$) does not lead to a corresponding equivalent reduction in the secondary pollutant. (Appendix A further describes this relationship).

The results and the contour plots produced from the scenario tests highlight that to achieve the annual mean AQS objective at all the locations, further measures would be needed. (See Figure 8, Figure 9 and Figure 10).

**Figure 8** Predicted annual mean concentrations for the 2010 base case (µg $m^{-3}$)

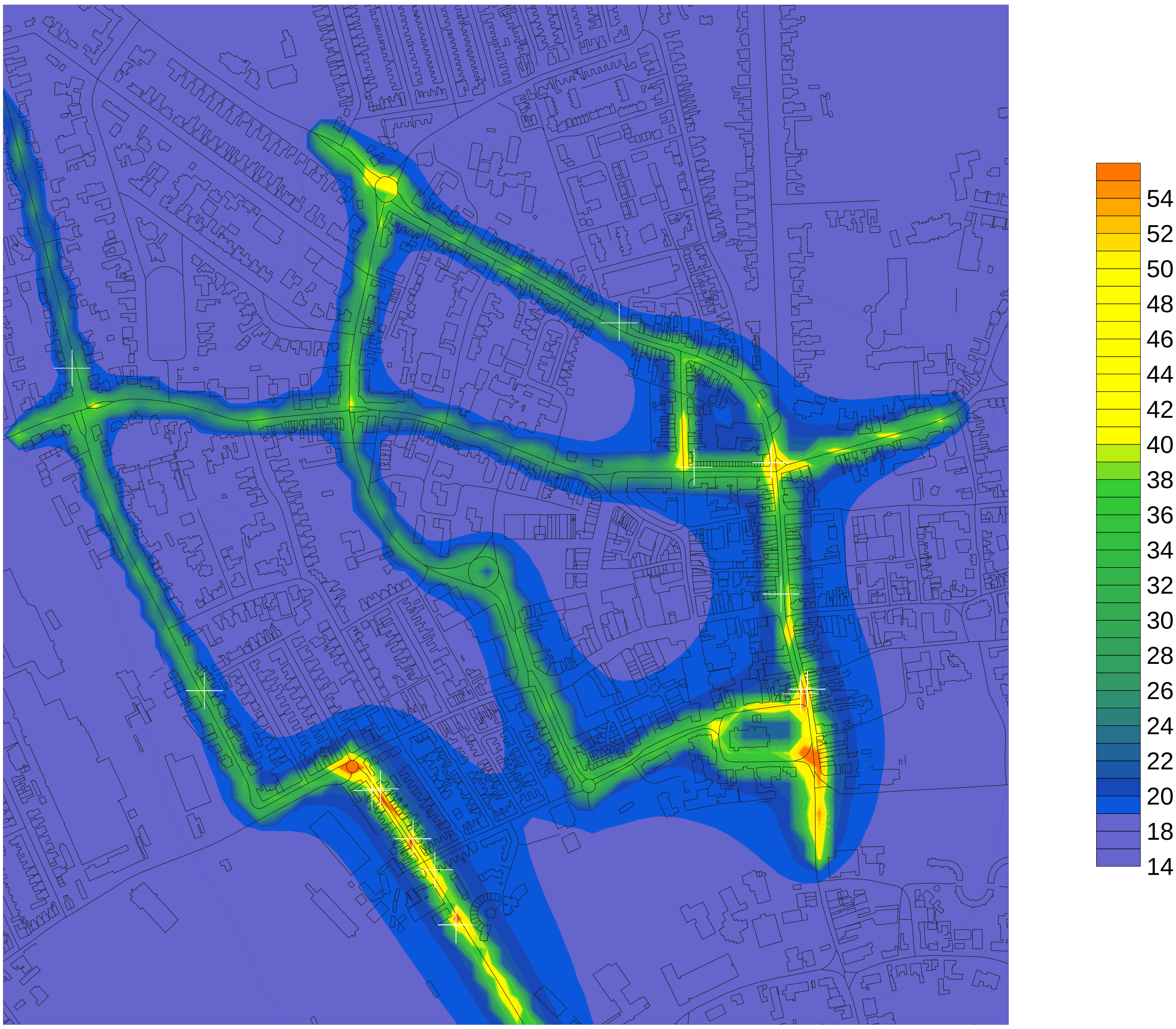

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**Figure 9** Predicted annual mean concentrations for 2010 with extra 10% traffic (µg $m^{-3}$)

