Report

Air Quality Review and Assessment – Stage 4

Report to Norwich City Council

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Executive Summary

The UK Government published its strategic policy framework for air quality management in 1995 establishing national strategies and policies on air quality, which culminated in the Environment Act, 1995. The Air Quality Strategy provides a framework for air quality control through air quality management and air quality standards. These and other air quality standards[1] and their objectives[2] have been enacted through the Air Quality Regulations in 1997 and 2000. The Environment Act 1995 requires Local Authorities to undertake an air quality review. In areas where the air quality objective is not anticipated to be met, Local Authorities are required to establish Air Quality Management Areas to improve air quality.

The first step in this process is to undertake a review of current and potential future air quality. A minimum of two air quality reviews are recommended in order to assess compliance with air quality objectives; one to assess air quality at the outset of the Air Quality Strategy and a second to be carried out towards the end of the policy timescale (2005). The number of reviews necessary depends on the likelihood of achieving the objectives. Each of these two reviews is split into components. For the first round of air quality review and assessment, there were four components. The components are: Stages 1 to 3; Stage 4 and Action Plans. Stage 4 and Action Plans are normally completed in parallel. Not all local authorities have to complete all the components.

This report is equivalent to a Stage 4 air quality review and assessment for Norwich, as outlined in the Government's published guidance.

Norwich City Council has completed a Stage 3 Air Quality Review and Assessment. The results of this indicated that there are areas of Norwich almost certain to exceed the annual mean objective for nitrogen dioxide (NO_2). As a result of this air quality review and assessment, Norwich City Council has declared three Air Quality Management Areas (AQMAs) within the city at Grapes Hill, the Castle area and St Augustines Street.

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[1] Refers to standards recommended by the Expert Panel on Air Quality Standards. Recommended standards are set purely with regard to scientific and medical evidence on the effects of the particular pollutants on health, at levels at which risks to public health, including vulnerable groups, are very small or regarded as negligible.
[2] Refers to objectives in the Strategy for each of the eight pollutants. The objectives provide policy targets by outlining what should be achieved in the light of the air quality standards and other relevant factors and are expressed as a given ambient concentration to be achieved within a given timescale.

The general approach taken to this Stage 4 assessment was to:

- Identify the improvement needed in concentrations of nitrogen dioxide at selected receptors (mostly housing) in the Air Quality Management Area, including the receptors where the greatest improvements were needed;
- Consider recent continuous monitoring and diffusion tube measurements;
- Identify the contributions of the relevant sources to the exceedences (local traffic, background sources, and other relevant sources);
- Use monitoring data from the NO_2 continuous monitors located at Norwich Centre, Norwich Roadside and Golding Place to assess the ambient concentrations produced by the road traffic and to calibrate the output of the NO_2 modelling studies;
- Model the concentrations of NO_2 around the selected AQMAs, concentrating on the locations (receptors) where people might be exposed over the relevant averaging times of the air quality objectives;
- Consider three scenarios to improve air quality and identify the improvements in air quality that might be possible for nitrogen dioxide;
- Present the concentrations as contour plots of concentrations;
- Consider any changes that are needed to the existing Air Quality Management Areas;
- Consider the feasibilities of implementing the options in a very simple way.

The monitoring and modelling carried out for this assessment show that nitrogen dioxide concentrations are expected to exceed the annual average objective at certain locations in each of the three declared AQMAs. However, the expected area of exceedence is rather smaller. The reduction needed in annual mean NO_2 concentrations to ensure that concentrations at all relevant receptors in the AQMAs did not exceed 40 $\mu g\ m^{-3}$ was: 8 $\mu g\ m^{-3}$ for the properties with facades on the section of St Augustines Street that forms a street canyon, 8 $\mu g\ m^{-3}$ for a small number of properties to the east of Grapes Hill and 8 $\mu g\ m^{-3}$ for some properties with facades facing Cattle Market Street, Agricultural Hall Plain and Bank Plain.

The source apportionment work identified emissions of oxides of nitrogen (NO_x) from traffic on roads close to the AQMA as the important source from which emissions might be reduced. The general background of NO_x cannot be easily reduced except by national or regional measures. Emissions of NO_x from local traffic accounted for approximately 68-79 % of the total modelled oxides of nitrogen concentration at the most affected properties within the AQMAs.

The following options have been considered in order to assess their potential to reduce the nitrogen dioxide concentration at the most sensitive receptors in the Norwich AQMAs.

For AQMA No 1, St Augustines, the options considered were:

1. A 20 % reduction in total traffic;
2. A reduction in congestion at the St Crispins Road roundabout and at the junction with Waterloo Road to increase average traffic speeds to 40 kph.
3. Both the above

For AQMA No2, Grapes Hill, the options considered were:

1. A 20% reduction in traffic;

2. A 40% reduction in traffic;

For AQMA No3, Castle, the options considered were:

1. Upgrade of buses (assumed 70% of HDV) to Euro IV standard;

2. Bus only zone

3. Both the above

These measures taken together would be sufficient to eliminate the exceedence of the objective for nitrogen dioxide at all relevant receptor locations in the Norwich AQMAs. However, the measures should be considered in detail in the context of the overall transport strategy for Norwich and the Air Quality Action Plan

The following changes to the AQMAs in Norwich are recommended.

AQMA	Changes recommended to the existing Air Quality Management Areas
No 1	No change recommended
No 2	Consider reducing the size of the AQMA to include only those properties with relevant public exposure within 30 m of the east side of Grapes Hill, south of Pottergate
No 3	Consider reducing the size of the AQMA to include only those properties with relevant public exposure with facades on Bank Plain, Agricultural Hall Plain and Cattle Market Street

Acronyms and definitions

AADTF	Annual Average Daily Traffic Flow
ADMS	an atmospheric dispersion model
AQDD	an EU directive (part of EU law) - Common Position on Air Quality Daughter Directives, commonly referred to as the Air Quality Daughter Directive
AQMA	Air Quality Management Area
AQS	Air Quality Strategy
AP	Action Plan
AURN	Automatic Urban Network (defra funded network)
base case	In the context of this report, the emissions or concentrations predicted at the date of the relevant air quality objective (2005 for nitrogen dioxide)
CO	Carbon monoxide
d.f.	degrees of freedom (in statistical analysis of data)
DETR	Department of the Environment Transport and the Regions (now defra)
defra	Department for the Environment, Food and Rural Affairs
DMRB	Design Manual for Roads and Bridges
EA	Environment Agency
EPA	Environmental Protection Act
EPAQS	Expert Panel on Air Quality Standards (UK panel)
EU	European Union
GIS	Geographical Information System
HA	Highways Agency
kerbside	0 to 1 m from the kerb
LADS	Urban background model specifically developed for Stage 3 Review and Assessment work by NETCEN. This model allowed contributions of the urban background and road traffic emissions to be calculated
Limit Value	An EU definition for an air quality standard of a pollutant listed in the air quality directives
n	number of pairs of data
NAEI	National Atmospheric Emission Inventory
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
NRTF	National Road Traffic Forecast
ppb	parts per billion
r	the correlation coefficient (between two variables)
receptor	In the context of this study, the relevant location where air quality is assessed or predicted (for example, houses, hospitals and schools)
roadside	1 to 5 m from the kerb
SD	standard deviation (of a range of data)
SO_2	Sulphur dioxide
TEMPRO	A piece of software produced by the defra used to forecast traffic flow increases
UWE AQMRC	University of the West of England Air Quality Management Resource Centre

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APPENDICES

Maps reproduced within this document

1 Introduction to this Stage 4 air quality assessment

This section outlines the reason that the Stage 4 air quality review and assessment was commissioned, and briefly explains what a Stage 4 air quality review and assessment is.

1.1 PURPOSE OF THE STUDY

Norwich City Council has completed a Stage 3 Air Quality Review and Assessment. The results of this indicated that there are areas of Norwich almost certain to exceed the annual mean objective for nitrogen dioxide (NO_2). As a result of this air quality review and assessment, Norwich City Council has declared three Air Quality Management Areas (AQMAs) within the city at Grapes Hill, the Castle area and St Augustines Street.

Norwich City Council now requires further review and assessment of its air quality – a Stage 4 review and assessment – as specified under Section 84 of the Environment Act (1995).

1.2 BRIEF EXPLANATION OF A STAGE 4 AIR QUALITY REVIEW AND ASSESSMENT

The 1995 Environment Act places duties on local authorities with regard to local air quality review and, where potential problems are identified, the management of local air quality. The air quality review is designed as a multi-stage process, with progressively more complex assessments at each stage.

If a local authority declares an air quality management area, Section 84(1) of the Environment Act 1995 requires the local authority to carry out a further assessment of existing and likely future air quality in the AQMA. This further assessment is called a Stage 4 air quality review and assessment, and is intended to supplement information the authority already has.

For each pollutant where there is an exceedence of the air quality, the Stage 4 should calculate:

- how great an improvement is needed; and
- the extent to which different sources contribute to the problem (source apportionment).

1.3 OVERVIEW OF APPROACH TAKEN

The general approach taken to this Stage 4 assessment was to:

- Identify the improvement needed in concentrations of nitrogen dioxide at selected receptors in the Air Quality Management Area, including the receptors where the greatest improvements were needed;
- Collect and interpret additional data to support the Stage 4 assessment, including detailed traffic flow data around locations where exceedences of the NO_2 objective were predicted;
- Consider recent continuous monitoring and diffusion tube measurements;
- Identify the contributions of the relevant sources to the exceedences (local traffic, background sources, and other relevant sources);
- Use monitoring data from the NO_2 continuous monitors located at Norwich Centre, Norwich Roadside and Golding Place to assess the ambient concentrations

produced by the road traffic and to calibrate the output of the NO_2 modelling studies;

- Model the concentrations of NO_2 around the selected AQMAs, concentrating on the locations (receptors) where people might be exposed over the relevant averaging times of the air quality objectives;
- Consider three scenarios to improve air quality and identify the improvements in air quality that might be possible for nitrogen dioxide;
- Present the concentrations as contour plots of concentrations and assess the uncertainty in the predicted concentrations;
- Consider any changes that are needed to the existing Air Quality Management Areas;
- Consider the feasibilities of implementing the options in a simple way

1.4 RELEVANT defra DOCUMENTATION USED

This report has used the guidance in LAQM.TG (03) published in January 2003. Reference has also been made to previous guidance LAQM.TG4 (00), published in May 2000.

1.5 NUMBERING OF TABLES AND FIGURES

The numbering scheme is not sequential, and the figures and tables are numbered according to the chapter or section that they relate to.

1.6 POLLUTANTS CONSIDERED IN THIS REPORT

Norwich has only declared an AQMA for nitrogen dioxide, and this is the only pollutant considered in this report.

1.7 UNITS OF CONCENTRATION USED AND CONVERSIONS TO OTHER UNITS

This report presents concentrations of nitrogen dioxide in units of $\mu g\ m^{-3}$, which is consistent with units used in the current UK Air Quality Strategy.

To convert concentrations of nitrogen dioxide between $\mu g\ m^{-3}$ and ppb (parts per billion), use the following relationships:

$$\mu g\ m^{-3} / 1.91 = ppb$$

$$1.91 \times ppb = \mu g\ m^{-3}$$

1.8 COPYRIGHT OF THE MAPS

2 The UK Air Quality Strategy

The Government published its proposals for review of the National Air Quality Strategy in early 1999 (DETR, 1999). These proposals included revised objectives for many of the regulated pollutants. A key factor in the proposals to revise the objectives was the agreement in June 1998 at the European Union Environment Council of a Common Position on Air Quality Daughter Directives (AQDD).

Following consultation on the Review of the National Air Quality Strategy, the Government prepared the Air Quality Strategy for England, Scotland, Wales and Northern Ireland for consultation in August 1999. It was published in January 2000 (DETR, 2000).

2.1 UPDATED AIR QUALITY STANDARDS AND OBJECTIVES

Table 2.1 Major elements of the Environment Act 1995

Part IV Air Quality	Commentary
Section 80	Obliges the Secretary of State (SoS) to publish a National Air Quality Strategy as soon as possible.
Section 81	Obliges the Environment Agency to take account of the strategy.
Section 82	Requires local authorities, any unitary or district, to review air quality and to assess whether the air quality standards and objectives are being achieved. Areas where standards fall short must be identified.
Section 83	Requires a local authority, for any area where air quality standards are not being met, to issue an order designating it an air quality management area (AQMA).
Section 84	Imposes duties on a local authority with respect to AQMAs. ***The local authority must carry out further assessments*** and draw up an action plan specifying the measures to be carried out and the timescale to bring air quality in the area back within limits.
Section 85	Gives reserve powers to cause assessments to be made in any area and to give instructions to a local authority to take specified actions. Authorities have a duty to comply with these instructions.
Section 86	Provides for the role of County Councils to make recommendations to a district on the carrying out of an air quality assessment and the preparation of an action plan.
Section 87	Provides the SoS with wide ranging powers to make regulations concerning air quality. These include standards and objectives, the conferring of powers and duties, the prohibition and restriction of certain activities or vehicles, the obtaining of information, the levying of fines and penalties, the hearing of appeals and other criteria. The regulations must be approved by affirmative resolution of both Houses of Parliament.
Section 88	Provides powers to make guidance which local authorities must have regard to.

This study essentially forms part of the requirements of Section 84 of the Part IV Air Quality of the Environment Act 1995.

2.2 OVERVIEW OF THE PRINCIPLES AND MAIN ELEMENTS OF THE AIR QUALITY STRATEGY

The main elements of the AQS can be summarised as follows:

- The use of a health effects based approach using national air quality standards and objectives.
- The use of policies by which the objectives can be achieved and which include the input of important actors such as industry, transportation bodies and local authorities.
- The predetermination of timescales with a target dates of 2003, 2004 and 2005 for the achievement of objectives and a commitment to review the Strategy every three years.

It is intended that the NAQS will provide a framework for the improvement of air quality that is both clear and workable. In order to achieve this, the Strategy is based on several principles that include:

- the provision of a statement of the Government's general aims regarding air quality;
- clear and measurable targets;
- a balance between local and national action and
- a transparent and flexible framework.

Co-operation and participation by different economic and governmental sectors is also encouraged within the context of existing and potential future international policy commitments.

2.2.1 National Air Quality Standards

At the centre of the AQS is the use of national air quality standards to enable air quality to be measured and assessed. These also provide the means by which objectives and timescales for the achievement of objectives can be set. Most of the proposed standards have been based on the available information concerning the health effects resulting from different ambient concentrations of selected pollutants and are the consensus view of medical experts on the Expert Panel on Air Quality Standards (EPAQS). These standards and associated specific objectives to be achieved between 2003 and 2008 are shown in Table 2.2. The table shows the standards in ppb and $\mu g\ m^{-3}$ with the number of exceedences that are permitted (where applicable) and the equivalent percentile.

2.2.2 The difference between 'standards' and 'objectives' in the UK AQS

Air quality *standards* (in the UK AQS) are the concentrations of pollutants in the atmosphere that can broadly be taken to achieve a certain level of environmental quality. The standards are based on assessment of the effects of each pollutant on human health including the effects on sensitive subgroups. The standards have been set at levels to avoid significant risks to health.

The *objectives* of the UK air quality policy are framed on the basis of the recommended standards. The objectives are based on the standards, but take into account feasibility, practicality, and the costs and benefits of fully complying with the standards.

Specific objectives relate either to achieving the full standard or, where use has been made of a short averaging period, objectives are sometimes expressed in terms of percentile compliance. The use of percentiles means that a limited number of exceedences of the air quality standard over a particular timescale, usually a year, are permitted. This is to account for unusual meteorological conditions or particular events such as November 5th. For example, if an objective is to be complied with at the 99.9th percentile, then 99.9% of measurements at each location must be at or below the level specified.

Table 2.2 Air Quality Objectives in the Air Quality Regulations (2000) for the purpose of Local Air Quality Management

Pollutant	Concentration limits		**Averaging period**	**Objective** [number of permitted exceedences a year and equivalent percentile]	
	(μg m^{-3})	(ppb)		**(μg m^{-3})**	date for objective
Benzene	16.25	5	**running annual** mean	**16.25**	by 31.12.2003
1,3-butadiene	2.25	1	**running annual** mean	**2.25**	by 31.12.2003
CO	11,600	10,000	**running 8-hour** mean	**11,600**	by 31.12.2003
Pb	0.5	-	**annual** mean	**0.5**	by 31.12.**2004**
	0.25	-	**annual** mean	**0.25**	by 31.12.**2008**
NO_2 (see note)	200	105	**1 hour** mean	**200**	by 31.12.2005
				[maximum of 18 exceedences a year or equivalent to the 99.8th percentile]	
	40	21	**annual** mean	**40**	by 31.12.2005
PM_{10} (**gravimetric**) (see note)	50	-	**24-hour** mean	**50**	by 31.12.2004
				[maximum of 35 exceedences a year or ~ equivalent to the 90th percentile]	
	40	-	**annual** mean	**40**	by 31.12.2004
	266	100	**15 minute** mean	**266**	by 31.12.2005
				[maximum of 35 exceedences a year or equivalent to the 99.9th percentile]	
SO_2	350	132	**1 hour** mean	**350**	by 31.12.2004
				[maximum of 24 exceedences a year or equivalent to the 99.7th percentile]	
	125	47	**24 hour** mean	**125**	by 31.12.2004
				[maximum of 3 exceedences a year or equivalent to the 99th percentile]	

Notes

1. Conversions of ppb (and ppm to μg m^{-3}) correct at 20°C and 1013 mb.
2. The objectives for nitrogen dioxide are provisional.
3. PM_{10} measured using the European gravimetric transfer standard or equivalent. The Government and the devolved administrations see this new 24-hour mean objective for particles as a staging post rather than a final outcome. Work has been set in hand to assess the prospects of strengthening the new objective.

2.2.3 Relationship between the UK National Air Quality Standards and EU air quality Limit Values

As a member state of the EU, the UK must comply with European Union Directives.

There are three EU ambient air quality directives that the UK has transposed in to UK law. These are:

- **96/62/EC** Council Directive of 27 September 1996 on ambient air quality assessment and management. (the Ambient Air Framework Directive)

- **1999/30/EC** Council Directive of 22 April 1999 relating to limit values for sulphur dioxide, nitrogen dioxide, oxides of nitrogen, particulate matter and lead in ambient air. (the First Daughter Directive)

- **2000/69/EC** Directive of the European Parliament and the Council of 16 Nov 2000 relating to limit values for benzene and carbon monoxide in ambient air. (the Second Daughter Directive)

The first and second daughter directives contain air quality Limit Values for the pollutants that are listed in the framework directive. The United Kingdom (i.e. Great Britain and Northern Ireland) must comply with these Limit Values. The UK air quality strategy should allow the UK to comply with the EU Air Quality Daughter Directives, but the UK air quality strategy also includes some stricter national objectives for some pollutants, for example, sulphur dioxide.

