BEDFORD BOROUGH COUNCIL

A Detailed Assessment of Nitrogen Dioxide in the Bedford Borough

A Consultation Document

September 2004

- 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 much progress has been made to improve air quality since the smogs of the 1950s. Despite these improvements, there still remain problems in some areas with certain air pollutants. In response to this the Environment Act 1995 was introduced and Part IV of this Act established a new framework for improving air quality, including the introduction of Local Air Quality Management. It also incorporated the development of the Air Quality Strategy for England, Scotland, Wales and Northern Ireland and the setting of health based standards and air quality objectives.

As part of its 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. This requires monitoring and the evaluation of air quality throughout the borough as part of a staged process to identify and 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 the air quality objectives. 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

In 2000 during the first round of Review and Assessment Bedford Borough Council concluded that the pollution levels were unlikely to exceed the air quality objectives. However, in 2003 using updated guidance, the Updating and Screening Assessment revealed that the air quality objectives for two air pollutants, sulphur dioxide and nitrogen dioxide, might be exceeded. Consequently Bedford Borough Council was required to carry out more in depth detailed investigations (Detailed Assessments). The Environmental Research Group at King's College London, who specialise in all areas of air quality Review and Assessment aided Bedford Borough Council in this process.

This report forms the basis of the Detailed Assessment for nitrogen dioxide in the Bedford Borough. A separate report has been produced in respect of the Detailed Assessment of sulphur dioxide within the Bedford Borough, copies of which can be obtained on request from the Environmental Health Service (tel: 01234 227270).

Detailed Assessment of Nitrogen Dioxide

The earlier Updating and Screening Assessment concluded that nitrogen dioxide concentrations on three roads: High Street (Bedford Town Centre), Prebend Street (Bedford Town Centre) and the A421 (Great Barford) could exceed the annual mean objective for nitrogen dioxide by the 31st December 2005. The Detailed Assessment builds on this and uses up to date monitoring information, improved modelling techniques and treatment of emissions to seek to confirm whether this air quality objective would be exceeded in any or all of these three locations. The Bedfordshire County Council provided up to date information regarding road traffic in these areas.

The Detailed Assessment reported recent monitoring results for three sites within the above areas and this showed that air pollution concentrations increased significantly between 2002 and 2003. The increases in concentrations were such that the objective for 2005 would be exceeded. Air pollution modelling was also undertaken to show how the air pollution varies across the areas. The predictions were checked against the monitored results and these showed reasonable agreement with the 2002 monitoring results. The results agreed less well with the higher 2003 monitored concentrations and following the government's technical guidance the predictions were adjusted to reflect the 2003 monitoring results, however the report notes that care is needed with the interpretation of these results due to the uncertainty of the method.

The modelling shows that the objective is only exceeded at the façade of several buildings at the south of the High Street for the predictions verified against the 2002 monitoring results. An assessment of these however confirmed that there is no relevant public exposure at these buildings.

For the predictions verified against the 2003 results there were exceedences of the objective along sections of all three roads, including areas where there is relevant public exposure.

Moving Forward - Improving Local Air Quality

Bearing in mind the above it is considered necessary to carry out further confirmatory monitoring. This will increase our current understanding of the air quality situation at these three locations and thus confirm whether the annual mean national standard will in fact be exceeded by the objective date of the 31st of December 2005. To this end, a decision was made to install a minimum of 4 additional diffusion tubes at roadside locations along the length of each of these roads. Therefore, a total of five diffusion tubes, or more, are now in place along each of these roads (as suggested in LAQM TG (03)). In addition, provisions are being sought to finance more accurate real time monitoring at each of these three roads. The data obtained from both this real time monitoring and the new diffusion tubes will be invaluable in enabling more effective local model verification so as to provide more confidence in the modelled results.

It is suggested that a review of the situation be conducted on receipt of sufficient additional monitoring data, possibly as part of the statutory 'Progress Report' required to be submitted in April 2005.

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 in mind the Council will use its best endeavours to secure the achievement of the national standards for nitrogen dioxide.

Ian Smith
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Revised Detailed Assessment of Nitrogen Dioxide for the Bedford Borough Council

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Executive Summary

This is the Detailed Assessment of air quality for the Bedford Borough Council ("the Council"). This assessment fulfils the Council's next step of the Local Air Quality Management (LAQM) process and is required as a result of the findings of the Council's 2003 Updating and Screening Assessment report.

This earlier screening assessment identified that the government's annual mean nitrogen dioxide objective might be exceeded in part of the Council's area, specifically close to the High Street and Prebend Street in Bedford, plus the A421 in Great Barford. The purpose of this report is therefore to provide an accurate assessment of the likelihood of the objective being exceeded at locations with relevant exposure.

To achieve this new modelling predictions have been made for the report, and these include both improved modelling methods and treatment of emissions. The report also incorporates the most recent monitoring results for the above areas. The report thus meets the requirements of the technical guidance LAQM. TG (03) produced by the Department of Environment, Food and Rural Affairs (DEFRA).

The monitoring results for the areas investigated in the report all indicate that the kerbside locations monitored meet the annual mean objective for 2002. The results for the same locations for 2003 however indicate that the annual mean is easily exceeded.

The modelling predictions for the High Street and Prebend Street in Bedford area and the A421 in Great Barford compare well to the monitored results for typical meteorology. This assessment of the identified roads and adjoining areas has indicated that the annual mean NO_2 objective using typical meteorology is not likely to be exceeded in 2005 where there is relevant exposure.

Using an adjustment factor, based on the 2003 diffusion tube results to represent a worst-case scenario, the same areas all indicate that the annual mean objective will be exceeded. However care is needed with this interpretation as the government's technical guidance advises that use of diffusion tubes as the sole means of model verification is not generally recommended.

The Council is recommended:

1) To seek to expand its monitoring capability, including the provision of continuous monitoring at locations most at risk, to confirm the findings of this report.

2) To undertake consultation on the findings arising from this report with the statutory and other consultees as required.

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1 Introduction to Detailed Assessment of Nitrogen Dioxide

1.1 Overview to Detailed Assessment

This is a revised Detailed Assessment of nitrogen dioxide (NO_2) for the Bedford Borough Council. It incorporates updated traffic data and monitoring results. This report therefore fulfils the statutory requirement for this, the Council's next step, of the Local Air Quality Management (LAQM) process. (Please note the Council has prepared a separate report for sulphur dioxide).

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. The conclusion of that work is that the Council needs to undertake a Detailed Assessment for NO_2 for parts of its area only.

The aim of the Council's Detailed Assessment is to determine with reasonable certainty whether or not there is a likelihood of the AQ objectives being achieved. The assumptions in the Detailed Assessment are therefore in depth and the data used are quality assured to a high standard. This allows the Council to have confidence in reaching its air quality management decisions. When carrying out its Detailed Assessment the Council applied its best estimates to all components used in producing estimated future concentrations.

The updating and screening assessment of NO_2 identified a risk of the objectives being exceeded after 2005 in the Council's area in close to the town centre of Bedford (in the High Street and Prebend Street) and in Great Barford (on the A421).

Table 1 Air quality objectives relevant to this Detailed Assessment

	Concentration	Measured as	Date to be achieved by
Nitrogen dioxide (NO_2)	40µg/m^3 (21ppb)	Annual mean	31-Dec-05

It should be noted that the one-hour mean (which is less stringent than the annual mean objective) does not need to be assessed further in this report.

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2 NO_2 monitoring results

2.1 Updated results

This section provides an update of the results of the Council's monitoring at the three areas under investigation. As reported in its Updating and Screening Assessment, the Council undertakes diffusion tube monitoring of NO_2 using Gradko diffusion tubes. The method of preparation is 50% TEA in acetone.

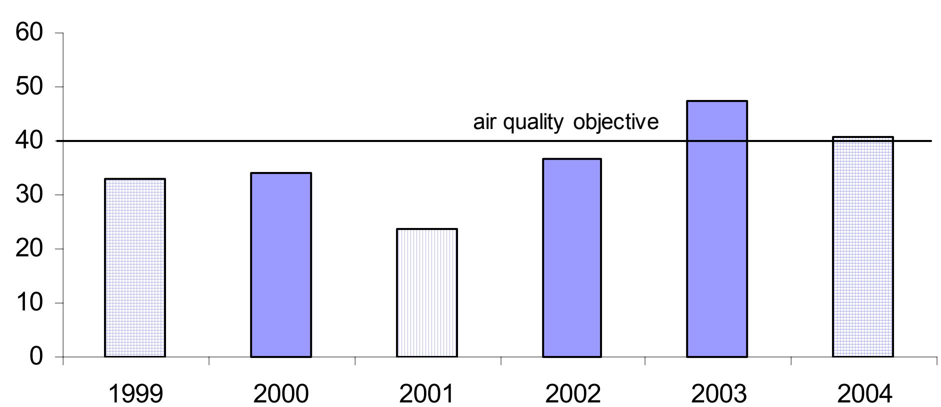
The Council does not operate a continuous analyser and consequently has not undertaken its own co-location study. It has however established a revised bias correction factor from that used in the previous report. This revised factor indicates that the diffusion tubes only slightly under predict concentrations, whereas the previous default factor indicated a much larger under prediction. The bias adjustment factor used in this report is 1.03 and it is derived from a co-location study undertaken by the Epping Forest District Council.

The revised results for the Council's sites are given below. It should be noted that a full year of measurements were not available for all years reported (including the current year) and these are marked as hatched columns (i.e. for these locations there were less than nine months monitoring data were available). These results are provided for information only and therefore care must be taken in interpreting these results.

2.2 A421 Great Barford

The bias adjusted results for the Great Barford site are given in Figure 1 below. The site is a kerbside site and is located 2.5m high and 1m from the kerb.