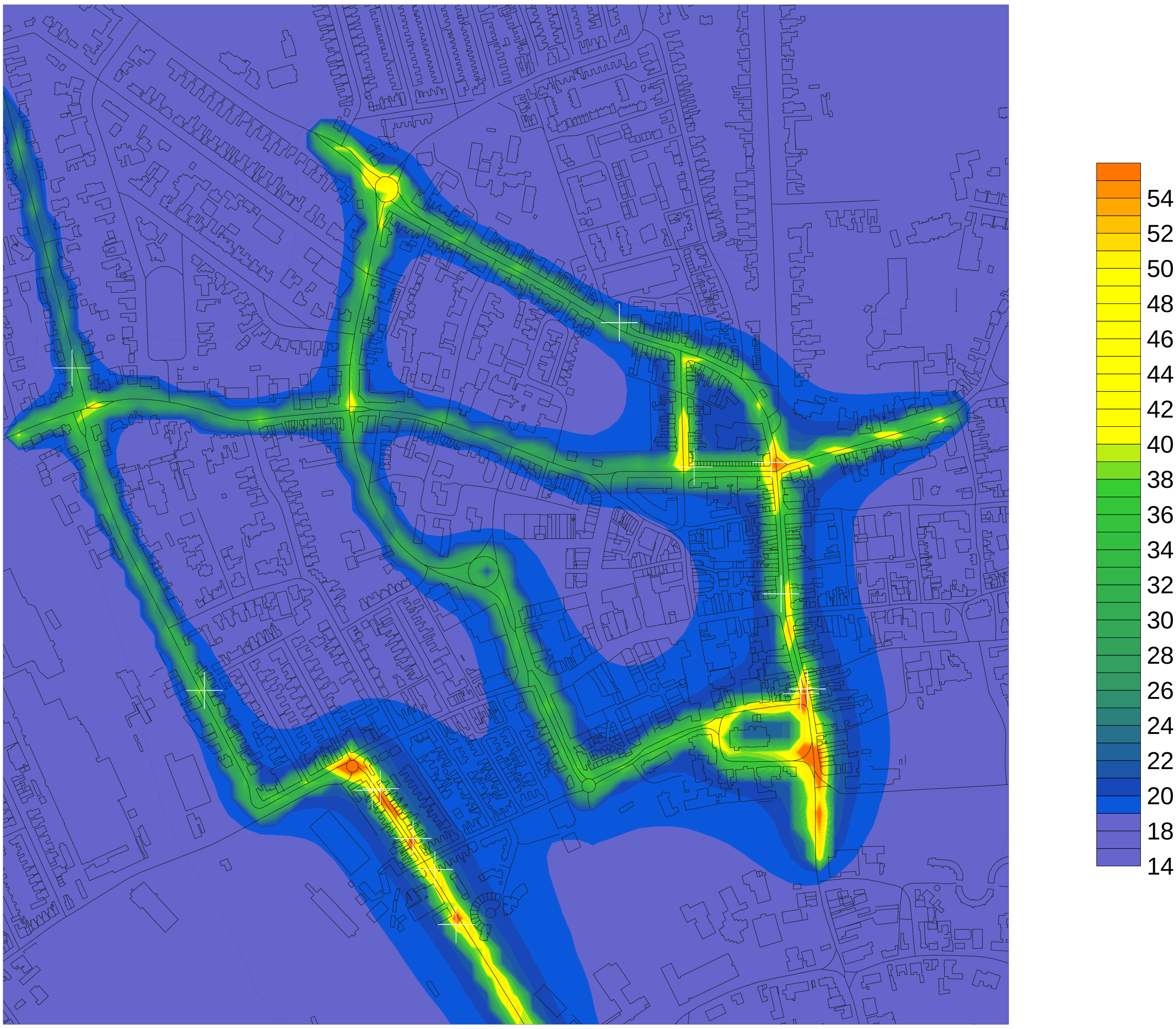

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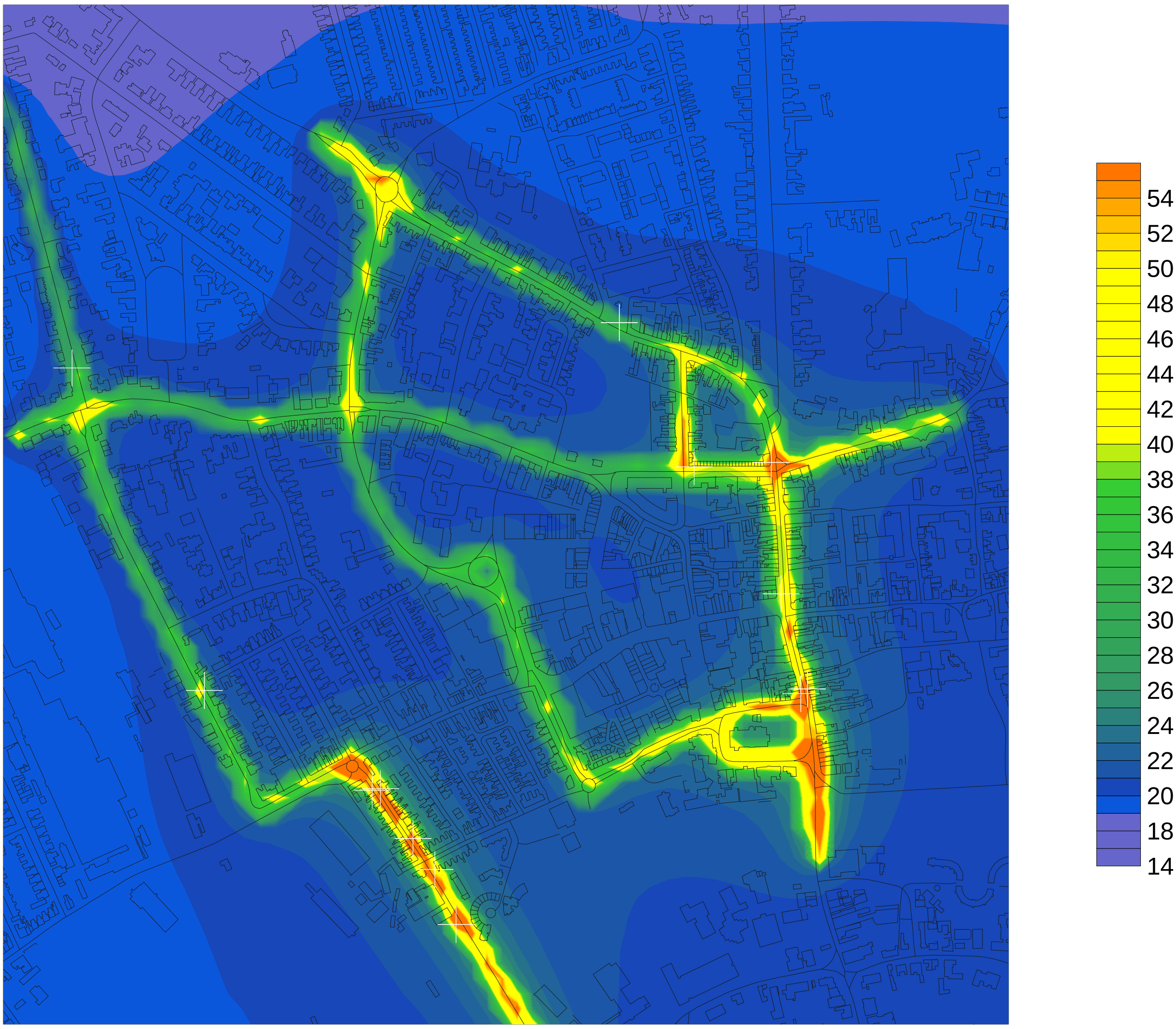
**Figure 10** Predicted 2005 annual mean concentrations with reduced 10% traffic (μg $m^{-3}$)



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# 6 Conclusion

This report fulfils the requirements of the DEFRA guidance for the Further Assessment and addresses relevant issues pertinent to the continuing LAQM process. The Further Assessment incorporates recent monitoring results and improved modelling techniques, plus an improved treatment of emissions using the most recent locally available traffic data.