The Government is ultimately responsibility for achieving the EU limit values. However, it is important that Local Air Quality Management is used as a tool to ensure that the necessary action is taken at local level to work towards achieving the EU limit values by the dates specified in those EU Directives.

2.2.4 Recent changes to the UK National Air Quality Standards

Defra issued a consultation document in 2001 with proposed changes to the UK AQS for benzene, carbon monoxide and particulate matter (defra, 2001). The proposed changes were:

For ***benzene***

- An objective derived from the long-term policy aim of **3.25 μg m^{-3} as a running annual mean** recommended by UK EPAQS (Expert Panel on Air Quality Standards). The objective for benzene included in the 2000 Strategy is 16 μg m^{-3} as a running annual mean to be achieved by 2003. This is derived from the EPAQS recommended standard. The UK adopted the second EU Air Quality Daughter Directive (which sets limit values for benzene and carbon monoxide) in 2000. This Daughter Directive sets a limit value for benzene of 5 μg m^{-3} as an annual mean to be achieved by 2010.

For ***carbon monoxide***

- Replacing the existing objective derived from the recently agreed EU limit value. The objective for carbon monoxide included in the 2000 Strategy is 11.6 mg m^{-3} as a running 8-hour mean to be achieved by 2003. This is derived from the UK EPAQS recommended standard. The second EU Air Quality Daughter Directive sets a limit value for carbon monoxide of 10 mg m^{-3} as a maximum daily 8-hour mean to be achieved by 2005. defra propose to set a new objective of achieving the EU limit value by the end of 2003, which is **10 mg m^{-3} as a maximum daily 8-hour mean** to be achieved by 2005.

For ***particulates*** new provisional objectives of

- for **all parts of the UK**, except London and Scotland, a **24-hour mean of 50 μg m^{-3} not to be exceeded more than 7 time s per year** and an **annual mean of 20 μg m^{-3}**, both to be achieved by the end of 2010;
- for London, a 24-hour mean of 50 μg m^{-3} not to be exceeded more than 10-14 times per year and an annual mean of 23-25 μg m^{-3}, both to be achieved by the end of 2010;
- for Scotland, a 24-hour mean of 50 μg m^{-3} not to be exceeded more than 7 times per year and an annual mean of 18 μg m^{-3}, both to be achieved by the end of 2010.

New objectives came into force towards the end of 2002 following the adoption of the Air Quality (England) Amendment Regulations, 2002. Local Authorities are not required to assess their air quality against these new objectives as part of the Stage 4 Review and Assessment.

2.2.5 Policies in place to allow the objectives for the pollutants in AQS to be achieved

The policy framework to allow these objectives to be achieved is one that that takes a local air quality management approach. This is superimposed upon existing national and international regulations in order to effectively tackle local air quality issues as well as issues relating to wider spatial scales. National and EC policies that already exist provide a good basis for progress towards the air quality objectives set for 2003 to 2008. For example, the Environmental Protection Act 1990 allows for the monitoring and control of emissions from industrial processes and various EC Directives have ensured that road transport emission and fuel standards are in place. These policies are being developed to include more stringent controls. Recent developments in the UK include the announcement by the Environment Agency in January 2000 on controls on emissions of SO_2 from coal and oil fired power stations. This system of controls means that by the end of 2005 coal and oil fired power stations will meet the air quality standards set out in the AQS.

Local air quality management provides a strategic role for local authorities in response to particular air quality problems experienced at a local level. This builds upon current air quality control responsibilities and places an emphasis on bringing together issues relating to transport, waste, energy and planning in an integrated way. This integrated approach involves a number of different aspects. It includes the development of an appropriate local framework that allows air quality issues to be considered alongside other issues relating to polluting activity. It should also enable co-operation with and participation by the general public in addition to other transport, industrial and governmental authorities.

An important part of the Strategy is the requirement for local authorities to carry out air quality reviews and assessments of their area against which current and future compliance with air quality standards can be measured. Over the longer term, these will also enable the effects of policies to be studied and therefore help in the development of future policy. The Government has prepared guidance to help local authorities to use the most appropriate tools and methods for conducting a review and assessment of air quality in their District. This is part of a package of guidance being prepared to assist with the practicalities of implementing the AQS. Other guidance covers air quality and land use planning, air quality and traffic management and the development of local air quality action plans and strategies.

2.2.6 Timescales to achieve the objectives for the pollutants in AQS

In most local authorities in the UK, objectives will be met for most of the pollutants within the timescale of the objectives shown in Table 2.2. It is important to note that the objectives for NO_2 remain provisional. The Government has recognised the problems associated with achieving the standard for ozone and this will not therefore be a statutory requirement. Ozone is a secondary pollutant and transboundary in nature and it is recognised that local authorities themselves can exert little influence on concentrations when they are the result of regional primary emission patterns.

2.3 AIR QUALITY REVIEWS – THE APPROACHES AND EXPECTED OUTCOMES

A range of Technical Guidance has been issued to enable air quality to be monitored, modelled, reviewed and assessed in an appropriate and consistent fashion. This includes LAQM.TG(03) 'Review and Assessment: Technical Guidance' and earlier guidance LAQM.TG4(00) May 2000, on 'Review and Assessment: Pollutant Specific Guidance'. This review and assessment has considered the procedures set out in this technical guidance.

The primary objective of undertaking a review of air quality is to identify any areas that are unlikely to meet national air quality objectives and ensure that air quality is considered in local authority decision making processes. The complexity and detail required in a review depends on the risk of failing to achieve air quality objectives and it has been proposed therefore that reviews should be carried out in stages. All the stages of review and assessment may be necessary and every authority was expected to undertake at least a first stage review and assessment of air quality in their authority area. The Stages are briefly described in the following table, Table 2.3.

Table 2.3 describes the stages of the first round of Review and Assessment. Local Authorities are currently undertaking a second round of Review and Assessment to be completed in 2003/4. Further rounds will take place in 2006/7 and 2009/10.

Table 2.3 Brief details of Stages in the Air Quality Review and Assessment process

Stage	Objective	Approach	Outcome
First Stage Review and Assessment	• Identify all significant pollutant sources within or outside of the authority's area.	• Compile and collate a list of potentially significant pollution sources using the assessment criteria described in the Pollutant Specific Guidance	
	• Identify those pollutants where there is a **risk** of exceeding the air quality objectives, and for which further investigation is needed.	• Identify sources requiring further investigation.	• Decision about whether a Stage 2 Review and Assessment is needed for one or more pollutants. If not, no further review and assessment is necessary.
Second Stage Review and Assessment	• Further screening of significant sources to determine whether there is a significant risk of the air quality objectives being exceeded.	• Use of screening models or monitoring methods to assess whether there is a risk of exceeding the air quality objectives.	
	• Identify those pollutants where there is a **risk** of exceeding the objectives, and for which further investigation is needed.	• The assessment need only consider those locations where the highest likely concentrations are expected, and where public exposure is relevant.	• Decision about whether a Stage 3 Review and Assessment is needed for one or more pollutants. If, as a result of estimations of ground level concentrations at suitable receptors, a local authority judges that there is no significant risk of not achieving an air quality objective, it can be confident that an Air Quality Management Area (AQMA) will not be required. • However, if there is doubt that an air quality objective will be achieved a third stage review should be conducted.

Table 2.3 (contd.) Brief details of Stages in the Review and Assessment process

Stage	Objective	Approach	Outcome
Third Stage Review and Assessment	• Accurate and detailed assessment of both current and future air quality. Assess the **likelihood** of the air quality objectives being exceeded.	• Use of validated modelling and quality-assured monitoring methods to determine current and future pollutant concentrations.	
	• Identify the geographical boundary of any exceedences, and description of those areas, if any, proposed to be designated as an AQMA.	• The assessment will need to consider all locations where public exposure is relevant. For each pollutant of concern, it may be necessary to construct a detailed emissions inventory and model the extent, location and frequency of potential air quality exceedences.	• Determine the location of any necessary Air Quality Management Areas (AQMAs). Once an AQMA has been identified, there are further sets of requirements to be considered. • A further assessment of air quality in the AQMA is required within 12 months, which will enable the degree to which air quality objectives will not be met, and the sources of pollution that contribute to this to be determined. A local authority must also prepare a written action plan for achievement of the air quality objective. Both air quality reviews and action plans are to be made publicly available.

Table 2.3 (contd.) Brief details of Stages in the Review and Assessment process

Stage	Objective	Approach	Outcome
Fourth Stage Review and Assessment **(to support the Action Plan)**	• Further accurate and detailed assessment of both current and future air quality. Should concentrate on areas where the Stage 3 assessment indicated exceedences of the objectives are likely.	• Use of validated modelling and quality-assured monitoring methods to determine current and future pollutant concentrations.	• Confirm outcome of original AQMA designation and alter if necessary (for example, as a result of changes in the emission factors used in the modelling)
	• Source apportionment in regions where there are exceedences. Understand contributions from traffic, industrial, domestic and background sources.	• Analyse modelling results.	• Understand the contributions from the various sources, and therefore select the source where action can be taken to reduce emissions
	• Assess a range of scenarios to improve air quality and reduce or eliminate the risk of air quality objectives being exceeded.	• Liase with stakeholders such as the Highways Agency, the Environment Agency and the local industry to help define scenarios	• Identify the most likely scenarios to improve air quality and use these in the modelling. Incorporate scenarios into any Action Plan produced.
	• Identify the geographical boundaries of any exceedences in the scenarios.	• Analyse modelling results.	• Incorporate modelling results of the scenarios into any Action Plan produced. Consider how to implement any Action Plan to improve air quality.

Local authorities are expected to have completed review and assessment of air quality by December 2000. A further review will also need to be completed for the purposes of the Act before the target date of 2003.

2.4 LOCATIONS THAT THE REVIEW AND ASSESSMENT MUST CONCENTRATE ON

For the purpose of review and assessment, the authority should focus their work on locations where members of the public are likely to be exposed over the averaging period of the objective. Table 2.4 summarises the locations where the objectives should and should not apply.

Table 2.4 Typical locations where the objectives should and should not apply

Averaging Period	**Pollutants**	**Objectives *should* apply at …**	**Objectives should *not* generally apply at …**
Annual mean	• 1,3 Butadiene • Benzene • Lead • Nitrogen dioxide • Particulate Matter (PM_{10})	• All background locations where members of the public might be regularly exposed.	• Building facades of offices or other places of work where members of the public do not have regular access.
		• Building facades of residential properties, schools, hospitals, libraries etc.	• Gardens of residential properties.
			• Kerbside sites (as opposed to locations at the building facade), or any other location where public exposure is expected to be short term
24 hour mean and 8-hour mean	• Carbon monoxide • Particulate Matter (PM_{10}) • Sulphur dioxide	• All locations where the annual mean objective would apply.	• Kerbside sites (as opposed to locations at the building facade), or any other location where public exposure is expected to be short term.
		• Gardens of residential properties.	

Table 2.4 (contd.) Typical locations where the objectives should and should not apply

Averaging Period	Pollutants	Objectives should apply at …	Objectives should generally not apply at …
1 hour mean	• Nitrogen dioxide • Sulphur dioxide	• All locations where the annual mean and 24 and 8-hour mean objectives apply.	• Kerbside sites where the public would not be expected to have regular access.
		• Kerbside sites (e.g. pavements of busy shopping streets).	
		• Those parts of car parks and railway stations etc. that are not fully enclosed.	
		• Any outdoor locations to which the public might reasonably expected to have access.	
15 minute mean	• Sulphur dioxide	• All locations where members of the public might reasonably be exposed for a period of 15 minutes or longer.	

It is unnecessary to consider exceedences of the objectives at any location where public exposure over the relevant averaging period would be unrealistic, and the locations should represent non-occupational exposure.

3 Stage 4 Air Quality Review and Assessment and Action Planning

This section contains information about Stage 4 Air Quality Review and Assessments and Action Plans. It explains the relationships between the Stage 4 and Action Plans, what each document should contain, and the timescales for producing the documents.

3.1 THE RELATIONSHIPS BETWEEN A STAGE 4 AIR QUALITY REVIEW AND ASSESSMENT AND AN ACTION PLAN

If a local authority declares an air quality management area, Section 84(1) of the Environment Act 1995 requires that local authority to carry out a further assessment of existing and likely future air quality in the AQMA. This further assessment is called a Stage 4 air quality review and assessment, and is intended to supplement information the authority already has. It is a duty of the LA to complete this Stage 4 air quality review and assessment.

For each pollutant where there is an exceedence of the air quality, the Stage 4 should calculate:

- how great an improvement is needed; and
- the extent to which different sources contribute to the problem (source apportionment of traffic, industrial, domestic and background – if appropriate).

This should give a clear picture of the sources that authorities can control or influence. It should ensure that Action Plans strike a balance between the contribution from local authorities and the contribution that must come from other sectors. It should allow them to target their responses more effectively and ensure that the relative contributions of industry, transport and other sectors are cost effective and proportionate. It should include, in particular, an estimate of the costs and feasibility of different abatement options to allow for the development of proportionate and effective Action Plans (although this information could be included within the Action Plan, rather than the Stage 4). Further liaison with other agencies (including, in particular, the Environment Agency and the Highways Agency) is likely to be essential.

Essentially, the production of the Stage 4 air quality review and assessment and the Action Plan are activities that the LA can complete in parallel, rather than sequentially.

3.2 RECENT defra GUIDANCE ON STAGE 4 AIR QUALITY REVIEW AND ASSESSMENT

defra have issued guidance on what they expect in a Stage 4. This expands on the information that is available in LAQM.G1(00) - Framework for review and assessment of air quality. It has been incorporated into new policy guidance LAQM.PG(03).

Essentially, the Stage 4 provides the technical justification for the measures an authority includes in its Action Plan. defra expect that the Stage 4 will allow Local Authorities:

- To calculate more accurately how much of an improvement in air quality is needed to deliver the air quality objectives within the AQMA
- To refine their knowledge of the sources of pollution so that air quality Action Plans can be properly targeted
- To take account of national policy developments that may come to light after the AQMA declaration (the revision of the vehicle emission factors is an example of this kind of policy development)
- To take account of local policy developments, for example, new transport schemes in the vicinity of the AQMA or of any new major housing or commercial developments
- To carry out more intensive monitoring in the problem areas to confirm earlier findings
- To corroborate other assumptions on which the designation of the AQMA was based and to check that the original designation is still valid, and does not need amending
- To respond to comments made by statutory consultees (if there were any relevant comments made)

3.3 ACTION PLANS

Local authorities are required to prepare a written Action Plan for each AQMA setting out the actions they intend to take in pursuit of the air quality objectives. This has to include a timetable for implementing the plan.

The Action Plan should contain the scenarios that have been modelled in the Stage 4 review and assessment. It should contain a summary of the air quality improvements that might be possible for each of the scenarios identified. The Stage 4 provides the technical justification for the measures an authority includes in its Action Plan.

The Action Plan should also contain simple estimates of the costs and feasibilities of implementing those scenarios. The Action Plan may also consider the non-health benefits of implementing scenarios in the Action Plan, for example, reductions in road traffic accident deaths as a result of road improvements that also reduce vehicle emissions.

The LA can then identify which scenario(s) offer the most cost-effective or cost-beneficial way of improving air quality.

3.4 STAGE 4 AND ACTION PLAN TIMESCALES

The Environment Act does not set any deadline for completing action plans, but the Government expects authorities to begin preparing them as soon as they have designated an AQMA, and in parallel with their further assessment of air quality required under section 84(1) of the Environment Act. Authorities should not wait until they have completed their further assessment of air quality before beginning their Action Plans. They should aim to consult on their draft AQMA Action Plans within 9-12 months of designation, and should have AQMA Action Plans in place within 12-18 months of designation.

Local authorities are required under section 84(2)(a) of the Environment Act to report on the further assessment of air quality (i.e. the Stage 4 Air Quality Review and Assessment) **within 12 months of designating the Air Quality Management Area**.

4 Information used to support this assessment

This section lists the key information used in this review and assessment.

4.1 MAPS AND DISTANCES OF RECEPTORS FROM ROADS

Norwich City Council provided detailed OS landline data for the parts of the City covered by the AQMAs. Individual buildings or groups of buildings (receptors) were identified from the electronic OS Landline maps of the areas and the distances of these receptors from the road determined from the maps.

4.2 ROAD TRAFFIC DATA

The main roads of concern for the Stage 4 assessment were the A147 Grapes Hill, A1067 St Augustines Street and Castle Meadow, Cattle Market Street, Farmers Avenue, and Market Avenue. Norwich District Council provided details given in their Stage 3 report of annual average daily traffic flows predicted from Norfolk County Council's SATURN traffic model for 1998. The data were supplemented with traffic counts from the SCOOT traffic management system during 1998 for a more limited set of roads. Additional traffic flow data derived from the DETR/Dtp link-based census for 1999 and 2000 was provided by Norfolk County Council and from the National Atmospheric Emissions Inventory. Norfolk County Council also provided count data from video surveys undertaken on 13 November 2001 and 29 May 2002. Vehicle mix data were taken from the NAEI inventory for 2000 and from the SATURN traffic model. Vehicle speeds were taken from the SATURN traffic model. A diurnal profile was applied to the traffic flows typical of the UK.

Norwich City Council indicated that there was substantial queuing along the whole of Pitt Street and St Augustines Street, along Aylsham Road as far as the junction with Drayton Road and along Barn Road leading to the Barn Road/St Crispins Road roundabout.

