Glasgow City Council

Air Quality Update & Screening Assessment

October 2006

Contents

Executive Summary

Under the Air Quality Strategy, local authorities must undertake regular reviews and assessments of air quality in their areas to assess compliance with statutory objectives for key air pollutants.

Should it appear at the conclusion of the review and assessment process that one or more of the objectives will not be complied with, the local authority must declare an Air Quality Management Area (AQMA) for affected area and draw up an Action Plan detailing the action to be taken to reduce pollutant concentrations.

Glasgow City Council's 2005 Progress Report concluded that several new roads and developments had the potential to result in exceedences of the statutory objectives. This Update & Screening Assessment considers these roads and developments in more detail, as well as all of the pollutants detailed in the Air Quality Strategy. Local Air Quality Management Technical Guidance was followed in the preparation of the report.

This report concludes that no exceedences of the National Air Quality Strategy objectives are predicted for carbon monoxide, benzene, 1,3-butadiene, lead and sulphur dioxide and consequently, that there is no requirement to proceed to a Detailed Assessment for these pollutants.

As exceedences of NO_2 objectives still occur within the existing city centre AQMA, there is no requirement to proceed to a Detailed Assessment for this part of the city and the AQMA will remain in force until such times as the objectives are met.

Exceedences of the objectives were predicted for NO_2 at the following additional locations:

- Bridge Street;
- Finnieston Street;
- Westmuir Street;
- Dunn Street;
- Anniesland Cross;
- Balshagray Avenue at Abbey Drive / Crow Road;
- Balshagray Avenue at Victoria Park Drive North / Victoria Park Gardens South;
- Maryhill Road at Queen Margaret Drive / Bilsland Drive.

It is necessary to proceed to a Detailed Assessment for these areas to determine whether further AQMAs should be declared for NO_2.

For new roads either constructed or proposed, such as the M74 extension, it is considered that monitoring will provide a more accurate picture of the impacts with respect to NO_2 and this will inform whether further detailed analysis is required.

Concentrations of PM_{10} were last considered in Glasgow during the Detailed Assessment and Progress Report of 2005. It was considered in both these reports that there may be exceedences of the air quality objectives for PM_{10} at locations across the city. However, it was concluded that there required to be further monitoring carried out to validate dispersion modelling results prior to declaration of one or more AQMAs. Glasgow City Council is currently going through the process of purchasing three TEOM/FDMS units for this purpose, which should be operational from the start of 2007.

The Detailed Assessment for 2005 stated that there will be requirement to declare an Air Quality Management Area for PM_{10} for the city centre and this will be carried out towards the end of 2006.

Further dispersion modelling has indicated that many busy roads and junctions will fail to meet the 2010 annual mean objective for PM_{10}. The estimated 2010 concentrations obtained were higher than those predicted by dispersion modelling in the 2005 Detailed Assessment. Given that potentially many main roads and busy junctions in Glasgow could fail to meet the 2010 objective, there is the possibility that the entire road network, or the entire City of Glasgow, would need to be declared as an AQMA for PM_{10}.

Therefore, it is considered important that a sufficient amount of monitored data for PM_{10} is available to provide a more detailed and accurate picture of PM_{10} concentrations in Glasgow before making decisions on the declaration of further AQMAs outwith the city centre. Therefore, it is proposed that *there is no requirement* for a Detailed Assessment for these sources at the present time, on the basis that monitoring will be carried out and a Detailed Assessment carried out at a later date.

1.0 Introduction

Local Authorities are required to regularly review and assess air quality within their area. These reviews and assessments are the basis of local air quality management and are intended to compare current and future concentrations of key air pollutants with the objectives detailed in Regulations as part of the National Air Quality Strategy.

This strategy has set and updated target concentrations for eight air pollutants, as detailed in 1.1 below.

This led to the publication in 1997 of the United Kingdom National Air Quality Strategy as well as associated Regulations and Guidance Notes. This was updated in early 2000 with new draft Regulations and Guidance Notes. Amended regulations for air quality were published in 2002. Subsequently amended regulations were published in 2003 and 2005 altering limits for benzene and carbon monoxide and adopting the latest European Directive respectively.

Currently, the United Kingdom Air Quality Strategy is under review, with stakeholders being consulted by the UK Government and the devolved administrations.

Local authorities are required to undertake a continuing review of air pollutants in their area and assess whether the target levels set will be achieved by the specified objective date. Ozone is being dealt with separately at a national level.

Local authorities are required to take action should their assessment indicate that levels of a pollutant will not achieve the objective by the target date.

Glasgow City Council has completed four rounds of review and assessment since the process has started.

Stage three was completed in 2001 and consisted of a Detailed Assessment of NO_2 and PM_{10}, the two pollutants considered to be of greatest concern in Glasgow. The report concluded that NO_2 was exceeding objectives in the city centre, but nowhere else. In contrast, no exceedences of the objectives were predicted for PM_{10} in any part of Glasgow.

As a result of these findings an Air Quality Management Area (AQMA) was declared for the whole of the city centre for NO_2.

Stage Four was started in 2003 and following the Detailed Assessment of 2005, it was found that the air quality objectives were being exceeded for NO_2 in areas outside the city centre and required AQMAs to be declared in these areas. Additionally, the Detailed Assessment concluded that the city centre and other areas of the city were predicted to exceed the Air Quality objectives for PM_{10}. However, as a corollary to this it stated that further monitoring in these areas is required to confirm the predictions.

Following an appraisal of the second round of Review and Assessment by the Department of Environment, Food and Rural Affairs together with the devolved administrations, it has been recommended that the current round of Review and Assessment be carried out in two steps, these being:

- **a)** Update and Screening Assessment to identify factors that have changed since the round one of review and assessment and potentially require further assessment;
- **b)** Detailed Assessment of pollutants and/ or locations, which have been, identified as requiring further research.

This report constitutes the Update and Screening Assessment using the checklist approach for each pollutant as described within Technical Guidance LAQM.TG(03).

1.1 Legislative Background

The Air Quality Strategy for England, Scotland, Wales and Northern Ireland assesses individual air pollutants and categorises eight of current concern.

These are: benzene, 1,3-butadiene, carbon monoxide, lead, nitrogen dioxide, particles, sulphur dioxide and ozone. All these air pollutants are known to adversely affect human health at sufficiently high concentrations. All are relatively widespread throughout the United Kingdom. Moreover, a reasonable amount is known about their ambient levels across the United Kingdom and about the major sources of each pollutant. Standards for each air pollutant are set by the Air Quality Strategy.

In order that standards and objectives can be accurately used as part of an air quality review and assessment, a number of points have to be considered.

Firstly, the time period for each of the standards varies according to the pollutant. This is done in order to reflect the health effect of the pollutant. For example, a sufficiently high concentration of SO_2 could potentially impact on a person's health within a short time period (minutes). For benzene, however, the time required for a health effect to occur would be much longer (years). Therefore, the respective objectives are of appropriate periods of exposure to represent this.

Secondly, is the allowance of a number of exceedences of a given standard. This approach is applied to those pollutants that have shorter averaging times and allows these standards to be exceeded at times when it would not be appropriate to try to prevent breaches. This would include those occasions when complete compliance would require disproportionately expensive abatement measures. Or it may arise during social or cultural occasions, such as bonfire night, which would be impractical to control. Or it could be due to uncontrollable natural sources or adverse weather conditions.

This means that for SO_2 for instance, 35 of the highest 15-minute values in any single year can be above 266 $\mu g/m^3$.

UK Government and the devolved administrations are currently consulting on a review of the current Air Quality Strategy for England, Scotland, Wales and Northern Ireland.

With regard to carrying out a review and assessment of air quality in their area, local authorities are required to have regard to statutory guidance '*Local Air Quality Management: Technical Guidance LAQM.TG(03)'* issued by the Department for Environment, Food and Rural Affairs (Defra), the Scottish Executive and the Welsh Assembly Government under section 88(1) of the Environment Act 1995.

1.2 Overview of Update & Screening Assessment

This Update & Screening Assessment follows on from the Progress Report of 2005, which identified a number of new roads and developments where there could be potential breaches of air quality objectives and concluded that further assessment was required. Each of the pollutants detailed in Table 1.1 have also been considered and conclusions made as to whether progression to a Detailed Assessment is required, which is the next step in the review and assessment program.

Technical Guidance LAQM.TG(03) states that the purpose of an Update & Screening Assessment is to:

*"identify those matters that have changed since the last review and assessment, which might lead to a **risk** of an air quality objective being exceeded. Use a checklist to identify significant changes that require further consideration. Where such changes are identified, then apply simple screening tools to decide whether there is sufficient risk of an exceedence of an objective to justify a Detailed Assessment."*

Pollutant	Air Quality Objective		Date to be achieved by
	Concentration	Measured as	
Benzene	3.25 µg m^{-3}	Running annual mean	31.12.2010
1,3-Butadiene	2.25 µg m^{-3}	Running annual mean	31.12.2003
Carbon Monoxide (CO)	10 mg m^{-3}	Running 8-hour mean	31.12.2003
Lead (Pb)	0.5 µg m^{-3} 0.25 µg m^{-3}	Annual mean Annual mean	31.12.2004 31.12.2008
Nitrogen Dioxide (NO_2)	200 µg m^{-3} not to be exceeded more than 18 times per year 40 µgm^{-3}	1-hour mean Annual mean	31.12.2005 31.12.2005
Particulate Matter (PM_{10})	50 µg m^{-3} not to be exceeded more than 35 times per year 40 µg m^{-3} 50 µg m^{-3} not to be exceeded more than 7 times per year 18 µg m^{-3}	24-hour mean Annual mean 24-hour mean Annual mean	31.12.2004 31.12.2004 31.12.2010 31.12.2010
Sulphur dioxide (SO_2)	266 µg m^{-3} not to be exceeded more than 35 times per year 350 µg m^{-3} not to be exceeded more than 24 times per year 125 µg m^{-3} not to be exceeded more than 3 times per year	15 minute mean 1-hour mean 24-hour mean	31.12.2005 31.12.2004 31.12.2004

Table 1.1 – Objectives for the seven key air pollutants in Scotland

2.0 Update and Screening of Carbon Monoxide

2.1 Introduction

Concentrations of carbon monoxide (CO) were last considered in Glasgow in the Update and Screening Assessment of 2003. At this time the Air Quality objective for CO was set at 11.6 mg/m^3 as a running 8 hour mean. Subsequently this was tightened to 10mg/m^3, which was to be achieved by 31st December 2003 to bring the standard into line with the European Union standard.

Highest monitored concentrations were observed at all three AURN sites in the city centre, with Glasgow Centre and Glasgow City Chambers experiencing greater maximum levels than Glasgow Kerbside. Although this occurred during a pollution episode in December 2002, CO concentrations were still below the air quality objective at all sites.

The Technical Guidance suggests that monitored data is preferable to modelled data in providing an accurate indication as to the likelihood of breaches of the objective. The guidance also states that "Studies at a national level, based on both measured and modelling data, suggest that there is little likelihood of the new objective for carbon monoxide being exceeded by 2003……. it is highly unlikely that any authority will be required to proceed beyond the Updating and Screening Assessment."

What follows is an analysis of recent monitoring for CO.

2.2 Sources of carbon monoxide

The main source of CO in the UK is road traffic. The National Atmospheric Emissions Inventory (NAEI) estimates for Glasgow 70% of CO emissions in 2003 came from road traffic, with another 21% from other transport source (air, rail, shipping). Only 9% came from a non-transport related source. In Glasgow city centre, it would be expected that road traffic would contribute an even higher proportion of total CO emissions. This can be seen in figure 2.1.

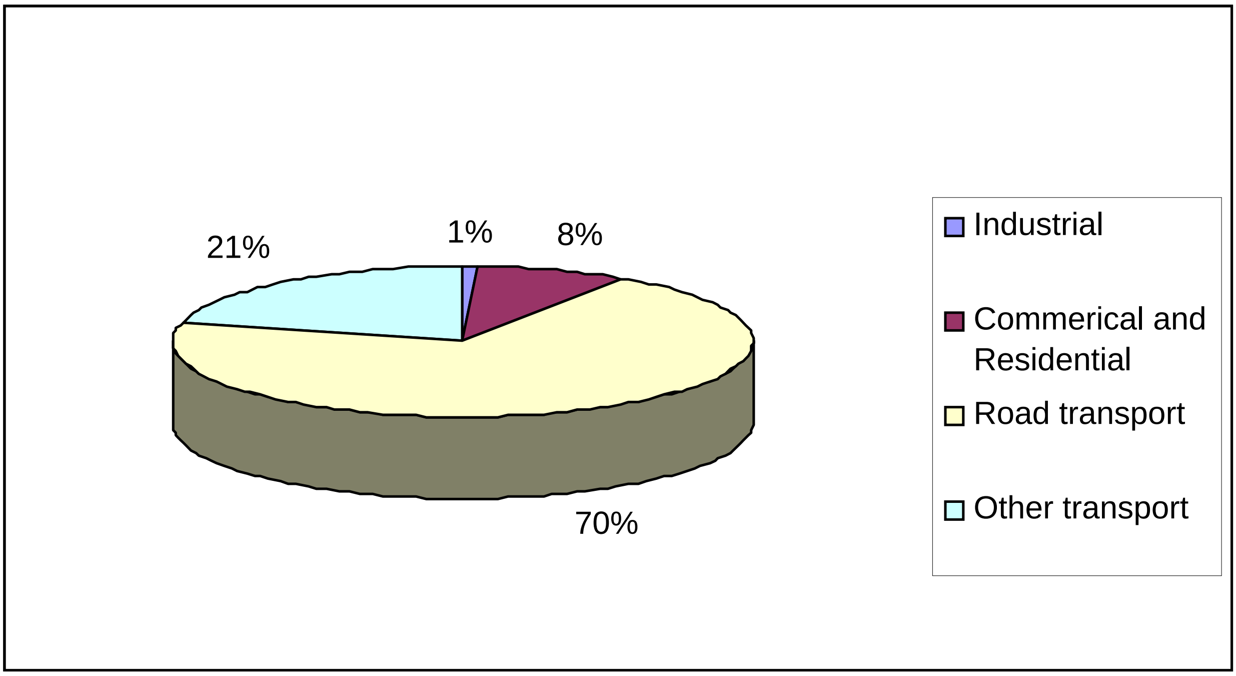


Figure 2.1 – Sources of CO in Glasgow, 2003 (NAEI)

CO emissions are increased when a vehicle's engine is cold or badly tuned, when it is idling, or the vehicle is moving slowly. Concentrations are highest close to busy roads in cities, especially during peak periods when traffic is slow moving.