The bias adjusted monitoring results for the areas investigated in the report indicate that the town centre locations monitored exceed the annual mean objective for 2005. This includes sites in the Council's AQMAs in the High Street and Prebend Street, plus newly established sites nearby.

New verified modelled predictions have been made for the AQMA for the base year of 2005. These predictions compare well to the monitored results despite the difficulties associated with modelling the narrow constricted and congested roads in the town centre. The modelling confirms the extent of the area exceeding the objective, as being mainly confined to the AQMAs, plus additionally close to the centre of roads and junctions elsewhere close to the town centre. This includes parts of the Broadway, St. Peters Street, Dame Alice Street, Midland Road, Ashburnham Road, River Street and Union Street.

Based on this model set up, additional model runs were undertaken to understand and apportion the sources of pollution in the area. This was undertaken for specific vehicles groupings (i.e. cars, buses (and coaches), light goods vehicles (LGVs) and heavy goods vehicles (HGVs)). A contribution representing background sources was also incorporated. The source apportionment modelling was based on concentrations of oxides of nitrogen ($NO_x$) rather than $NO_2$, as $NO_x$ is predominantly emitted as the primary pollutant. The source apportionment was undertaken for specific sites relating to the diffusion tube monitoring sites.

The results of the source apportionment indicated that HGVs were the main group of emission sources, although the contribution from Cars approached that of HGVs in some locations. The combined contribution from Buses and LGVs was less than that of both Cars and HGVs individually for the sites investigated. The contribution of the background sources also formed a major part of the total predicted $NO_x$ at each site investigated.

A series of scenarios were separately modelled to assist in understanding the likely impact of changes over time and in response to changing vehicle flows. The scenarios modelled incorporate a base case for 2010 with no vehicle growth to 2010 from 2005; a 2010 scenario with additional growth of 10% for this period and a 2005 scenario with reduced traffic.

The results for all scenarios indicate that annual mean $NO_2$ concentrations reduce from that of the 2005 base case. The 2010 base scenario indicates the greatest reduction in concentrations. The 2010 with additional vehicle growth of 10% results in higher predicted concentrations than the 2010 base scenario. The 2005 scenario reduced vehicles indicates least improvement for the 2005 base case. For this scenario, only one additional location is predicted to achieve the objective (in Ashburnham Road).

# 7 Recommendation

The Council is recommended to undertake the following actions, in respect of the findings for the statutory objectives relating to annual mean nitrogen dioxide:

1) Retain its existing AQMAs and undertake consultation on the findings arising from this report with the statutory and other consultees as required.

2) Amend its existing town centre AQMAs, or alternatively to declare new AQMAs to incorporate those areas of the town centre where the newly identified relevant exposure arises and where the annual mean objective for $NO_2$ is exceeded.

3) Use the results of the source apportionment work in this report to identify potential actions that will enable the Council to work towards improving air quality.

4) Provide a high quality continuous $NO_2$ analysing capability in the town centre AQMAs to improve its current monitoring capability and to confirm the findings of this report.

5) For the Great Barford AQMA, to maintain the current $NO_2$ monitoring - capability for at least the next 12 months to assess the extent of the likely air quality improvements arising as a result of the recently opened A421 Bypass.

6) If the above findings for the Great Barford AQMA indicate that the annual mean $NO_2$ objective is no longer exceeded, prepare a Detailed Assessment with a view to revoking the AQMA.

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# Appendix A

## 1 Model Development

### 1.1 Model Overview

The modelling approach adopted in this report is refined from that used by the ERG on behalf of local authorities in the southeast of England; including the Mayor of London, London Boroughs, plus Unitary, Borough and District local authorities in Sussex, Surrey, Kent, Essex, Herts and Beds and Berkshire.

A receptor based approach was first developed by ERG through combining both modelling and measurement further. Separate modelling was undertaken of two categories of sources: 1) the road network close to measurement sites and 2) all sources, including roads further away. These were combined with a constant representing emission sources. A multiple regression analysis was then undertaken with the monitoring results from the London Air Quality Network and other regional networks in the southeast to establish the modelling relationship used.

This approach describes the balance between the local road contribution and the background since it provides a good comprise between the most robust aspects of both modelling and measurements.

Further details on the methodology developed can be found on the GLA website (see http://www.london.gov.uk/mayor/environment/air_quality/docs/modelling.pdf)

### 1.2 $NO_X$ and $NO_2$ Relationships

#### 1.2.1 The Adopted Method

To determine the predicted $NO_2$ the ERG method builds on the approach described by Carslaw et al. (2001). In summary, the relationship between hourly $NO_X$ and $NO_2$ can be described by plotting $NO_2$ against $NO_X$ in different $NO_X$ 'bins', for example 0-10 ppb, 10-20 ppb etc, (Derwent and Middleton, 1996). The resulting $NO_X$ to $NO_2$ relationship describes the main features of $NO_X$ chemistry, first the $NO_X$ -limited regime where $NO_2$ concentrations increase rapidly with $NO_X$ and second the $O_3$-limited regime where a change in $NO_X$ concentration has little effect on the concentration of $NO_2$. A third and final regime also exists where, once again $NO_X$ and $NO_2$ increase pro-rata, related to extreme wintertime episodes. In all cases, the precise relationship is always both year and site dependent.

#### 1.2.2 Roadside/ Background Concentrations

Of more use than the hourly relationship discussed earlier is the relationship between the annual mean $NO_X$ and $NO_2$ concentrations. The construction of these curves described in Carslaw et al. (2001) and is both site and year specific. The relationship for a site relates annual mean concentrations of $NO_X$ to $NO_2$ whilst implicitly including the full distribution of concentrations measured each hour of the year.