Table 4.1: Annual average daily traffic flows

	Annual average daily traffic flow	Percentage heavy duty vehicles	Speed, kph	Source, year
A147 Grapes Hill	34305	3.3	45	NAEI 2000
Chapelfield Road	29736	5[&]	55	SCOOT, 1998
Convent Road	23503	4	20	SATURN, 1998
Unthank Road	7001	2	55	SATURN, 1998
Earlham Road	16770	3	55	SATURN, 1998
Dereham Road	17662	4.6	55	NAEI 2000
Barn Road	35616	2.3	45	NAEI 2000
Castle Meadow	4521	50	30	Video 2001,
Red Lion Street	10907	6	40	SATURN, 1998
Farmers Avenue	10658	6	30	SATURN, 1998
Cattle Market Street	23819	2.3	30	Video, 2002
Market Avenue	16772	9	30	Video, 2001
Golden Ball Street	14798	7[&]	40	SCOOT, 1998
Rouen Road	7652	3	45	SATURN, 1998
Redwell Street (Bank Plain)	17466	6	30	SATURN, 1998
Agricultural Hall Plain	16772	9	30	Video 2001
Rose Lane	19963	6.5	30	Video, 2002
Pitt Street	17303	2.1	10	NAEI, 1999
St Augustines Street	17303	2.1	10	NAEI, 1999
Aylsham Road	17303	2.1	10	NAEI, 1999
Waterloo Road	9640	5	45	SATURN, 1998
St Crispins Road (east of roundabout)	29469	2.3	10	NAEI 2000
St Crispins Road (west of roundabout)	35616	2.3	10	NAEI 2000
Duke Street	14857	3	45	SATURN, 1998
Ber Street	11058	2	45	SATURN, 1998

& Number of HDV vehicles taken from SATURN model

4.2.1 Traffic Growth

The National Roads Traffic Forecast (NRTF, 1997) indicates that in the absence of further information on the severity of capacity limitations a central estimate is considered the most likely outcome. Therefore, in this assessment, we have assumed that traffic volume will increase in future years by factors calculated from the NRTF central estimate together with local (Norwich) and national growth factors taken from TEMPRO v4.2.3 Table 4.2 shows the growth factors applied.

Table 4.2: Traffic growth factors applied

Year	Growth factor
1998	1
1999	1.02
2000	1.03
2001	1.05
2002	1.07
2005	1.13

4.3 AMBIENT MONITORING

Nitrogen dioxide concentrations were monitored at a background continuous monitoring site at Norwich Centre (Friars Quay) and at roadside sites at Norwich Roadside, Ber Street and at Golding Place. The Norwich Centre and Norwich Roadside sites are part of defra’s Automatic Urban and Rural Network and have operated from 1997 onwards.

The Norwich Centre monitoring station (TG230089) is within a self-contained, air-conditioned housing located within the south western corner of a central Norwich public garden. The nearest road is located approximately 12 metres away at St George's Street although traffic flow is free flowing and very light (1 or 2 vehicles per minute observed off peak). The manifold inlet is approximately 3 metres high. The surrounding area is generally open and comprises of residential and light industrial premises.

The Norwich Roadside site (TG234078) is within an existing office building complex approximately 6 metres from a busy 2-lane urban street (Ber Street). Traffic flow is approximately 16,000 vehicles per day and is subject to frequent congestion. The manifold inlet is approximately 6 metres above ground and is mounted close to the building facade. The surrounding area comprises retail outlet and business premises.

The Golding Place continuous monitor is located in a residential street approximately 25 m from the kerb of the A147 Grapes Hill.

Nitrogen dioxide diffusion tube measurements were made at 27 locations throughout Norwich City. Of these sites, 12 are within the designated Air Quality Management Areas

4.4 EMISSION FACTORS USED IN THIS REVIEW AND ASSESSMENT

The vehicle emission factors used for national mapping have recently been revised by defra[3]. The most recent emission factors have been used in this Stage 4.

In the Norwich Stage 3 report, older emission factors were used. Using the newer factors will result in differences in the modelled results between the Stage 3 and the Stage 4.

[3] The new set of emission factors on the NAEI website (www.naei.org.uk/emissions/index.php) approved by DEFRA and DTLR for use in emissions and air quality modelling, following consultation of the TRL Report "Exhaust Emission Factors 2001: Database and Emission Factors" by TJ Barlow, AJ Hickman and P Boulter, TRL, September 2001

5 Stage 4 Review and Assessment for Nitrogen Dioxide

This section summarises

- the work that was done at Stage 3 and the areas of exceedence of the air quality objectives for nitrogen dioxide;
- monitoring that was completed for the Stage 3 Air Quality Review and Assessment;
- the additional monitoring that has been done after Stage 3 to confirm the predicted concentrations in the Air Quality Management Area or to more generally assess concentrations around Norwich;
- the Stage 4 modelling, which includes predictions of concentrations of nitrogen dioxide for a range of Action Plan scenarios to improve air quality.

5.1 LATEST STANDARDS AND OBJECTIVES FOR NITROGEN DIOXIDE

In June 1998, the Common Position on Air Quality Daughter Directives (AQDD) agreed at Environment Council included the following objectives to be achieved by 31 December 2005 for nitrogen dioxide:

- An annual average concentration of 40 $\mu g\ m^{-3}$ (21 ppb);
- 200 $\mu g\ m^{-3}$ (100 ppb) as an hourly average with a maximum of 18 exceedences in a year.

The National Air Quality Strategy was reviewed in 1999 (DETR, 1999). The Government proposed that the annual objective of 40 $\mu g\ m^{-3}$ be retained as a provisional objective and that the original hourly average be replaced with the AQDD objective. The revised Air Quality Strategy for England, Scotland, Wales and Northern Ireland (DETR, 2000) and the Air Quality Regulations (2000) include the proposed changes.

The new hourly objective is slightly more stringent than the original hourly objective. Modelling studies suggest that in general achieving the annual mean of 40 $\mu g\ m^{-3}$ is more demanding than achieving either the former or current hourly objective. If the annual mean is achieved, the modelling suggests the hourly objectives will also be achieved.

5.2 KEY FINDINGS OF THE STAGE 3 REVIEW AND ASSESSMENT

Norwich City council carried out a combined Stage 2 and Stage 3 assessment (City of Norwich, 2001). The Stage 3 Review and Assessment included detailed dispersion modelling around selected hotspots to predict areas of exceedence of the nitrogen dioxide objectives (Chatterton, 2001). Further assessment of nitrogen dioxide concentrations was carried out in a Stage 3 update (netcen, 2002). The Stage 3 update considered whether there was relevant exposure in areas of Norwich at which the modelling study had shown that it was likely that the annual average objective for nitrogen dioxide would be exceeded.

The Stage 2/3 report concluded that the annual mean air quality objective for nitrogen dioxide is almost certain to be exceeded in 2005 in areas of Norwich, based on the information available at the time.

5.3 AREA DECLARED BY NORWICH AS AN AIR QUALITY MANAGEMENT AREA

Three areas were declared by Norwich as AQMAs. Fig.5.1 shows the general location of the three AQMAs within Norwich. Figs 5.2, 5.3 and 5.4 show the AQMAs in more detail.

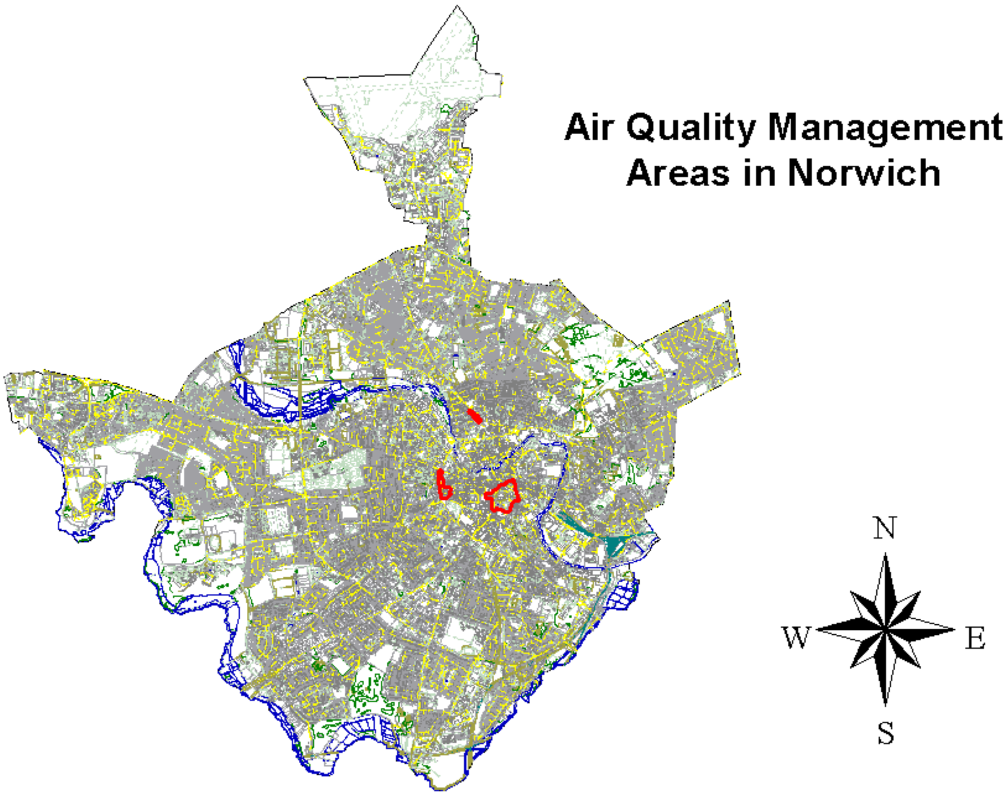

Fig.5.1: Location of AQMAs in Norwich

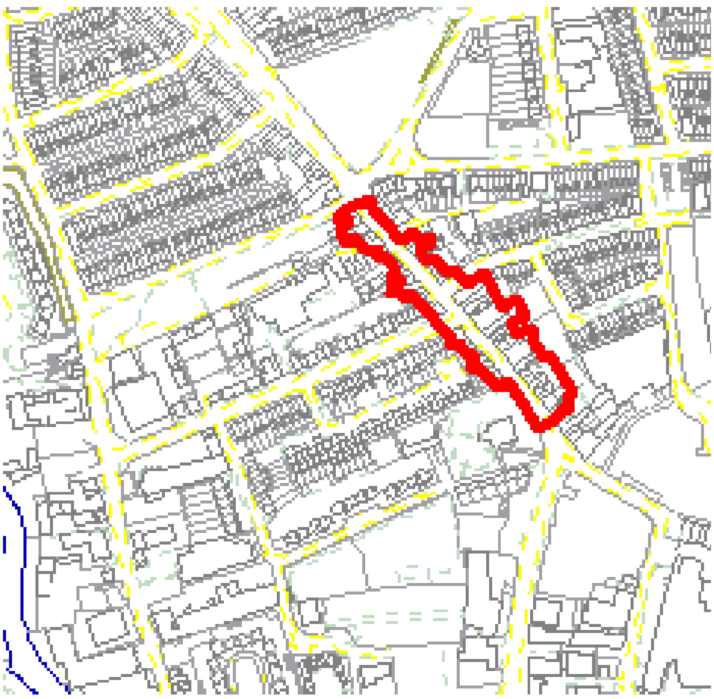

Fig. 5.2: AQMA No 1: St Augustines

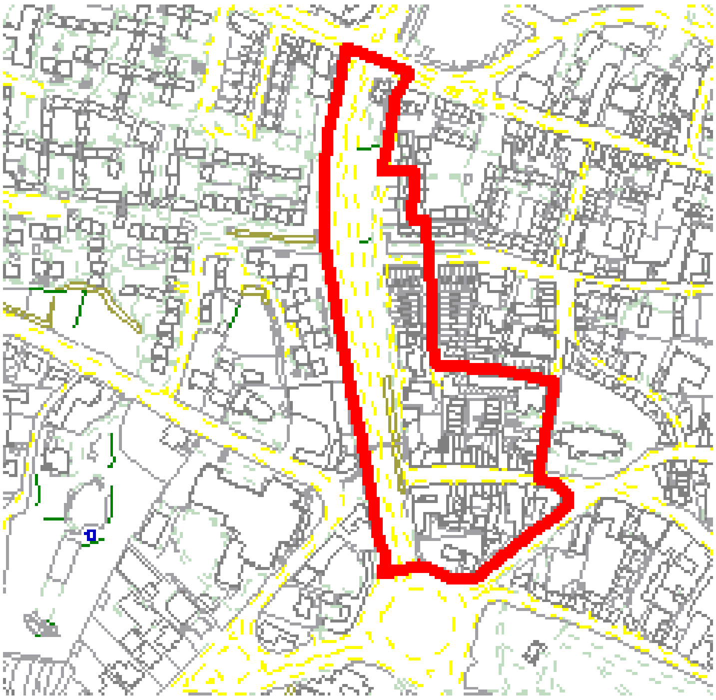

Fig. 5.3: AQMA No 2: Grapes Hill

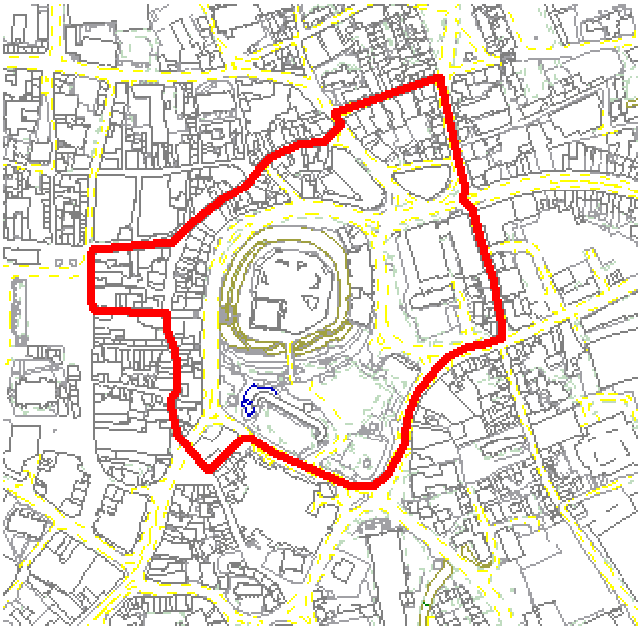

Fig. 5.4: AQMA No 3: Castle

5.4 MONITORING

5.4.1 QA/QC of continuous monitoring data

The Norwich Centre and Norwich Roadside continuous monitoring stations are included in defra's Automatic Urban and Rural Network. The data are checked and ratified by netcen.

The Golding Place site is operated by Norwich City Council. The equipment is calibrated and the data are checked and ratified by netcen to the same standard as the Automatic Urban and Rural Network.

5.4.2 Summary of continuous monitoring data

Table 5.1 summarises the measurements of nitrogen dioxide concentrations at the Norwich Centre, Norwich Roadside and Norwich Goldings Place continuous monitoring stations for relevant periods. Data for Cambridge Roadside is included for comparison.

Table 5.1: Continuous monitoring data

Site	Period	Data capture, %	NO_x, concentration, $\mu g\ m^{-3}$ as NO_2	NO_2 Concentration, $\mu g\ m^{-3}$	
				Period average	Period 99.8th percentile hourly mean
Norwich Centre	2002	94.9	39.1	25.3	88
	12/4/02-28/2/03&	95.2		25.8	99
	12/4/02-4/10/02	93.8		18.7	69
	3/9/02-10/6/03&	92.5		30.3	103
Norwich Roadside	2002	97.7	61.5	30.3	96
	12/4/02-28/2/03&	96.4		30.8	100
	12/4/02-4/10/02	96.8		26.9	93
	3/9/02-10/6/03&	94.7		35.3	107
Norwich Golding Place	3/9/02-10/6/03&	94.2	71.6	38.1	122
Cambridge Roadside	2002	94.0		42.7	104
	12/4/02-28/2/03&	94.8		43.1	103
	12/4/02-4/10/02	93.4		40.6	105
	3/9/02-10/6/03&	95.3		44.0	103

& Ratified to 31/12/02

5.4.3 Estimation of annual mean nitrogen dioxide concentrations from short-term monitoring data

It was only possible to carry out a diffusion tube monitoring survey at sites within the AQMA between April and October 2002. Data from other diffusion tube sites was available from April 2002 to February 2003. The Norwich Goldings Place site started in September 2002. The measurements at these sites were adjusted to provide estimates of annual mean concentrations during 2002 by reference to measurements made over the same periods at the Norwich Centre, Norwich Roadside and Cambridge Roadside sites. Table 5.2 provides details of measurements used to derive the adjustment factor.

Table 5.2: Adjustment factors used to estimate annual mean concentrations from part year data.

Period	Long term site	Annual mean 2002	Period mean	Ratio
12/4/02-28/2/03	Norwich Centre	25.3	25.8	0.981
	Norwich Roadside	30.3	30.8	0.984
	Cambridge Roadside	42.7	43.1	0.991
	Average			0.985
12/4/02-4/10/02	Norwich Centre	25.3	18.7	1.353
	Norwich Roadside	30.3	26.9	1.126
	Cambridge Roadside	42.7	40.6	1.052
	Average			1.177
3/9/02-10/6/03	Norwich Centre	25.3	30.3	0.835
	Norwich Roadside	30.3	35.3	0.858
	Cambridge Roadside	42.7	44.0	0.970
	Average			0.888

The annual mean nitrogen dioxide concentration for 2002 for Golding Place derived from the part year data was 38.1 x 0.888=34 $\mu g\ m^{-3}$.

5.4.4 Method of adjustment of bias in the reported diffusion tube concentrations

In this report, we have assessed the bias in diffusion tube data using the concentrations recorded using diffusion tubes collocated with the Norwich Centre continuous monitoring site on Ber Street. Table 5.3 shows the concentrations measured by continuous monitor and by diffusion tube at the site for relevant periods. Bias adjustment factors have been calculated for each period following LAQM TG(03) guidance. Part year adjustment factors, calculated in Table 5.2 above have then been applied to derive an overall adjustment factor to convert part year diffusion tube measurements to 2002 annual mean concentrations.

Table 5.3: Assessment of bias in nitrogen dioxide diffusion tube measurements

Diffusion tube period	Continuous monitor concentration, $\mu g\ m^{-3}$	Diffusion tube concentration, $\mu g\ m^{-3}$	Bias adjustment factor for period	Bias adjustment factor to 2002
12/4/02-28/2/03	25.8	25.0	1.032	1.016
12/4/02-4/10/02	18.7	20.8	0.899	1.058

5.4.5 Factors used to predict future diffusion tube concentrations from current concentrations

The defra Review and Assessment: Technical Guidance. LAQM.TG (03) provides factors to project forward concentrations at background locations, based on the concentrations measured in recent years.

Background

- 2002 to 2005 0.93

Kerbside

- 2002 to 2005 0.92

The projected concentrations at each of the diffusion tube sites are shown in Table 5.4. Figs 5.5-5.7 show the estimated concentrations ($\mu g\ m^{-3}$) in 2005 at locations close to the AQMAs based on the diffusion tube measurements.