Improvements in engine design and increased use of catalytic converters have contributed to large reductions in CO emissions.

2.3 Monitoring methodology

2.3.1 Monitoring equipment and locations

Glasgow has several automatic units that measure ambient CO concentrations. Three of these are part of the UK-wide Automatic Urban and Rural Network (AURN). These are:

Glasgow City Chambers (Montrose Street)
The site is located on the 2nd floor of Glasgow City Chambers in Cochrane Street (259527 665297) and samples are from a height of approximately 8 metres. Cochrane Street is a street canyon and the site is classified as urban background.

Glasgow Centre (St. Enoch)
This site is in St Enoch Square, an open, pedestrianised area in the centre of Glasgow. (258943 665027). It is around 20m from Argyle Street. The site is classed as an urban centre site.

Glasgow Kerbside (Hope Street)
Positioned at the southern end of Hope Street next to Centre Station (258696 665166) close to the junction with Argyle Street in a street canyon. It is a kerbside site with its inlet less than 1m from the road. Traffic flow here is more than 25,000 vehicles per day.

Glasgow City Council operates another two air quality monitoring units that measure CO, as follows:
Glasgow 1 (St .Patrick's Primary School)
This has been located in St Patrick's Primary School, Anderston since May 2001. This site has been prone to breakdowns and data capture rates are not as good as expected.

Glasgow 2 (Byres Road)
Previously located in the Townhead area of the city, this has been located at the junction of Byres Road and University Avenue since April 2004.

These sites, except Glasgow 2, are highlighted in Figure 2.2.

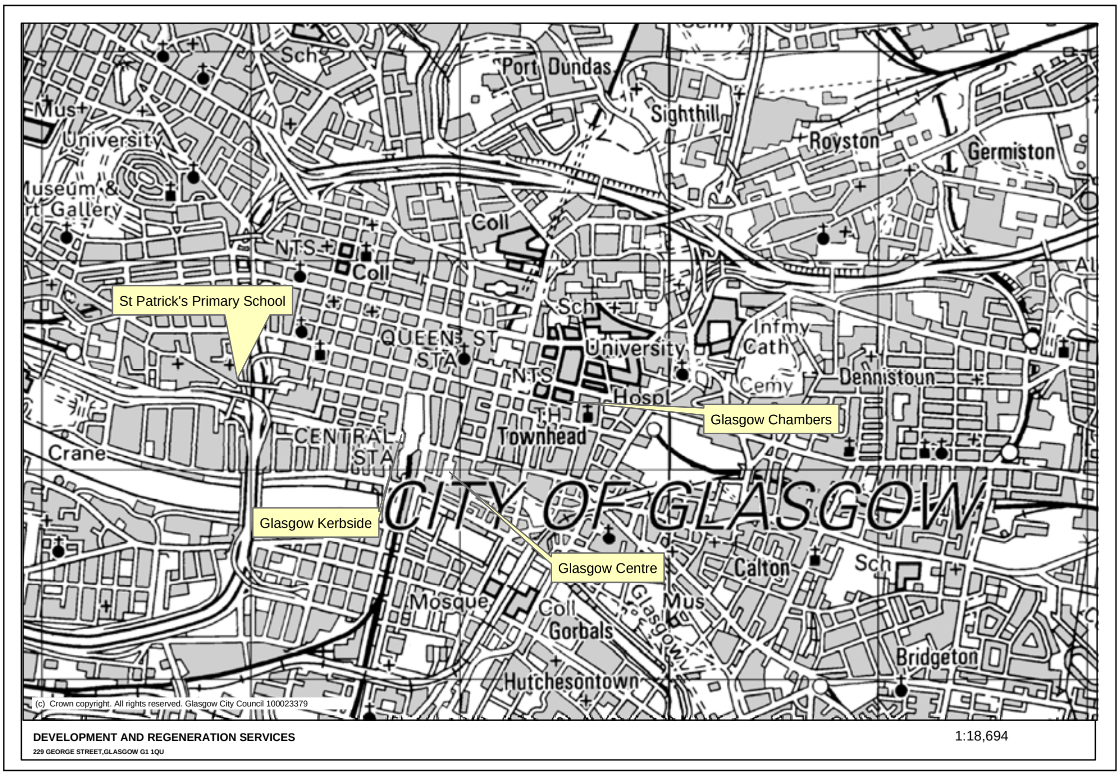


Figure 2.2. Air Quality Monitoring Stations in and around the city centre

2.3.2 Public exposure

When assessing concentrations of pollutants, published guidance states that the only sites that should be considered are those which represent relevant exposure against the objective. In the case of CO, the objective is an 8-hour mean. Locations where this should be considered include all background and roadside locations up to the façade of properties, such as residencies, schools, hospitals and other buildings where the public may visit or remain for long periods.

The objective would not apply at building facades of offices or other places of work where members of the public do not have regular access or at kerbside locations where public exposure will be short.

2.4 Update and Screening of CO

Update and screening of CO will have two steps, which will consider different CO sources, locations or data sets. The headings are listed below and will be considered in turn:

- Monitoring data;

- Very busy roads and junctions.

2.4.1 Monitoring data

Figure 2.3 displays the maximum running 8-hour mean CO concentrations measured at Glasgow's three AURN sites. The assessment is presented from 2000 onwards. Data capture is generally excellent at all three AURN sites and is at all times greater than 95%.

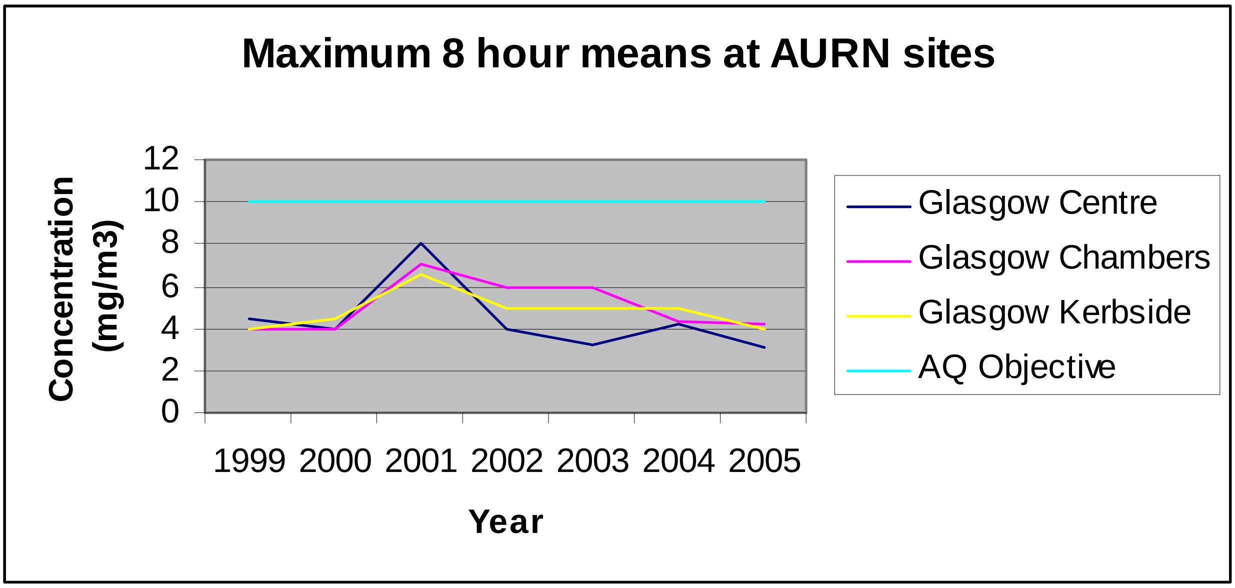


Figure 2.3 maximum running 8-hour mean CO concentrations measured at Glasgow's three AURN sites

Monitoring from the AURN sites has shown that there were no exceedences of the CO objective at any AURN site in Glasgow. The three AURN sites give a good indication of typical CO levels expected across the city, as they range from urban background, giving typical exposure levels, to the kerbside site, which would be expected to show the 'worst-case' scenario due to its proximity to traffic.

CO concentrations have dropped since 2001, when a peak was observed at all 3 AURN sites. This was the result of a pollution episode. Nevertheless, even during this period, CO concentrations were still below the air quality objective at all sites.

The results for the non-AURN sites are shown below. The data capture rate for St Patrick's Primary School is too low to demonstrate compliance with the objective. (This was due to a problem with the air conditioning unit at this station). However, considering the maximum 8-hour mean that has been recorded at either site is well below the objective, and that no exceedences are noted at the AURN sites, it is very unlikely that there would have been exceedences at other times of the year.

Site	Dates	Maximum 8 hour mean (mg/m^3)	Data Capture (%)
Glasgow 2	1 Jan 05 - 31 Dec 05	3.0	93.4
Glasgow 1	1 Jan 05 - 31 Dec 05	2.6	46.3

Table 2.1 - Maximum 8 hour means at Glasgow City Council sites

2.4.2 Very busy roads and junctions in built-up areas

As road traffic is responsible for the majority of CO in Glasgow, any possible exceedences would be most likely to occur close to very busy roads or junctions. These locations are described in the guidance note as:

"*…'very busy' roads and junctions in areas where the 2006 background is expected to be above 1 mg/m^3".*

'Very busy' road are defined as:

- *"Single carriageway roads with daily average traffic flows which exceed 80,000 vehicles per day";*
- *"Dual carriageway (2 or 3-lane) roads with daily average traffic flows which exceed 120,000 vehicles per day";*
- *"Motorways with daily average traffic flows which exceed 140,000 vehicles per day".*

Estimated annual mean background concentrations of CO for 2001 are provided on the air quality website (www.airquality.co.uk/archive/laqm/tools/). In Glasgow, the highest background CO concentration is 0.488mg/m^3 and this is expected to decrease further by 2006. While some roads may meet the criteria in terms of traffic flow, as the background concentration is so low, it is not necessary to carry out screening at any roads or junctions, and it can be assumed that there are not potential exceedences of the CO objective.

2.5 Conclusions

Monitoring of CO has taken place across Glasgow city centre and concentrations were compared against the air quality objective, which is a maximum 8-hour running mean of 10mg/m^3. Results showed that there were no exceedences of this objective at any site where sufficient data was available. These sites are representative of concentrations across Glasgow, so it is not likely that there were exceedences at other locations.

In terms of screening, although some locations in Glasgow fulfilled the criteria for a busy road or junction, it is anticipated that no exceedences of the CO objective will occur.

As a result of monitoring and screening procedures, *there will be no requirement* for Glasgow City Council to progress to a Detailed Assessment for carbon monoxide.

3.0 Update and Screening Assessment of Benzene

3.1 Introduction

Concentrations of benzene in ambient air were last considered in Glasgow during the Update and Screening Assessment in the last round the review and assessment process.

The air quality objective for benzene was set at 16.25µg/m^3 as a running annual mean from 31st December 2003. The previous review concluded that Glasgow would comply with the air quality objective for benzene.

Subsequently, the air quality objective for benzene has been tightened and is now a running annual mean of 3.25µg/m^3 to be met by 31st December 2010.

3.2 Sources of benzene

The main sources of benzene in the UK are petrol engine vehicles, petrol refining and the emissions from petrol station forecourts without vapour recovery systems. The National Atmospheric Emissions Inventory (NAEI) estimates that for Glasgow, 38% of benzene emissions came from road traffic. In Glasgow city centre, road traffic would contribute an even higher proportion of total benzene emission. Other sources in Glasgow include residential, commercial and industrial combustion, and other form of transport (air, rail, shipping). This is shown below:

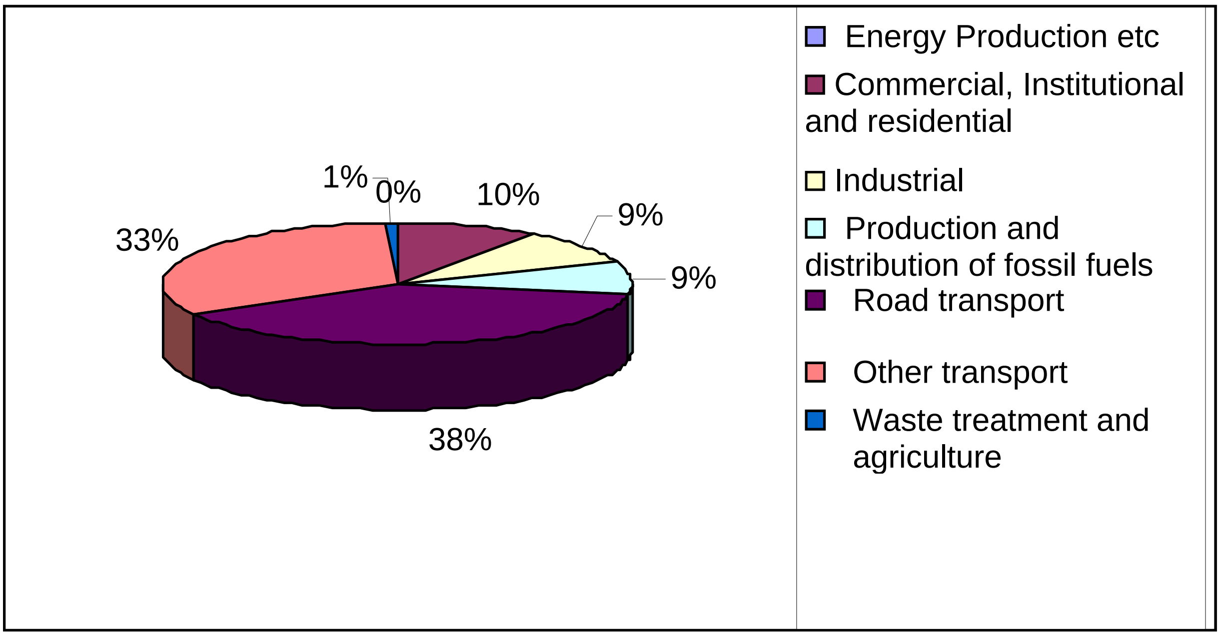


Figure 3.1 Sources of benzene in Glasgow, 2003 (NAEI)

From January 2000, EU legislation was introduced to reduce the maximum benzene content of petrol from 5% to 1%. Additional measures are further expected to reduce emissions from cars and light-duty vehicles. However, these reductions could be offset by the increase in traffic volume on the roads.