When using these relationships it is important to differentiate between those applicable to background locations and those applicable to roadside locations for any given predicted year.

The $NO_X$ and $NO_2$ relationships described above are year and site dependent. However, analysis of 1999, the year for which there are most sites shows that the roadside concentrations of $NO_2$ for any $NO_X$ concentration lies within a range of values that can be related to location. The range is from a central London, busy street canyon, at Marylebone Road to an outer London suburb with an open road location, i.e. the A3 dual carriageway. The contrast between the two locations relates specifically to the background concentration of $NO_X$ and $NO_2$, with Marylebone Road (70,000 vehicles per day) in a region of very high background concentration and the A3 site (120,000 vehicles per day) in an area with a low background concentration of $NO_X$ and $NO_2$, and thus it is similar to a rural motorway. For all years Marylebone Road provides the upper limit of $NO_2$ concentrations and A3, the lower limit for any given concentration of $NO_X$. The hierarchy of $NO_X$ and $NO_2$ relationships is summarised in Figure 11.

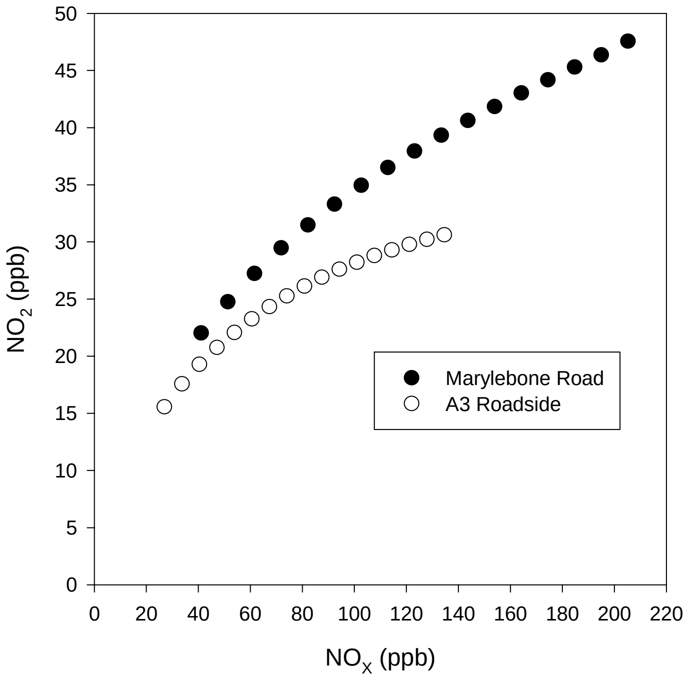



**Figure 11** $NO_X$ and $NO_2$ Relationships at Roadside Sites across London

The range of $NO_2$ concentrations, for a given $NO_X$ concentration at the roadside are much larger than for background locations. This is because of a number of factors, including the relative contribution of the road to total $NO_X$ concentrations, the rapid fall-off in concentration away from a road and the rapid reaction between NO and $O_3$ to form $NO_2$. The use of the roadside/ background curves is decided within the model itself by examination of the ratio of the other source $NO_X$ contribution and local roadside $NO_X$ contribution made at each prediction point.

# Appendix B

## 1 Modelling Detailed Road Networks

### 1.1 Geographic Accuracy of Model Predictions

Significant progress has been made towards improving the geographic accuracy of predictions. All major roads have been split up into 10 m sections, as shown in Figure 12, below. There are several benefits, which result from this development. First, each 10 m point can act as a source of emissions, thus allowing emissions to be varied along each link. This approach allows, for example, emissions near junctions where vehicle idling is important to be increased. Second, the emissions sources are geographically accurate, enabling roundabout and complex road junctions be modelled thoroughly. Third, maps of concentration will also be geographically accurate allowing more accurate assessments to be made of population exposure.

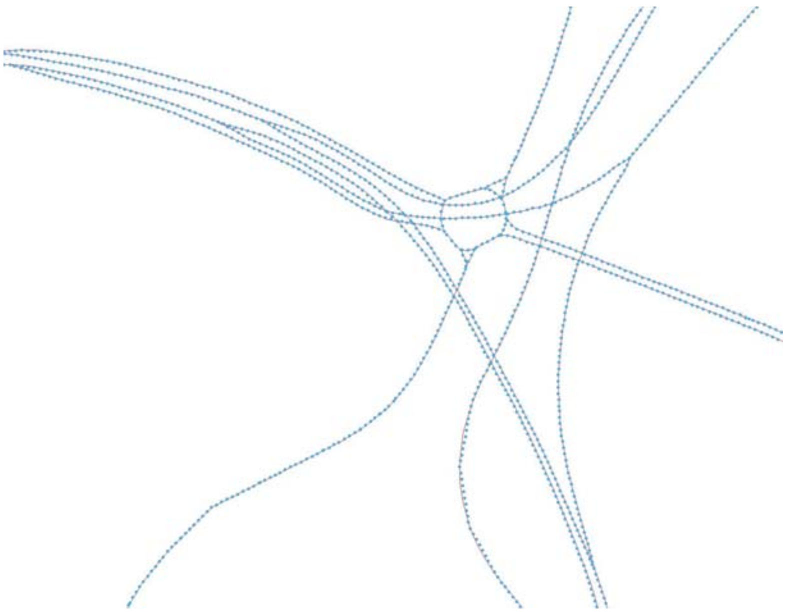


**Figure 12** 10m sections of road, showing complex junction details

This is further demonstrated in Figure 13 overleaf which shows that features such as roundabouts and curved roads are accurately represented.