Figure 1 NO_2 diffusion tube results for Great Barford (BF16)

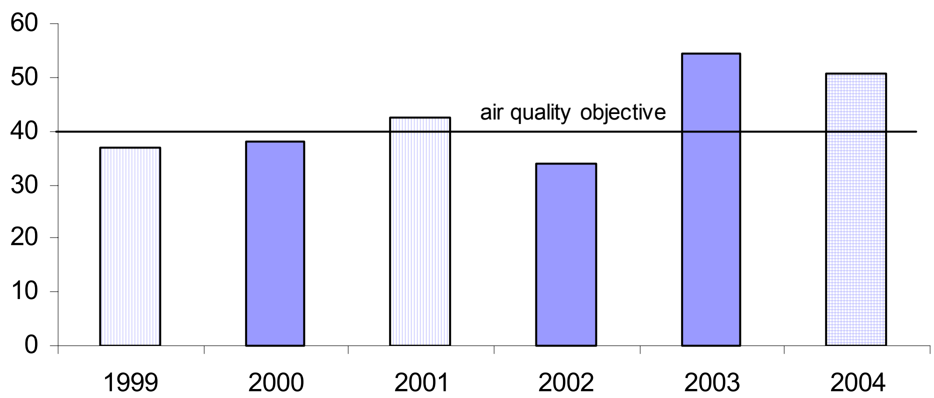


The results using the revised bias factor indicate that the annual mean objective was not exceeded for the two years with sufficient measurements (i.e. 2000 and 2002). The objective was however easily exceeded in 2003.

2.3 Prebend Street, Bedford

The bias adjusted results for the Prebend Street site are given in Figure 2 below. The site is a kerbside site and is located 3m high and 1m from the kerb.

Figure 2 NO_2 diffusion tube results for Prebend Street (BF30)

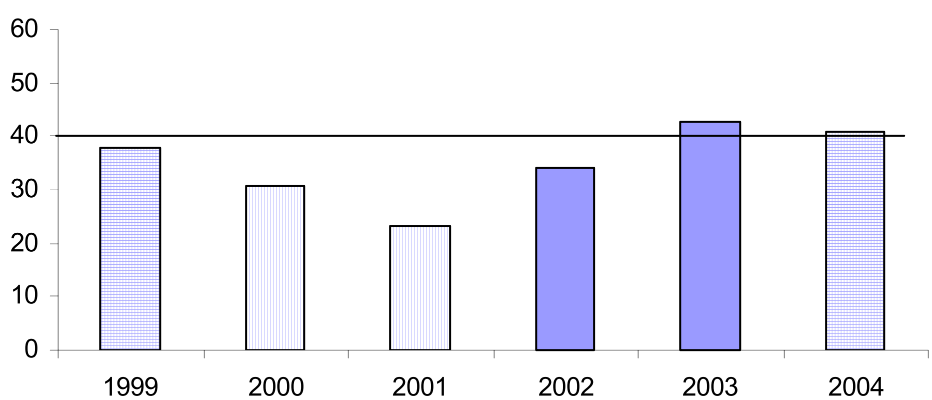


The results for this site using the revised bias factor also indicate that the annual mean objective was not exceeded for the two years with sufficient measurements (i.e. 2000 and 2002). The objective was however easily exceeded in 2003.

2.4 High Street, Bedford

The bias adjusted results for the High Street site are given in Figure 3 below. The site is a kerbside site and is located 3m high and 2m from the kerb.

Figure 3 NO_2 diffusion tube results for High Street, Bedford (BF06)



The results for this site using the revised bias factor also indicate that the annual mean objective was not exceeded for 2002, which was the only year having sufficient measurements. The objective was however exceeded in 2003.

2.5 Commentary on diffusion tube results

The above bias corrected diffusion tube results for the three sites all provide similar findings, with only the results for 2003 exceeding the annual mean objective. In each case the measurements for the previous year did not exceed the same objective. The increase in concentration for the three sites between 2002 and 2003 for the sites is as follows: Great Barford 29%; Prebend Street 59%; and the High Street 26%.

These increases are clearly counter intuitive as to what might have been expected, with large increases arising rather than small decreases (due a continuing uptake and use of less polluting vehicles). Thus it is necessary to seek some explanation for these increases.

High quality continuous monitoring elsewhere has indicated that annual mean nitrogen dioxide concentrations increased in 2003. For example the Preliminary 2003 report for the London Air Quality Network describes an average increase of 13% during 2003 at a sample of London background sites. The highly polluted kerbside site in Marylebone Road also measured a 30% increase in concentrations. These results suggest that the increases measured in Bedford are not unique and consequently are likely to be as a result of the prevailing meteorology during 2003. Further analysis of the results in London is underway although it is likely that the higher concentrations arose as a result of photochemical episodes during the year.

The average increase in concentrations for all of Bedford's monitoring sites was 31%. This suggests that the 59% increase in Prebend Street may be due to other factors in addition to meteorological factors. Brief discussions with the Highway Authority at Bedfordshire County Council have confirmed that major roadworks took place during 2003 south of Prebend Street and that this influenced traffic in Prebend Street and thus may have contributed to the higher concentrations. The roadworks started and were completed during 2003 and the traffic conditions in this road are now considered to be back to normal.

The 2002 and 2003 monitoring data have been corrected to 2005 using the correction factors provided in the LAQM.TG03 guidance. These corrected results indicate that the High Street, Prebend Street and Great Barford locations will exceed the annual mean objective, based on a correction of the 2003 results, but will meet the objective based on the 2002 results.

Table 2 2005 predictions based on corrected monitoring results

2005 Corrected	Based on 2002 results	Based on 2003 results
Great Barford	35.9	46.1
Prebend Street	34.2	54.5
High Street	33.1	41.7

3 Predictions of NO_2 in the Bedford B.C

3.1 Outline of modelling developments

The Detailed 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;
- 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 the southeast including an urban town centre, where there is a high quality continuous monitoring site within the Herts and Beds Monitoring Network. Details of the model validation are given in Appendix C.

The sites identified in the screening assessment and investigated in this report are shown below in Figures 3 and 4. The façade of the nearest buildings with relevant exposure are also shown.

Revised traffic data are used for the modelling; these were supplied by the Bedfordshire County Council and based upon the recent traffic count sites for the road links. Traffic information details are given in Appendix D.

Figure 4 Location of High Street and Prebend Street in the Bedford town centre

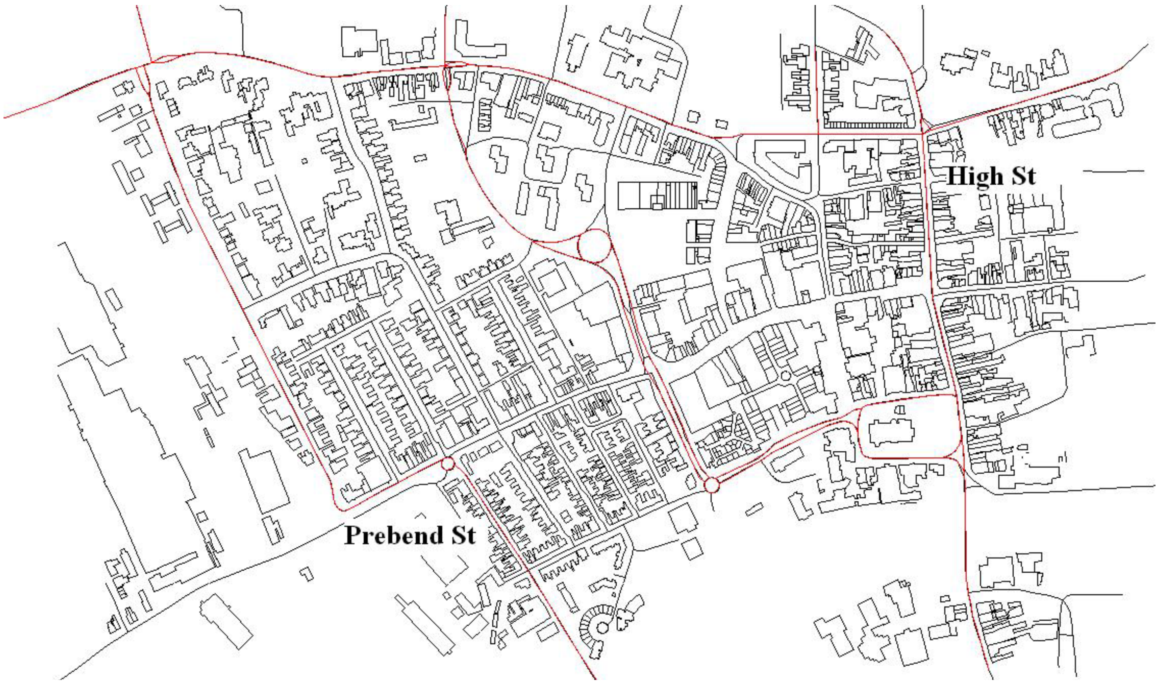
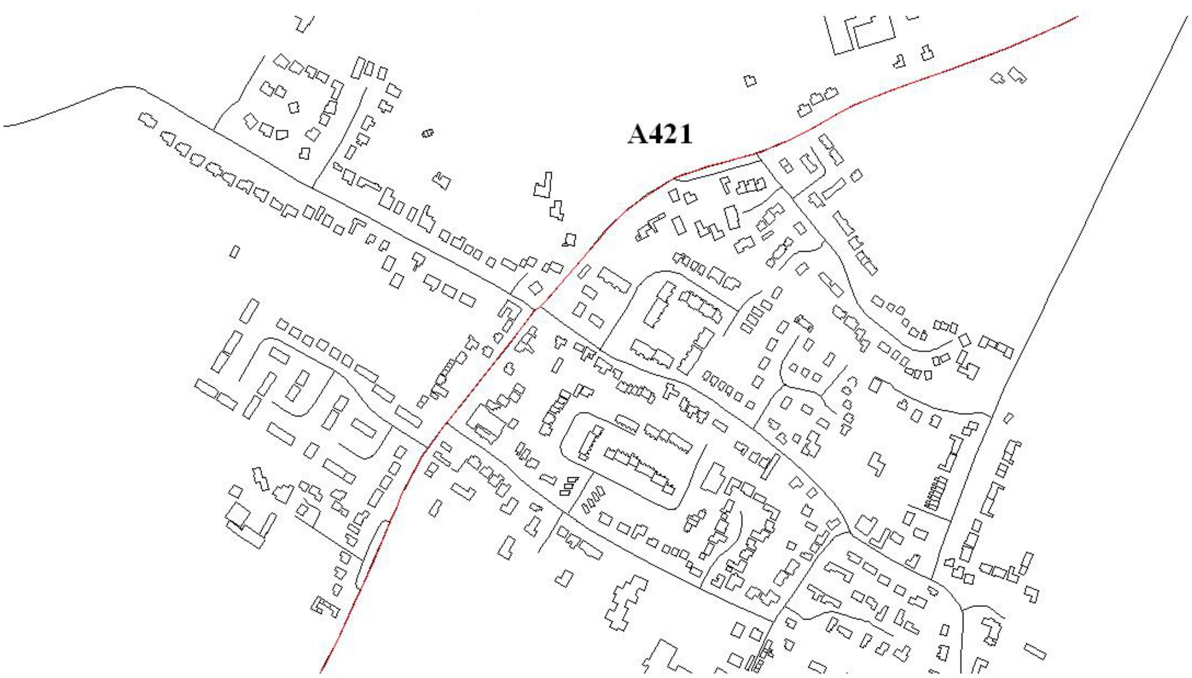


Figure 5 Location of A421 in Great Barford



3.2 Annual mean NO_2 ($\mu g/m^3$) in 2005

The predicted concentrations of the annual mean of 40 $\mu g/m^3$ for the 2005 base case, assuming that the meteorology of the year 1999 was repeated, are shown in the following figures. This year represents a typical meteorological year. 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.