Since the last round of review and assessment, there have been no new major industrial processes that are major emitters of benzene, or changes to existing processes that would lead to an increase in benzene emissions.

It has recently been recognised that there is a potential for high benzene emissions around petrol filling stations. This can be caused by either petrol vapours being displaced when filling underground storage tanks or by petrol vapour being displaced from vehicle petrol tanks during refuelling.

3.3 Monitoring methodology

3.3.1 Monitoring equipment and locations

Monitoring of benzene is carried out using passive diffusion tubes. These tubes contain a Chromosorb absorbent, on which ambient benzene accumulates before being analysed. Tubes are exposed for periods of four weeks.

Since 1999, monitoring of benzene has taken place at four locations in the city centre, and has continued uninterrupted, to the present. Two of the monitoring sites are on opposite sides of Argyle Street under the Heilanman's Umbrella, the railway bridge that carries rail traffic over the River Clyde and into Central Station. The third site is located on the enclosed roadway under the Buchanan Galleries on Cathedral Street. These sites are highlighted in Figure 3.2. These sites have been consistently giving results below the objective for several years and have been moved to more relevant locations in the last 6 months. Two tubes have been placed at or near petrol filling stations. The locations at Heilanman's Umbrella South and Buchanan Galleries were removed in December 2005.

In addition, an automatic hydrocarbon analyser has been in operation at Glasgow Kerbside AURN (Hope Street) since 2003.

3.3.2 Public exposure

When assessing concentrations of pollutants, published guidance states that the only sites should be considered are those that represent relevant exposure against the objective.

In the case of benzene, the standard is a running annual mean. Sites that should be considered are all background and roadside locations up to the building façade of properties such as residences, schools, hospitals and other buildings where the public may visit or remain for long periods. The objective would not apply at building facades or offices or other places of work where members of the public do not have regular access or at kerbside locations where public exposure is likely to be short.

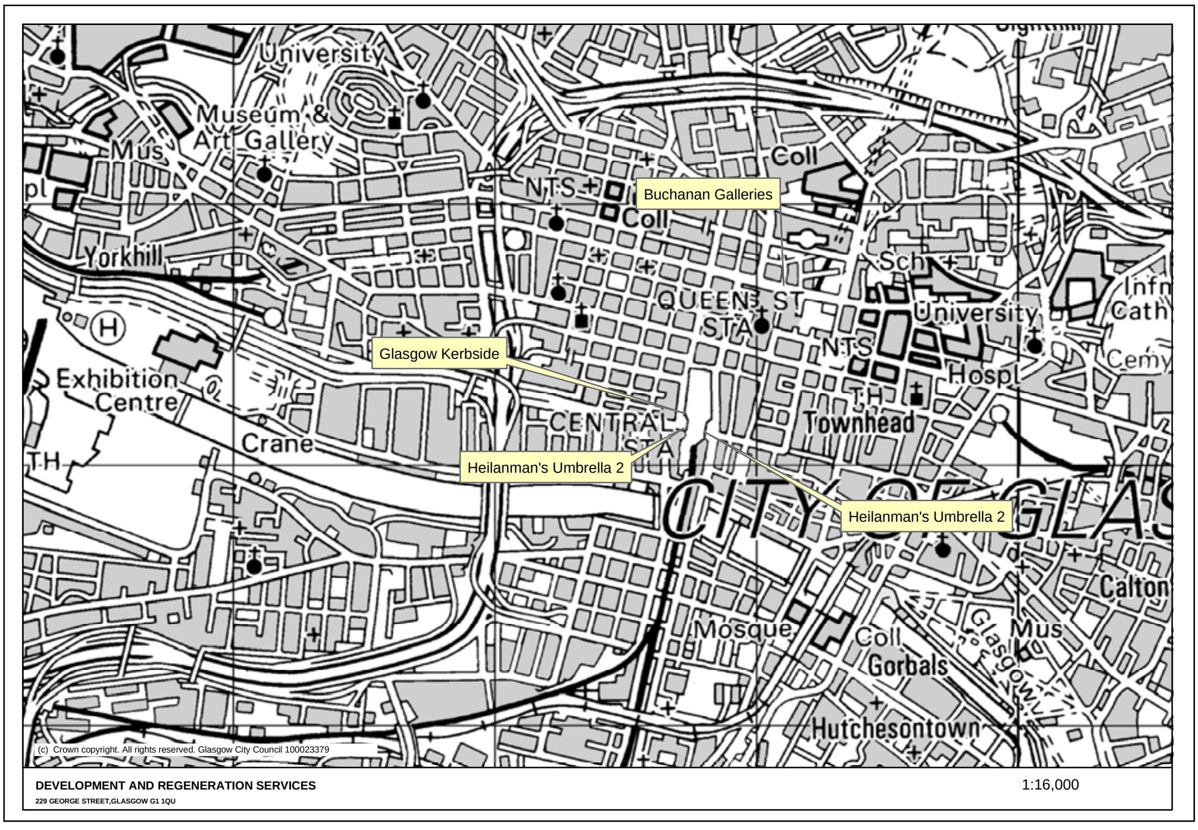


Fig 3.2 Location of benzene diffusion tubes

3.4 Update and Screening of benzene

The update and screening assessment for benzene will consider benzene sources, locations and data separately, in the form of a checklist. The headings of these are listed below, and each will be considered in turn.

- Monitoring data;
- Very busy road and junctions in built-up areas;
- Industrial sources;
- Petrol stations;
- Major fuel storage depots (petroleum only).
-

3.4.1 Monitoring data

Figure 3.3 presents the running annual mean measured using the diffusion tubes since 1999 against the 2010 objective at the three diffusion tube sites described above.

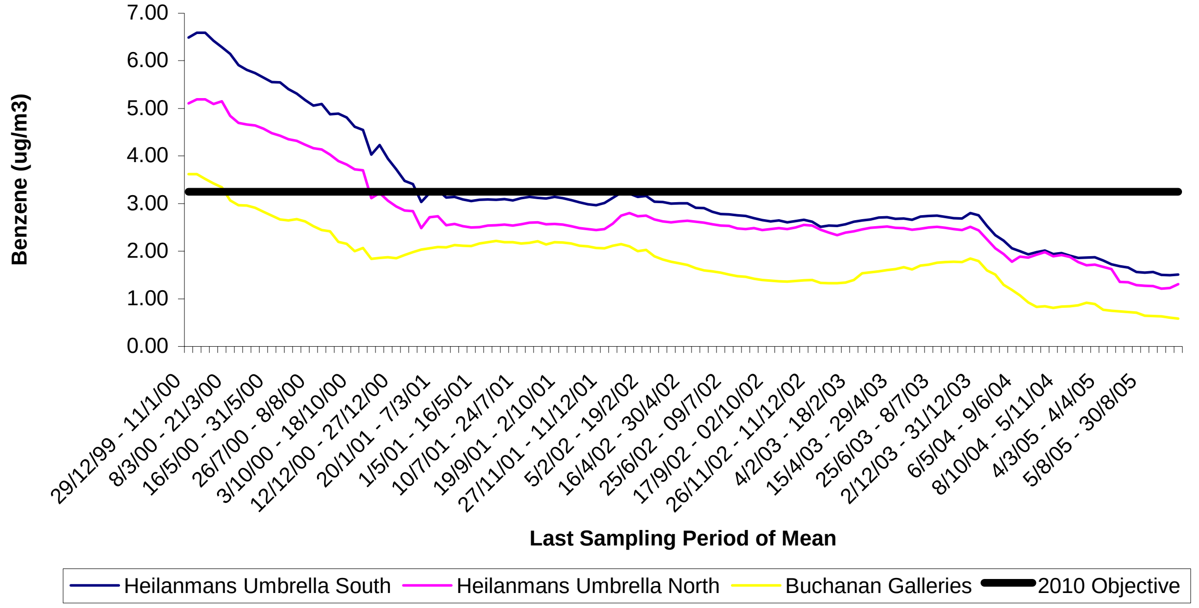


Fig 3.3 benzene annual mean concentrations

The largest decline in benzene concentrations occurred around 2000 (not shown in Fig 2.3), which coincides with the reduction of benzene content in fuel as discussed above. Concentrations have continued to decrease since 2000, although not at the same rate.

Clearly, there have been exceedences of the 2003 running annual mean objective of 16.25µg/m^3 from the diffusion tube data. Exceedences of the 2010 objective occurred regularly before 2000, but since then have been very rare.

The diffusion tubes are all kerbside sites, two of which are situated underneath a canopy at Heilanman's Umbrella and one of which is underneath a canopy at Buchanan Galleries. For this reason, dispersion will be very low and measured benzene concentrations will be higher than normally expected. Therefore, these diffusion tube sites represent the 'worst case' benzene concentrations in ambient air. Since these sites are no longer failing the 2010 objective, it is extremely unlikely that there would be any other sites that might fail the objective.

The guidance states kerbside locations should not be assessed in terms of human exposure.

3.4.2 Very busy roads and junctions in built-up areas

There are suggestions that there could be a few locations, close to busy roads, where background concentrations are high and these locations may be at risk of exceeding the objective and must be considered. The locations are described in the guidance as,

"..*very busy road and junctions in areas where the 2010 background is expected to be above 2µg/m^3"*

'Very busy' roads are defined as,

- "*Single carriageway roads with daily average traffic flows which exceed 80,000 vehicles per day"*
- *"Dual carriageway (2 or 3-lane) road with daily average traffic flows which exceed 120,000 vehicles per day."*
- *"Motorways with daily average traffic flows which exceed 140,000 vehicles per day"*

While in Glasgow there may be roads which fulfil the above criteria, background concentrations are not expected to be above 2µg/m^3 by 2010. Estimated annual background concentrations of benzene in 2001 are provided on the air quality website (www.airquality.co.uk/archive/laqm/tools). In Glasgow, the highest background benzene concentration is 0.901µg/m^3. Since benzene concentrations are expected to decline by 2010, background concentrations at this time will be well below 2µg/m^3.

For this reason it will not be necessary to assess benzene concentrations near busy road and junctions.

3.4.3 Industrial sources

Since Glasgow has no major industrial sources of benzene, there is no need to make an assessment of industrial sources.

3.4.4 Petrol stations

Petrol stations that are to be considered for benzene emissions are defined in the guidance as,

"..all petrol stations with an annual throughput of more than 2000m^3 of petrol (2 million litres) per annum and with a busy road nearby."

A busy road is identified as,

"..*one with more than 30,000 vehicles per day."*

In Glasgow, there are no locations with a busy road, a sufficiently large petrol station and relevant exposure in the immediate vicinity. However, as discussed earlier, two of the diffusion tube sites have been moved to locations that are close to petrol filling stations to confirm this statement. One tube is now located at Ochiltree Avenue in Temple adjacent to a petrol filling station and one is located on Pollokshaws Road opposite Queens Park, again adjacent to a petrol filling station. Therefore, *there will be no requirement* to make a Detailed Assessment of benzene around petrol stations at the present time.

3.4.5 Major fuel storage depots

As Glasgow has no major fuel storage depots within its boundaries, or within the surrounding areas. *There will be no requirement* to make a Detailed Assessment for benzene at these locations.

3.5 Conclusions

Monitoring of benzene has taken place across Glasgow city centre and concentrations have been compared against the air quality objective, which is a running annual mean of 3.25µg/m^3. Results show that levels of benzene have been declining since 2000, coinciding with the reduction of benzene content in petrol. There have been no exceedences of the objective at any monitoring location since 2000.

As the monitoring locations are representative of the worst benzene concentrations in Glasgow due to their locations under bridges, it is likely that there are no exceedences at other locations in Glasgow.

In terms of screening at busy roads and junctions, with the low background concentrations of benzene in Glasgow, it is not considered likely that there would be any exceedences.

There are no industrial sources or petroleum storage depots in Glasgow that could contribute to elevated benzene concentrations.

There are no locations been identified with a large petrol station close to a ‘busy’ road and with relevant public exposure that could result in elevated benzene concentrations.

As a result of monitoring and screening procedures, *there will be no requirement* for Glasgow City Council to progress to a Detailed Assessment for benzene.

4.0 Update and Screening Assessment of 1,3-butadiene

4.1 Introduction

Concentrations of 1,3-butadiene in ambient air were last considered in Glasgow in the Update and Screening Assessment of 2003. At this time, the air quality objective for 1,3-butadiene was set at 2.25 $\mu g/m^3$ as a running annual mean to be achieved by 31st December 2003.

There have been no alterations to the air quality objective for 1,3-butadiene since the last round of review and assessment.

4.2 Sources of 1,3-butadiene

The main source of 1,3-butadiene in the UK is emissions from road traffic. In Glasgow, 76% of emissions are from road transport, with 23% of emissions from other forms of transport (rail, shipping, and air). 1,3-butadiene is also an important industrial chemical in certain industrial processes, mainly the manufacture of synthetic rubber for tyres, and is used in bulk in these procedures. However, there are no industrial sources of this nature in or around Glasgow.

Figure 4.1 shows a breakdown of 1,3-butadiene sources, as given by the National Atmospheric Emissions Inventory (NAEI), in 2003.