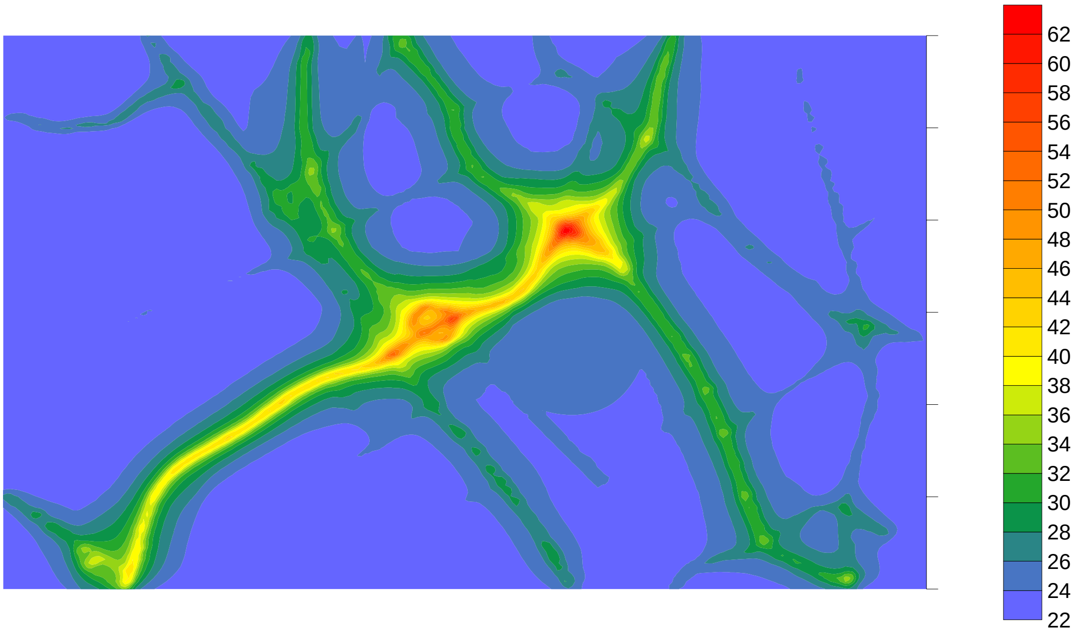



**Figure 13** Modelled example showing concentrations near complex road junctions.

### 1.2 Emissions at Major Road Junctions

The new approach of separating road links into 10 m sections allows emissions near to junctions to be explicitly accounted for. Within a short distance of each junction it is assumed that vehicle idling is increased and the average speed of vehicle is reduced significantly. The assumption used in the model predictions is that 30 m[2] from a major road junction vehicles travel on average at 5 km/hr and that this includes significant periods of idling. Having made significant improvements in the predictions of average link speed, using 'floating car' data, care was taken to keep the link emissions constant, by increasing the emissions at the ends of the links and reducing the emissions elsewhere on the link. In summary the effect of junctions is accounted for through a redistribution of the emissions along each of the road links.

A further set of assumptions is required for the application of such a scheme. First, the road junctions are assumed to be congested on one side of the road only and second, that there is a combination of periods of free flowing traffic and traffic travelling at 5 km/hr. The assumption for the proportion of time spent at the average link speed was assumed to be 50 % on the side of the road affected by the queue. The application of the emissions redistribution was taken only on roads that were greater than 150 m in length as it is assumed that the congested nature of such short links would be well reflected in the measured average speed.

The assumptions used in the emission model are a first estimate and it is accepted that individual road links should be treated independently, for example, using detailed traffic models. However, data on delay times and average speeds are not available, for specific road junctions. Furthermore, emission factors of the type used to develop large-scale emissions inventories are not a suitable method by which to represent emissions

[2] 30 m was assumed as being a typical length for queuing traffic. In practice, road traffic activity is more variable and there is a lack of quality data available from which to improve the predictions made here.

for specific driving characteristics (idling, acceleration/deceleration), which are unique to each junction separately.