Table 5.4 Diffusion tube measurements and projected concentrations

Site	OS Grid reference, m		Concentration, $\mu g\ m^{-3}$		
	X	Y	Period	2002, bias adjusted	2005 estimate
Vulcan Rd	622226	311746	36.9	37.4	34.4
Heartsease	625231	310098	30.2	30.6	28.2
Tombland	623335	308853	34.8	35.4	32.5
Cattlemarket	623290	308394	36.8	37.4	34.4
St Stephens	622847	308025	34.2	34.8	32.0
Ipswich Rd	622546	307504	28.6	29.1	26.8
Earlham Rd	619120	308259	30.5	31.0	28.5
Colman Rd	621084	308519	34.8	35.3	32.5
Unthank Rd	622003	308112	34.7	35.3	32.5
Johnstone Pl	622460	308444	38.6	39.2	36.1
Chapelfield	622596	308238	23.4	23.8	21.9
Castlemeadow	623155	308604	34.7	35.3	32.4
Guildhall	622931	308560	23.1	23.4	21.6
Exchange St	623000	308714	31.3	31.8	29.3
St Georges	623085	308895	23.7	24.1	22.2
St Augustines	622818	309582	43.6	44.3	40.7
Ber St 1	623451	307811	25.0	25.4	23.3
Parmeter Pl	623467	308418	20.4	21.6	19.9
Rouen Rd	623302	308310	26.4	27.9	25.7
Paragon Pl	622381	308648	25.5	27.0	24.8
Upper St Giles	622457	308571	23.4	24.7	22.7
Copeman St	622451	308701	22.5	23.8	21.9
Opie St	623182	308633	23.0	24.3	22.4
Cassella	622392	308844	22.9	24.2	22.3
Golding Pl	622392	308761	23.4	24.7	22.7
St Augustines - Colmans	622915	309485	27.4	29.0	26.7
St Augustines - top	622795	309626	34.1	36.1	33.2
Bull Close			22.7	24.1	22.1
Spencer St			20.8	22.1	20.3

Sites in *italics* based on 6 months data only

The Golding Place diffusion tube is not co-located with the continuous monitor

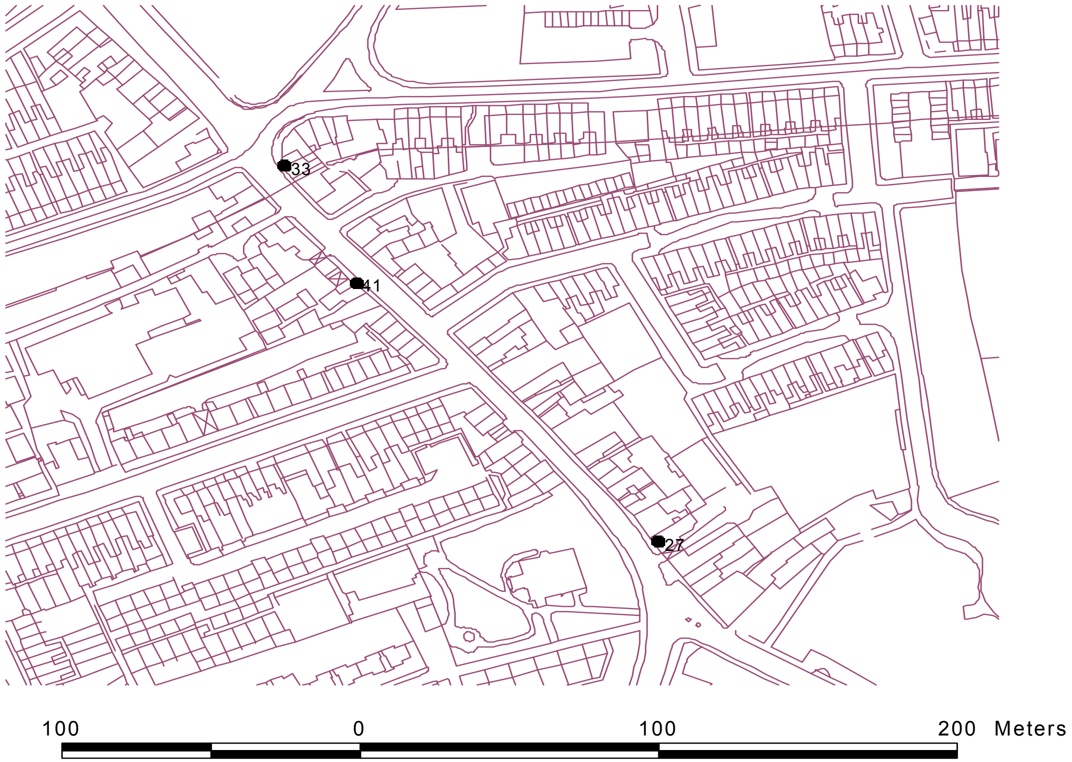

Fig.5.5 : Nitrogen dioxide concentration ($\mu g\ m^{-3}$) estimates for 2005, based on diffusion tube measurements: St Augustines Street

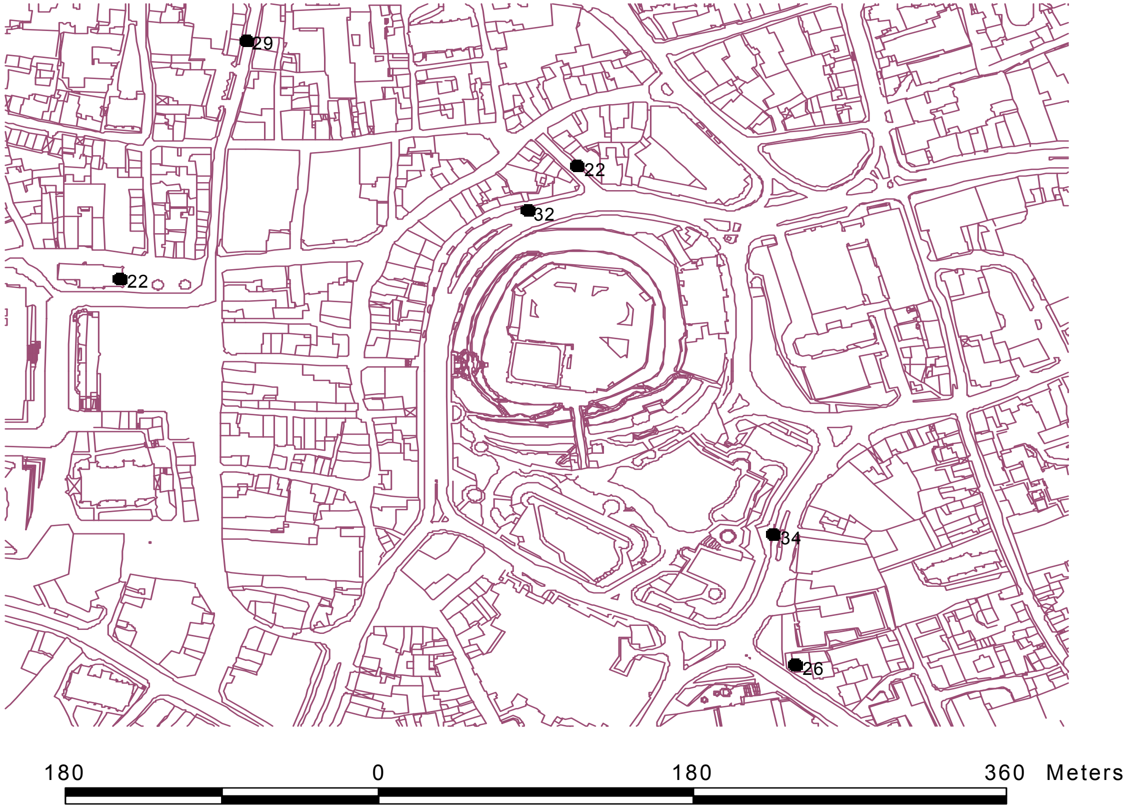

Fig.5.6 : Nitrogen dioxide concentration ($\mu g\ m^{-3}$) estimates for 2005, based on diffusion tube measurements: Castle

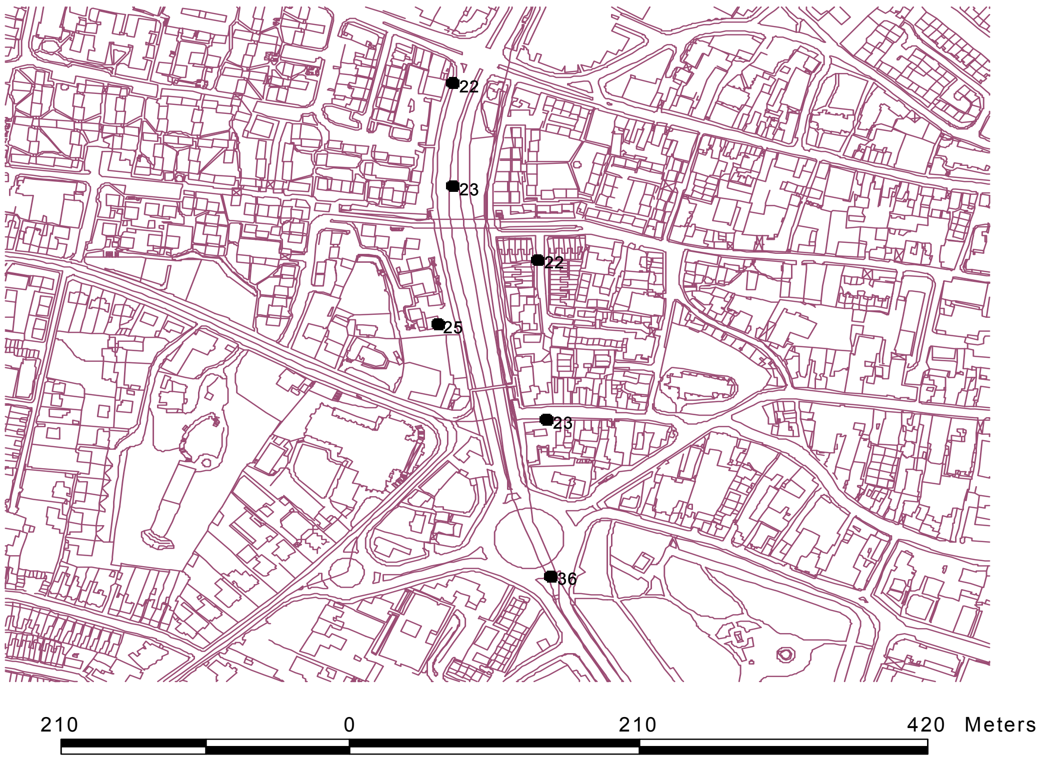

Fig.5.7 : Nitrogen dioxide concentration ($\mu g\ m^{-3}$) estimates for 2005, based on diffusion tube measurements: Grapes Hill

5.4.6 Comparison of the monitoring results with the relevant air quality objectives

The annual average nitrogen dioxide concentrations measured at the background continuous monitoring sites at Norwich Centre, Norwich Roadside and Golding Place were all markedly less than the 2005 objective of 40 $\mu g\ m^{-3}$ as an annual mean. The concentrations are expected to decrease from the current values in the period to 2005 and so it is concluded that the objective will be met at these sites.

The Golding Place continuous monitor is located close to the Grapes Hill AQMA and the exposure is likely to be representative of public exposure in the area. The forecast concentration in 2005 derived from the continuous monitoring results is 34x0.92= 31 $\mu g\ m^{-3}$. It seems unlikely based on the continuous monitoring results that members of the public will be exposed to concentrations exceeding the objective of 40 $\mu g\ m^{-3}$ in the vicinity of the Goldings Place continuous monitor close to Grapes Hill AQMA in 2005.

Nitrogen dioxide concentrations are not expected to exceed the objective at diffusion tube locations within the Castle AQMA. However, it is not clear whether the diffusion tube sites correspond to worst case public exposure.

It is estimated that the objective will be exceeded at one of the diffusion tube sites , midway along St Augustines Street in the St Augustines AQMA. It is likely that members of the public will be exposed to similar concentrations of nitrogen dioxide over the annual mean averaging time of the objective.

5.5 OVERVIEW OF THE AIR QUALITY MODELLING FOR THIS STAGE 4 ASSESSMENT

5.5.1 Summary of the models used in this Stage 4 assessment

The air quality impact from roads has been assessed using our proprietary urban model. There are two parts to this model:

- The *Local Area Dispersion System (LADS) model*. This model calculates background concentrations of oxides of nitrogen on a 1 km x 1 km grid. The estimates of emissions of oxides of nitrogen for each 1 km x 1 km area grid square were obtained from the 1998 NAEI Area Emissions Inventory.
- The *DISP model*. This model is a tool for calculating atmospheric dispersion using a 10 m x 10 m x 3 m volume-source kernel to represent elements of the road. The volume source depth takes account of the initial mixing caused by the turbulence induced by the vehicles. Estimates of emissions from vehicles have been calculated using the latest (and finalised for this round of Review and Assessment) vehicle emission factors.

Particular attention was paid to the avoidance of "double counting" of the contribution from major roads in the modelled areas. Thus the emissions from sections of roads modelled using DISP were removed from the LADS inventory.

Parts of St Augustines Street are enclosed by buildings on both sides of the road. The buildings create a "street canyon" effect that hinders the dispersion of pollutants released from the motor vehicles. The DISP model does not take full account of the street canyon effect.

More detailed modelling was therefore carried out using netcen's street canyon model LADS-FDS. LADS-FDS utilises dispersion kernels derived for the principal wind directions using the US National Institute of Standards and Technology FDS3 Large Eddy Simulation (Computational Fluid Dynamics) model. The dispersion kernels are applied to calculate roadside concentrations for each hour of the modelled year: annual average concentrations are then calculated from the hourly concentrations. Fig 5.8 shows the layout of the St Augustines Street area modelled and the buildings taken into account.

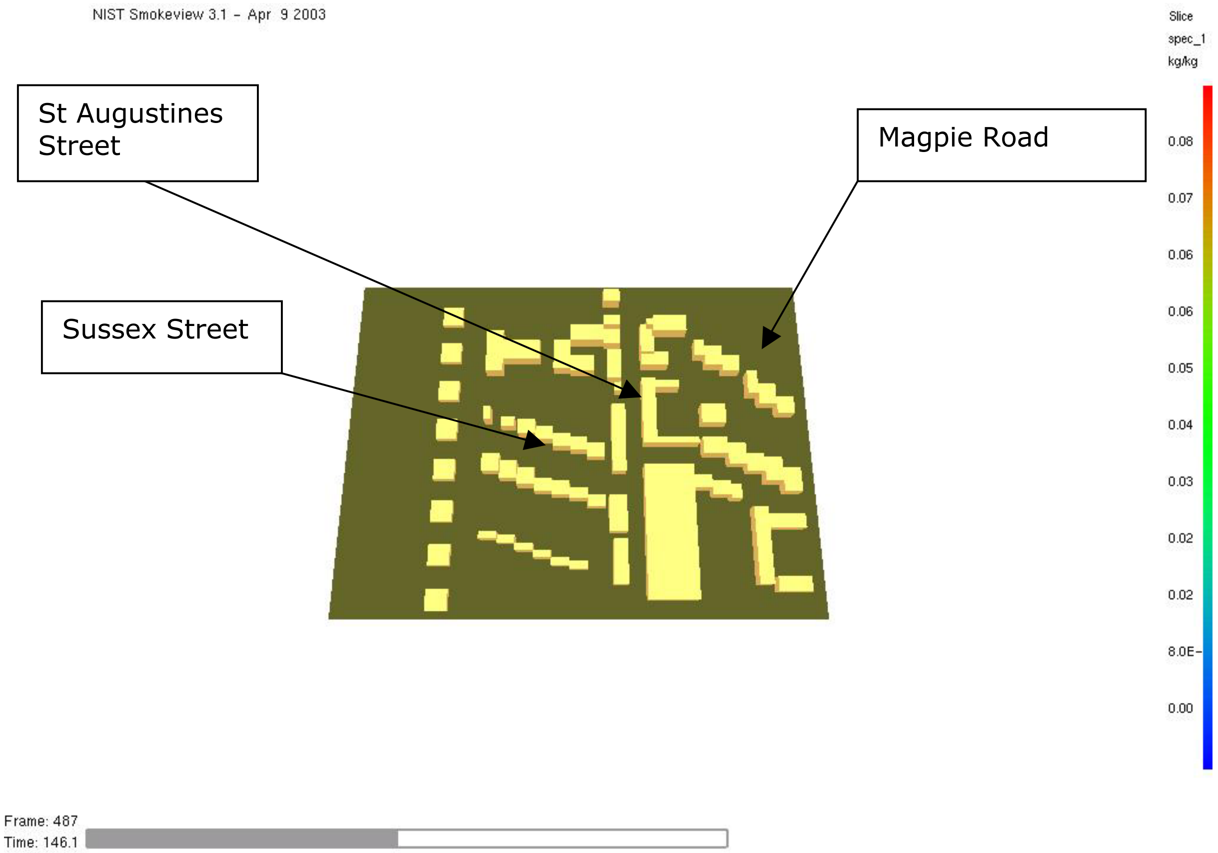

Fig. 5.8: Area of St Augustines Street and associated buildings modelled using LADS-FDS

The LADS Urban model calculates nitrogen dioxide concentrations from predicted oxides of nitrogen concentrations using empirical relationships determined from monitoring results throughout the UK. For the Norwich study the empirical relationship between roadside oxides of nitrogen contribution and roadside nitrogen dioxide contribution provided by LAQM.TG(03) was used. The LAQM.TG(03) method involves the calculation of a factor F to estimate the proportion of roadside oxides of nitrogen converted to nitrogen dioxide. For the Norwich Roadside site the F factor derived from the empirical relationship is 0.25: this value may be compared with 0.22 derived from the monitoring results at Norwich Roadside and Norwich centre for 2002.

5.5.2 Validation and verification of the model

In simple terms, model validation is where the model is tested at a range of locations and is judged suitable to use for a given application. The modelling approach used in this assessment has been validated, and used in numerous **netcen** air quality review and assessments. Details of the model validation are given in Appendix 1 and Appendix 2.

Verification of the model involves comparison of the modelled results with any local monitoring data at relevant locations. Table 5.5 compares modelled predictions using LADS Urban of nitrogen dioxide concentrations with measured values at Norwich Centre, Norwich Roadside and Golding Place.

Table 5.5: Comparison of modelled and measured concentrations, 2002

	Nitrogen dioxide concentration, $\mu g\ m^{-3}$	
	Modelled	Measured
Norwich Centre	20.5	25.3
Norwich Roadside	23.8	30.3
Golding Place	26.7	34

5.5.3 Bias adjustment of the model

Bias adjustment is the process where the concentrations of the model are adjusted to agree with local air quality monitoring data. In this case, the model has been used to predict concentrations at the site of the continuous monitors. The difference in the modelled and measured nitrogen dioxide concentration has been used to correct for modelled bias.

For 2002, the adjusted model output from LADS Urban has been calculated from :

Bias adjusted NO_2 =(Modelled background NO_2+4.8)+1.39xModelled roadside NO_2

based on a "best fit" line through the data points shown in Table 5.5.