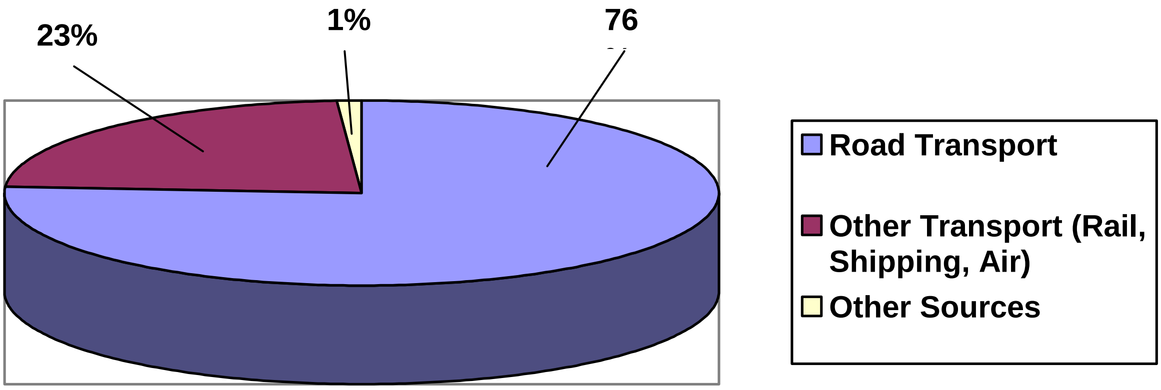


Figure 4.1 – Sources of 1,3-butadiene in Glasgow, 2003 (NAEI)

Reductions in 1,3-butadiene content of petrol and the increasing number of vehicles equipped with three way catalysts have resulted in greatly decreasing concentrations of 1,3-butadiene. The emission limits agreed for cars, light vans and heavy goods vehicles sold from 2001 – 2006 and fuel quality standards agreed for 2000 – 2005 as part of the Auto-Oil programme will both contribute to further decreases in ambient levels for future years.

The measures introduced or adopted by the government have led to dramatic falls in 1,3-butadiene and will continue to do so. EPAQS (Expert Panel in Air Quality Standards) considered that its recommended standard for this pollutant should be reviewed after a period of five years, in light of additional data on human health and the experience of improved pollution control.

4.3 Monitoring methodology

4.3.1 Monitoring equipment and locations

At present, Glasgow City Council does not operate a monitoring network for 1,3-butadiene. However, since 1st August 2002, an automatic monitor for hydrocarbons has been installed in Glasgow Kerbside (Hope Street).

4.3.2 Public exposure

When assessing concentrations of pollutants, published guidance states that the only sites that should be considered are those which represent relevant exposure against the objective.

In the case of 1,3-butadiene, the standard is a running annual mean. Sites which should be considered are all background and roadside locations up to the building façade of properties such as residencies, schools, hospitals and other buildings where the public may visit or remain for long periods. The objective would not apply at building facades of offices or other places of work where members of the public do not have regular access or at kerbside locations where public exposure is likely to be short.

4.4 Update and Screening of 1,3-butadiene

Update and screening of 1,3-butadiene has three steps, which consider different sources, locations or data sets. The headings of the steps are listed below, and each one is then addressed in turn.

- Monitoring data;
- New industrial sources;
- Existing industrial sources with significantly increased emissions.

4.4.1 Monitoring data

As mentioned previously, an automatic hydrocarbon analyser has been in operation at Glasgow Kerbside since 2002. The following table demonstrates data available in order to make an assessment against the objective of 2.25µgm^{-3} as a running annual mean.

	Year		
Location	**2003**	**2004**	**2005**
Glasgow Hope Street	0.42	0.28	0.21

Table 4.1 Running Annual Mean of measured 1,3-butadiene (µgm^{-3})
(Data obtained from www.airquality.co.uk/archive)

The results given in table 4.1 suggest that concentrations of 1,3-butadiene are significantly below the National Air Quality Strategy Objective. Given the kerbside monitoring location, it is unlikely that any relevant locations would have higher 1,3-butadiene concentrations.

Therefore, *there is no requirement* to proceed to a Detailed Assessment at these locations.

4.4.2 New industrial sources/ existing industrial sources with significantly increased emissions

There are no new or existing industrial sources in Glasgow that are high emitters of 1,3-butadiene. As such, *there is no requirement* to proceed to a detailed assessment for 1,3-butadiene.

4.5 Conclusions

Monitoring has shown that concentrations of 1,3-butadiene are significantly below the National Air Quality Strategy Objective. Utilising this data, it is unlikely that any exceedences of the 1,3-butadiene objective have occurred in Glasgow.

There are no industrial sources in Glasgow that could make a large contribution to ambient 1,3-butadiene concentrations.

There will be no requirement for Glasgow City Council to progress to a Detailed Assessment for 1,3-butadiene.

5.0 Update and Screening Assessment of Lead

5.1 Introduction

Concentrations of lead in ambient air were last considered in the Progress Report of October 2005. The current objective is set at 0.5µg/m^3, which was to be achieved by 31st December 2004. This has been tightened to an annual mean of 0.25µg/m^3, which is to be met by 31st December 2008. The Progress Report concluded that there would be no exceedences of the 2008 level for lead.

5.2 Sources of lead

Lead is a naturally occurring element found in the form of minerals in the earth's crust and released by a variety of processes. However, anthropogenic activities represent the major sources of atmospheric lead. These include processes such as ore mining and smelting and the manufacture of lead containing products. Road traffic emissions have been considered as a primary source of atmospheric lead in recent decades, due to the utilisation of tetraethyl lead as a petrol additive. Leaded petrol was banned throughout the EU from 1st January 2000. Emissions of lead are now largely restricted to certain industrial activities.

5.3 Monitoring methodology

Monitoring of atmospheric lead pollution has been carried out at nine locations across Glasgow since 1997 and seven locations since 2002. These sites are listed in Table 5.1 and the approximate locations of each are present in Figure 5.1.

Monitoring Site Name	Grid Reference
Baillieston	2679 6642
Carmyle	2653 6622
Fastnet Street	2645 6659
Dalmarnock	2612 6627
St. Anne's Primary School	2613 6644
Montrose Street	2595 6653
Glasgow Cross	2597 6649

Table 5.1 Locations of lead monitoring sites in Glasgow (St Anne's site is part of the UK national network)

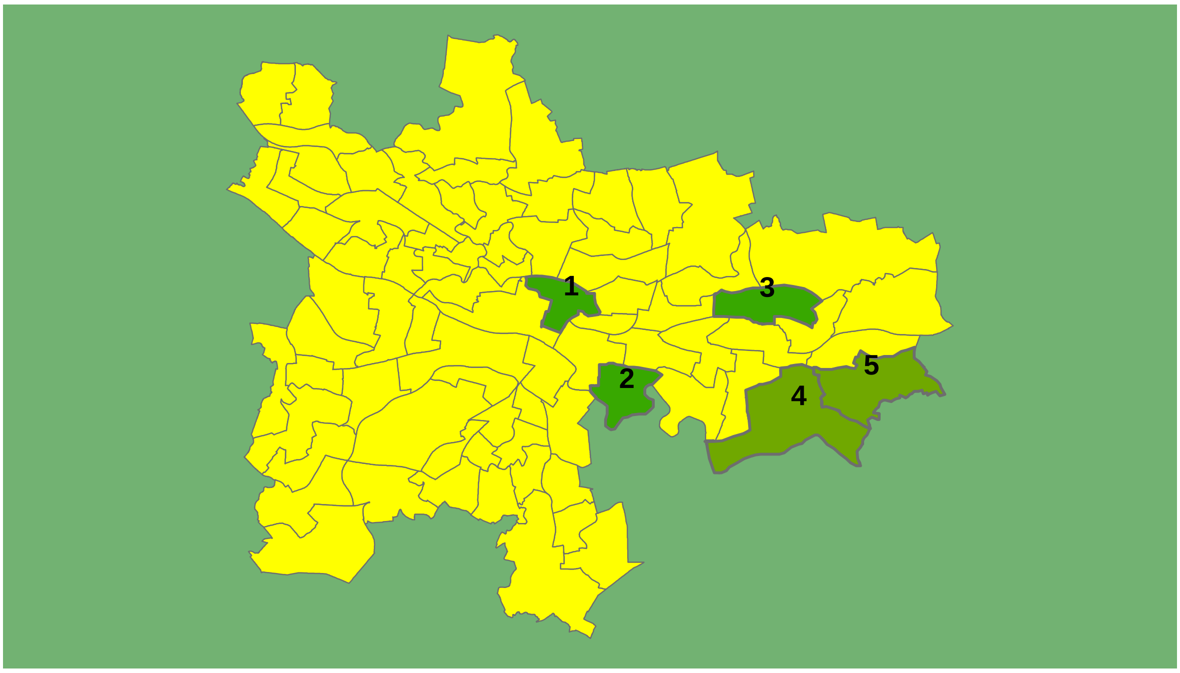


Fig 5.1 Metal monitoring locations

1. City Chambers & Glasgow Cross
2. Dalmarnock & St Anne's Primary School
3. Fastnet Street
4. Carmyle
5. Baillieston

Air is sampled through a cellulose filter at a rate of 5 $Lmin^{-1}$ for periods of 7 days, and lead concentrations determined by analysing filter deposits by atomic absorption spectroscopy.

5.3.2 Public exposure

When assessing atmospheric concentrations of pollutants, the technical guidance is clear that the only sites that should be considered are those relevant to the averaging period of the objective. For the annual objective for lead this includes locations where members of the public might be regularly exposed, such as building facades of residential properties, schools, hospitals, libraries and other buildings where members of the public may be present for prolonged periods of time. The objective does not apply at locations where members of the public have restricted access and at kerbsides, where exposure is likely to be short-term.

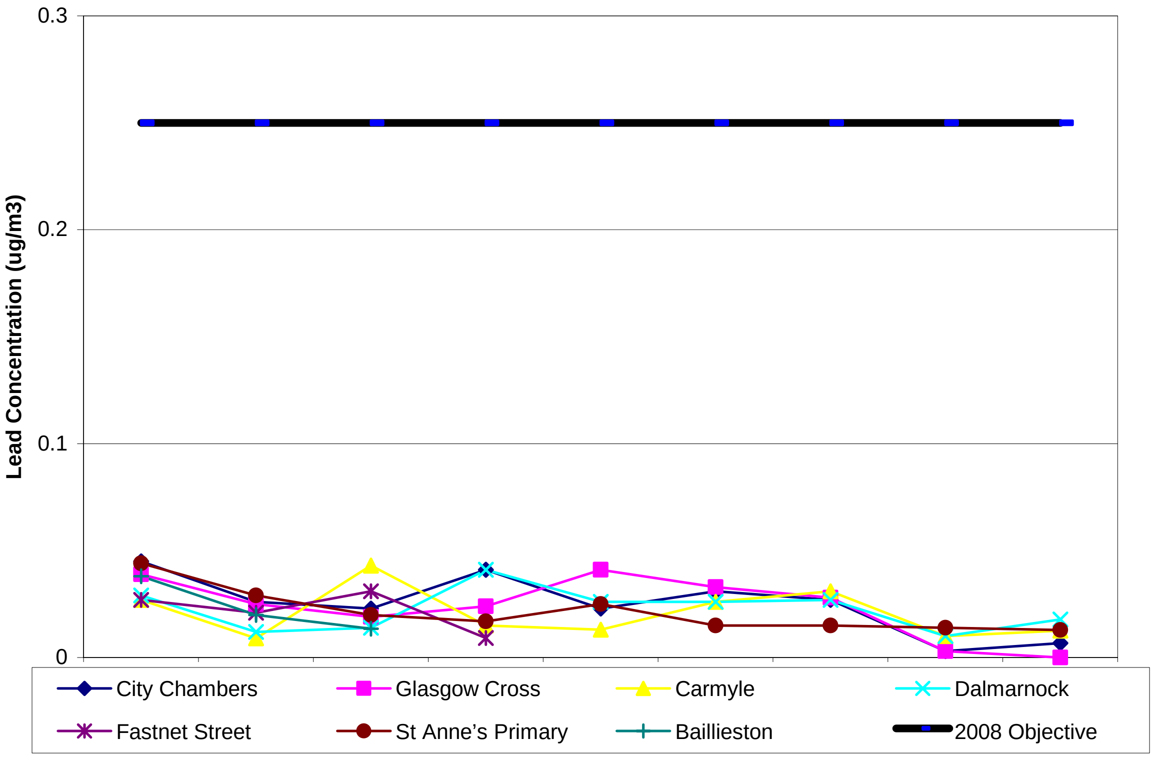
5.4 Update and Screening of Lead

The update and screening of lead has three steps that consider different sources, locations and data sets. The headings of the steps are listed below and each one is addressed in turn.

- Monitoring data outside an AQMA;
- New industrial sources;
- Industrial sources with substantially increased emissions.

5.4.1 Monitoring data outside an AQMA

As there has been no AQMA declared for lead, the results from the seven valid monitoring locations listed in Table 5.1 will be considered in this report. Graph 5.1 presents results of annual atmospheric lead concentrations detected at all seven monitoring locations utilised in Glasgow from 1997 to 2005.



Graph 5.1 lead concentrations detected at monitoring locations utilised in Glasgow from 1997 to 2005

The data presented in this graph indicates that there have been no exceedences of the 2004 air quality objective (annual mean 0.5µg/m^3) at any of Glasgow's monitoring locations since the Progress Report. All mean annual atmospheric concentrations of lead detected in Glasgow were approximately an order of magnitude lower than the 0.5 µg/m standard for lead, and in addition were considerably lower than the annual mean of 0.25 µg/m^3 that is to be met by 31st December 2008 (as show in the graph above).

Therefore, there *is no requirement* to proceed to a Detailed Assessment of lead.

5.4.2 New/existing industrial sources with substantially increased emissions

Since the last round of review and assessment, no new industrial sources in Glasgow that are high emitters of lead have commenced operations.

There has been no industrial source of lead emissions into the atmosphere since 1999. Therefore, *there is no requirement* to proceed to a Detailed Assessment of any industrial sources.