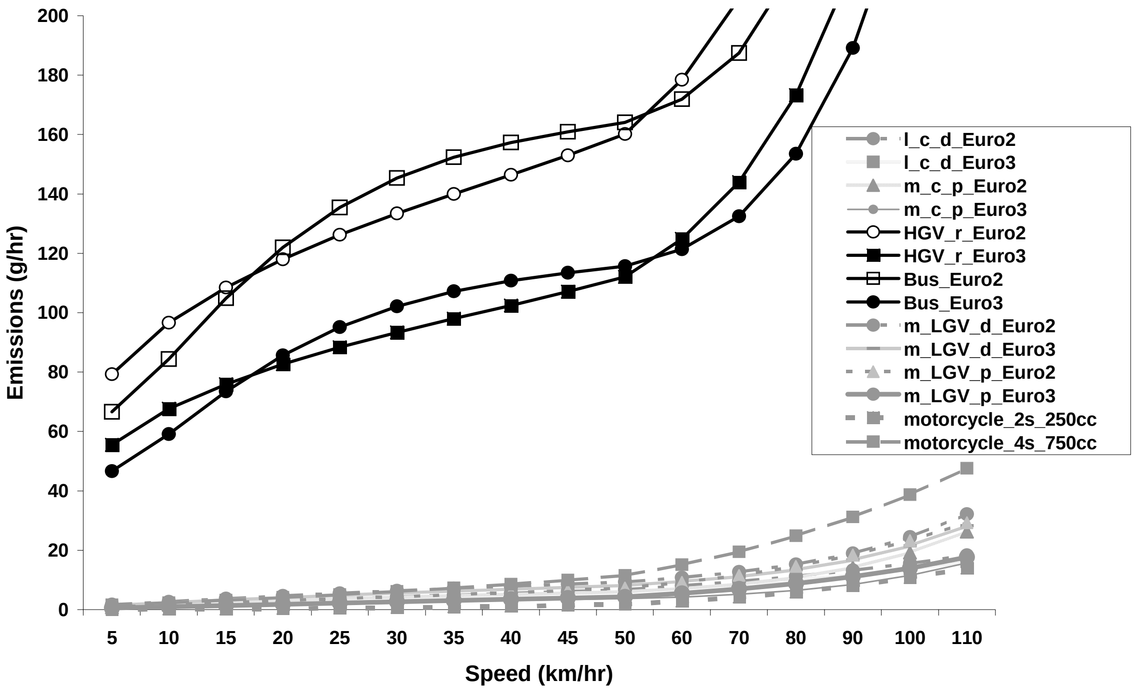



**Figure 14** Emissions $NO_X$ (g/hr) for Euro 2 and 3 Vehicles at different Average Speeds (km/hr)

The detailed DMRB emission factors are applicable down to a speed of 5 km/hr, although factors at this speed are highly uncertain. These data were employed in the redistribution of junction emissions described above. It is worth therefore investigating the effect of low speeds on the emissions of, in this case $NO_X$, from different vehicle types. By multiplying the g/km results for different average speeds by the speed the emissions may be expressed in g/hr. A sample of the g/hr vehicle emissions for Euro 2 and 3 vehicles is summarised in Figure 14 above. It shows that as LGV (petrol and diesel), cars (petrol and diesel) and motorcycles increase their speed so the emissions increase steadily and are at a maximum at 110 km/hr. This increase in emissions is related to the additional work, which is being done by the engine. It is important to note however, that for these vehicle types the g/hr emissions approaches zero at 5 km/hr. Also plotted in black are rigid HGVs, and buses in the Euro 2 and 3 technology categories. These vehicles contrast significantly with the cars, LGVs and motorcycles by showing emissions up to a factor 40 times greater than for smaller vehicles at very slow speeds. It is therefore these specific vehicle types, which provide the majority of the emissions close to road junctions. Since comparatively little work has been carried out on emissions from heavy vehicles, the emission factors derived at such slow speeds should be treated with considerable caution. It is important to considered these effects when considering the results from the modelling.

# Appendix C

## 1 Model Validation and Verification

### 1.1 Model validation

A comprehensive validation exercise has been undertaken for the ERG $NO_X$-$NO_2$ model at measurement sites in London. A very extensive data set exists for the years 1996, 1997, 1998 and 1999 and these were used in the exercise. Comparisons were made with sites located at roadside and kerbside in both open locations and street canyons, as well as in background locations. All sites were not available for every year and for $NO_X$ and $NO_2$ $PM_{10}$.

To ensure the validity of the exercise care was taken to locate the site locations as accurately as possible, particularly in relation to roadside sites, where a steep concentration gradient exists and poor site locations may lead to significant changes to the model performance.

Overall the model performed very well with the average modelled and measured predictions showing close agreement. A summary of the overall performance of the model gives the standard deviation of the measured minus the predicted $NO_2$ concentrations as 12 % (1996), 9 % (1997), 11 % (1998), and 11 % (1999). The percentages were calculated by dividing the standard deviation by the all site average measured $NO_2$ concentration.

This level of accuracy does not apply to all sites and certain roadside sites are not as well predicted, this might be a result of the very low vehicle speeds at this site (approximately 10 km/hr throughout the day) and the uncertainty in emission factors at this speed, as described in Appendix E.

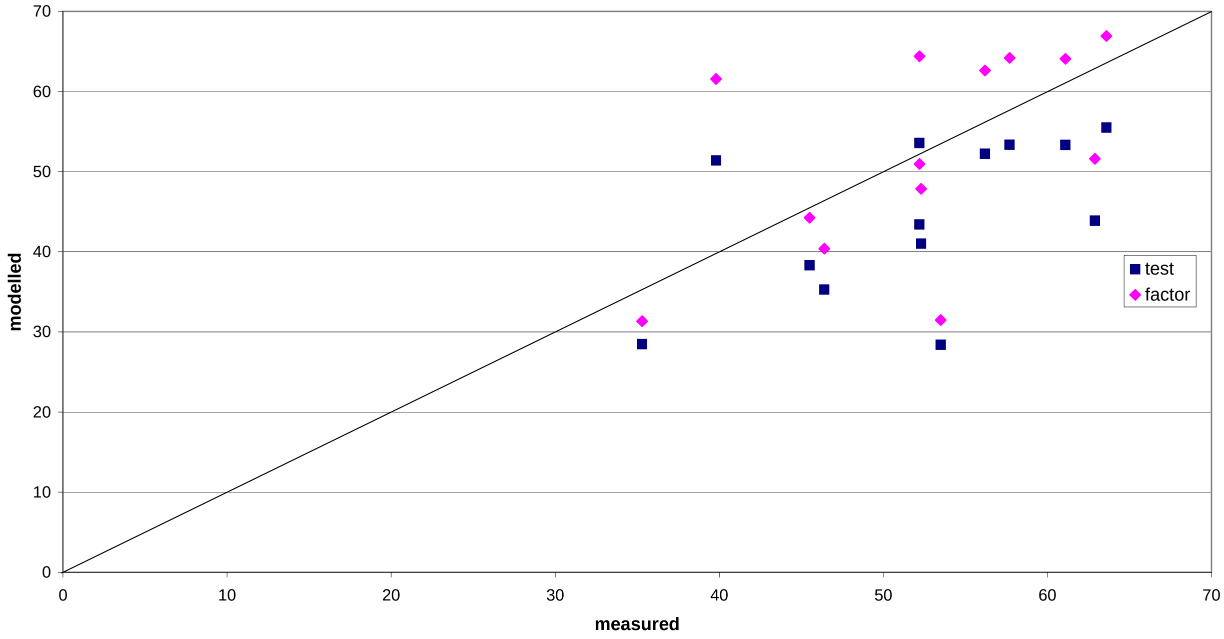
Further details on the methodology developed can be found on the GLA website (see http://www.london.gov.uk/mayor/environment/air_quality/docs/modelling.pdf)

### 1.2 Model verification

The TG03 guidance suggests where there is disparity between predicted and measured results an appropriate adjustment factor should be determined. The guidance also highlights that this is not generally recommended based on solely on diffusion tubes. However in the absence of locally available high quality continuous monitoring data an adjustment factor was derived from the town centre diffusion tube results.

To determine applicability of the ERG model to Bedford a series of model tests were run for 2005. A comparison of the measured to modelled results is given below. The measured results are the bias adjusted diffusion tube results for 2005. (Note for a line indicating a complete agreement between modelled and measured results is included in the figure).