3.3 Modelled predictions

The following figures provide isopleths based on the modelled prediction for annual mean NO_2.

Figure 6 Annual mean NO_2 in Great Barford area in 2005

Figure 7 Annual mean NO_2 in the Prebend Street area in 2005

Figure 8 Annual mean NO_2 in the High Street in 2005

The predictions confirm that the air quality objective is exceeded in each of the identified locations, but only in very small areas close to the centre of roads and close to junctions.

3.4 Comparison with monitored results

The monitored results for the three sites were given in the previous section. These indicated for 2002 that the three sites were not exceeding the annual mean objective. Correcting the results for 2005 using TG03 factors also indicates that the annual mean objective would not be exceeded. These corrected results compare well with the predictions above.

The predictions however do not compare well with measurements for 2003, which as explained above had much higher concentrations. This is further discussed in the next section on verification of 2003 results.

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Figure 6 Predicted annual mean NO_2 in Great Barford for 2005 based on 1999 meteorology

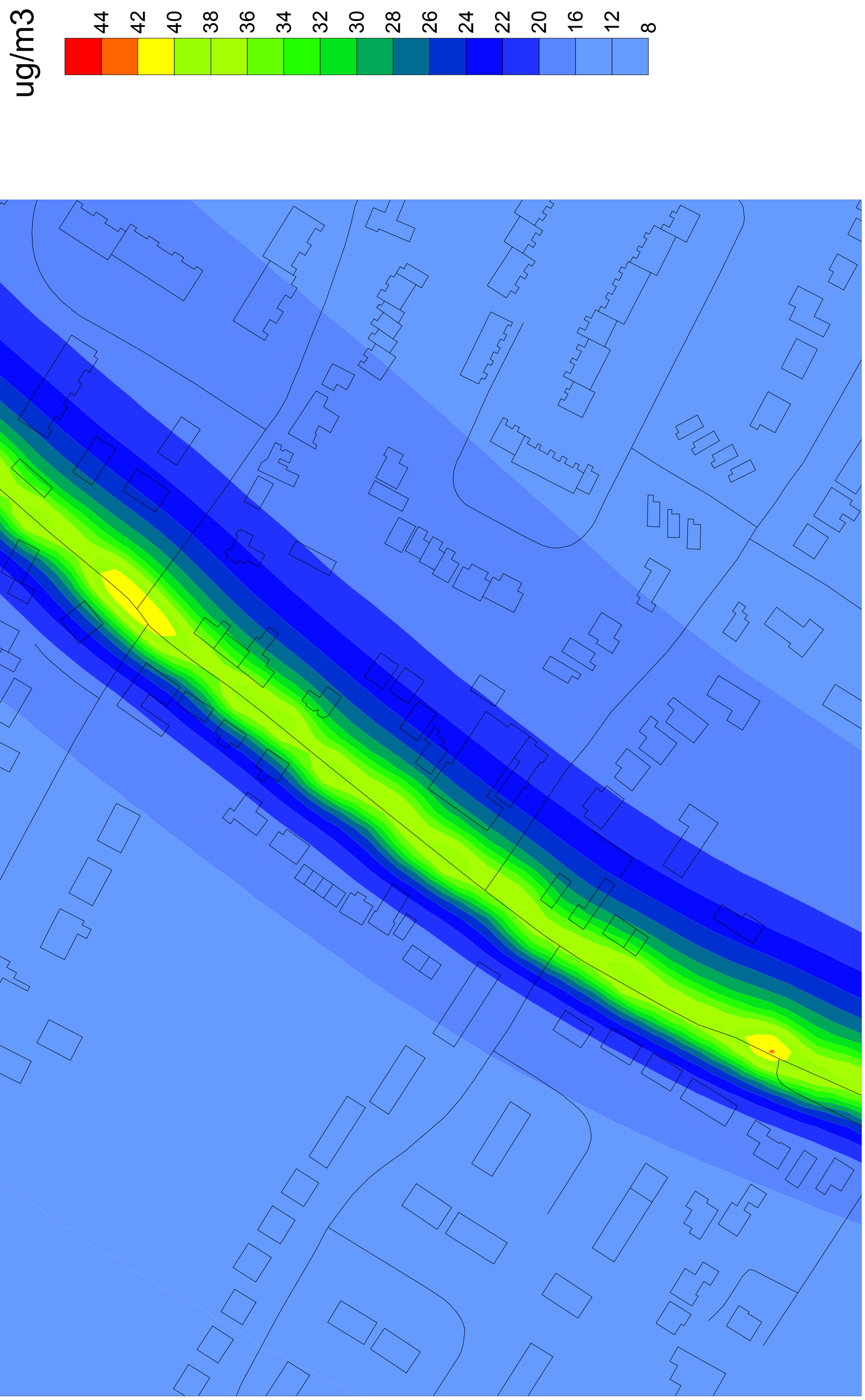


Figure 7 Predicted annual mean NO_2 in Prebend Street, Bedford for 2005 based on 1999 meteorology