5.5 Conclusions

Results of monitoring for lead in Glasgow have demonstrated there are no exceedences of the air quality objective since the last Update and Screening Assessment (2003). This data, combined with that compiled with last year's progress report, has indicated that there have been no recorded exceedences of the air quality objective in Glasgow since 1978. Furthermore, all detected atmospheric concentrations of lead in Glasgow were safely below the annual mean of 0.25µg/m^3, to be met by 31st December 2008.

Taking this into consideration along with the absence of significant industrial sources of lead in Glasgow, it is considered extremely unlikely that the annual lead objectives for 2004 and 2008 will be exceeded. Consequently, it is considered that *there will be no requirement* for Glasgow City Council to progress to a Detailed Assessment for lead at this time.

6.0 Update and Screening Assessment of Nitrogen Dioxide

6.1 Introduction

Concentrations of nitrogen dioxide (NO_2) in ambient air were last considered in Glasgow during the Detailed Assessment and Progress Report in 2005. At this time, the air quality objectives were set at 40µg/m^3 as an annual mean and 200µg/m^3 as an hourly mean, with 18 exceedences allowed. Both these objectives were to be achieved by 31st December 2005.

The Detailed Assessment concluded that exceedences of the annual mean objective for NO_2 were likely at the following locations:

- Royston Road
- North Street
- Byres Road
- Dumbarton Road
- Parkhead Cross

Consequently, the report stated that there was a requirement to declare AQMAs at these locations for NO_2. In addition, it stated that the annual mean objective was likely to be exceeded at Napiershall Street in 2005, but further assessment of NO_2 was required at this site (see table 6.6).

Public consultations are currently taking place concerning the boundaries of the proposed AQMAs. The AQMAs will be declared formally by Order in 2006.

The city centre of Glasgow was formally declared an AQMA for NO_2 in 2002. This encompasses the entire city centre, as shown below:

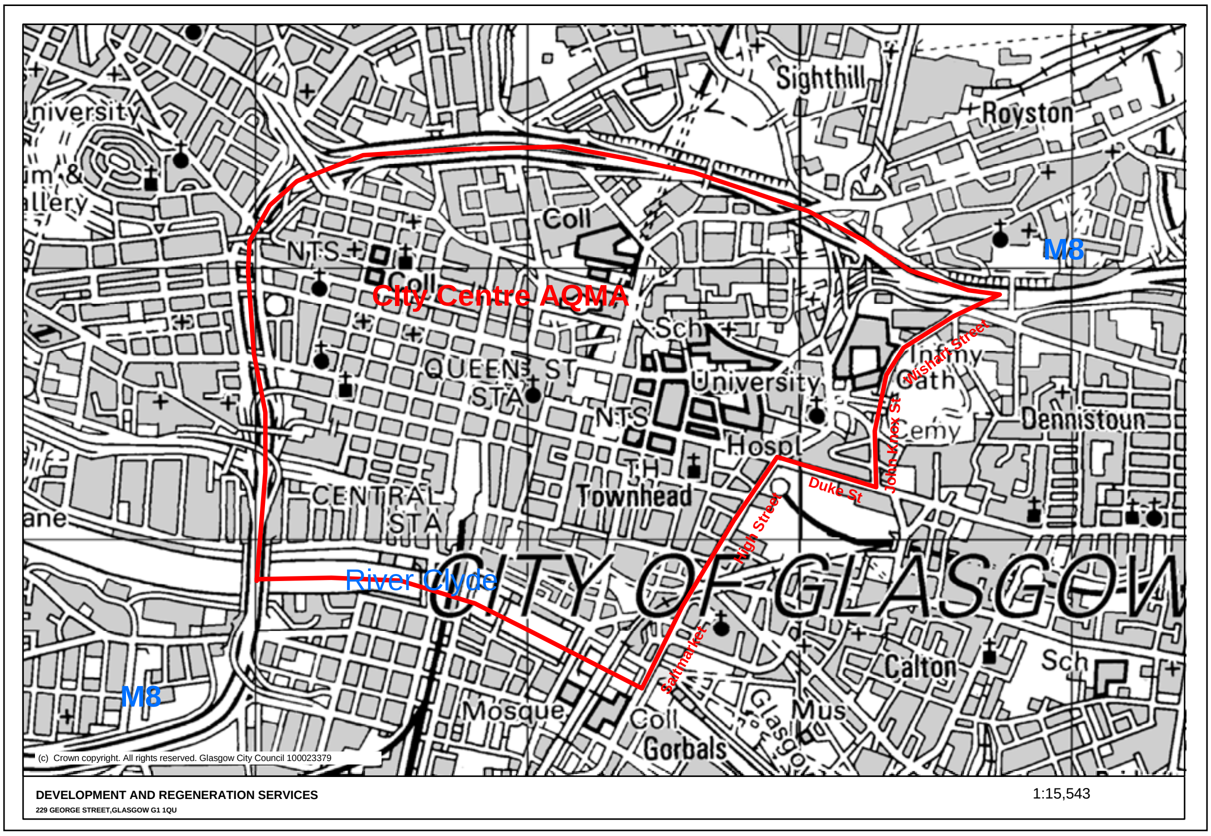


Fig 6.1 AQMA map for City Centre

Actions being undertaken to address elevated concentrations within this area are outlined in the Air Quality Action Plan (2004).

6.2 Sources of nitrogen dioxide

All combustion processes produce emissions of nitrogen oxides (NO_x), which consist of nitrogen dioxide and nitric oxide (NO). Emissions of NO_x from combustion are mainly initially in the form of NO, which is then converted to NO_2 through chemical reactions in air, primarily reactions with ozone.

The principal source of NO_x is road transport, with other sources including industrial, commercial and residential combustion. In urban areas, road transport is by far the most significant source of NO_x. The National Atmospheric Emissions Inventory (NAEI) estimated that 75% of NO_x emissions in Glasgow in 2003 came from road sources.

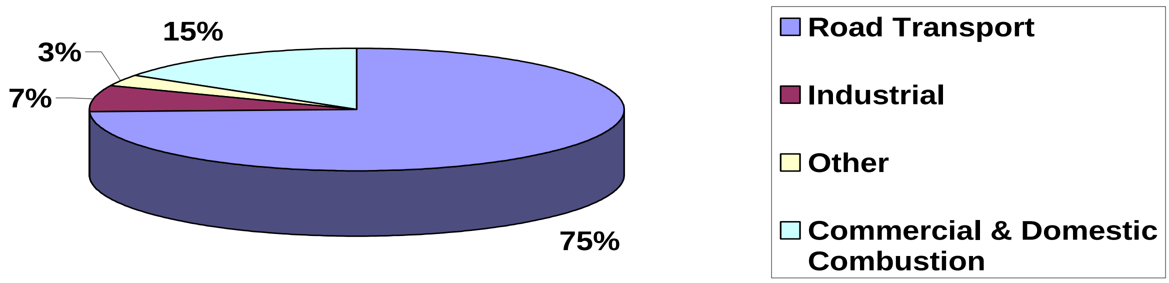


Fig 6.2: Sources of NO_x emissions in Glasgow 2003 (NAEI)

NO_x emissions from road transport have been declining due to various policy measures and this trend is expected to continue. Urban NO_x emissions from traffic are expected to fall by about 46% between 2000 and 2010. However, this will be partly offset by increases in traffic volume.

There are a few industrial processes in Glasgow that have the potential to emit significant quantities of NO_x. These are identified in Table 6.1 below.

Name	Process	Location
A Cohen	Non-ferrous metals	254298 664460
Sacones	Incineration	263821, 664591
Allied Distillers	Combustion	259832, 663996

Table 6.1 – Industrial processes with potential high NO_2 emissions

These processes were all considered during Stage IV of the Review and Assessment process, which concluded that these processes were unlikely to result in exceedences of the air quality objectives for NO_2. These processes are not believed to have changed significantly since that time. No new industrial processes, which have potential for high NO_2 emissions, have commenced operation in Glasgow.

6.3 Monitoring methodology

6.3.1 Monitoring equipment and locations

Monitoring of NO_2 is carried out across the city by both automatic analysers and diffusion tubes. Concentrations detected at all sites have been compared against the objectives and are presented in data tables later in this section.

There are seven automatic monitoring sites for NO_2 that utilise chemiluminescent analysers across the city, although they are concentrated in or just outside the city centre AQMA.

There is also a large NO_2 diffusion tube network in operation across Glasgow, with tubes located within and outwith the AQMA.

Three of the seven automatic monitors are part of the national Automatic Urban and Rural Network (AURN) run by the Scottish Executive and DEFRA. These are:

Glasgow City Chambers (Montrose Street)
The site is located on the 2nd floor of Glasgow City Chambers in Cochrane Street (259527 665297) and samples air from a height of approximately 8 metres. Cochrane Street is a street canyon, and the site is classified as urban background.

Glasgow Centre (St. Enoch)
The sites is located in St Enoch Square, a pedestrian precinct in the centre of Glasgow (258943 665027). It is about 20m from Argyle Street which has a traffic flow of approximately 20,000 vehicles a day. This is classed as an urban centre site.

Glasgow Kerbside (Hope Street)
This is located at the south end of Hope Street adjacent to Central Station (258696 665166) close to the junction with Argyle Street in a street canyon. It is a kerbside site with its inlet less than 1m from the road. Traffic flow here is more than 25000 vehicles per day.

Glasgow City Council independently operates another three air quality monitoring units which measure NO_2. These are described below:

Glasgow 1 (St .Patrick's Primary School)
This unit has monitored at St Patrick's Primary School (257925, 665487) in Anderston since 2001 after being located at various sites in the city. In past, it has suffered numerous communication problems, resulting in an extremely poor data capture rate. An estimation of the annual mean from short collection periods by applying adjustment factors to the available data has been used when necessary. This method is detailed in the technical guidance note LAQM.TG(03).

Glasgow 2 (Byres Road)
The rollalong mobile unit has been located at the junction of University Avenue with Byres Road (256553 665487) since April 2004.

Glasgow 3 (Waulkmillglen Reservoir)
A third mobile unit has been in operation at Waulkmillglen reservoir (252520, 658095), located just outside the south-east boundary of Glasgow since 2002. This monitors background concentrations.

Glasgow 4 (Battlefield Road)
In 2005, a new air quality monitoring station was installed at the junction of Battlefield and Holmlea Road (258371, 661370) in the south side of Glasgow.

The last 2 stations are not included on the indicative map.

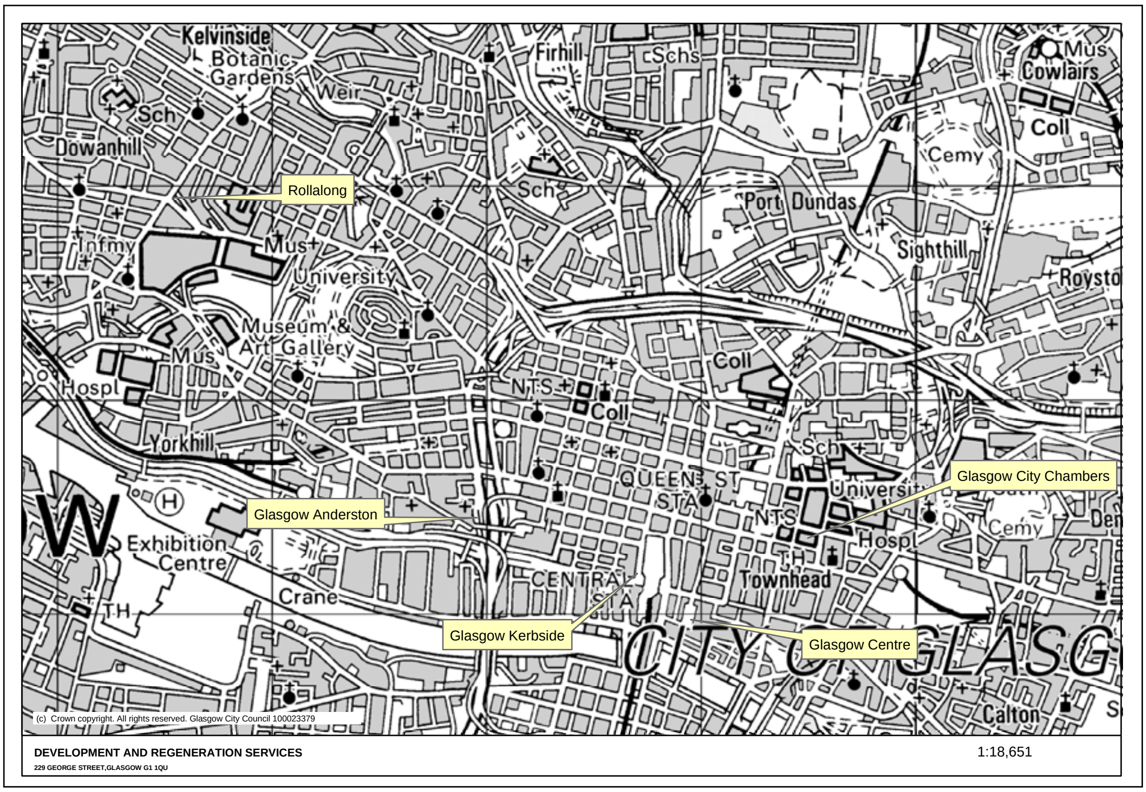


Fig 6.3 Automatic monitoring stations in Glasgow

6.3.2 Public Exposure

When assessing concentrations of pollutants, the guidance is clear that the only sites that should be considered are those which represent relevant exposure against the objective.

For the annual mean objective, this means considering all background and roadside locations up to the building façade of properties such as residencies, schools, hospitals and other buildings where the public may visit or remain for long periods. The objective would not apply at building facades of offices or other places of work where members of the public do not have regular access, or at kerbside locations where public exposure is likely to be short.

The hourly NO_2 objective is applicable at any outdoor location where the public might reasonably be expected to have access and will include all background, roadside and kerbside sites.