**Figure 15** Comparison of measured results and monitored predictions




The results indicate that the test model did not well with the bias adjusted measured results, with the model results under predicting the measured for all sites, apart from one site which agrees very well and another site that is over predicted. The site that agrees well is BF45 in Prebend Street, whereas the site that is over predicted is BF25, which is also in Prebend Street. As commented in the main text the BF25 site measurement is also less than the other four measurements from Prebend Street (by more than 13 µg $m^{-3}$).

The comparison with the factored model result indicates better agreement, with some sites slightly under predicting measured concentrations and a similar number over predicting slightly. Despite factoring, some sites remain difficult to predict, including the BF25 site again and also BF43 at Shakespeare Road. The BF43 site is located just in front of a large wall and over hanging shrub; it is also close to a pedestrian crossing. The DEFRA guidance note for $NO_2$ diffusion tube monitoring highlights that such sites should be avoided, if possible. However overall this comparison shows that there is no specific bias between modelled and measured results.

The derived factor applied to the roads element only in the modelling is 1.32.

# Appendix D

# 1 Emissions from Road Transport in Bedford

## 1.1 Major Road Flows

Recent AADT traffic counts for 2004 were obtained from the Department for Transport for roads in the AQMA and nearby. These counts are undertaken for the principal A roads in the town centre. For 2005 it was assumed that vehicle growth had increased by 1% based on assumptions used in the Council's Detailed Assessment.

## 1.2 Vehicle Classification, Age and Speed

The breakdown of vehicle ages was based on the national model.

**Table 6** Roads modelled 2005

| Road |
|---|
| St Peter's Street |
| Shakespeare Road |
| Clapham Road |
| St Marys Street |
| Bromham Road |
| The Broadway |
| Bromham Road |
| Dame Alice Street |
| Tavistock Street |
| High Street |
| Ashburnham Road |
| Greyfriars |
| Harpur Street |
| Union Street |
| St Paul's Square |
| Bromham Road |
| St Paul's Square |

Vehicle speeds in the AQMA were not available and therefore assumptions were made of average speeds along links in the area, based on previous discussions with the Bedfordshire County Council and evidence from visiting the town centre. These were estimated at 16kph in the town centre, increasing to 24kph on road links at the periphery of the area modelled. For both Prebend Street and the High Street speeds of 8 kph were assumed.

# Appendix E

## 1 Model Uncertainty Assessment

### 1.1 Introduction

This appendix describes the application of Bayesian Monte Carlo (BMC) analysis to the ERG model developed to predict present and future concentrations of annual average $NO_2$ in London. Model uncertainties arise because of limited scientific knowledge, limited ability to assess the uncertainty of model inputs, for example, emissions from vehicles, poor understanding of the interaction between model and/or emissions inventory parameters, sampling and measurement error associated with $NO_X$ sites in London and whether the model itself completely describes all the necessary atmospheric processes. The application of the BMC technique here results in the reduction in uncertainties predicted through the additional information provided by the measurements themselves.

### 1.2 Uncertainty Assumption in Model Input Parameters

Selection of the uncertainty of input variables are obtained through access to published literature, the opinions of experts in the field, and through the assessment of relationships used within the model. A summary of the assumptions made for the model are given in the table below:

**Table 7** Uncertainty Assumptions (1 σ) use for the Uncertainty Predictions

| | (%) |
|---|---|
| Road Traffic Emissions | 30 |
| Other Emissions | 50 |
| London + Rural $NO_X$ Contribution | 10 |
| Pollution Climate Mapping ($NO_X$) | 11 |
| $NO_X$-$NO_2$ Relationship | 10 |
| Roadside Dispersion | 20 |

### 1.3 Bayesian Monte Carlo Analysis

In Monte Carlo analysis, the model is run with the input variables varied simultaneously and independently of each other and a resulting probability distribution of the output information, obtained. Bayes' theorem is then applied to derive a final uncertainty estimate, by assigning a high probability to those predictions that agree with the measurements and a low or zero probability to those, which do not. The application of probabilities to the model prediction uses the likelihood function (Equation 1) and results in the best estimate of overall model uncertainty.

$$L(Y_k \mid O) = \frac{1}{\sqrt{2\pi\sigma_e}} \exp\left( -\frac{1}{2}\left[\frac{O - Y_k}{\sigma_\varepsilon}\right]^2 \right) \qquad (1)$$

A mathematical summary of BMC is given below. From Bayes' theorem the final probability of model output is defined by equation 2 as

$$p(Y_k \mid O) = \frac{L(Y_k \mid O)\, p(Y_k)}{\sum_{j=1}^{N} L(Y_j \mid O)\, p(Y_j)} \qquad (2)$$

### 1.4 Results at Background

A BMC uncertainty analysis was carried out for annual average $NO_2$ concentration throughout London. The application of BMC analysis reduces the final uncertainty giving a standard deviations in this case are 2.0 ppb (8.5 %).

The BMC analysis was then applied for 5 sites individually and the results summarised in Table 9. Again BMC analysis results in a significant reduction in σ providing a reduction in uncertainty. The average σ for the 5 sites was 1.8 ppb.

**Table 8** Final uncertainty and measured annual mean $NO_2$ concentrations (ppb) at all sites in London for 1998

| Average Model Prediction (ppb) | σ (ppb) | Uncertainty % | Measured Result (ppb) |
|---|---|---|---|
| 23.6 | 2.0 | 8.5 | 23.2 |

**Table 9** Final uncertainty and measured annual mean $NO_2$ Concentrations for separate Sites in London for 1998

| Site Location | Final Model Prediction (ppb) | | Uncertainty % | Measured Results (ppb) |
|---|---|---|---|---|
| | | σ (ppb) | | |
| Bridge Place | 30.6 | 2.2 | 7.2 | 30.2 |
| Bexley 2 | 19.1 | 1.5 | 7.8 | 18 |
| Tower Hamlets 1 | 24.1 | 1.8 | 7.5 | 24.6 |
| West London | 26.8 | 2.0 | 7.5 | 26.8 |
| Sutton 2 | 18.6 | 1.4 | 7.5 | 19.8 |

### 1.5 Results at Roadside

Predictions of the concentration of $NO_2$ at roadsides throughout London have shown a high sensitivity to the pass/fail standard. These predictions are crucial to the development of air pollution control, through local authority action plans, and it is therefore essential to completely understand the uncertainty associated with them. Only then will the strengths and weaknesses of the predictive process be understood enough for decision-makers to make informed policy judgements. It is the uncertainties associated with these predictions, which are the subject of this appendix.