For the 2005 modelled predictions of concentrations, the background bias has been corrected for expected future declines in concentrations of nitrogen dioxide. The background bias correction applied to 2005 predictions was 4.5 $\mu g\ m^{-3}$.

5.5.4 Comparison of modelled concentrations with forecasts based on diffusion tube measurements

The diffusion tube survey has not been used for the verification of the model because the majority of the diffusion tube sites within the AQMAs have only operated for six months and so there is an inadequate basis for model adjustment. Diffusion tubes were installed at Johnstone Place, Cattlemarket, Castlemeadow and St Augustines Street for 12 months but these four sites were all approximately 1 m from the kerbside and therefore may not provide a satisfactory basis for model verification (A3.172). Nevertheless, Table 5.5 allows a direct comparison between modelled and diffusion tube results at these four sites. Model results are shown unadjusted and adjusted according to the results from the continuous monitoring sites.

Table 5.5: Comparison of modelled concentrations with diffusion tube estimates

	Concentration, $\mu g\ m^{-3}$		
Site	Modelled, unadjusted	Modelled, adjusted	Diffusion tube estimate
St Augustines	32.0	41.3	44.3
	38.4 (LADS-FDS)	43.2 (LADS-FDS)$	44.3
Johnstone Place	42.6	55.4	39.2
Castlemeadow	32.5	41.9	35.3
Cattlemarket	33.2	43.7	37.4

$ adjusted for background only

Comparison of the LADS Urban predictions with the diffusion tube measurements at the non-canyon kerbside sites (Johnstone Place, Castlemeadow and Cattlemarket) suggests that the LADS Urban model as adjusted overestimates the concentration at these sites. The Fluid Dynamic Simulation (LADS-FDS) results agree well with the measurement at the single site where comparison was possible.

5.6 IMPROVEMENTS NEEDED IN AIR QUALITY

5.6.1 The improvement that is needed – general points

A key step in the Stage 4 Review and Assessment process is to identify the improvements needed in air quality, when there are exceedences of the UK air quality objectives.

An important point to note is that the Local Authority does not need to attempt to improve air quality beyond the air quality objective that is being exceeded. This applies even if that authority has taken a precautionary approach and deliberately set the boundary of their AQMA at, for example, the 36 $\mu g/m^3$ contour rather than the 40 $\mu g/m^3$ contour, in the case of the annual mean NO_2 objective.

For example, an AQMA may have been declared for NO_2, and for administrative reasons, the boundary of the AQMA may include houses where the concentrations of NO_2 are not predicted to exceed the annual mean objective of 40 $\mu g/m^3$. Let us say the maximum exceedence of the annual mean NO_2 objective at a relevant receptor in the AQMA was 43 $\mu g/m^3$. The maximum improvement that would be needed in this example AQMA will therefore be 3 $\mu g/m^3$. In this example, this will mean that some houses in the AQMA will experience concentrations of NO_2 possibly much lower than the annual mean objective.

5.6.2 Areas of predicted exceedence of the air quality objectives considered in this Stage 4 assessment

Norwich City Council identified three AQMAs on the basis of the Stage 3 Review and Assessment where it was considered likely that the annual mean objective for nitrogen dioxide would not be achieved.

The following contour maps show the areas where the modelling has predicted exceedences of the annual mean NO_2 objective (in 2005).

Fig. 5.9: LADS-FDS Modelled nitrogen dioxide concentrations, μg m^{-3}, 2005, AQMA No 1, St Augustines Street

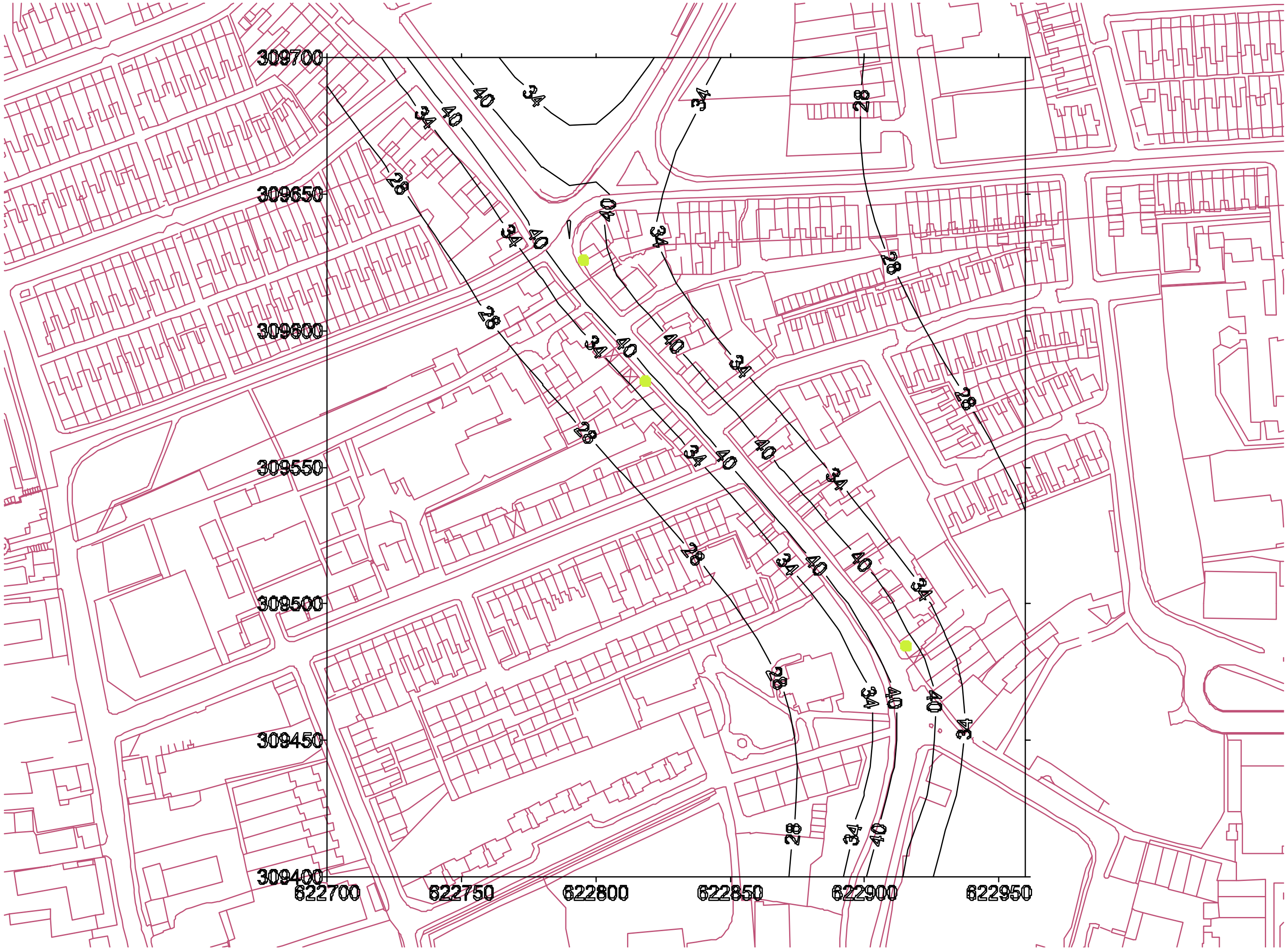

Fig. 5.10: LADS-Urban modelled nitrogen dioxide concentrations, $\mu g\ m^{-3}$, 2005, AQMA No 1, St Augustines Street

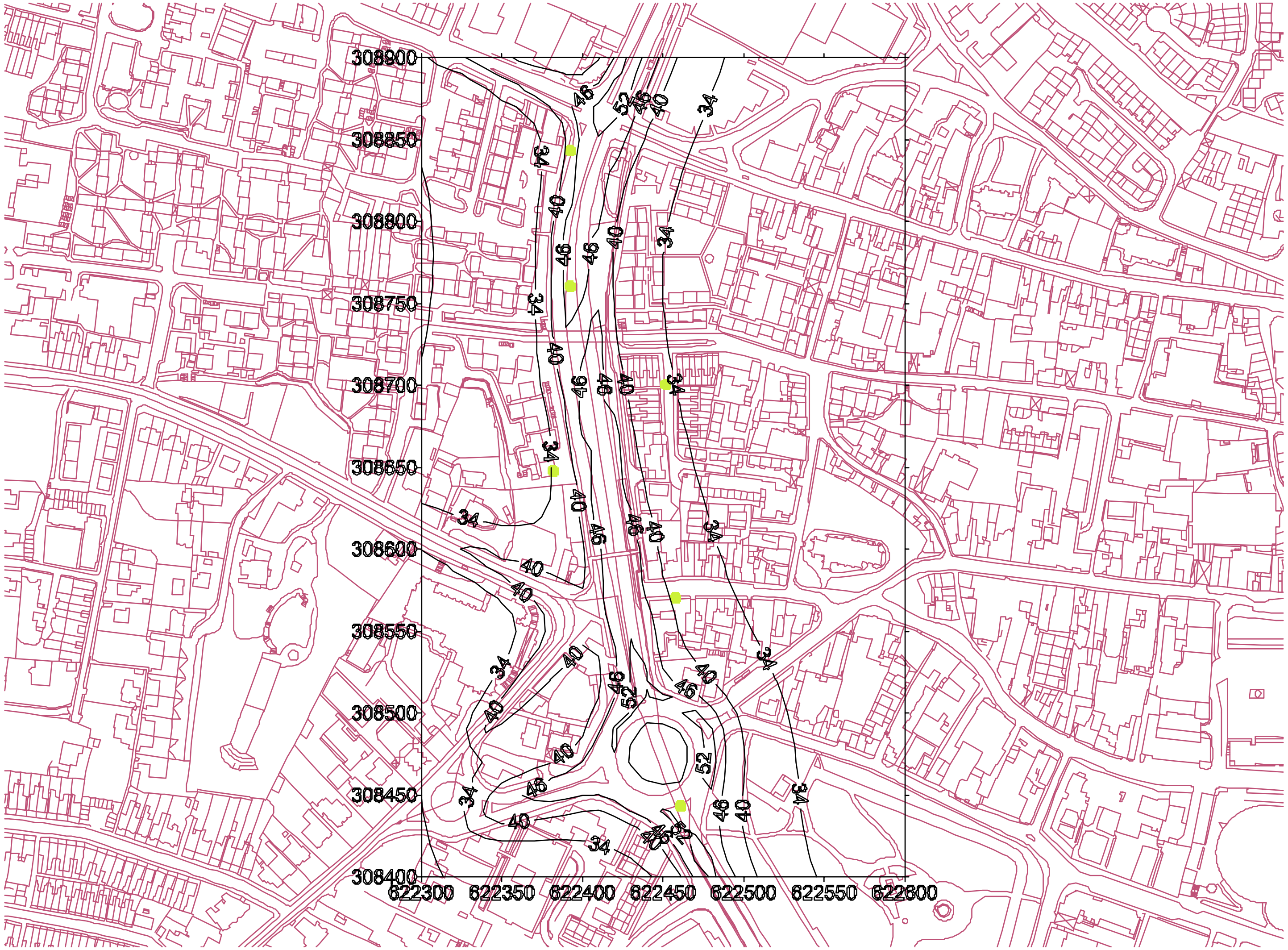

Fig. 5.11: Modelled nitrogen dioxide concentrations, $\mu g\ m^{-3}$, 2005, AQMA No 2, Grapes Hill

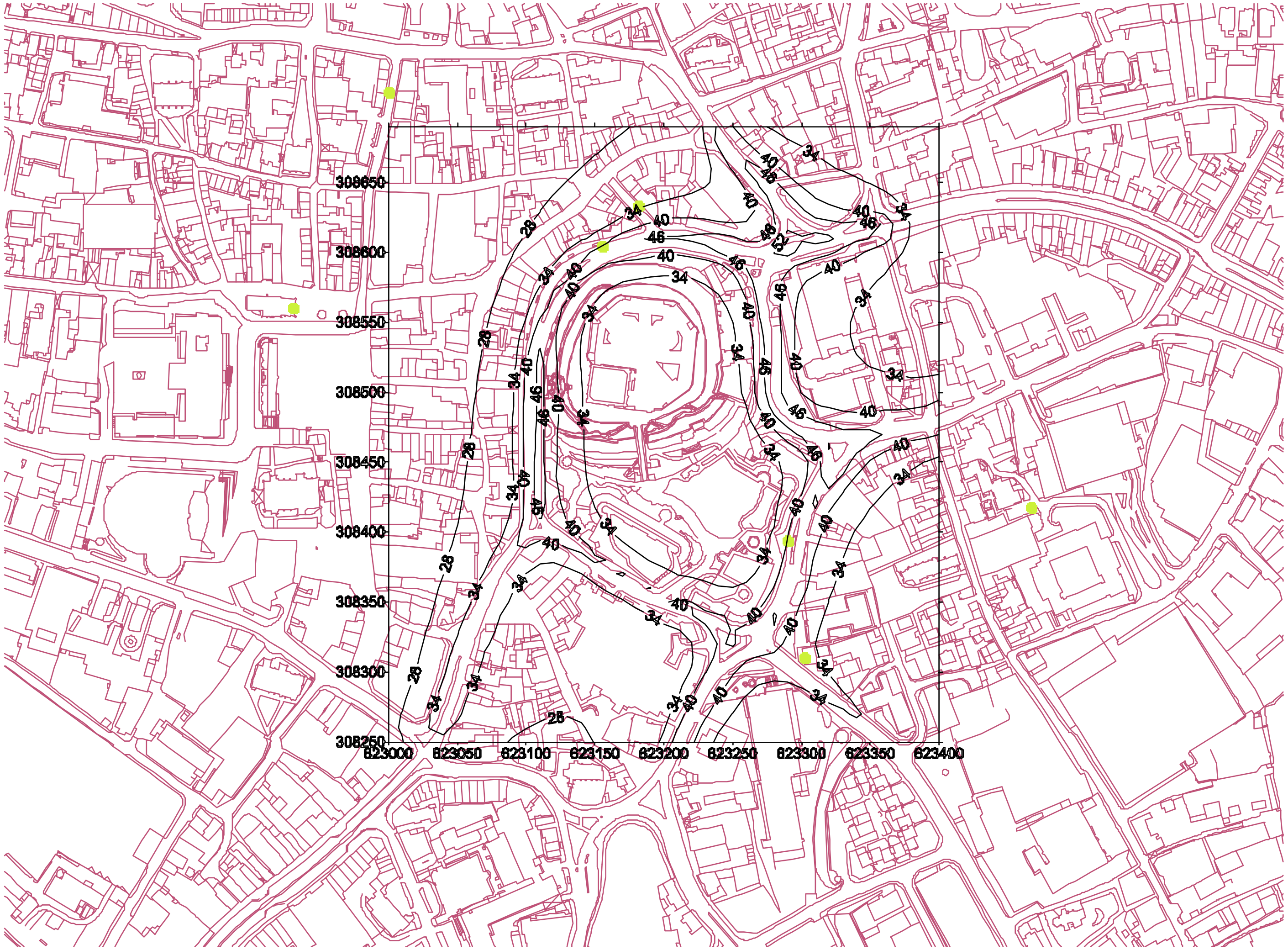

Fig. 5.12: Modelled nitrogen dioxide concentrations, $\mu g\ m^{-3}$, 2005, AQMA No 3, Castle Area

5.6.3 Magnitude of exceedence of the air quality objectives – the improvements needed

AQMA No 1 , St Augustines contains residential properties at various places close to the kerb of this street canyon. The results of the Fluid Dynamic Simulation, Fig. 5.9, show that nitrogen dioxide concentrations are expected to be markedly greater than the 40 $\mu g\ m^{-3}$ objective at the facades of many properties along the street. The LADS-Urban model results (Fig. 5.10) also indicate that the objective will be exceeded at properties along the street. A reduction of 8 $\mu g\ m^{-3}$ in concentrations is required if the annual average objective for nitrogen dioxide for2005 is to be achieved. The model predicts that the objective will be exceeded at locations throughout the length of the existing AQMA and so no changes are recommended to the existing AQMA.

AQMA No 2, Grapes Hill contains residential properties on the east side of Grapes Hill. Fig. 5.11 shows that nitrogen dioxide concentrations are expected to exceed the 40 $\mu g\ m^{-3}$ objective at several properties on the east side of Grapes Hill. Concentrations of 48 $\mu g\ m^{-3}$ are predicted at properties in the AQMA close to the Grapes Hill/Convent Road/Chapelfield Road: a reduction in nitrogen dioxide concentrations of 8 $\mu g\ m^{-3}$ is required to achieve the annual average objective for nitrogen dioxide in 2005. There are no properties north of Pottergate where the nitrogen dioxide concentration is expected to exceed the objective: similarly there are no properties more than 30 m to the east of the Grapes Hill (measured from the kerb) where the objective is likely to be exceeded. Norwich City Council may consider reducing the size of the AQMA.

AQMA No 3, Castle Area contains limited numbers of residential properties with most of the buildings containing commercial premises or offices. Fig. 5.12 shows that nitrogen dioxide concentrations are expected to be markedly less than the 40 $\mu g\ m^{-3}$ objective in much of the area currently designated as an AQMA. Building facades on the west side of Castle Meadow are not expected to exceed the objective. Opie House and the Bank at the junction of Castle Meadow and Bank Plain are expected to experience concentrations in excess of the objective but are not likely to be associated with relevant exposure of members of the public. Nos. 5-21 Bank Plain are expected to be exposed to concentrations of approximately 42 $\mu g\ m^{-3}$ and may be associated with relevant exposure. The façade of the Royal Hotel may receive concentrations of approximately 48 $\mu g\ m^{-3}$. Concentrations in excess of the objective are expected at Anglia House and Hardwick House on the Agricultural Hall Plain and Shirehall House and Shirehall on Market Street but are unlikely to be associated with relevant public exposure. Buildings with facades on the south/east side of Cattlemarket Street are also predicted to exceed the objective. The Council may consider reducing the size of the AQMA, however the following buildings should remain within the designated area if there is the possibility of relevant public exposure: Royal Hotel, 5-21 Bank Plain, 23a-38 Cattlemarket Street. A reduction in nitrogen dioxide concentrations of 8 $\mu g\ m^{-3}$ is required at the façade of the Royal Hotel.

5.7 SOURCE APPORTIONMENT OF 'BASE CASE' PREDICTIONS

Source apportionment is the process whereby the contributions from the sources of a pollutant are determined. In local air quality, the relevant sources could include: traffic; local background; industrial and domestic. Contributions from the different types of vehicles (for example, cars, lorries and buses) can also be considered to highlight which class of vehicle is contributing most to the emissions from traffic. Source apportionment allows the most important source or sources to be identified and options to reduce ambient concentrations of pollutants can then be considered and assessed.