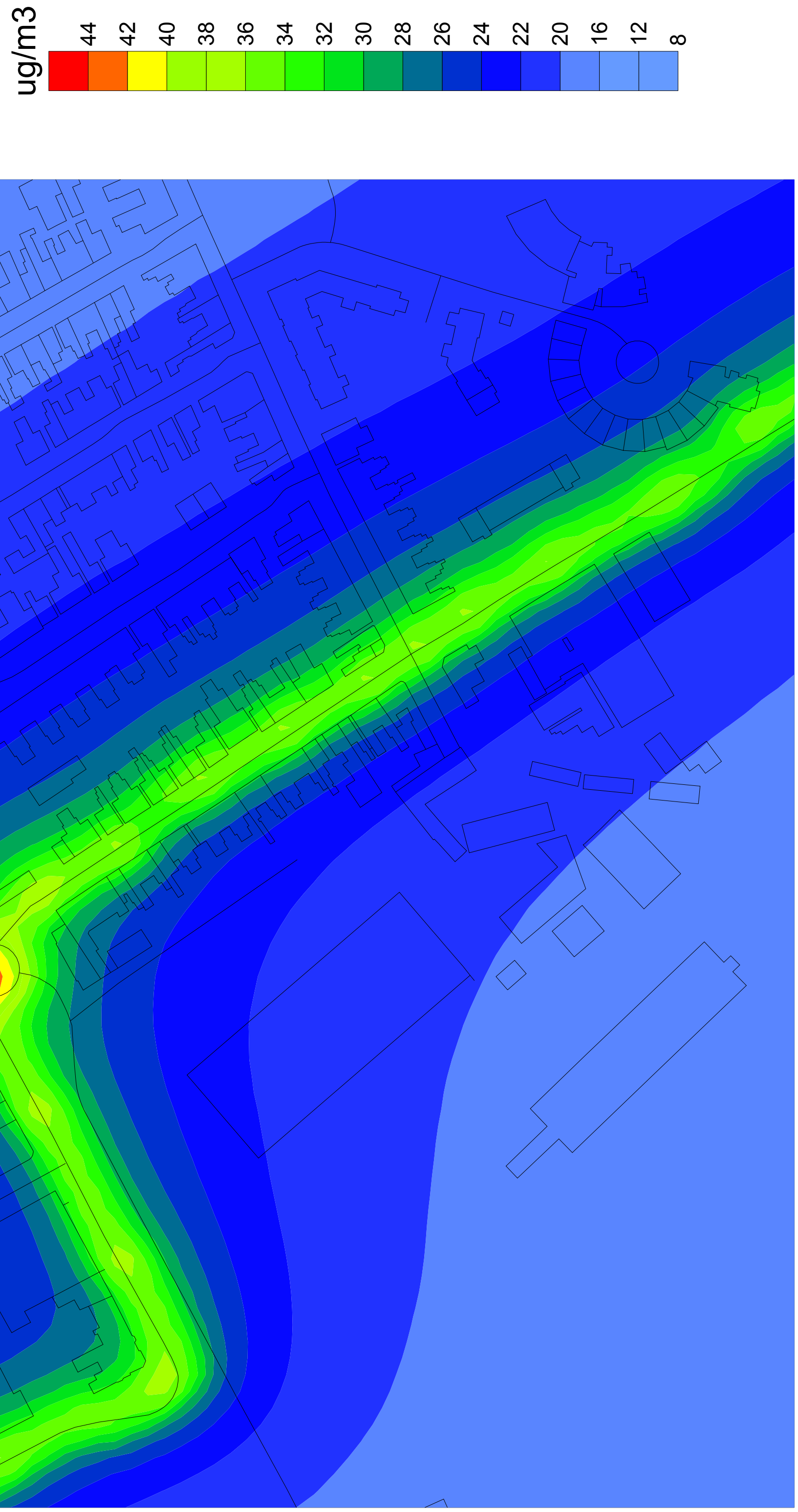
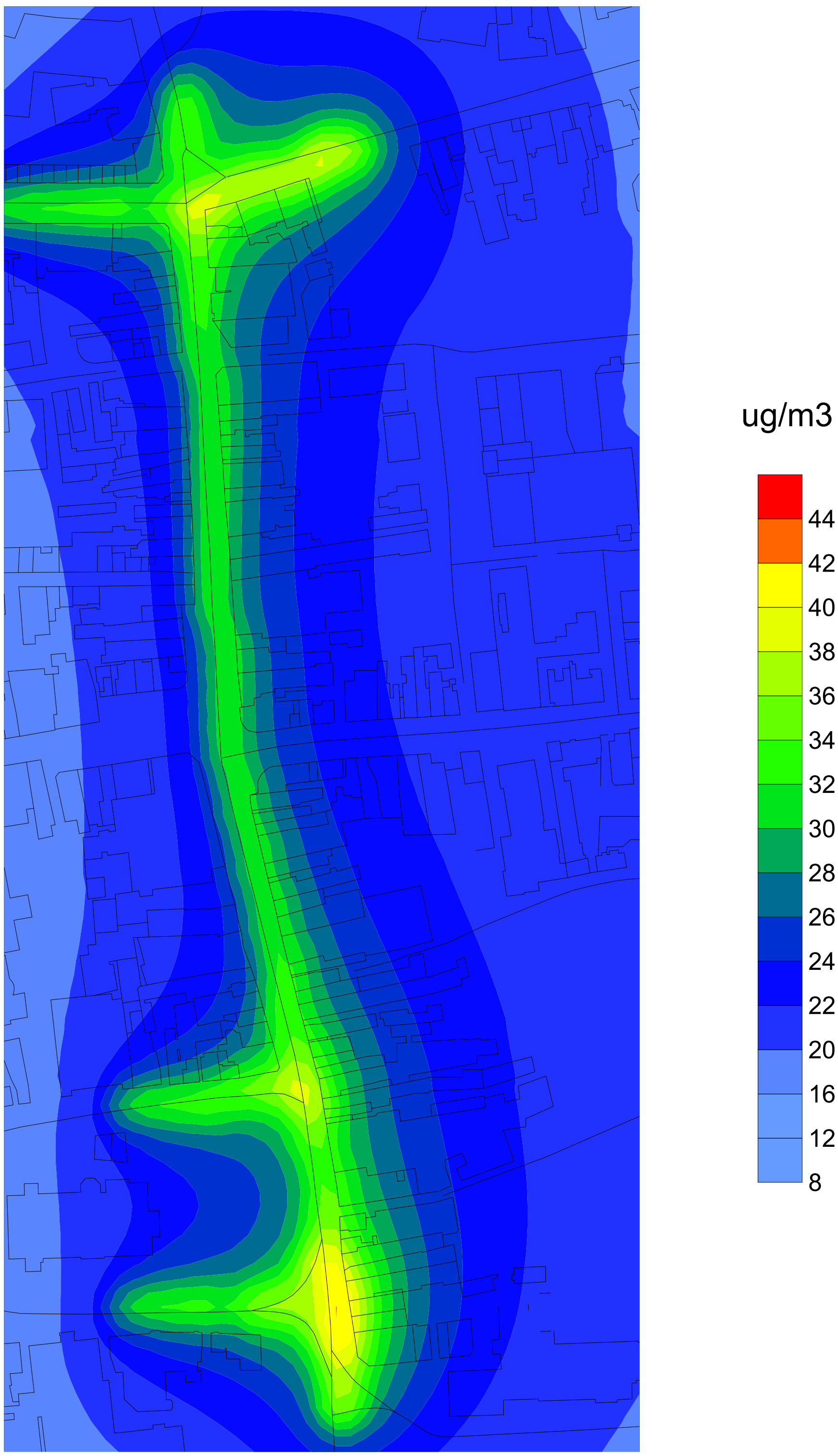


Figure 8 Predicted annual mean NO_2 in High Street, Bedford for 2005 based on 1999 meteorology



4 Model Verification of 2003 Monitored Results

4.1 Model verification using 2003 results

The commentary on the monitored results above for 2003 highlighted the increase in modelled concentrations over that of the previous year for the three sites under investigation. Significantly these results indicate that the annual mean objective was exceeded at the monitoring locations, whereas the previous year indicated that this was not the case.

The assessment for a typical year (based on 1999 meteorology) indicated that the model performs well. However this agreement is not applicable to the 2005 corrected results based on 2003.

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 has been derived from the diffusion tube results for the three sites.

The factor chosen is based on average of the Great Barford and High Street sites, due to the potential confounding issue relating to Prebend Street and the roadworks that took place during 2003. The factor is based on the 2005 corrected result and is 1.27.

The following figures provide isopleths based on the adjusted prediction for annual mean NO_2.

Figure 9 Annual mean NO_2 in Great Barford area in 2005

Figure 10 Annual mean NO_2 in the Prebend Street area in 2005

Figure 11 Annual mean NO_2 in the High Street in 2005

Figure 9 Predicted annual mean NO_2 in Great Barford for 2005 based on adjustment factor for 2003

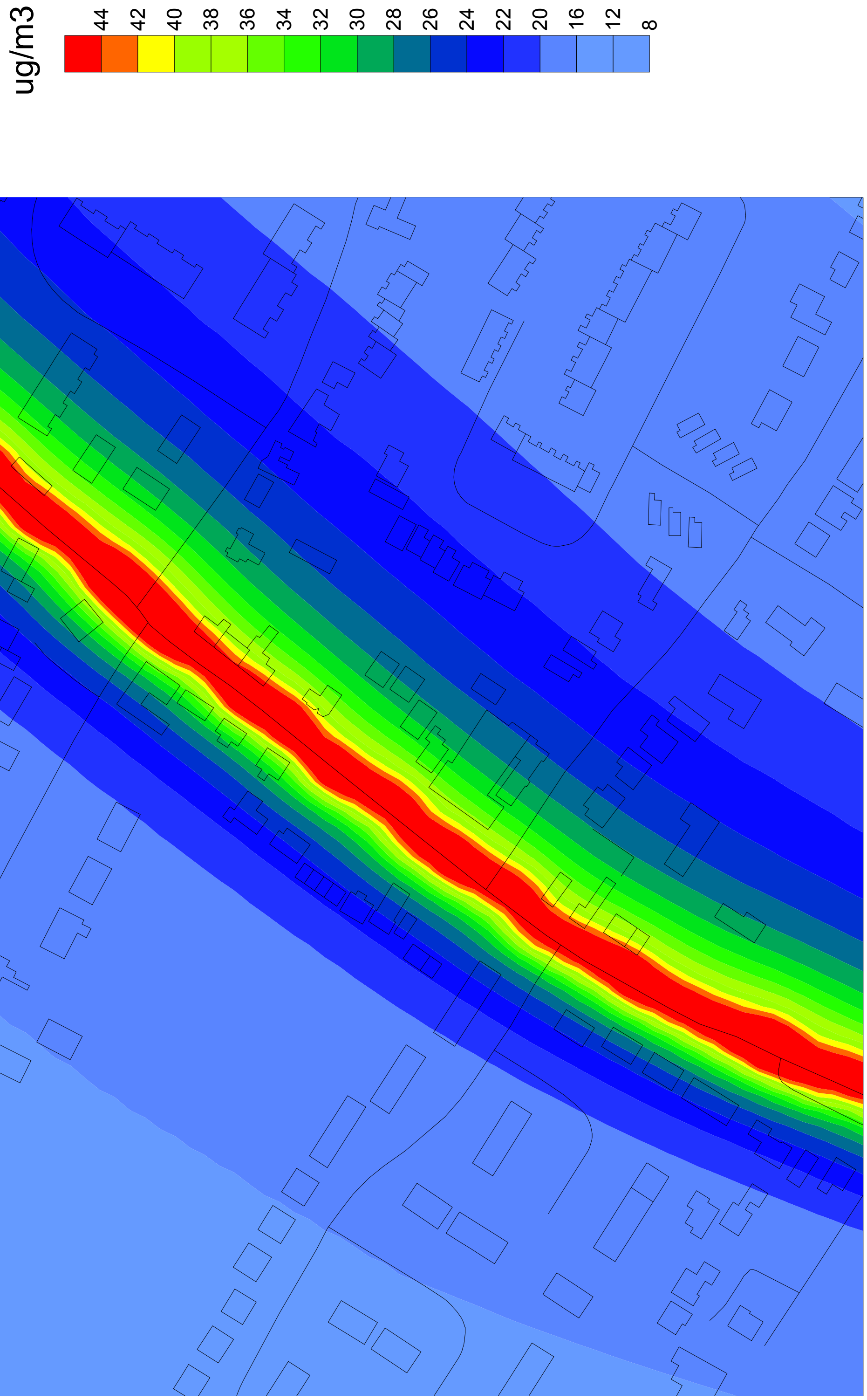


Figure 10 Predicted annual mean NO_2 in Prebend Street, Bedford based adjustment factor for 2003