Monte Carlo modelling techniques have been used to calculate the uncertainties associated with roadside $NO_2$ predictions. It also includes a full sensitivity analysis to determine the most important input variables to the model. Specific tests include the uncertainties associated with flows and emissions from LGVs, HGVs and buses, vehicle speed, the dispersion model, and the pollution climate mapping technique, used for calculating background concentrations.

In *Monte Carlo* analysis, the input variables are varied simultaneously and independently of each other, and the effect on important outputs assessed. The model uncertainty, relating to the input parameters, is calculated by treating them as random variables. By studying the resulting probability distribution of the output (i.e. the concentration or emission estimate), information is obtained regarding the model uncertainty.

The original study has focused on Marylebone Road for a base year of 1997 for meteorology and atmospheric chemistry and uses the London Transportation Studies (LTS) traffic model. Further uncertainty assessments have also been undertaken for an “average road’ in central and outer London, as well as a ‘Motorway’ in outer London.

The sensitivity analysis revealed that roadside $NO_X$ predictions are mostly sensitive to the assumptions regarding HGV emissions and flows and the dispersion model used to predict roadside concentrations. For the prediction of $NO_2$, the $NO_X$-$NO_2$ relationship used is the most important factor. Table 10 below shows how each input data or modelling method affects the final concentration, for the Marylebone road example.

**Table 10** The Relative Importance of Model Parameters in Predicting $NO_2$ at Marylebone Road

| Model Parameter | Relative Importance 2005 (% of mean at $2\sigma$) | Relative Importance 1997 (% of mean at $2\sigma$) |
|---|---|---|
| $NO_X$-$NO_2$ relationship | 13.9 | 11.9 |
| HGV emissions | 7.9 | 8.1 |
| Dispersion model | 7.3 | 6.8 |
| HGV flow | 5.5 | 5.5 |
| LGV emissions | 4.2 | 4.7 |
| LGV flow | 4.2 | 4.7 |
| Vehicle speed | 3.6 | 2.1 |
| Background mapping | 1.8 | 1.7 |
| Bus emissions | 1.2 | 0.9 |
| Bus flow | 0.6 | 0.4 |

For 1997, $NO_X$ was predicted to be 258 +/- 83 ppb and $NO_2$ 47 +/- 10 ppb, at two standard deviations – equivalent to the 95 % confidence interval. These statistics assume that the resultant distribution is normal.

The overall uncertainty of $NO_2$, which corresponds to 22 %, is less than that for $NO_X$ (32 %). This feature is a result of the non-linear $NO_2$ relationship, which is quite insensitive to $NO_X$ concentrations, implying that a stated $NO_X$ uncertainty is a better indication of the quality of a prediction.

Measurements for the Marylebone Road site for $NO_X$ and $NO_2$ are within the uncertainty limits calculated here. $NO_X$ was between 213 and 229 ppb and $NO_2$ between 44 and 48 ppb for 1997. The range reflects the two different monitoring techniques used at the Marylebone site.

Similarly, for 2005, $NO_X$ is estimated to be 117 +/- 35 ppb and $NO_2$ 33 +/- 7 ppb, at two standard deviations – equivalent to the 95 % confidence interval. It can therefore be concluded that with a probability of 95 % the true value lies within the ranges given above. This would indicate that, despite the calculation of uncertainty associated with the 2005 predictions, the $NO_2$ concentration always exceeds 21 ppb and therefore Marylebone Road will exceed the AQS objective. This may not always be the case however and with a prediction whose range straddles 21 ppb, a decision must be made concerning the approach to be taken. For example, a prediction of 20 +/- 2 ppb could be considered a pass or a fail.

It is further concluded that the prediction of $NO_2$ concentrations in London depend most on the $NO_X$-$NO_2$ relationship used and the traffic data for HGVs. It is flows of, and emissions from, HGVs and buses that become more important in the future, as emissions from these vehicles will make up a greater proportion of the total.

The results from the analysis of a further three roads is given in Table 11. These represent an average road at a central and outer location and an average motorway in outer London. The flow and percent HGV for the average road was derived from all 10,000 roads in the LTS 91 network.

**Table 11** $NO_2$ Uncertainty Estimates for Typical Roads in London in 2005

| Road Type/Location | Total vehicle flow | Percent HGV | Uncertainty (% of mean at 2σ) |
|---|---|---|---|
| Average road (central London) | 17,000 | 9 | 16 |
| Average road (outer London) | 17,000 | 9 | 18 |
| Motorway (outer London) | 80,000 | 9 | 21 |

***Our best estimate of the uncertainty in annual mean $NO_2$ predictions is therefore +/- 16-21 % at two standard deviations.***

## Appendix F

**Table 12** Location of sites used for source apportionment

| Reference | Road | Easting | Northing | Distance (m) road centre to façade |
|---|---|---|---|---|
| BF46 | Ashburnham Road | 504266 | 249742 | 7.5 |
| BF48 | Prebend Street | 504488 | 249610 | 5.1 |
| BF25 | Prebend Street | 504499 | 249612 | 5.1 |
| BF42 | Prebend Street | 504542 | 249546 | 5.4 |
| BF38 | Prebend Street | 504571 | 249505 | 10 |
| BF45 | Prebend Street | 504599 | 249432 | 10 |
| BF37 | High Street | 505055 | 249738 | 6.3 |
| BF41 | High Street | 505064 | 249744 | 5.5 |
| BF06 | High Street | 505029 | 249870 | 10.2 |
| BF40 | The Broadway | 505016 | 250044 | 7.2 |
| BF53 | Dame Alice Street | 504914 | 250038 | 7.4 |
| BF50 | Tavistock Street | 504815 | 250229 | 8.9 |
| BF43 | Shakespeare rd | 504091 | 250169 | 14.6 |