6.4 Update and Screening of NO_2

The Update and Screening Assessment of NO_2 will consider the individual sources, locations and data separately, in the form of a checklist. There are 13 steps for NO_2, which are listed below and then addressed in the following section in turn:

- Monitoring data outside an AQMA;
- Monitoring data within an AQMA;
- Narrow congested streets with residential properties close to the kerb;
- Junctions;
- Busy streets where people may spend 1-hour or more close to traffic;
- Road with high flow of buses and/or HGVs;
- New roads constructed or proposed since first round of review and assessment;
- Roads close to the objectives during the first round of review and assessment;
- Roads with significantly changed traffic flows;
- Bus stations;
- New industrial sources;
- Industrial sources with substantially increased emissions;
- Aircraft.

6.4.1 Monitoring data outside an AQMA

Glasgow 1, 2 and 3 sites provide automatic monitoring of NO_2 outside the city centre AQMA. Results from these sites are presented below.

Where monitoring did not achieve a data capture above 90%, the 99.8th percentile of hourly means is used. Any breaches of the objectives are highlighted red and concentrations are given in µg/m^3.

Year	Data Capture	Measured mean over period	Max Hourly mean	Max daily mean
2005	56.3%	34	187	107

Table 6.2 - Glasgow 1 (St Patrick's School) monitoring results

Year	Data Capture	Measured mean over period	Max Hourly mean	Max daily mean
2005	99.5%	38	202	124

Table 6.3 – Glasgow 2 (Byres Road) monitoring results

Year	Data Capture	Measured mean over period	Max hourly mean	Max daily mean
2005	99.9%	10	96	66

Table 6.4 Glasgow 3 (Waulkmillglen Reservoir) monitoring results

An network of 40 NO_2 diffusion tubes has also been utilised to monitor NO_2 at sites outside the AQMA. Diffusion tubes are prepared and analysed by Glasgow City Council's Scientific Services. The tubes are stored in a cool location prior to use and end caps only removed as and when they are placed at the monitoring location.

In order to determine bias-correction factors for diffusion tube results, triplicate tubes are co-located with the automatic NO_2 analysers at Glasgow Centre, Glasgow Kerbside and Glasgow City Chambers. Concentrations detected by these tubes were compared against those recorded through chemiluminescent detection over the same sampling period and a bias-correction factor determined using the guidance outlined in TG(03).

Site Name	NO_2 Diffusion Tube [Annual Mean] (µg/m^3) DM	NO_2 Chemiluminescent Detection [Annual Mean] (µg/m^3) CM	Bias correction factor CM/DM
Glasgow Centre	50.6	33	0.652
Glasgow Kerbside	96.7	62	0.64

Table 6.5 Determination of Bias-correction factor for 2005

Diffusion tube results in the following tables have been subject to adjustment with the relevant correction factor for each year and monitoring location. Any breaches of the objective are highlighted red and concentrations are given in µg/m^3.

Location	Grid ref	Annual mean/year		
		2003	2004	2005
Mosspark Boulevard	255392 663286	34	30	29
Thornliebank Road	255193 659969	27	25	20
Moss-side Road	257235 662064	35	31	30
Royston Road	260278 666186	49	45	47
Bridge St/Norfolk St	258702 664480	45	36	38
Aikenhead Road	259323 661763	36	30	30
Balshagray Ave	254566 667431	39	31	33
North Street	257971 665654	47	43	47
Dumbarton Rd	256209 666525	43	34	27
Dougrie Road 1	259586 658996	-	19	19

Dougrie Road 2	259879 659059		18	19
Anniesland X	254646 668820	-	39	42
Lawrence Street	256295 666816	-	23	28
Coburg Street	258760 664473	-	29	29
Hillcrest Rd (UK)	256485 663205	30	18	19
Hillcrest Road	256485 663205	22	17	19
Dumbreck Road	255497 663126	27	25	23
St Andrews Dr	256214 662536	25	20	21
Haggs Road	256263 661781	29	25	26
Pollokshaws Road	255839 661189	29	26	27
Dunn Street	261328 663817	41	32	40
Byres Road	256530 666939	50	42`	45
Queen Margaret Dr	257440 668016	32	26	26
Westmuir Street	262559 664181	43	50	49
Finnieston St	257235 665108	43	34	37
Napiershall St	257774 666795	-	54	34
Dougrie Road 3	260204 659127	-	21	20
Queen Margaret Dr2	257216 667639	-	30	31
Queen Margaret Dr3	256941 667363	-	27	36
Cooperswell St	256154 666478		23	26
Castle St, Partick	256160 666452	-	25	29
Royston Road2	260430 666263	-	39	42
Oxford Street	258731 664590	-	28	28
Sutherland Ave (UK)	256343 663153	24	15	16
Kinning Park	257335 664239	53	32	42
Ascaig Crescent	254119 662931	25	15	16
Belmont Street	257535 667378	38	24	24
Mallaig Place	253984 665299	32	23	21
Govanhill Street	258545 665299	39	23	23
Drumhead Road	263744 662327	27	17	19
Caledonia Road	259504 663055	32	21	21
Westercraigs	260943 665225	36	23	26
Inveresk Lane	264162 664854	30	21	19
Maxwellton Road	262705 666577	45	32	29
Kippen Street	259727 668476	27	17	24
Broomhill Road	254904 666873	37	21	26
Celtic Park 1	261799 663987	32	21	22
Celtic Park 2	261788 664091	31	19	18
Sacone SW	263920 664570	-	19	22
Castlemilk	260156 659189	26	15	14
Invergarrie Rd	253824 658589	22	13	14
Easterhouse	266933 666154	36	23	25

Table 6.6 NO_2 levels detected by diffusion tube at kerbside sites outwith the city centre AQMA

Exceedences of the 2005 annual mean objective are observed from diffusion tube data at Royston Road, North Street, Westmuir Street, Byres Road, Dunn Street and Anniesland Cross. Detailed Assessments have been carried out in some of these areas and have led to the proposal to declare AQMAs for Byres Road/Dumbarton Road, North Street/Royston Road and Parkhead Cross. For the other locations it is necessary to proceed to a Detailed Assessment to determine whether an AQMA should be declared.

6.4.2 Monitoring data within an AQMA

Monitoring data within the city centre AQMA is to be assessed in the same way as data gathered outside the AQMA. There are currently four automatic sites within the city centre AQMA. There are the three AURN stations at Glasgow Kerbside, Glasgow Centre and Glasgow City Chambers and the new non-AURN site at Glasgow Queen Street Train Station, which was installed in April 2006.

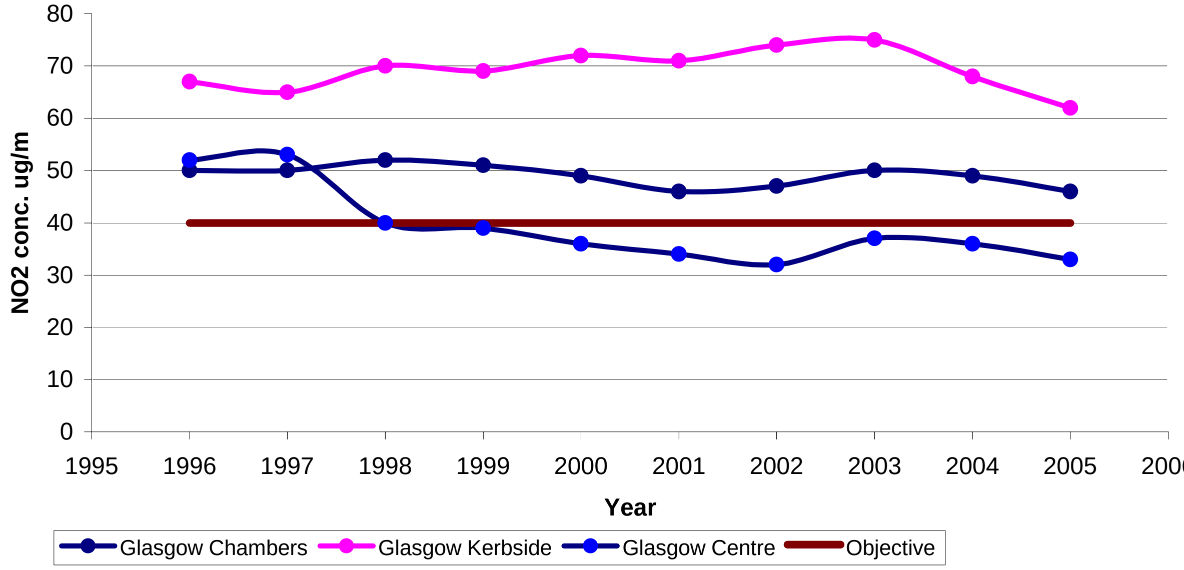


Figure 6.4 Annual Mean NO_2 concentrations at AURN sites

The annual means of 2005 and previous 5 years are presented in the table below. Any breaches of the objective are highlighted red and concentrations are given in µg/m^3.

Location	Annual Mean/Year					
	2000	2001	2002	2003	2004	2005
Glasgow City Chambers	49	42	47	50	49	46
Glasgow Centre	37	33	32	38	36	37
Glasgow Kerbside	72	71	74	75	68	62

Table 6.7 Annual mean NO_2 concentrations measured at AURN sites

In addition to the automatic monitoring sites, Glasgow City Council also operates a system of NO_2 diffusion tube sites within the city centre. The annual mean NO_2 concentration detected from these tubes is presented below. Bias correction has been undertaken for diffusion tubes within Glasgow in accordance with the TG(03) guidance. The tubes are grouped together according to the type of location they are located, e.g. kerbside, urban centre and roadside.

Location	Grid ref.	Annual Mean/Year		
		2003	2004	2005
Hope Street	258730 665322	101	67	66
Argyle Street	258846 665088	85	70	57
George Square	259246 665442	65	49	48
Union Street	258833 665210	73	68	67
Glasgow Cross	259658 664868	44	43	40
Bath Street	258215 665864	53	45	51
Glassford Street	259361 665250	58	46	60

Briggait	259420 664703	46	37	42
St Vincent Street	258844 665446	84	75	72
N. Hanover Street	259375 665900	52	39	47
Castle Street	260100 665579	54	45	46
Hope Street 2 mid	258730 665405	68	64	64
Hope Street 3 (N)	258857 665913	61	49	60
Montrose Street	259543 665332	53	37	26
Cochrane Street1	259524 665294	46	43	33
Cochrane Street 2	259430 665316	46	38	51
Ingram Street	259524 665253	41	37	-
Renfield Street	258954 665873	63	51	54
George Street	259551 665380	50	41	52
Broomielaw	258561 664931	55	45	24

*Table 6.8 NO_2 levels detected by diffusion tube at **kerbside** sites within the city centre*

Location	Grid ref.	Annual Mean/Year		
		2003	2004	2005
Hope Street 1 (south)	258730 665322	81	67	67
Gordon Street	258766 665347	87	64	54
Heilan'man's Umbrella north	258770 665117	80	73	75
Heilan'man's Umbrella south	258769 665106	84	73	73
Saltmarket	259545 664739	42	37	52
High Street	259732 664991	54	48	65
Dobbies loan	259302 666289	39	37	34

*Table 6.9 NO_2 levels detected by diffusion tube at **roadside** sites within the city centre*

Location	Grid ref.	Annual Mean/Year		
		2003	2004	2005
McLeod Street (UK)	260077 665481	50	33	33
McLeod Street	260077 665481	46	32	34

*Table 6.10 NO_2 levels detected by diffusion tube at **urban centre** sites within the city centre*

A review of the NO_2 diffusion tube locations was carried out in 2005. Several sites were removed from the network due to either consistently low results, or not being representative of human exposure. A number of new sites were also created to take into account new development within the city.

The following sites have been added or their original position has been adjusted to make them more relevant to human exposure.

Location	Grid ref	New location
Mosspark Boulevard	255392, 663286	255435, 663274
Aikenhead Road	259323,661763	259229,662581
Haggs Road	256263, 661781	256925, 661792
St Andrews Drive	256214, 662536	256230, 662587
Balshagray Avenue	254566, 667431	254497, 667298
Dunn Street	261238, 663817	261288, 663931
Westmuir Street/Parkhead X	262559, 664181	262589, 664139
Easterhouse/Auchinlea Road	266933, 666154	267005, 666215
Montrose Street	259543, 665232	259548, 665283

Cochrane Street (2)	259430, 665316	Removed
Bridgegate	259420, 664703	259458, 664701
Glassford Street	259361, 665260	259335, 665254
George Square	259246, 665442	259296, 665389
Union Street	258833, 665210	258829, 665201
Hope Street (2)	258730, 665405	258733, 665363
Dobbies Loan	259302, 666289	259414, 666194
Dundasvale Street	258828, 666289	258820, 666305
Napiershall Street	257774, 666795	257793, 666794
Belmont Street	257535, 667378	257733, 667418
St Vincent Street	258844, 665446	257883, 665650
Castle Street/Cathedral St	260100, 665579	260068, 665589
Royston Road 2	260430, 666263	Removed
Anniesland Cross	254646, 668820	254613, 668885
Renfield Street	258954, 665873	258898, 665644
Dougrie Road 2	259879, 659059	Removed
Dougrie Road 3	260204, 659127	Removed
Kinning Park/ Stanley Street	257335, 664239	Removed
Ascaig Crescent	254119, 662931	Removed
Maxwellton Road	262705, 666577	Removed
Celtic Park 1	261799, 663987	Removed
Celtic Park 2	261788, 664901	Removed
Craigton Road	254515, 664510	Removed
Coburg Street	258760, 664473	Removed
Castle Street, Partick	256160, 666452	Removed
Dumbreck Road	255497, 663126	Removed
Drumhead Road	263744, 662327	Removed
Broomhill Road	254904, 666873	254904, 666856
Carrick Street	258319, 665076	258300, 665062

Table 6.11 NO_2 diffusion tube relocations and deletions

The following table contains the locations of new sites added to the diffusion tube network at the beginning of 2006.

Location	Grid ref
Main Street (Bridgeton)	260654, 663429
Langside Primary School	257135, 661622
Pollokshaws Road	255864, 661180
Glasgow Harbour	254475, 666544
Mavisbank Gardens	257118, 664914
Springburn Road, Colston	269540, 669268
Kennedy Path	259726, 665980
St Mungo Avenue	259389, 665867
Main Street (Bridgeton)	260254, 663249

Table 6.12 NO_2 diffusion tube new locations

Data from these locations will be reported in subsequent review and assessment reports.