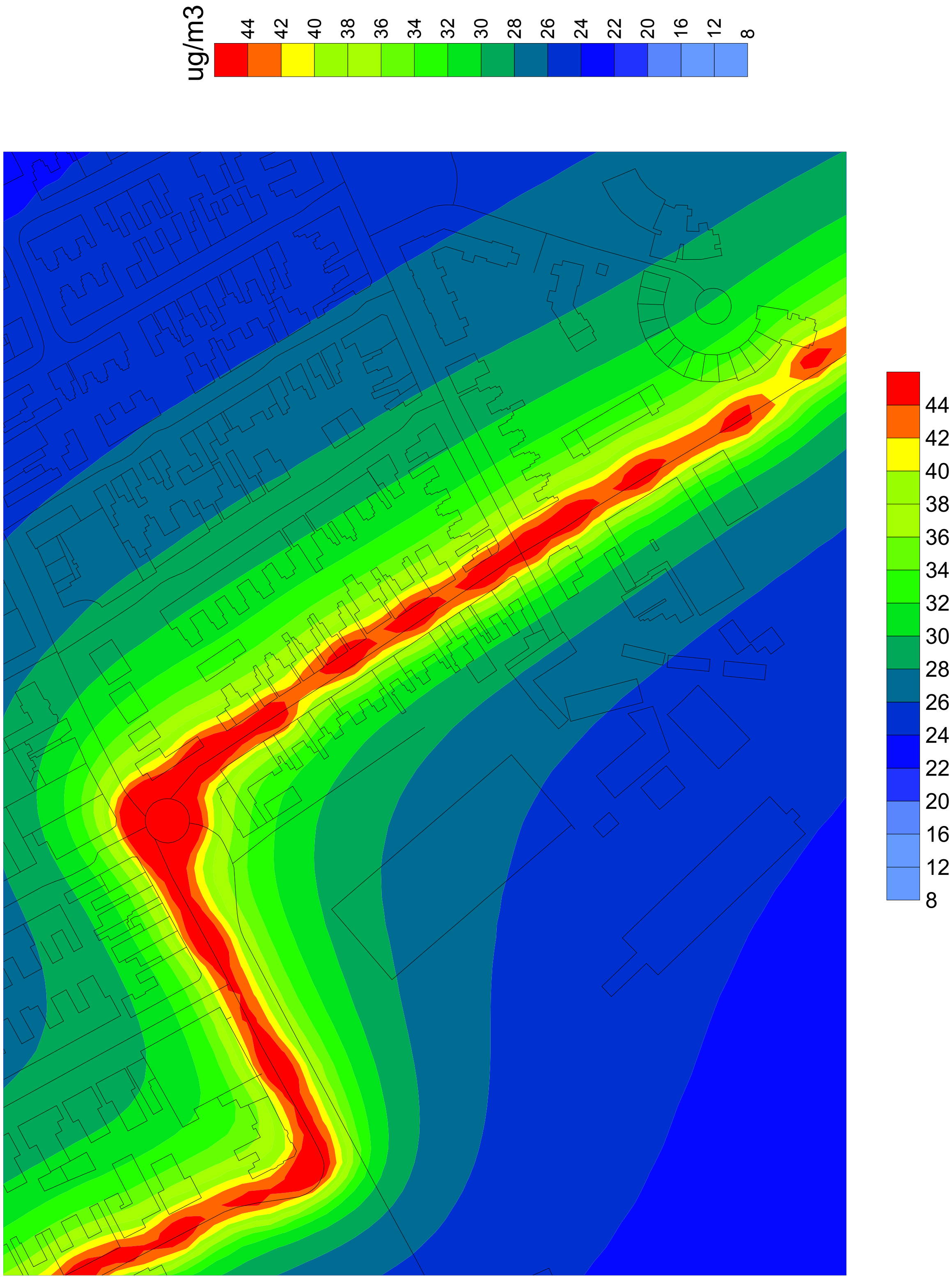
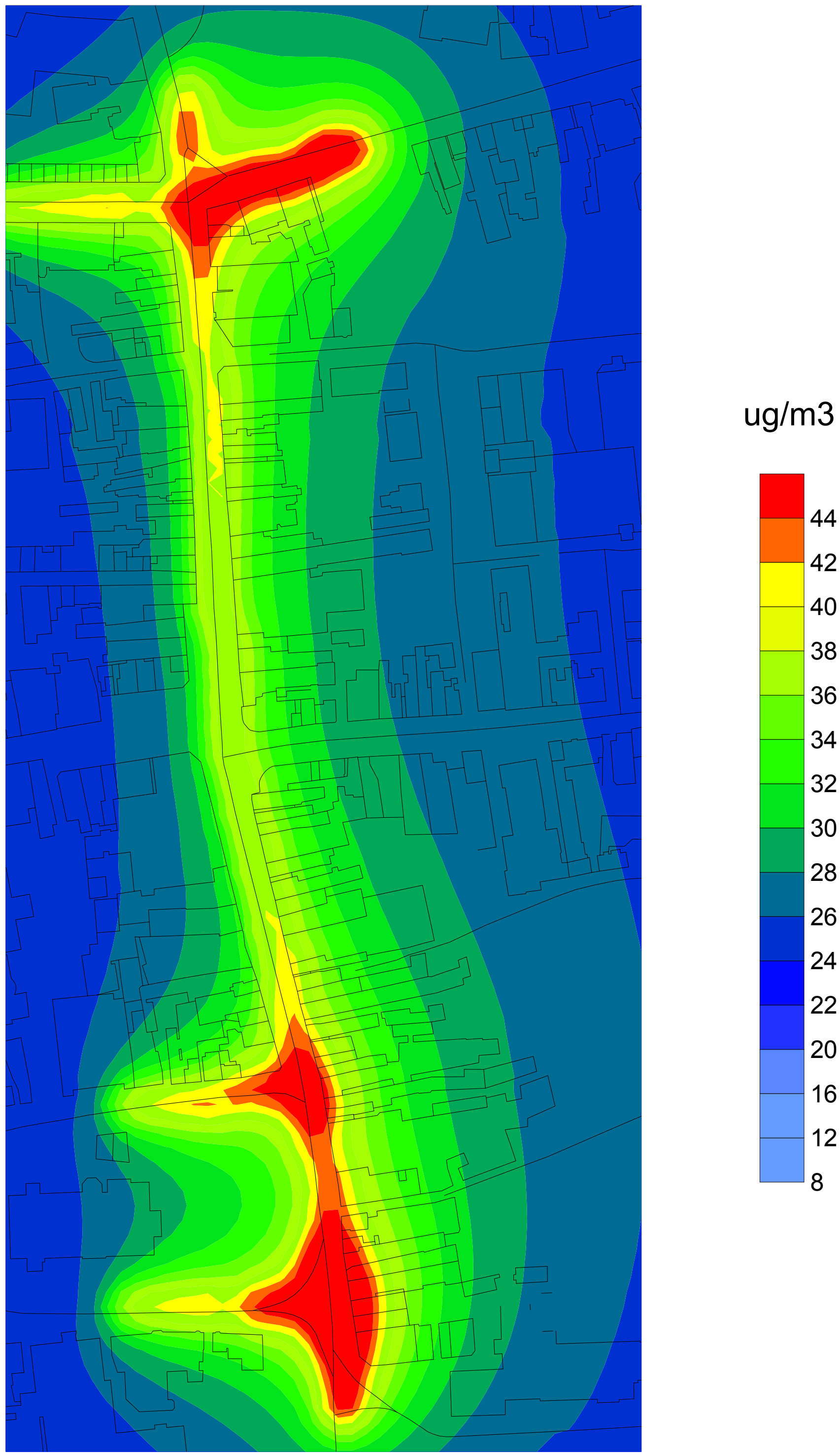


Figure 11 Predicted annual mean NO_2 in High Street, Bedford based on adjustment factor for 2003



4.2 Commentary on adjusted predictions

The adjusted predictions for 2005, derived using an adjustment factor for 2003, all indicate larger areas that exceed the annual mean objective, than those based on the base model predictions using 1999 meteorology. The adjusted predictions are intended to represent worst-case meteorology (based on 2003), as opposed to the base predictions, which represent typical meteorology.

Conclusion

This report fulfils the requirements of the DEFRA guidance for the Detailed Assessment. The Detailed Assessment incorporates recent monitoring results and improved modelling techniques, plus an improved treatment of emissions using the most recent locally available traffic data.

The monitoring results for the areas investigated in the report all indicate that the kerbside locations monitored meet the annual mean objective for 2002. The results for the same locations for 2003 however indicate that the annual mean is easily exceeded.

Modelled predictions are made for the areas under investigation and these compare favourably to the monitored results for typical meteorology. This assessment of the identified roads and adjoining areas has indicated that the annual mean NO_2 objective using typical meteorology is not likely to be exceeded in 2005 where there is relevant exposure.

Using an adjustment factor, based on the 2003 diffusion tube results to represent a worst-case scenario, the same areas all indicate that the annual mean objective will be exceeded. However care is needed with this interpretation as the government's technical guidance advises that use of diffusion tubes as the sole means of model verification is not generally recommended.

Recommendations

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. To seek to expand its monitoring capability, including the provision of continuous monitoring at locations most at risk, to confirm the findings of this report.

2. Undertake consultation on the findings arising from this report with the statutory and other consultees as required.

Appendix A

Model Development

Annual mean NO_2 vs. NO_X relationships

The modelling approach adopted in this report uses the approach described by Carslaw et al. (2001) and a summary of the key points is given here. The relationship between hourly NO_X and NO_2 has in the past been summarised 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.

NO_X and NO_2 Relationships, the Adopted Method

Background Concentrations

The ERG has made predictions of NO_x at background locations i.e. greater than 50m from a major road, based on use of the National Atmospheric Emissions Inventory. For predictions in future years each part of the emissions information has been changed independently. For example, in 2005 it has been assumed that the rural NO_x concentration reduces in line with national NO_x emissions (i.e. 50 %).

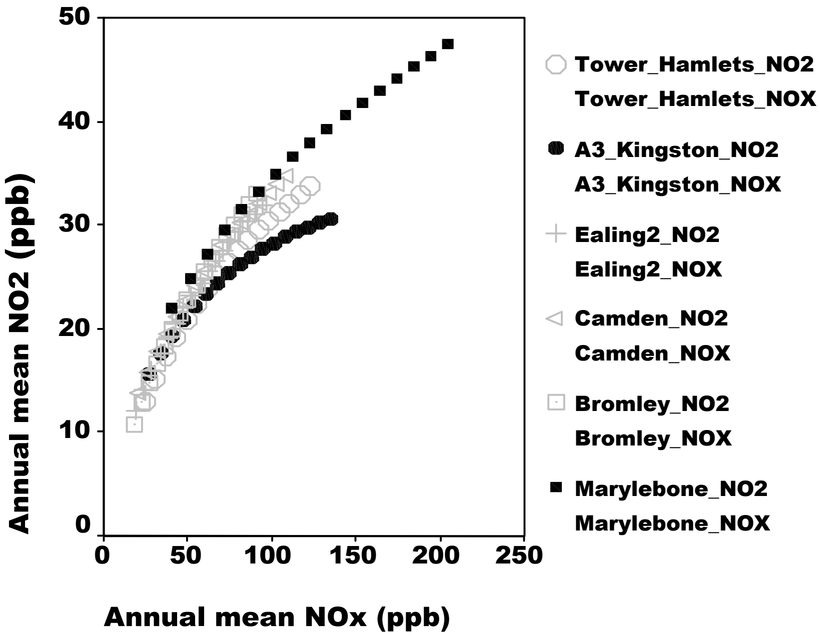
Roadside Concentrations

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 is 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 shows that the roadside concentrations of NO_2 for any NO_x concentration lies within a range of values and that this relates 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 12 below.