The source apportionment should:

- Confirm that exceedences of NO_2 are due to road traffic (for Norwich)
- Determine the extent to which different vehicle types are responsible for the emission contributions to NO_2 within Norwich's AQMAs: this will allow traffic management scenarios to be modelled/tested to reduce the exceedences
- Quantify what proportion of the exceedences of NO_2 is due to background emissions, or local emissions from busy roads in the local area. This will help determine whether local traffic management measures could have a significant impact on reducing emissions in the area of exceedence, or, whether national measures would be a suitable approach to achieving the air quality objectives

5.7.1 What is the 'base case'?

The base case in this assessment is defined as the annual mean concentrations of NO_2 that are predicted in the absence of any measures to improve air quality in Norwich. They are the concentrations that should be relevant to defining the current extent of the Air Quality Management Area.

The concentrations in the base case have been calculated using the new traffic emission factors.

5.7.2 Receptors considered

The most affected relevant receptors in the AQMAs have been considered:

AQMA 1: Even nos. 22-52 St Augustines Street (622826 309573);
AQMA 2: 94 Upper St Giles (622440 308560)
AQMA 3: Royal Hotel (623320 308620).

5.7.3 Sources of pollution considered

We have considered the effect of the following sources in this Stage 4 assessment at the receptor considered:

Background from sources outside the local area
Traffic-Light Duty Vehicles in the local area
Traffic - Heavy Duty Vehicles in the local area

There is a complex relationship between oxides of nitrogen and nitrogen dioxide concentrations. The modelling assumed that the contribution to nitrogen dioxide concentration from road traffic could be estimated by multiplying the contribution to oxides of nitrogen concentrations by a factor derived from Technical Guidance LAQM.TG(03): the same factor has been applied for source apportionment calculations.

The concentrations apportioned to each source category and the fractions of the total concentrations are shown in Table 5.6.

Table 5.6: Source apportionment to concentrations of NO_2 and NO_x

AQMA	Source category	Fraction attributed to each source	
		NO_x	NO_2
1	Local LDV	0.53	0.33
	Local HDV	0.26	0.16
	Total Local traffic	0.79	0.49
	Background	0.21	0.51
	Total	1.00	1.00
2	Local LDV	0.47	0.32
	Local HDV	0.21	0.14
	Total Local traffic	0.68	0.46
	Background	0.32	0.54
	Total	1.00	1.00
3	Local LDV	0.36	0.25
	Local HDV	0.35	0.24
	Total Local traffic	0.71	0.49
	Background	0.29	0.51
	Total	1.00	1.00

Examination of Table 5.6 shows that local traffic in the AQMA makes a significant contribution to the total oxides of nitrogen` and nitrogen dioxide concentrations. The major part of this local contribution comes from light duty vehicles in the St Augustine and Grapes Hill AQMAs: there is a more even split in the Castle Area AQMA where there is a significant contribution from buses.

5.8 OPTIONS CONSIDERED TO IMPROVE AIR QUALITY AND THE EFFECTS OF THOSE OPTIONS

The following options have been considered to assess their potential to reduce the nitrogen dioxide concentration at the most sensitive receptors in the Norwich AQMAs.

For AQMA No 1 St Augustines, the options considered were:

4. A 20 % reduction in total traffic;

5. A reduction in congestion at the St Crispins Road roundabout and at the junction with Waterloo Road to increase average traffic speeds to 40 kph.

6. Both the above

For AQMA No2 Grapes Hill, the options considered were:

3. A 20% reduction in traffic;

4. A 40% reduction in traffic;

For AQMA No3 Castle, the options considered were:

4. Upgrade of buses (assumed 70% of HDV) to Euro IV standard;

5. Bus only zone
6. Both the above

5.8.1 Effects of those options on concentrations

Table 5.7 summarises the reductions in nitrogen dioxide that might be possible if the scenarios that have been considered are fully implemented.

Table 5.7: Effects of the scenarios considered on nitrogen dioxide concentrations at key receptors

AQMA	Scenario	Nitrogen dioxide concentration, $\mu g\ m^{-3}$
St Augustines	Baseline	48
	20 % reduction in traffic	44
	Increase speeds to 40 kph	43
	Both the above	40
Grapes Hill	Baseline	48
	20 % reduction in traffic	44
	40 % reduction in traffic	40
Castle	Baseline	48
	Euro IV buses	44
	Bus only zone	36
	Both the above	30.4

5.9 SIMPLE ASSESSMENT OF THE FEASIBILITIES OF THE OPTIONS CONSIDERED

This section of the report provides a simple assessment of the feasibility of the options considered to try and reduce or eliminate the chances of exceedences of the air quality objectives for NO_2 in Norwich. It is not intended as a full cost-benefit assessment; defra do not require such as analysis in a Stage 4 assessment.

St Augustines Street and Grapes Hill are both "A" roads feeding traffic into the centre of Norwich. As such, it is likely that it would be difficult to bring about significant reductions in traffic without rerouting the vehicles elsewhere. Some reduction may be possible as the result of general improvements in public transport into the city, the development of cycle strategies and the implementation of park and ride schemes. However, detailed consideration of such schemes is outside the scope of this Stage 4 report.

The levels of congestion on St Augustines Street may be improved by preferential access from Pitt Street onto St Crispins Road and giving preference to traffic on St Augustines Street at the Waterloo Road junction. Such actions are likely to displace congestion elsewhere: however, the increased congestion may be less detrimental elsewhere because pollutants may be able to disperse more freely than in the St Augustine's street canyon.

The upgrade to Euro IV buses would be feasible in principle but is likely to have significant cost implications for the bus operators.

Restricting access to the Castle Area to public transport providers only would lead to substantial improvements in local air quality. However, such measures would require detailed consideration in the context of the overall transport strategy for the city.

6 Implications of this Stage 4 air quality review and assessment for Norwich

This section highlights the implications of this Stage 4 assessment for Norwich.

The section explains any changes that may be needed to the current extent of the current Air Quality Management Areas.

6.1 CHANGES TO THE AIR QUALITY MANAGEMENT AREA AS A RESULT OF THIS STAGE 4 MODELLING

defra have specified that the Stage 4 assessment must comment on any changes that might be necessary to the extent of the AQMA as a result of the Stage 4 modelling.

The following table summarises any changes that might be needed.

Table 6.1 Summary of changes to the Air Quality Management Area in Norwich as a result of this Stage 4 assessment

AQMA	Changes recommended to the existing Air Quality Management Areas
No 1	No change recommended
No 2	Consider reducing the size of the AQMA to include only those properties with relevant public exposure within 30 m of the east side of Grapes Hill, south of Pottergate
No 3	Consider reducing the size of the AQMA to include only those properties with relevant public exposure with facades on Bank Plain, Agricultural Hall Plain and Cattle Market Street

7 The next steps for Norwich

7.1 OBTAINING defra APPROVAL

defra will need to approve this Stage 4 assessment. Norwich should now send a copy of this report to defra. defra will then forward this report to their external assessors who will comment on the work. defra will then forward the critique of the work to Norwich

Norwich should then forward a copy of this critique to **netcen**. Norwich should also consider if they could answer any of the questions directly.

7.2 LOCAL CONSULTATION ON THIS STAGE 4 ASSESSMENT

Norwich can ask for feedback from stakeholders who may be interested in the outcome of this Stage 4 air quality review and assessment. Important local stakeholders may include:

External to Norwich

- Norfolk County Council
- Adjoining local authorities

Internal

- Local residents in the AQMA
- The traffic department
- The planning department

Efficient ways of disseminating the information include:

- placing the report on the local authority web site
- producing a small poster for display in the local authority offices
- producing a small poster for display in other public places (post offices, libraries etc.)

7.3 IMPLEMENTING THE OPTIONS IDENTIFIED TO IMPROVE AIR QUALITY

If Norwich Council wishes to seriously consider implementing one or more of the options identified, they should now consider a more detailed cost benefit analysis. This could be completed as part of the Action Plan.

8 References

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9 defra compliance checklist

defra Stage 4 requirements compliance checklist
This section has been introduced to indicate where the work expected by defra in a Stage 4 air quality review and assessment can be found in this document. Only nitrogen dioxide is considered in this Stage 4.

Work area	**Included or considered?**	**Location within the report and comments**
Monitoring		
• Has further monitoring been undertaken?	yes	5.4
• Is the 'totality' of the monitoring effort sufficient?		
• Has monitoring confirmed 2005 exceedences?	partially	5.4.6
• Has sufficient detail of QA/QC procedures been provided?	yes	5.4.1
• Has monitoring amended the conclusions of Stage 3?	yes	6.1
Modelling		
• Has further modelling been undertaken?	yes	5.5
• Is the further modelling considered appropriate?		
• Has the model been appropriately validated?	yes	5.5.2, 5.5.3, Appendix 1, Appendix 2
• Has modelling confirmed 2005 exceedences?	yes	5.6.1
• Has modelling amended the conclusions of Stage 3?	yes	6.1
General		
• Have both the magnitude and geographical extent of any exceedences been further changed?	yes	6.1
• Has the decision to declare an AQMA been reversed at Stage 4?	No	6.1
• Is this decision soundly based?		
• Has the authority taken account of the new vehicle emission factors	yes	4.4
• Has the authority considered source apportionment?	yes	5.7
• Has the authority considered the cost effectiveness of different abatement options?	as far as possible	5.9
• Has the authority considered feasibility and effectiveness of different abatement options?	as far as possible	5.9
• Has the authority considered the extent to which air quality improvement is required?	yes	5.6.3

Work area	Included or considered?	Location within the report and comments
Monitoring & modelling work		
• Have monitoring uncertainties been addressed fully?	yes	5.4.1
• Does the additional monitoring assessment appear sufficiently robust?		
• Have modelling uncertainties been addressed?	yes	Appendix 1
• Has the model been carefully validated?	yes	Appendix 1
• Does the overall modelling assessment appear sufficiently robust?		
AQO exceedences & AQMA declaration		
• Have areas of exceedence been further defined?	No, reduction in size of the AQMA to be considered	6.1
• Is the decision to amend or revoke the AQMA(s) at Stage 4, soundly based?		No decision taken yet to amend the AQMA
• Is the decision reached based principally on monitoring?		
• Is the decision reached based principally on modelling?		
General		
• Has the authority focused on areas already identified as predicted to exceed objectives?	yes	5.6
• Has consideration been given to the exposure of individuals in relevant locations?	yes	5.6.3
• Has the authority considered new national policy developments?	yes	
• Has the authority considered new local developments?	None identified	
• Does the report reach the expected conclusions? (in part/full?)		
• Has the authority undertaken further liaison with other agencies (in particular HA and EA?)	Not yet	

Appendices

CONTENTS

Appendix 1

Model validation
Nitrogen dioxide roadside concentrations

CONTENTS

INTRODUCTION

The dispersion model ADMS-3 was used to predict nitrogen dioxide concentrations at roadside locations. ADMS-3 is a PC-based model that includes an up-to-date representation of the atmospheric processes that contribute to pollutant dispersion.

The model was used to predict

- the local contribution to pollutant concentrations from roads; and
- The contribution from urban background sources.

The contribution from urban background sources was calculated from the ADMS-3 output using the NETCEN Local Area Dispersion System (LADS) model. The LADS model provides efficient algorithms for applying the results of the dispersion model over large areas.

The model was verified by comparison with monitoring data obtained at a number of roadside, kerbside or near-road monitoring sites in London.

- London Marylebone
- Camden Roadside
- Haringey Roadside
- London Bloomsbury
- London North Kensington
- London A3 Roadside

London Marylebone site is located in a purpose built cabin on Marylebone Road opposite Madame Tussauds. The sampling point is located at a height of 3 m, around 1 m from the kerbside. Traffic flows of over 80,000 vehicles per day pass the site on six lanes. The road is frequently congested. The surrounding area forms a street canyon and comprises of education buildings, tourist attractions, shops and housing

Camden Roadside site (TQ267843) is located in a purpose built cabin on the north side of the Swiss Cottage Junction. The site is at the southern end of a broad street canyon. Sampling points are approximately 1 m from the kerbside of Finchley Road at a height of 3 m. Traffic flows of 37,000 vehicles per day pass the site and the road is often congested. Pedestrian traffic is also high. The surrounding area mainly consists of shops and offices.

London North Kensington site (TQ240817) is located within the grounds of Sion Manning School. The sampling point is located on a cabin, in the school grounds next to St Charles Square, at a height of 3 m. The surrounding area is mainly residential.

London A3 monitoring station (TQ193653) is within a self-contained, air-conditioned housing immediately adjacent to the A3 Kingston Bypass (6 lane carriageway). Traffic flow along the bypass is approximately 112,000 vehicles per day and is generally fast and free flowing with little congestion. The manifold inlet is approximately 2.5 m from the kerbside at a height of approximately 3 m. The surrounding area is generally open and comprises residential dwellings and light industrial and commercial properties.

London Bloomsbury monitoring station (TQ302820) is within a self-contained, air-conditioned housing located at within the southeast corner of central London gardens. The gardens are generally laid to grass with many mature trees. All four sides of the gardens are surrounded by a busy (35,000 vehicles per day), 2/4 lane one-way road system which is subject to frequent congestion. The nearest road lies at a distance of approximately 35 metres from the station. The manifold inlet is approximately 3 metres high. The area in the vicinity of the manifold is open, but there are mature trees within about 5 metres.

London Haringey site (TQ339906) is located in a purpose built cabin within the grounds of the Council Offices. The sampling point is at a height of 3 m located 5 m from High Road Tottenham (A1010) with traffic flows of around 20,000 vehicles per day. The road is frequently congested. The surrounding area consists of shops, offices and housing.

MODEL APPLICATION

Study area

Two study areas were defined- a local study area and an urban background study area. The local study area was defined for each of the monitoring sites extending 200 m in each direction (NSEW) from the monitoring site. Roads in the study area were identified. Each road in the study are was then treated as a quadrilateral volume source with depth 3 m, with spatial co-ordinates derived from OS maps. The urban background study area extended over an 80 km x 80 km area covering the London area. The background study area was divided into 1 km x 1 km squares-each 1 km square was then treated as a square volume source with depth 10 m.

Traffic flows in the local study area

Traffic flows, by vehicle category, on each of the roads within the local study area for 1996 were obtained from the DETR traffic flow database. The traffic flows were scaled to 1998 by factors shown in Table A3.1 obtained by linear interpolation from Transport Statistics GB, 1997.

Table A3.1 Traffic growth 1998:1996

	Growth factor
Cars	1.05
Light goods vehicles	1.05
Heavy goods vehicles	1.04
Buses	1.00
Motorcycles	1.00

Traffic flows follow a diurnal variation. Table A3.2 shows the assumed diurnal variation in traffic flows.

Table A3.2 Assumed diurnal traffic variation

Hour	Normalised traffic flow
0	0.20
1	0.11
2	0.10
3	0.07
4	0.08
5	0.18
6	0.49
7	1.33
8	1.97
9	1.50
10	1.33
11	1.46
12	1.47
13	1.51
14	1.62
15	1.74
16	1.94
17	1.91
18	1.53
19	1.12
20	0.88
21	0.68
22	0.46
23	0.33

Vehicle speeds in the local study area

Vehicle speeds were estimated on the basis of TSGB, 1997 data for central area, inner area and outer area average traffic speeds in London, 1968-1995 and for non-urban and urban roads for 1996. Table A3.3 shows the traffic speeds applied to each of the sites. The low speeds in Central London reflect the generally high levels of congestion in the area.

Table A3.3 Traffic speeds used in the modelling

Site	Road class	Vehicle speed, kph
London Marylebone	Central London	17.5
Camden Roadside	Central London	17.5
London Bloomsbury	Central London	17.5
London A3 Roadside	Non-urban dual carriageway	88
London Haringey	Outer London	32
London North Kensington	Background site	Not applicable

Vehicle emissions in the local study area

Vehicle emissions of oxides of nitrogen were estimated using the Highways Agency Design Manual for Roads and Bridges, 1999 (DMRB). DMRB provides a series of nomograms that allow the effect on emission rates of the proportion of heavy goods vehicles and the average vehicle speed to be taken into account. The estimated emissions are based on average speeds and take account of the variations in emissions that follow from normal patterns of acceleration and deceleration. DMRB provides estimates of the emissions of particulate material from vehicle exhausts.

Emissions in the urban background study area

Emission estimates for each 1 km square in the urban background study area were obtained from two emission inventories. The London inventory for 1995/6 (LRC, 1997) was used for most of the urban background study area: the National Atmospheric Emission Inventory, 1996 was used for areas within the urban background study area not covered by the London inventory.

The emission estimates for each square for 1996 were scaled to 1998 using factors taken from DMRB.

Meteorological data

Meteorological data for Heathrow Airport 1998 was used to represent meteorological conditions. The data set included wind speed and direction and cloud cover for each hour of the year. It was assumed that a surface roughness of 0.5 m was representative of the suburban area surrounding Heathrow Airport.

The meteorological conditions over London are affected by heat emissions from buildings and vehicles. This "urban heat island" effect reduces the frequency and severity of the stable atmospheric conditions that often lead to high pollutant concentrations. In order to take this into account the Monin-Obukhov length (a parameter used to characterise atmospheric stability in the model) has been assigned a lower limit as shown in Table A3.4.

Table A3.4: Monin-Obukhov limits applied

Site	Limit, m	Note
London Marylebone	100	Large conurbation
Camden Roadside	100	Large conurbation
London Bloomsbury	100	Large conurbation
London A3 Roadside	30	Mixed urban/industrial
London Haringey	30	Mixed urban/industrial
London North Kensington	100	Large conurbation
Small towns <50,000	10	
Urban background area	100	
Rural	1	

Surface roughness

The surface roughness is used in dispersion modelling to represent the roughness of the ground. Table A3.5 shows the surface roughness values applied.

Table A3.5 Surface roughness

Site	Surface roughness, m	Note
London Marylebone	2	Street canyon
Camden Roadside	1	City
London Bloomsbury	1	City
London A3 Roadside	0.5	Suburban
London Haringey	1	City
London North Kensington	1	Suburban
Urban background area	1	

Model output

The local model was used to estimate:

- Annual average road contribution of oxides of nitrogen ;
- road contribution to oxides of nitrogen concentrations for each hour of the year.

The urban background model was used to estimate:

- the contribution from urban background sources to annual average oxides of nitrogen concentrations;
- the contribution from roads considered in the local model to urban background concentrations;
- the contribution from urban background sources to oxides of nitrogen concentrations for each hour of the year.