The data presented in Figure 6.4 demonstrate that exceedences of the annual mean objective continue to occur at Glasgow Kerbside and Glasgow City Chambers, although the trend in concentrations is downward. Glasgow Centre continues to achieve the annual objective.

The non-AURN sites show that, although levels are high at Glasgow Anderston and Byres Road, they achieved the annual mean objective in 2005.

In terms of the 1-hour objective and the permitted number of annual exceedences, this has been met in 2004 and 2005 at all locations.

The data presented for the NO_2 diffusion tube network within the AQMA demonstrate that the annual mean for NO_2 of 40µg/m^3 is commonly exceeded within the city centre.

Recent dispersion modelling work commissioned by Glasgow City Council and carried out by BMT Cordah, has shown that the annual mean of 40 µg/m^3 continues to be breached over most of the city centre.

As exceedences of the annual mean air quality objective is still a regular occurrence within the AQMA, *there is no requirement* to proceed to a Detailed Assessment for this part of the city and the AQMA will remain in force until such times as the objectives are met.

6.4.3 Narrow congested streets with residential properties close to the kerb

A location with a combination of high traffic volume and narrow streets is where exceedences of the objectives are most likely. Slow moving, stop/start driving can cause high emissions, with buildings on either side of the road reducing dispersion. Such locations should be assessed for potential exceedences of the air quality objectives.

Glasgow City Council recently commissioned consultants BMT Cordah to carry out a study on NO_2 concentrations in street canyons in Glasgow and to assess how concentrations vary with height, which can be found in the appendices to this report.

The guidance note specifies those roads which should be considered in this section. It details that:

"*Only include areas where the average speed is 50kph or less. Only include roads where the carriageway is less than 10m wide."*

It also states that road should be considered that:

"*..have a flow of greater than 10,000 vehicles per day."*

There are currently no roads in Glasgow that fulfil the above criteria. There are only a few roads in Glasgow which have traffic flow of more than 10000 vehicles per day, and these are generally found in the city centre, or on arterial routes, where the road width is much greater than 10m. For this reason, *there is no requirement* to proceed to a Detailed Assessment for NO_2 at these locations.

6.4.4 Junctions

Busy road junctions are areas where concentrations of NO_2 can increase due to build up of traffic. Busy junctions are those with more than 10,000 vehicles per day. It is not necessary to assess those junctions that do not have relevant exposure.

Most busy junctions in Glasgow are located within the city centre. This area is already an AQMA and there is no need to assess these junctions at the present time.

Busy junctions outside the city centre AQMA were also assessed in the 2005 Detailed Assessment. This concluded that exceedences of the annual mean objective were likely at a number of junctions and that further AQMAs were required. These junctions were:

- Parkhead Cross
- Royston Road
- Byres Road
- Dumbarton Road
- North Street

BMT Cordah were asked by Glasgow City Council to assess busy roads/junctions outwith the city centre using the Council's ADMS-Urban model. This assessment also included Springburn Road at its junction with Colston Road and Kirkintilloch Road.

This assessment has indicated that exceedences of the 2005 annual mean objective are likely at the following junctions:

Junction	Grid Reference
Balshagray Avenue at Abbey Drive / Crow Road	254602, 667707
Balshagray Avenue at Victoria Park Drive North / Victoria Park Gardens South	254516, 667278
Maryhill Road at Queen Margaret Drive / Bilsland Drive	257439, 668037

Table 6.13 junctions where further assessment required

Therefore, *there is a requirement* to proceed to a Detailed Assessment for these locations.

6.4.5 Busy streets where people may spend 1-hour or more close to traffic

There are certain locations where members of the public may be expected to spend 1-hour or more on a regular basis, such as shopping areas. These need to be assessed if they are next to a busy road where there is the potential for exceedences of the 1-hour objective.

Glasgow has a number of locations such as these. However, the busiest streets for traffic and for shopping are currently within the existing boundary of the city centre AQMA. Therefore, these will not to be assessed further at the present time.

Several locations in this category were identified in the Update and Screening Assessment of 2003. These were screened with the outcome that Dumbarton Road will now be declared as part of an Air Quality Management Area later in 2006. Great Western Road at Kelvinbridge was considered in the 2005 Detailed Assessment and it was thought unlikely that there would be an exceedence of the 1-hour mean objective for NO_2 in the Great Western Road area.

It is not thought that any other streets meet the required criteria of an AADT flow of 10,000 or more vehicles.

Consequently, it is considered that *there is no requirement* to proceed to a Detailed Assessment for these locations.

6.4.6 Roads with high flow of buses and/or HGVs

Certain streets may not have an exceptionally high traffic flow, but if there is a high proportion of buses or heavy goods vehicles (HGVs), which are large emitters of NO_x, there may still be elevated concentrations of pollution. Again, criteria is set out in the guidance and described below,

> *"Identify all roads with an unusually high proportion of heavy duty vehicles. An unusually high proportion can be taken to be greater than 25%. Determine whether there is relevant exposure within 10m of the kerb. There would be no need to look for relevant exposure if the flow is less than 2,500 HGV vehicles per day."*

As above, there is no need to investigate locations within the AQMA, as it is already known that the air quality objectives are exceeded at these locations. Outwith the AQMA, it is considered that there are no roads which meet the above criteria. Consequently, it is considered that *there is no requirement* to proceed to a Detailed Assessment for these locations.

6.4.7 New roads constructed or proposed since the first round of review and assessment

M74 Extension - The recent public local inquiry and appeal hearing regarding the proposed completion of the M74 motorway ended in June 2006 with a decision that the construction of the motorway would go ahead in 2008 and hopefully be completed by 2010. This will be constructed in connection to the proposed East End Regeneration Route.

The M74 extension was considered in the 2005 Detailed Assessment. Modelling work previously undertaken on the project by consultants ERM revealed that there may be exceedences of the annual mean NO_2 objective at some locations along the route. To supplement this, the Council's Land Services are undertaking diffusion tube monitoring along the route of the proposed road and this monitoring will continue during and after construction. This should provide a more accurate picture of the impacts of the road with respect to NO_2 and this will inform whether further detailed analysis is required and whether the road, or part of the road, needs to be incorporated into an AQMA. Therefore, *there is no requirement* to proceed to a Detailed Assessment for this road at the present time.

East End Regeneration Route - This is to provide a connection between the Polmadie Road junction on the new M74 link at its southern end and the M80/M8 at its northern end. The Planning Application was signed off on 9th November 2005 and the Draft CPO published on 13 September 2005. CPO objections are currently being considered. The road should be completed by 2008/09.

Dispersion modelling studies have predicted that this road will have a neutral effect on emissions and concentrations of NO_2. However, some localised improvements in air quality are predicted due to reduced traffic congestion and the provision of improved public transport facilities.

As with the M74 extension, monitoring will provide a more accurate picture of the impacts of the road with respect to NO_2 and this will inform whether further detailed analysis is required. It is the intention to carry out monitoring at relevant locations once the road development has been completed. Therefore, *there is no requirement* to proceed to a Detailed Assessment for this road at the present time.

Finnieston Street Road Bridge - the bridge, which links the north and south banks of the river between Finnieston Street and Govan Road, opened to traffic in September 2006. It has four lanes; two lanes dedicated to public transport and two for private and commercial traffic, with additional pedestrian and cyclist paths.

An assessment of the impact on air quality from the bridge was carried out as part of the planning process. The DMRB (Design Manual for Roads and Bridges) model was used to carry out the initial air quality assessment. The assessment concluded that the construction of the bridge will not have a significant effect on the air quality of the local area. Also, due to the conservative nature of the DMRB model it states that a further air quality study using a detailed model such as ADMS-Roads is not required.

However, it is proposed that monitoring of NO_2 is carried out at relevant locations near to the bridge in order to provide a clearer picture of its impact on NO_2. Should monitoring reveal exceedences, or potential exceedences, of air quality objectives, further assessment using accurate traffic flow data can be undertaken to supplement the monitored data.

Consequently, it is considered that *there is no requirement to proceed to a Detailed Assessment* for the Finnieston Street Road Bridge at the present time.

6.4.8 Roads close to the objective during the first round of review and assessment

These are locations which were addressed in the first round of review and assessment and were found to be close to the objective. "Close" is defined as:

"…any roads where annual mean concentrations in 2005 were predicted to be above 36 μg/m^3 but below 40μg/m^3.."

This applies to the annual mean objective for 2005 where AQMAs were not declared. Since it is the intention of Glasgow City Council to declare four new air quality management areas in the west end of the city, Parkhead Cross, Royston Road and North Street, these have not been included in this screening.

Several locations have recently been measured by diffusion tube to be just below or above the current objective. These locations are at Balshagray Avenue, Anniesland Cross, Bridge Street, Dunn Street and Finnieston Street.

Location	Annual Mean/Year		
	2003	2004	2005
Balshagray Avenue	39	41	33

Anniesland Cross		52	42
Bridge St/Norfolk St	58	48	38
Dunn Street	53	43	40
Finnieston Street	47	45	37

Table 6.14 Roads close to the annual mean objective

Three of these monitoring locations, Balshagray Avenue, Dunn Street and Anniesland Cross, are kerbside and do not have a relevant receptor. These locations have been recently adjusted to be more relevant to human exposure (as per Table 6.11) and the results will be reported on in due course.

However, it is considered that *there is a requirement* to proceed to a Detailed Assessment for these locations.

6.4.9 Roads with significantly changed traffic flows

Those roads which were previously at risk of exceeding the objectives may be subject to higher concentration of pollutants if there has been a 'large' increase in traffic flow, where 'large' is defined as,

"*..more than 25% increase in traffic flow."*

The road network in Glasgow has not undergone any major changes since Stage III (2001) that could lead to such a significant increase in traffic flow.

Consequently, it is considered that *there is no requirement* to proceed to a Detailed Assessment.

6.4.10 Bus stations

Because of the high volume of buses and coaches using bus stations on a regular basis, there is a risk of exceedences of the hourly objective. The main bus station in Glasgow is Buchanan Bus Station, located within the AQMA. The guidance advises to,

"*Determine whether there is relevant exposure within 10m of the bus station (20m in major conurbations."*

The public have access to Buchanan Bus Station and there are partially enclosed waiting areas within the station that would be relevant to human exposure.

However, a recent air dispersion modelling study using ADMA-Urban concluded that there would be no exceedences of the 1-hour mean objective at Buchanan Bus Station. This bus station is also already located within an AQMA. There are some other smaller bus stations in Glasgow, such as Partick and Govan Bus Stations. However, it is understood that the bus movements at these sites are less than 1000 per day. It should also be noted that Partick Bus Station is scheduled to be included in the new AQMA for the west end of Glasgow.

As a result, it is considered that *there is no requirement* to a Detailed Assessment bus stations.

6.4.11 New industrial sources

Industrial sources can make a significant contribution in relation to the 1-hour objective. They are not as important in terms of annual mean concentrations.

No new industrial sources which could make a significant contribution to NO_2 concentrations have commenced operation in Glasgow since the last round of review and assessment.

As a result, it is considered that *there is no requirement* to proceed to a Detailed Assessment for this source.

6.4.12 Industrial sources with substantially increase emissions

Existing industrial sources that were considered in Stage III could cause exceedences of the 1-hour objective if emissions have increased substantially, defined as,

"A substantial increase can be taken to be one greater than 30%."

Emissions from existing industrial sources in Glasgow have not increased significantly since the last round of review and assessment.

Consultation with SEPA indicates that an application for a variation in emissions from Wellpark Brewery may have an impact on the city centre AQMA. A dispersion modelling study was carried out by Entec as part of this process, which concluded that there will be no exceedences of either the 1-hour mean or the annual mean NO_2 objectives.

Therefore, it is considered that *there is no requirement* to proceed to a Detailed Assessment for these sources.

6.4.13 Aircraft

Aircraft are significant sources of nitrogen oxide emissions, most particularly during takeoff. It is thought that they can make a significant contribution to ground-level concentrations when they are below 200m.

Glasgow International Airport is located outwith the city boundary and falls within the jurisdiction of Renfrewshire Council. Guidance suggests to,

...establish whether there is relevant exposure within 500m of the airport boundary…

Since the airport is more than two kilometres from the city boundary, there is no relevant exposure and so emissions from aircraft takeoff are not predicted to have any effect on air quality in Glasgow.

In addition, recent reports from monitoring stations adjacent to the airport within Renfrewshire Council indicate that no exceedences are occurring.

For this reason, it is considered that *there is no requirement* to proceed to a Detailed Assessment for this source.

7.0 Update and Screening Assessment for Sulphur Dioxide

7.1 Introduction

There are three main objectives for sulphur dioxide (SO_2), a 15-minute mean, an hourly mean and a 24-hour mean. These objectives are outlined in the table below:

Averaging period	**Air Quality objective (µg/m^3)**	**Number of permitted exceedences**	**Compliance date**
15 minutes	266	35	31 Dec 2005
1 hour	350	24	31 Dec 2004
24 hour	125	3	31 Dec 2004

Table 7.1 – SO_2 air quality objectives

Concentrations of SO_2 in ambient air were last considered in Glasgow in the Progress Report of October 2005. This report concluded that there would be no exceedences of any of the objectives for SO_2. There have been no changes in the air quality objectives since the last Update and Screening Assessment for SO_2.

7.2 Sources of sulphur dioxide

Across the UK as a whole, power stations are the most significant sources of SO_2, accounting for 71% of total emissions, with other industrial combustion sources another major source. Nationally, domestic sources and road transport account for only 4% and 1% respectively. The National Atmosphere Emissions Inventory (NAEI) for Glasgow paints a very different picture.