Figure 12 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.

It is recognised that the approaches developed here are new and perhaps unfamiliar. However, confidence can be gained in their application through comprehensive validation, which is described in Appendix C. Further information can be found at www.london.gov.uk/approot/mayor/air_quality/modelling.pdf.

Appendix B

Modelling Detailed Road Networks

Geographic Accuracy of Model Predictions

To improve the geographic accuracy of predictions all major roads have been split up into 10 m sections, as shown in Figure 13 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.

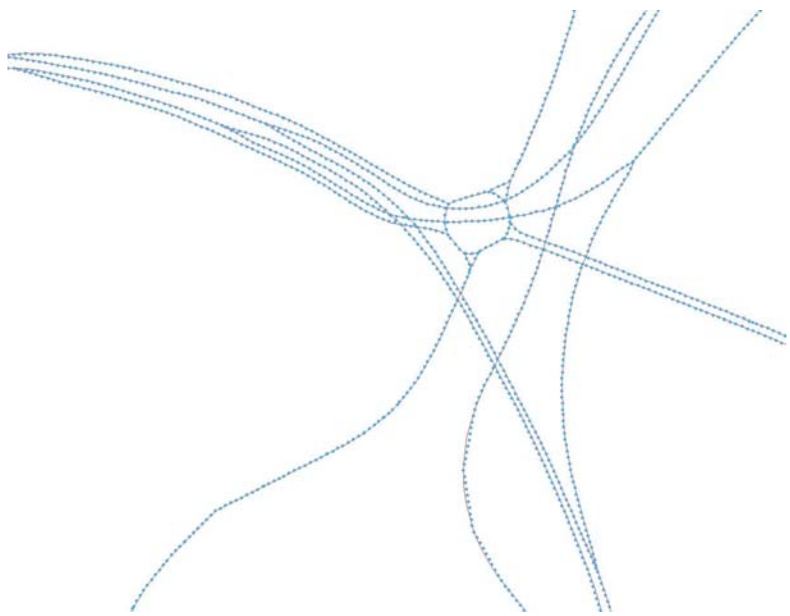


Figure 13 10m sections of road, showing complex junction details

This is further demonstrated in Figure 14 overleaf which shows that features such as roundabouts and curved roads are accurately represented.

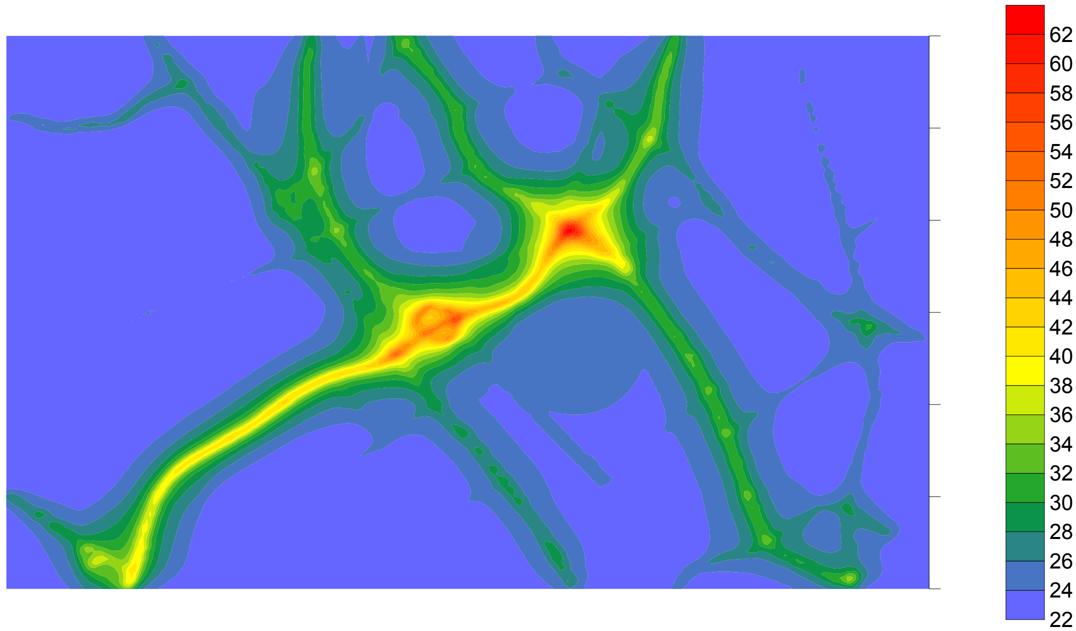


Figure 14 Modelled example showing concentrations near complex road junctions.

Treatment of Emissions

The model has used the detailed emission factors released by DEFRA in 2003, these are applicable down to a speed of 5 km/hr, although factors at this speed are highly uncertain.

It is therefore worth 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 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 15 below. 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.

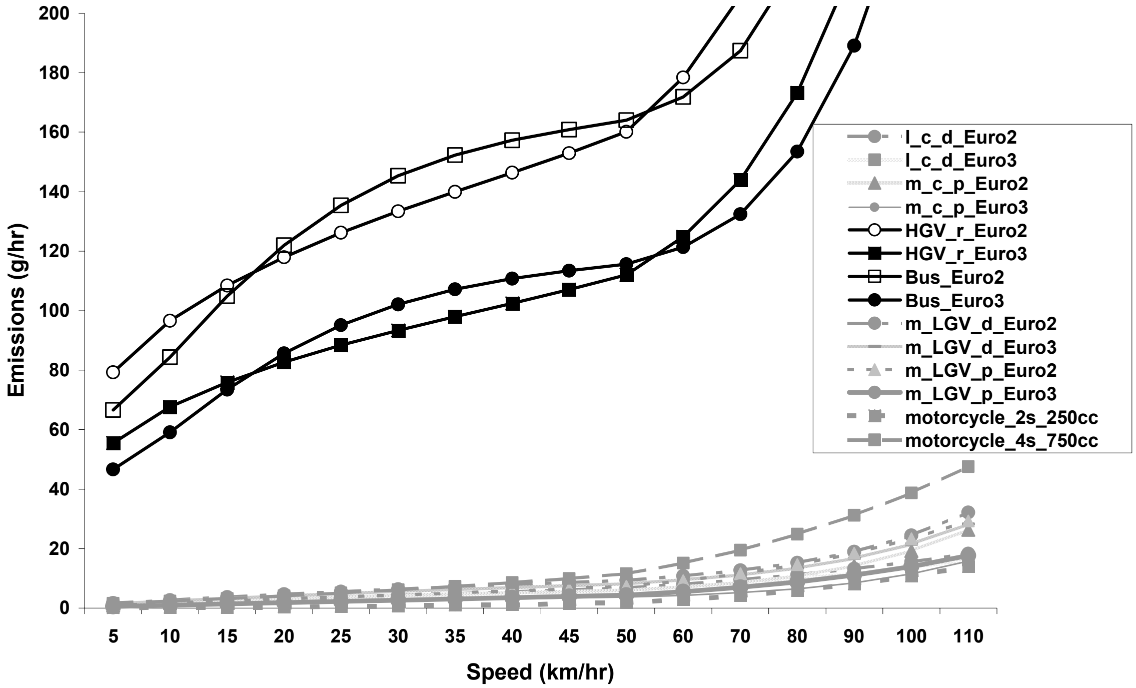


Figure 15 Emissions NO_X (g/hr) for Euro 2 and 3 Vehicles at different Average Speeds (km/hr)

Appendix C

Model Validation

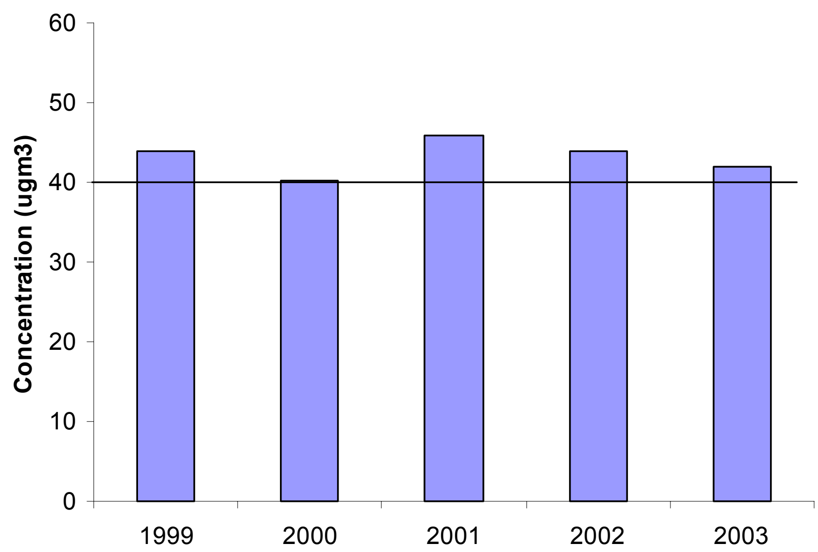
A comprehensive validation exercise has been undertaken for the NO_x-NO_2 models at measurement sites in London and the southeast and this is presented below.