Background concentrations

A rural background concentration of 20 $\mu g\ m^{-3}$ was added to the urban background oxides of nitrogen concentration.

Calculation of annual average nitrogen dioxide concentrations

Nitrogen dioxide is formed as the result of the oxidation of nitrogen oxides in air, primarily by ozone. The relationship between oxides of nitrogen concentrations and nitrogen dioxide concentrations is complex; an empirical approach has been adopted.

The contribution from locally modelled roads to urban background oxides of nitrogen concentrations was first subtracted from the calculated urban background concentration. The annual average urban background nitrogen dioxide concentration was then calculated from the corrected annual average urban background oxides of nitrogen concentration using the following empirical relationship based on monitoring data from AUN sites:

For NO_x>23.6 μg m^{-3}

$$NO_2 = 0.348.NO_x + 11.48 \ \mu g\ m^{-3}$$

For NO_x<23.6 μg m^{-3}

$$NO_2 = 0.833.NO_x \ \mu g\ m^{-3}$$

The contribution of road sources to nitrogen dioxide concentrations was then calculated using the following empirical relationship (Stedman):

$$NO_2 = 0.162.NO_x$$

The contributions from road and background sources to annual average nitrogen dioxide concentrations were then summed.

The calculated value was then corrected so that there was agreement between modelled and measured concentrations at a reference site (London North Kensington (LNK)):

NO_2(corrected, site)= NO_2(modelled, site)+ NO_2(measured, LNK)- NO_2(modelled, LNK)

Calculation of 99.8th percentile hourly average concentrations

A simple approach has been used to estimate 99.8th percentile values. The approach relies on an empirical relationship between 99.8th percentile of hourly mean nitrogen dioxide and annual mean concentrations at kerbside/roadside sites, 1990-1998:

NO_2(99.8th percentile)=3.0 NO_2(annual mean)

99.8 th percentile values were calculated on the basis of the modelled annual mean.

The calculated value was then corrected so that there was agreement between modelled and measured concentrations at a reference site (London North Kensington (LNK)):

NO_2(corrected, site)= NO_2(modelled, site)+ NO_2(measured, LNK)- NO_2(modelled, LNK)

RESULTS

Modelled results are shown in Table A3.6. Fig. A3.1 shows modelled annual average nitrogen dioxide concentrations plotted against the measured values. Similarly Fig. A3.2 shows modelled 99.8th percentile average nitrogen dioxide concentrations plotted against measured values.

Table A3.6 Comparison of modelled and measured concentrations

Site	Nitrogen dioxide concentration, ppb			
	Annual average		99.8th percentile hourly	
	Modelled	Measured	Modelled	Measured
London A3	32	30	94	73
North Kensington	24	24	70	70
Bloomsbury	28	34	83	78
Camden	32	33	95	89
London Marylebone	45	48	134	121
Haringey	22	28	65	77

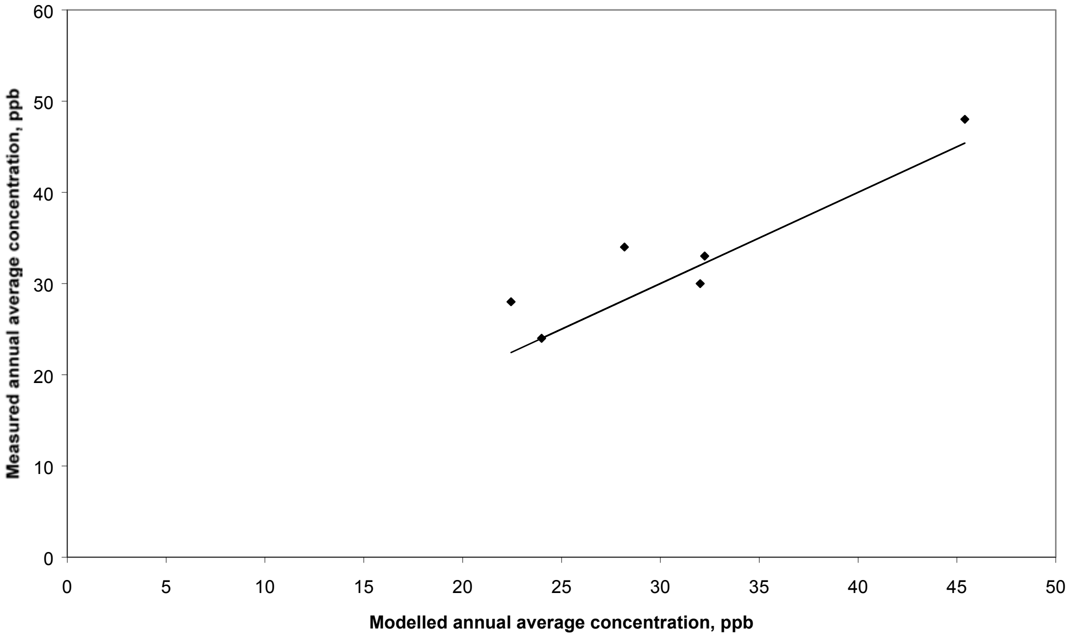

Fig. A3.1 Comparison of modelled and measured annual average nitrogen dioxide concentrations

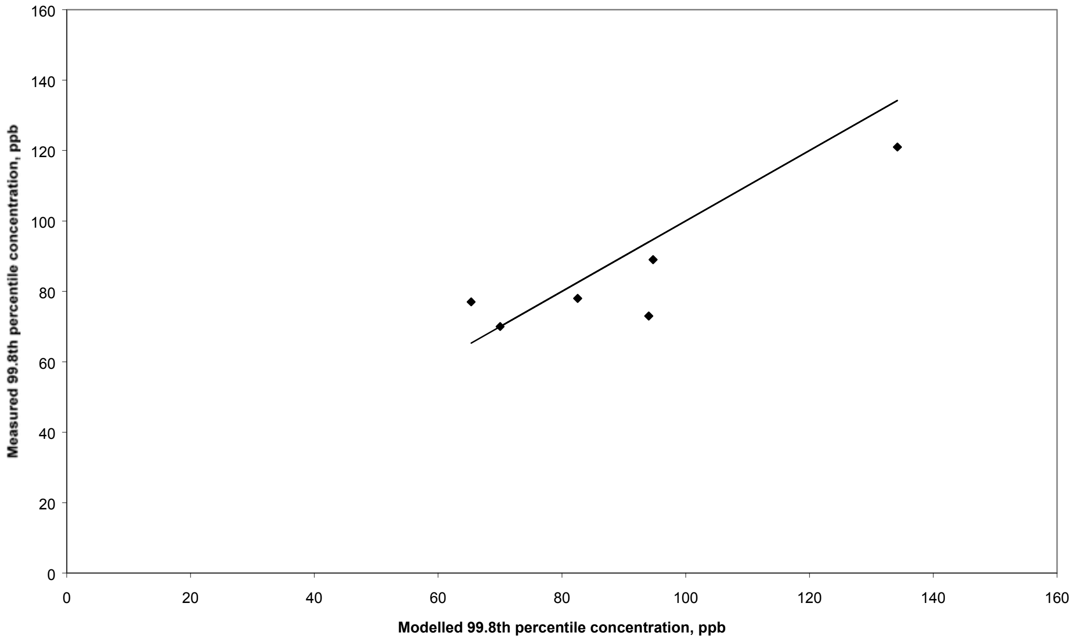

Fig. A3.2 Comparison of modelled and measured 99.8th percentile hourly average nitrogen dioxide concentrations

DISCUSSION

Model errors

The error in the modelled annual average at each site was calculated as a percentage of the modelled value. The standard deviation of the errors was then calculated: it was 12% with five degrees of freedom.

The error in the 99.8 th percentile concentration at each site was calculated as a percentage of the modelled value. The standard deviation of the errors was then calculated: it was also 12% with five degrees of freedom.

Year to year variation in background concentrations

Nitrogen dioxide concentrations at monitoring sites show some year to year variations. Reductions in emissions in the United Kingdom are responsible for some of the variation, but atmospheric influences and local effects also contribute to the variation.

In order to quantify the year to year variation monitoring data from AUN stations with more than 75% data in the each of the years 1996-1998 was analysed using the following procedure.

First, the expected concentrations in 1997 and 1996 were calculated from the 1998 data.

$$c_e = \frac{d_{1998}}{d_y}.c_{1998}$$

where c_{1996} is the concentration in 1998;

d_{1998}, d_y are correction factors to estimate nitrogen dioxide concentrations in future years (1996=1, 1997=0.95, 1998=0.91) from DETR guidance;

The difference between the measured value and the expected value was then determined for each site and normalised by dividing by the expected value. The standard deviation of normalised differences was determined for each site. A best estimate of the standard deviation from all sites was then calculated. The standard deviation of the annual mean was 0.097 with 2 degrees of freedom. The standard deviation of the 99.8th percentile hourly concentration was 0.21 with 2 degrees of freedom.

Short periods of monitoring data

Additional errors can be introduced where monitoring at the reference site (used to calibrate the modelling results against) takes place over periods less than a complete year, typically of three or six months.

In this case, a whole year of data was available at the monitoring site (1999 in Glasgow Centre), and so no correction was necessary for short periods of monitoring.

Confidence limits

Upper confidence limits for annual mean and 99.8th percentile concentrations were estimated statistically from the standard deviation of the model error and the year to year standard deviation:

$$u = c + \sqrt{(t_m s_m)^2 . \left(1 + \frac{1}{k}\right) + (t_y s_y)^2 + \sum (t_p s_p)^2 / k}$$

where:

s_m, s_y, s_p are the model error standard deviation , the year to year standard deviation and the standard error introduced using part year data;

c is the concentration calculated for the modelled year;

t_m, t_y, t_p are the values of Student's t distribution for the appropriate number of degrees of freedom at the desired confidence level;

k is the number of reference sites used in the estimation of the modelled concentration.

In many cases, the concentration estimate is based on a single reference site (k=1). However, improved estimates can be obtained where more than one reference site is used.

Table A3.7 shows confidence levels for predictions as a percentage of modelled values

Table A3.7 Upper confidence levels (k=1) for modelled concentrations for future years

Confidence level	Annual mean	99.8^{th} percentile
80 %	+19%	+27%
90%	+31%	+47%
95%	+44%	+70%

In practical terms,

- there is less than 1:5 chance (i.e.100-80=20%) that the 40 $\mu g\ m^{-3}$ objective will be exceeded if the modelled annual average concentration in 2005 is less than 34 $\mu g\ m^{-3}$ (i.e. 40/1.19);
- there is less than 1:20 (i.e. 100-5=5%) chance that the objective will be exceeded if the modelled roadside concentration is less than 28 $\mu g\ m^{-3}$ (i.e. 40/1.44).

- Similarly, there is less than 1:5 chance that the 200 $\mu g\ m^{-3}$ 99.8^{th} percentile concentration will be exceeded if the modelled concentration for 2005 is less than 157 $\mu g\ m^{-3}$;
- there is less than 1:20 chance that the objective will be exceeded if the modelled concentration in 2005 is less than 117 $\mu g\ m^{-3}$.

In the figures shown in the report, the intervals of confidence limits for the 'probable' and 'likely' annual average and hourly objective concentrations have been set equal to those for 'possible' and 'unlikely', respectively. In reality, the intervals of concentration increase as the probability of exceeding the annual and hourly objective increases from 'unlikely' to 'likely'. The advantage to setting symmetrical concentration intervals is that the concentration contours on the maps become simpler to interpret. This is a mildly conservative approach to assessing the likelihood of exceedences of the NO_2 objectives since a greater geographical area will be included using the smaller confidence intervals.

A simple linear relationship can be used to predict the 99.8^{th} percentile concentration of NO_2 from the annual concentration: the 99.8^{th} percentile is three times the annual mean at kerbside/roadside locations. Therefore, plots of the modelled annual mean NO_2 concentrations can be used to show exceedences of both the annual and hourly NO_2 objectives. However, the magnitude of the concentrations used to judge exceedences of the hourly objective need to be adjusted so they may be used directly with the plots of annual concentration. This has been performed by simply dividing the concentrations of the confidence limits by three.

The following table shows the difference between assigning symmetrical confidence intervals and assigning intervals based directly on the statistics.

Table A3.8a Confidence levels for modelled concentrations for future years based on symmetrical concentration intervals and concentration intervals derived purely from the statistics

Description	Chance of exceeding objective	Confidence limits for the modelled annual average concentrations ($\mu g\ m^{-3}$)			
		Annual average objective (symmetrical intervals)	Symmetrical intervals	Annual average objective (intervals based on statistics)	Interval
Very unlikely	Less than 5%	< 28		< 28	
Unlikely	5 to 20%	28 to 34	6.0	28 to 34	6.0
Possible	20 to 50%	34 to 40	6.3	34 to 40	6.3
Probable	50 to 80%	40 to 46	6.3	40 to 47	7.5
Likely	80 to 95%	46 to 52	6.0	47 to 58	10.3
Very likely	More than 95%	> 52		> 58	

Table A3.8b Confidence levels for modelled concentrations for future years based on symmetrical concentration intervals and concentration intervals derived purely from the statistics

Description	Chance of exceeding objective	Confidence limits for the modelled annual average concentrations ($\mu g\ m^{-3}$)			
		Hourly average objective (symmetrical intervals)	Symmetrical intervals	Hourly average objective (intervals based on statistics)	Interval
Very unlikely	Less than 5%	< 39		< 39	
Unlikely	5 to 20%	39 to 52	13.2	39 to 52	13.2
Possible	20 to 50%	52 to 67	14.3	52 to 67	14.3
Probable	50 to 80%	67 to 81	14.3	67 to 85	18.1
Likely	80 to 95%	81 to 94	13.2	85 to 113	28.7
Very likely	More than 95%	> 94		> 113	

Appendix 2

FDS 3 Model validation studies

CONTENTS

INTRODUCTION

The FDS3 large eddy simulation model has been extensively validated by the model developers, the US National Institute of Standards and Technology. However, the developers recommend that the model performance is verified by comparison with relevant experiments. Relevant experiments have been carried out by Hall et al (1995, 1999): this Appendix compares model predictions with the results from selected wind tunnel experiments.

MODEL DOMAIN

The large model domain used for street canyon modelling extended 200 m x 200 m x 108 m high with an upwind turbulence conditioning domain extending over an additional 70 m x 200 m x 108 m. Grid resolution throughout the domain was 2 m. An air flow was introduced at the edge of the turbulence conditioning domain to represent the wind with a velocity of 4 m/s at 10 m above ground and a power law velocity profile in the vertical direction given by $u=u_{10}(z/z_{10})^{0.25}$. A zero temperature lapse rate corresponding to neutral stability conditions was imposed. Upwind turbulence was generated by specifying the velocity time series on 30 planar surfaces at the upwind end of the turbulence conditioning domain. The velocity time series on each surface was generated by means of a first order Markov process such that the turbulent kinetic energy and the turbulent length scales in the flowstream were representative of the surface boundary layer. The spacing of the turbulence devices was of the same order as the turbulent length scale.

The small model domain also used for validation studies extended 40 m x 40 m x 20 m high with an upwind turbulence conditioning domain extending over an additional 20 m x 40 m x 20 m. Grid resolution throughout the domain was varied between 0.5 m, 1 m and 2 m to allow the assessment of the magnitude of numerical truncation errors. An air flow was introduced at the edge of the turbulence conditioning domain to represent the wind with a velocity of 4 m/s at 10 m above ground and a power law velocity profile in the vertical direction given by $u=u_{10}(z/z_{10})^{0.25}$. A zero temperature lapse rate corresponding to neutral stability conditions was imposed. Upwind turbulence was generated by specifying the velocity time series on 3 planar surfaces at the upwind end of the turbulence conditioning domain. The velocity time series on each surface was generated by means of a first order Markov process such that the turbulent kinetic energy and the turbulent length scales in the flowstream were representative of the surface boundary layer. The spacing of the turbulence devices was of the same order as the turbulent length scale.

VELOCITY AND TURBULENCE PROFILES

Preliminary numerical experiments were carried out to determine the velocity and turbulence profiles in the large model domain. During most of the experiments additional turbulence is provided by the modelled obstacles and so the turbulence levels determined in the preliminary experiment may not be representative of the actual turbulence levels when modelled obstacles are present. Nevertheless, it useful to show that levels of "background" turbulence are representative of atmospheric conditions at least to a first order of approximation . For this preliminary assessment, 12 m square , 4 m high roughness elements were placed at 24 m intervals on a rectangular grid covering the model domain. Fig. A1 shows the velocity profile at the upwind and downwind edges of the modelled domain and the midpoint. Fig. A2 shows the turbulent kinetic energy $((u'^2+v'^2+w'^2)/2)$ at various heights at the midpoint of the modelled domain. Fig. A3 shows the autocorrelation coefficient for the vertical velocity at various heights at the midpoint of the model domain.