Validation of model using Herts and Beds Monitoring Network site

To determine the applicability of the model to Bedford town centre a separate model validation was undertaken of a roadside site within the above regional network of local authority sites. This network is operated at a high standard of QA/QC, which meets the requirements of TG03. Further details can be obtained from the annual reports provided on the Herts and Beds Monitoring Network's website (http://www.seiph.umds.ac.uk/hbnet.htm).

The model was validated against the Watford roadside site, which is located in the middle of Watford and therefore represents a similar location to that modelled in Bedford town centre. The Watford site has consistently measured the highest concentrations of NO_2 across the network, with the exception of the roadside site in Broxbourne that is adjacent to the M25 and therefore far less comparable to Bedford. The annual mean concentrations monitored at the site are given in Figure 16 below. For all years the data capture is greater than 90% and for all years the annual mean objective has been exceeded.

Figure 16 Annual mean concentrations – Watford roadside site (1999 – 2003)



The emissions data used for the Watford site validation represent 1999 and were obtained from Department for Transport traffic counts.

The results of the validation exercise for 1999 are given in the following table. These indicate that the model performs well for this site with the modelled predictions closely agreeing with those monitored.

Table 3 Comparison of modelled and monitored NO_2 ($\mu g/m^3$) for Watford roadside site

	Modelled 1999	Monitored 1999
Watford roadside	44.4	43.5

Sites used for model validation

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. However, Figure 17 below summarises sites used during the validation exercise. The validation exercise encompasses all types of location. This is beneficial since it is only though a comparison with many sites types in different locations can the approaches used in this study be properly tested.

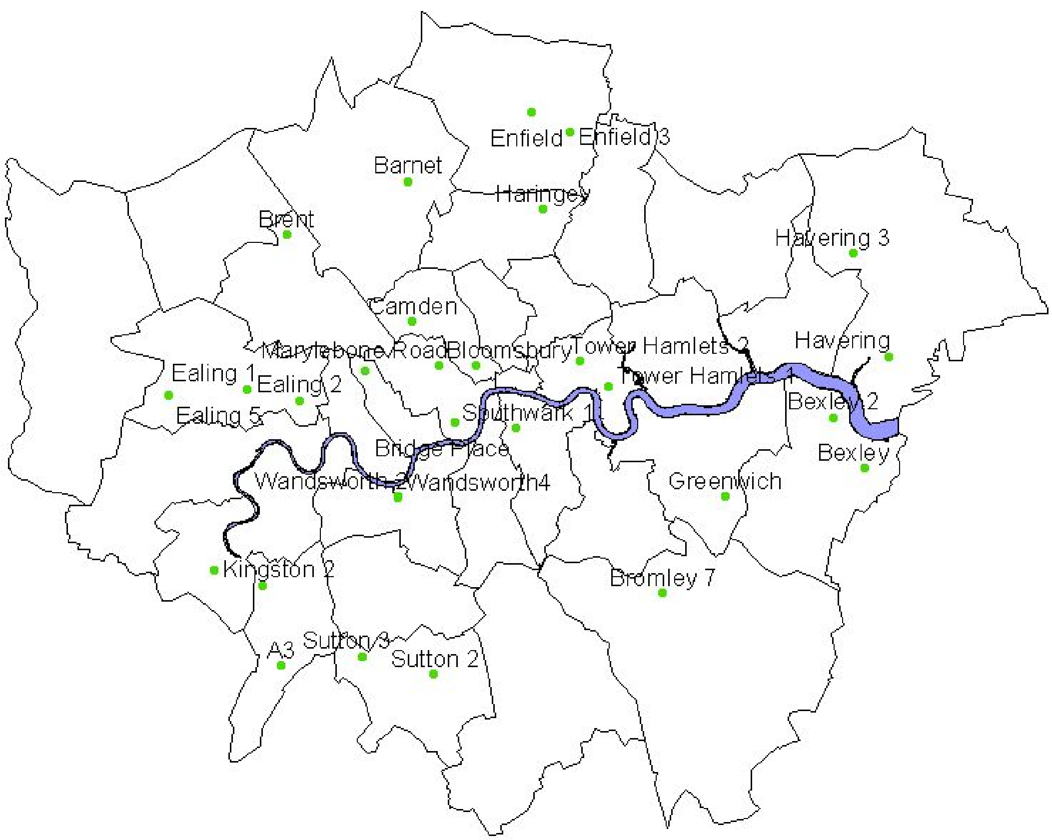


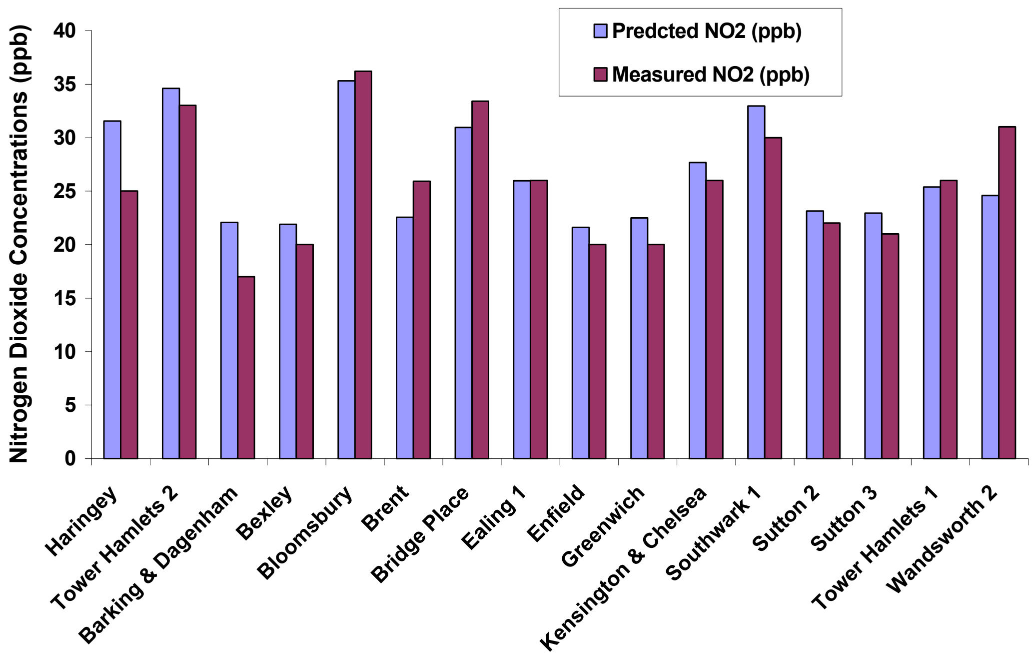
Figure 17 Sites used to Validate Model Predictions

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.

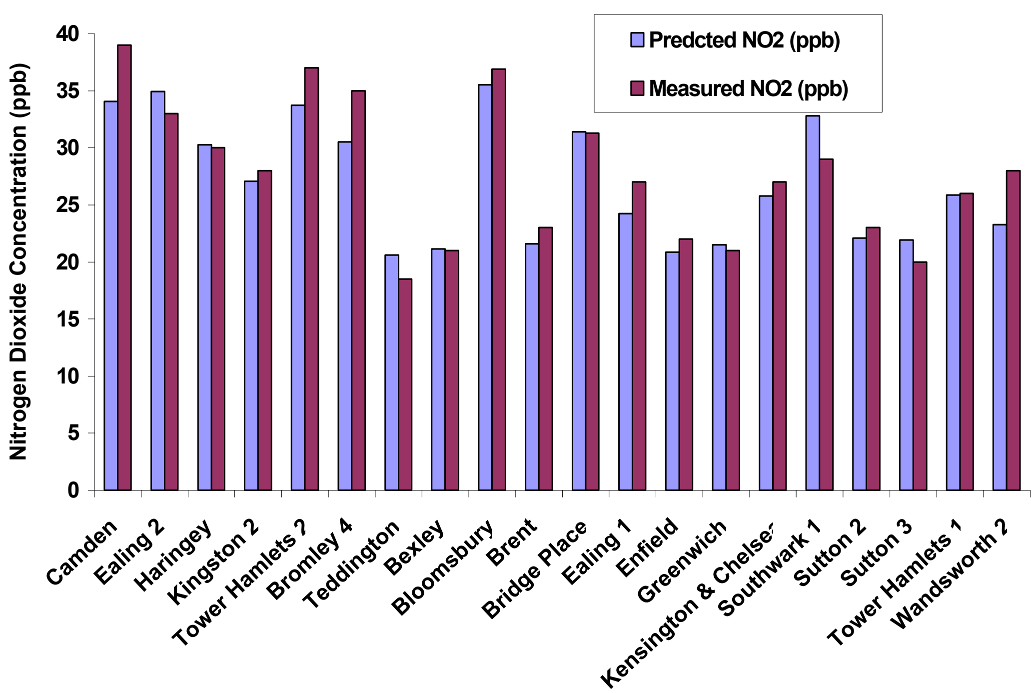
Predictions of Annual Average NO_2

The column plots in Figure 18 show predicted against measured concentrations of NO_2 for 1996 (first plot) to 1999 (last plot). Additionally Table 4 and Table 5 provide the actual results and a summary of the overall model performance. Sites were not included with low data capture rates and by way of example, the all site 1999 data capture rates averaged 94 %.