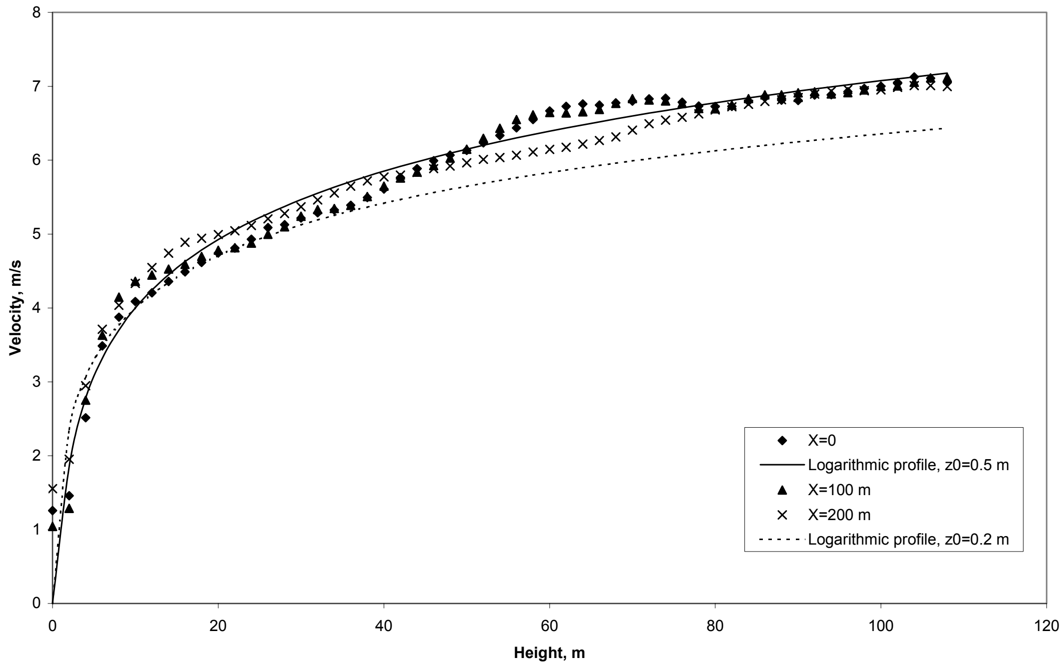

Fig. A1: Velocity profile

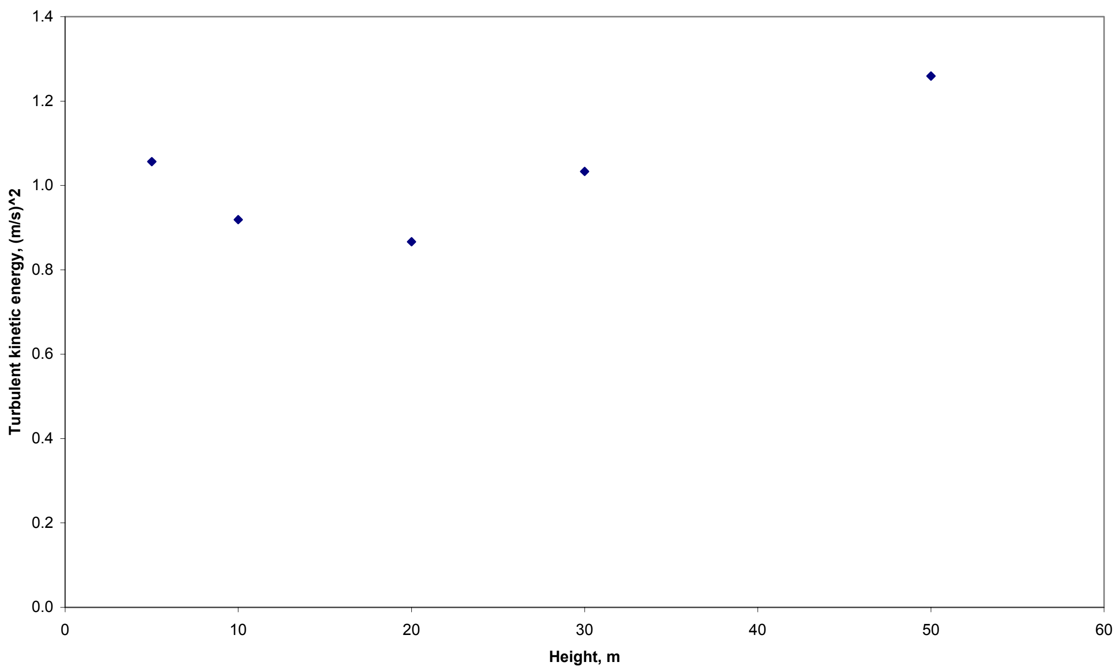

Fig. A2: Turbulent kinetic energy

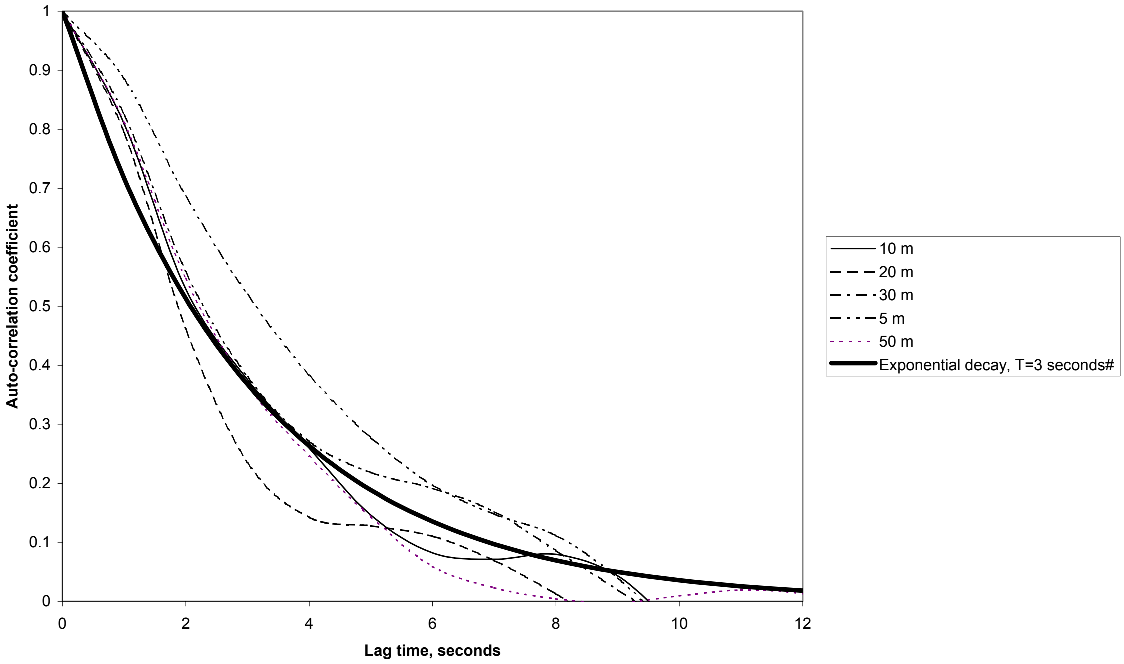

Fig. A3: Autocorrelation coefficient for vertical velocity component.

The measured velocity profile approximates to a logarithmic velocity profile with surface roughness in the range 0.2-1 m, characteristic of the suburban/built up areas. The turbulent kinetic energy is characteristic of the surface boundary layer with surface roughness of approximately 0.2 m.

The autocorrelation coefficient for the vertical velocity corresponds approximately with an exponential decay with time constant of 3 seconds. The peak in the nF(n) spectrum of the vertical velocity is thus likely to occur at a frequency of about 1/3 s^{-1} corresponding to a wavelength of 12 m for a wind speed of 4 m s^{-1}. This value may be compared with wavelengths measured in the atmosphere of around 50 m at 10 m height above the ground.

HORIZONTAL AND VERTICAL PLUME SPREAD

A further preliminary numerical experiment was carried out to determine the horizontal and vertical plume spreads. A point source discharge was introduced into the model domain 20 m above the ground and 50 m from the upwind edge of the model domain. Mean concentrations were then calculated on a vertical plane across the model domain 100 m downwind of the source. The horizontal concentration profile was approximately Gaussian, with a lateral dispersion coefficient of 14 m. This value may be compared with a value of 8 m given by

Clarke(1979) and a value of 17 m provided for these conditions by the well-established dispersion model ADMS3.1.

The modelled vertical concentration profile is shown in Fig.A4 . Also shown is the Gaussian concentration profile (including ground level reflection) for a vertical dispersion coefficient of 9 m (c.f. Clarke 1979- 7 m and ADMS3.1- 9 m).

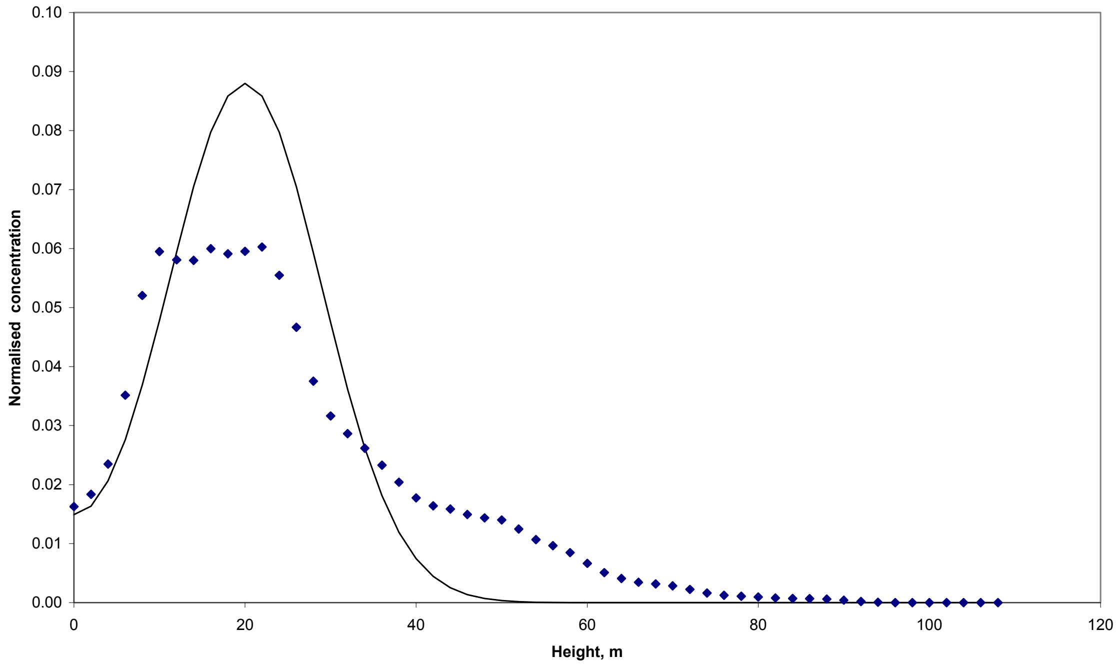

Fig.A4: Vertical plume spread (FDS 3 results shown as points, full line is reflected Gaussian concentration profile with vertical dispersion coefficient of 9 m.

MOMENTUM SOURCE FROM A LARGE BUILDING

Hall et al (1995) have carried out wind tunnel experiments to assess the ambient concentration of pollutants released through holes in the roof of warehouse buildings of various shapes and sizes. Fig A5 compares the model predictions for a single 2 m diameter momentum source in the roof of a warehouse building with dimensions 100 m x 30 m x 10 m high to the eaves. The momentum flux parameter (M/U^2L^2) was 0.1.

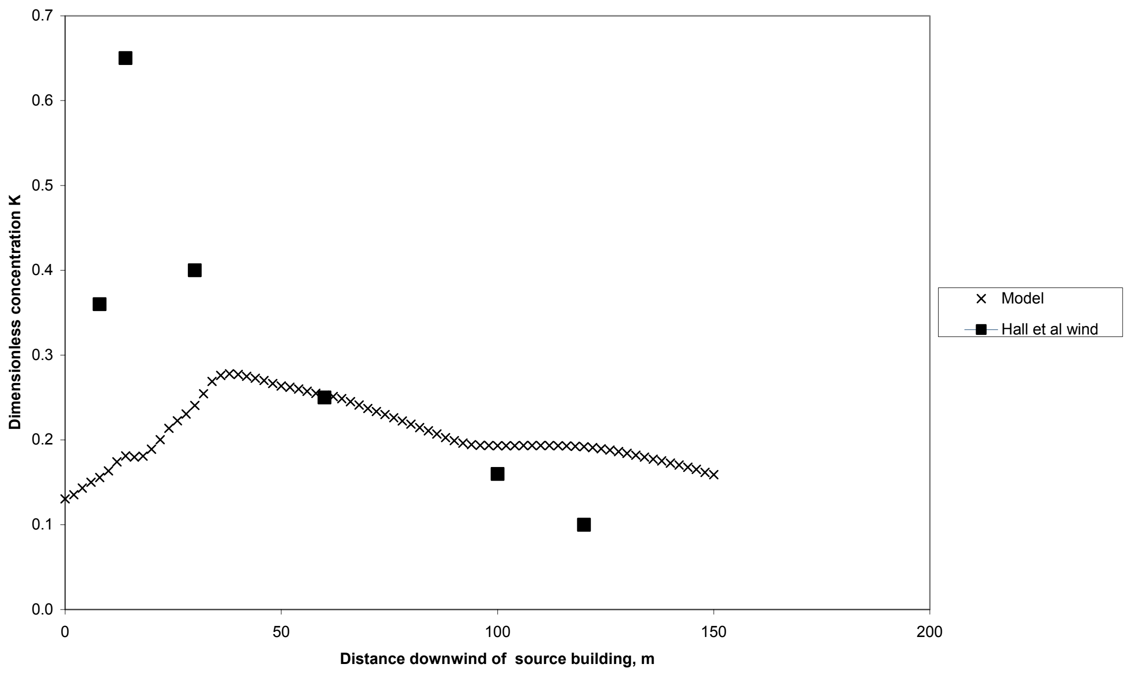

Fig. A5: Comparison of model predictions and wind tunnel studies carried out by Hall et al 1995 of a large warehouse building (100 m x 30 m x 10 m) with single 2 m diameter discharge in the roof with momentum flux parameter=0.1. Large-scale model with grid resolution 2 m.

GROUND LEVEL SOURCE IN FRONT OF A RECTANGULAR BUILDING

Hall et al (1999) carried out wind tunnel experiments to assess the ambient concentration of pollutants released at ground level in front of buildings. Fig. A6 compares the model predictions and wind tunnel measurements of the concentration on the windward face of a 40 m x 10 m x10 m building for a non-buoyant low-momentum source 10 m in front of the building.

Hall et al (1999) also measured the concentrations on the face of buildings in arrays of buildings in a wind tunnel. Fig. A7 shows such an array of buildings as modelled using FDS3. The buildings are each 40 m x 10 m x 10m with an overall building density of 44 %. The emission source was located midway between two buildings. Fig. A8 compares the concentration on the face of the building immediately downwind of the source predicted by the FDS3 model with the wind tunnel measurement.

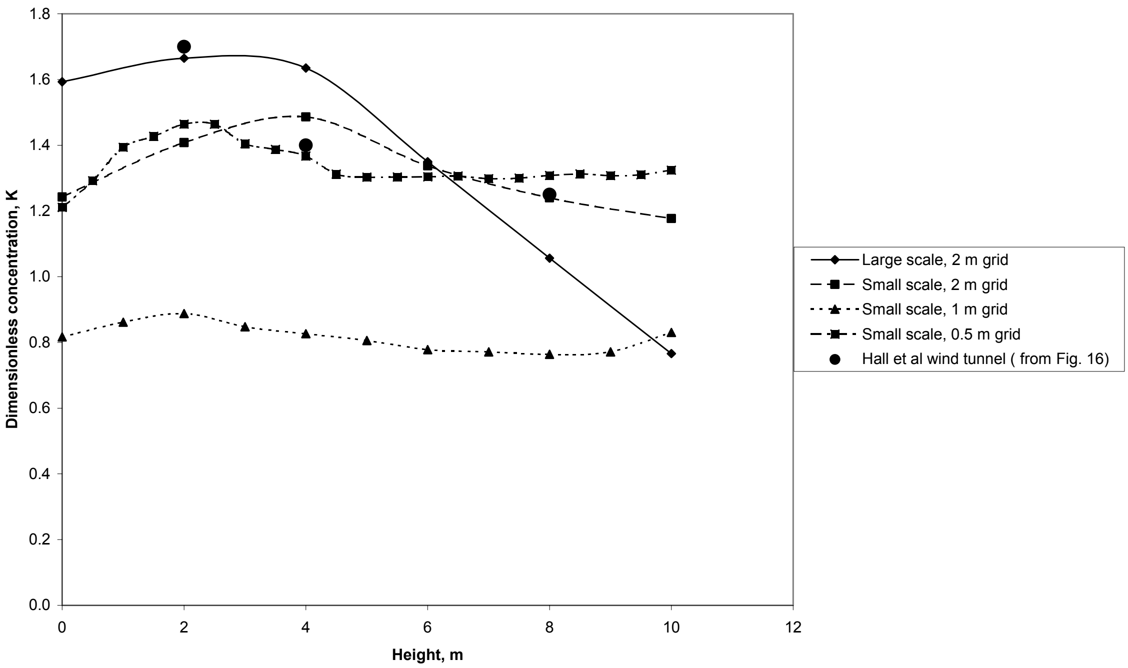

Fig. A6: Comparison of model predictions and wind tunnel studies carried out by Hall et al 1999 of a 4:1 building (40 m x 10 m x 10 m) with single discharge 10 m from the upwind wall. Large scale model with grid resolution 2 m and small-scale model with resolution 2 m, 1 m and 0.5 m.

Fig. A7: Modelled array of buildings

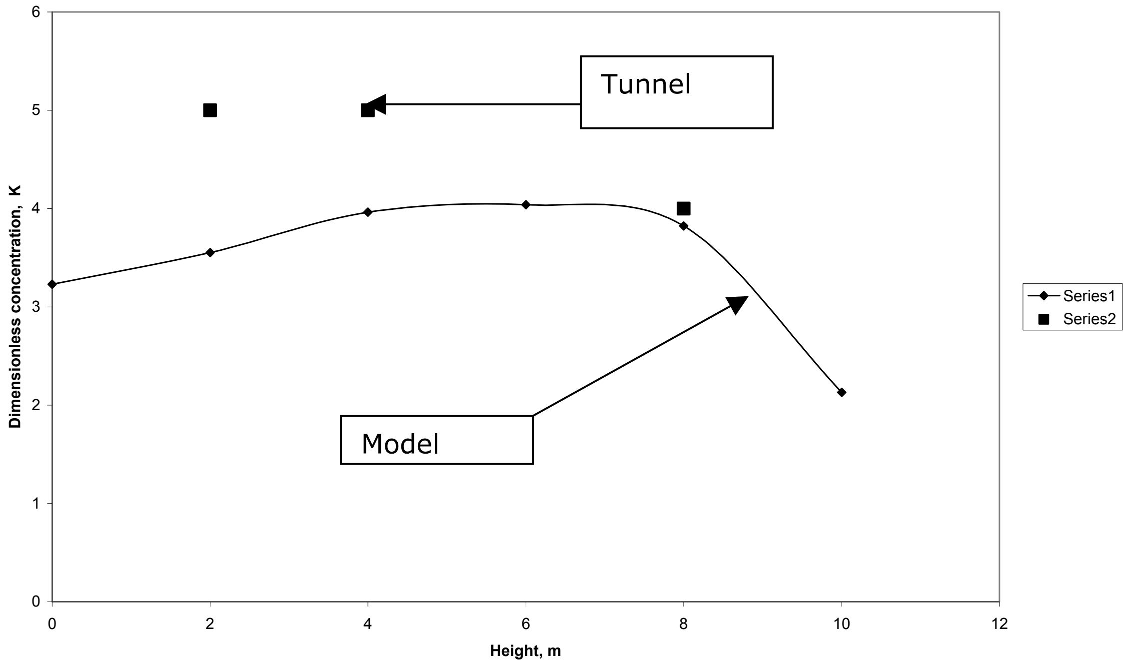

Fig. A8: Comparison of concentrations derived from model predictions and wind tunnel studies carried out by Hall et al 1999 of an array of 4:1 buildings (40 m x 10 m x 10 m, 44% building density –see Fig. A7) with single discharge between buildings. Large-scale model with grid resolution 2 m