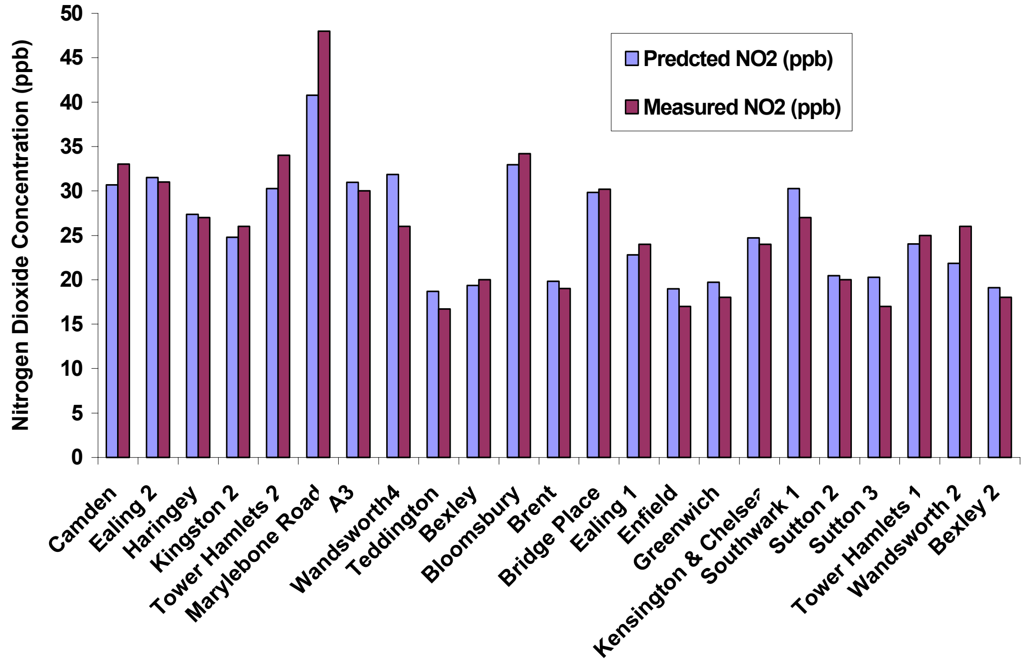
1996


Predcted NO2 (ppb)
Measured NO2 (ppb)
Nitrogen Dioxide Concentrations (ppb)
0
5
10
15
20
25
30
35
40
Haringey
Tower Hamlets 2
Barking & Dagenham
Bexley
Bloomsbury
Brent
Bridge Place
Ealing 1
Enfield
Greenwich
Kensington & Chelsea
Southwark 1
Sutton 2
Sutton 3
Tower Hamlets 1
Wandsworth 2

1997


Predcted NO2 (ppb)
Measured NO2 (ppb)
Nitrogen Dioxide Concentration (ppb)
0
5
10
15
20
25
30
35
40
Camden
Ealing 2
Haringey
Kingston 2
Tower Hamlets 2
Bromley 4
Teddington
Bexley
Bloomsbury
Brent
Bridge Place
Ealing 1
Enfield
Greenwich
Kensington & Chelsea
Southwark 1
Sutton 2
Sutton 3
Tower Hamlets 1
Wandsworth 2

1998



1999

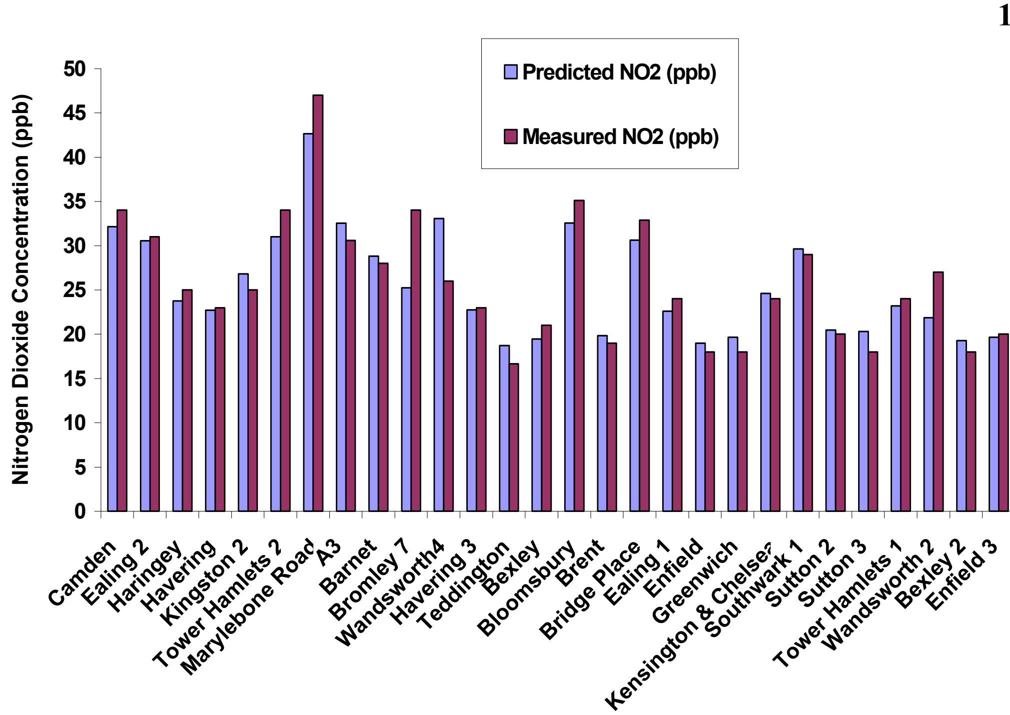


Figure 18 Predicted and Measured Annual Average NO_2 for 1996, 1997, 1998 and 1999

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 is given in Table 5, which 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.

Table 4 Annual Mean NO_2 (ppb) Validation Results

SITE	Predicted NO_2 1999 (ppb)	Measured NO_2 1999 (ppb)	Predicted NO_2 1998 (ppb)	Measured NO_2 1998 (ppb)	Predicted NO_2 1997 (ppb)	Measured NO_2 1997 (ppb)	Predicted NO_2 1996 (ppb)	Measured NO_2 1996 (ppb)
A3	33	31	31	30				
Barking & Dagenham							22	17
Barnet	29	28						
Bexley	19	21	19	20	21	21	22	20
Bexley 2	19	18	19	18				
Bloomsbury	33	35	33	34	36	37	35	36
Brent	20	19	20	19	22	23	23	26
Bridge Place	31	33	30	30	31	31	31	33
Bromley 4					31	35		
Bromley 7	25	34						
Camden	32	34	31	33	34	39		
Ealing 1	23	24	23	24	24	27	26	26
Ealing 2	31	31	31	31	35	33		
Enfield	19	18	19	17	21	22	22	20
Enfield 3	20	20						
Greenwich	20	18	20	18	22	21	22	20
Haringey	24	25	27	27	30	30	32	25
Havering	23	23						
Havering 3	23	23						
Kensington & Chelsea	25	24	25	24	26	27	28	26
Kingston 2	27	25	25	26	27	28		
Marylebone Road	43	47	41	48				
Southwark 1	30	29	30	27	33	29	33	30
Sutton 2	20	20	20	20	22	23	23	22
Sutton 3	20	18	20	17	22	20	23	21
Teddington	19	17	19	17	21	19		
Tower Hamlets 1	23	24	24	25	26	26	25	26
Tower Hamlets 2	31	34	30	34	34	37	35	33
Wandsworth 2	22	27	22	26	23	28	25	31
Wandsworth4	33	26	32	26				

This level of accuracy does not apply to all sites and certain roadside sites are not as well predicted. The most obvious example of this is the Croydon 2, which is poorly predicted for all years and has not been included in the summary above. This site exhibits a very low NO_2 to NO_X ratio, which are more typical rural motorway site, as thus the model over predicts by a large margin, typically 10 ppb. Other sites, included in the summary above, that also identify poor model performance are Bromley 7, which is under predicted by 9 ppb and Wandsworth 4, which is over predicted by 7 ppb. Bromley 7's first full year of operation was during 1999 and so it is difficult to draw firm conclusions from this result alone, Over prediction at Wandsworth 4 occurred in both 1998 and 1999, which 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.

Table 5 All Site Average NO_2 (ppb)

Year	Predicted Average (ppb)	Measured Average (ppb)	Average difference (measured - predicted) (ppb)	Standard Deviation (measured - predicted) (ppb)
1996	26.6	25.8	-0.8	3.2
1997	27.0	27.8	0.8	2.4
1998	25.7	25.7	0.0	2.7
1999	25.5	25.9	0.4	2.9

Appendix D

Emissions from Road Transport

Major Road Flows

Recent traffic counts for 2003 and 2004 were obtained from the Bedfordshire County Council (BCC) for the identified roads in Bedford town centre and Great Barford. The principal data source used was the annual average daily flows (AADF).

Vehicle Classification, Age and Speed

The vehicle classification used for the roads was based on the vehicle split provided in automatic traffic counts undertaken by the Department for Transport for the same roads.

The breakdown of vehicle ages was based on the national model. The BCC have confirmed that these assumptions are appropriate.

The Council previously assessed vehicle speeds in the town centre in its previous "Air Quality Review" in 2001 (see www.bedford.gov.uk). These indicated for the town centre roads an average speed of 31kph. The BCC have subsequently advised from a recent town centre study that an average speed of 24kph was used. This speed was used in this report.

Road Traffic Assumptions in 2005

To establish the 2005 base case a growth factor of 2% per annum was applied, discussions with the BCC indicate that this is an upper estimate. For the A421 in Great Barford, it is important to note that no account has been made of the new by pass road is likely to be completed around 2007. The traffic flows used for the base case modelling are given in Table 6 below.

Table 6 Estimated traffic flows for 2005

Location	Road number	M/cycles	Cars	Bus and coaches	LGV	HGV Rigid	HGV Artic
Great Barford	A428	235	19091	196	3023	670	551
Prebend St	A5141	226	18349	201	2325	550	94
High Street	A6	105	12305	139	1577	283	75

Appendix E

Model Uncertainty Assessment

Note: This appendix contains extracts of a report written on behalf of the former Department of Environment, Transport and the Regions (DETR), entitled: *Estimating the Uncertainty of Model Predictions using a Monte Carlo Simulation***.** Please note that although the DETR report addresses modelling in London, the same principles apply to the Council's report, as a similar methodology was used.

Predictions of the concentration of NO_2 at roadsides have shown a high sensitivity to the pass/fail standard of 40 $\mu g/m^3$ (21 ppb). 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 7 below shows how each input data or modelling method affects the final concentration, for the Marylebone Road example.

Table 7 The Relative Importance of Model Parameters in Predicting NO_2 at Marylebone Road

Model Parameter	Relative Importance 2005 (% of mean at 2σ)	Relative Importance 1997 (% of mean at 2σ)
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 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 8. 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 8 NO_2 Uncertainty Estimates for Typical Roads 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.

References:

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