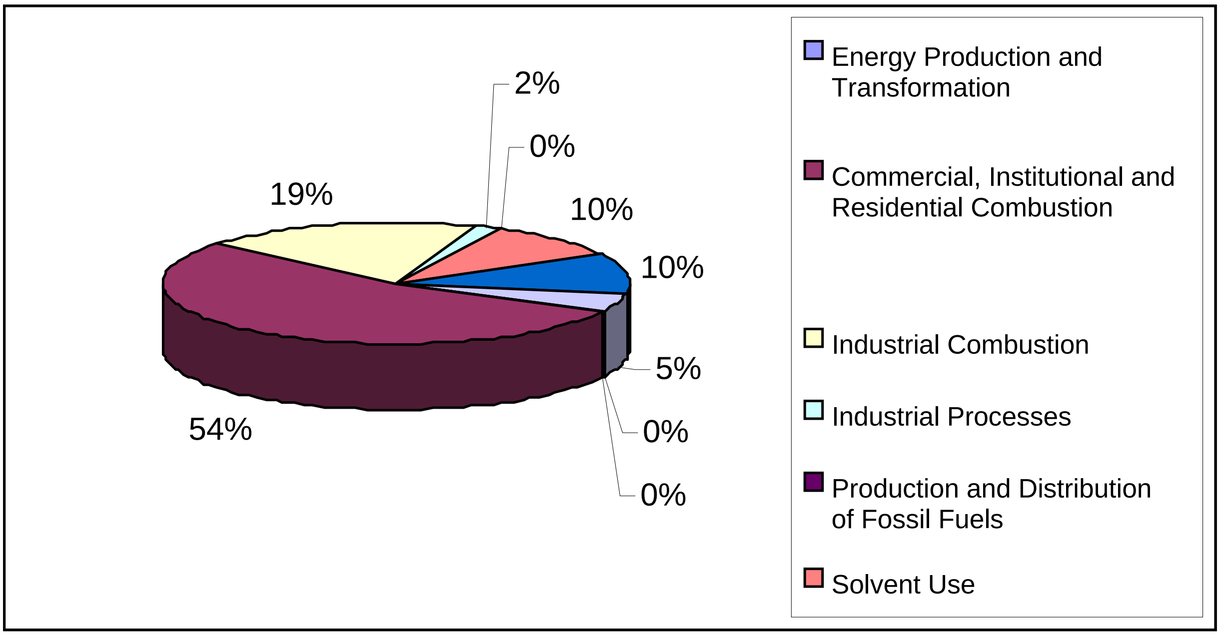


Fig 7.1 Sources of SO_2 in Glasgow, 2003 (NAEI)

Residential and commercial sources that are likely to be significant will include small (>5MW) combustion plants and boilers from places including schools, hospitals and universities. These sources may lead to exceedences of the objectives in the immediate area, principally the 15-minute objective.

There are three Prescribed Processes in Glasgow that may have the potential to contribute to SO_2 concentrations, again most notably in the local area. There are listed below:

Name	Grid reference	Process
James Reid	263096, 664469	Non-ferrous metals
A Cohen	254298, 664460	Non-ferrous metals
Allied distillers	259832, 663996	Combustion

Table 7.2 – Potentially significant industrial sources of SO_2

These sources were considered in Stage II, and it was concluded that there would not be exceedences of any air quality objectives in the vicinity of these sites. These processes have not substantially changed since that time.

While road transport accounts for a large amount of total SO_2 emissions in Glasgow, it is not considered likely that it will result in exceedences of any air quality standards.

7.3 Monitoring methodology

7.3.1 Monitoring equipment and locations

Historically, SO_2 was primarily generated by the burning of coal, which was extremely widespread and often lead to pollution episodes. For this reason, Glasgow operated an extensive SO_2 monitoring network dating back to the 1950's; at one time running more than 40 sites. Until the end of 2005 there were four sites that operated in the national network, and these are listed in the table below with their corresponding grid positions. At the end of 2005, the sites at Berryknowes Road and North Cardonald were removed.

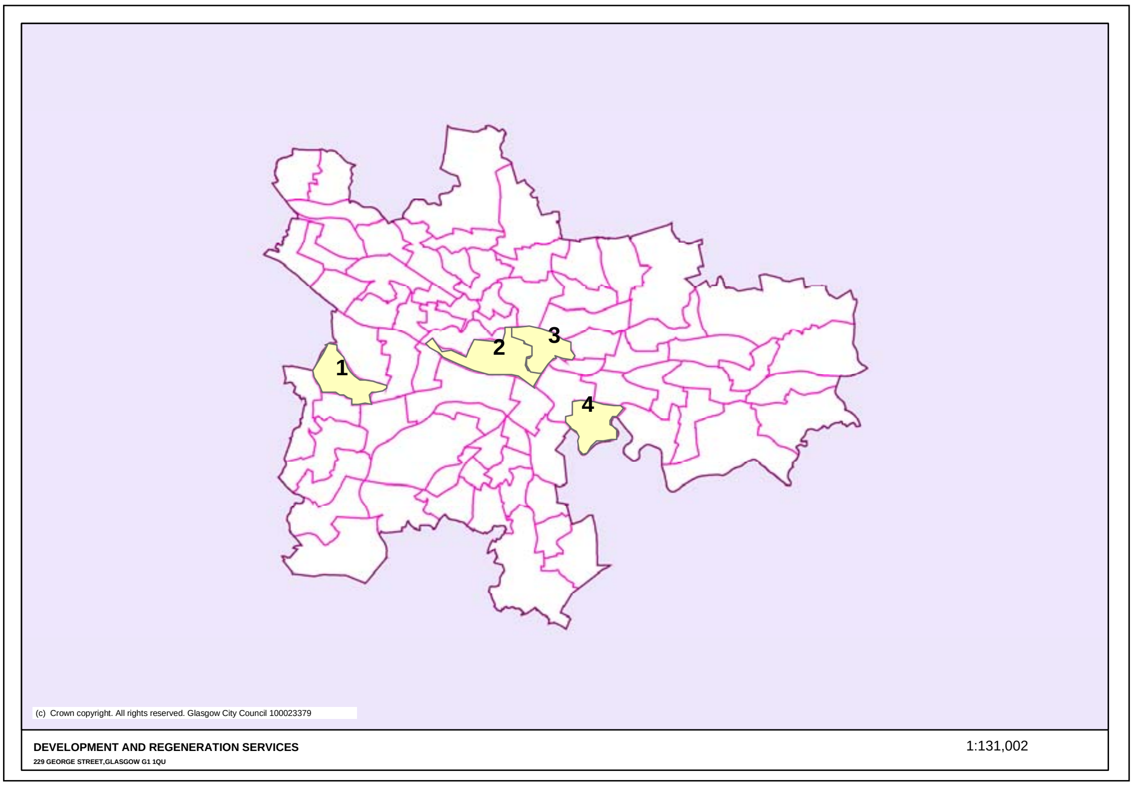


Fig 7.2 8-port bubbler locations: 1. Ward 56 North Cardonald
2. Ward 17 Anderston
3. Ward 27 Merchant City
4. Ward 35 Dalmarnock

At these sites, atmospheric SO_2 is sampled by bubbling ambient air through a solution of hydrogen peroxide over a 24-hour period. The solution is analysed by net acidity titration, and a daily concentration of SO_2 is derived. However, analysis by acidity titration increases the uncertainty in the results, and a correction factor must be applied when making comparisons against objectives which relate to peak SO_2 concentrations. This is set at 1.25.
Since the bubble technique is only able to supply SO_2 concentrations over a 24-hour period, empirical relationships are required to allow comparisons with the 15-minute and 1-hour objectives. These relationships are given below:

- 99.9^{th} percentile of 15 minute mean = 1.8962 x maximum daily mean;
- 99.7^{th} percentile of 1 hour mean = 1.3691 x maximum daily mean.

However, due to the uncertainty of these relationships, the Technical Guidance states that:

"*It may be assumed that the 15-minute mean objective is unlikely to be exceeded if the maximum daily mean concentration is less than 80µg/m^3, and the 1-hour objective is unlikely to be exceeded if the maximum daily mean concentration is less than 200µg/m^3"*

There are also three sites where SO_2 is monitored using automatic, real-time samplers. This method is more accurate than the bubble technique, and also has the advantage of being able to make direct comparisons against all three air quality objectives. A description of the sites follows below, and their locations are also highlighted in the map:

Glasgow Centre (St. Enoch)
This site is in St Enoch Square, an open, pedestrianised area in the centre of Glasgow (258943 665027). It is around 20m from Argyle Street which has a traffic flow of approximately 20,000 vehicles per day and is classed as an urban centre site.

Glasgow 1 (St .Patrick's Primary School)
This is located at St Patrick's Primary School, Anderston. It has been sited here since May 2001. While data capture problems meant that there was little continuous data available at first this has improved since then.

Glasgow 5 (Queen Street Station)
A new Air Quality Monitoring Station has recently been installed on the main platform of Queen Street Station to monitor particulates and SO_2 from the diesel trains that are operated from there. This site has not been operating for long enough to give any real data.

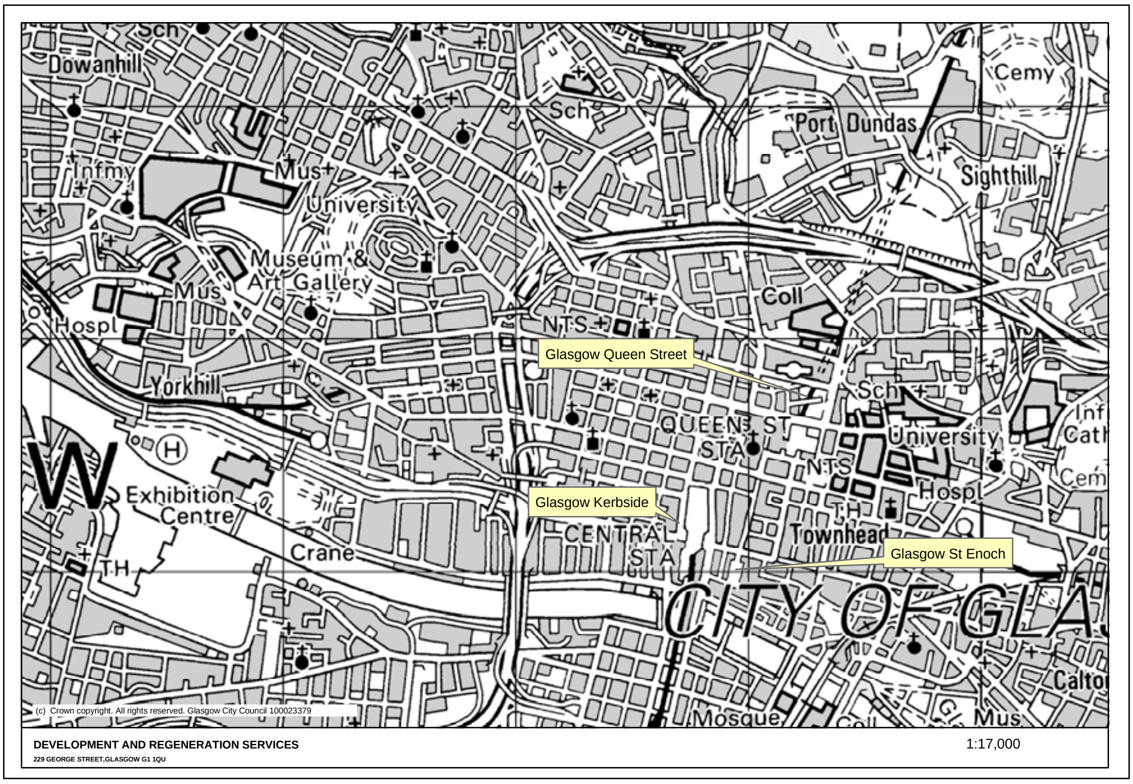


Fig 7.3 Location of automatic SO_2 monitors

7.3.2 Public exposure

When assessing concentrations of pollutants, the guidance is clear that the only sites that should be considered are those that represent relevant exposure against the objective.

For the annual mean objective, this means considering all background and roadside locations up to the building façade of properties such as residencies, schools, hospitals and other buildings where the public may visit or remain for long periods. The objective would not apply at building facades of offices or other places of work where members of the public do not have regular access, or at kerbside locations where public exposure is likely to be short.

The hourly SO_2 objective is applicable at any outdoor location where the public might reasonably be expected to have access and will include any background, roadside and kerbside sites. The 15-minute objective is applicable at all locations where members of the public may be exposed for a period of 15-minutes or longer.

7.4 Update and Screening of SO_2

There are 8 stages that are required to be carried out for the Update and Screening Assessment of SO_2. These headings are listed below, and each will then be addressed in turn:

- Monitoring data outside an AQMA;
- Monitoring data within an AQMA;
- New industrial sources;
- Industrial sources with substantially increased emissions;
- Areas of domestic coal burning;
- Small boilers (>5$MW_{(thermal)}$) burning coal or oil;
- Shipping;
- Railway locomotives.

7.4.1 Monitoring data outside/within an AQMA

Since there is no AQMA declared for SO_2 in Glasgow, both these sections will be addressed together. In relation to the AQMA which was declared for NO_2, the Glasgow Centre automatic monitoring site, the Montrose Street bubbler and Queen Street automatic monitoring site are inside the AQMA the other two are outside the AQMA. Last year's Progress Report indicated that there had been no exceedences of the objectives for SO_2 in recent years and the data below shows that 2005 was no exception. Data from the Quenn Street site will be reported at a later date.

	Montrose Street	**Berryknowes Road**	**Dalmarnock**	**Baillieston**	**Wellfield**	**Carmyle**	**Glasgow Centre**
Average	18.51	18.8	13.7	34.3	11.7	13.6	-
Max	53	60	39	106	41	56	-
15 min 99.7^{th} Percentile	100.5	113.8	74	201	77.7	106.2	59
1 hr 99.7^{th} percentile	72.56	82.1	53.4	145.1	56.1	76.7	35
24hr 99^{th} percentile	46.48	40	33	81	28.66	44.9	12.57

Table 7.3 SO_2 monitoring results for 2005

The results show no exceedences for SO_2 at any of the sites and therefore *there is no requirement* for further assessment.

7.4.2 New Industrial Sources

Since the last round of review and assessment, there have been no new industrial sources which have the potential to emit large amounts of SO_2 into ambient air. There is therefore *no requirement* to make a further assessment of SO_2 against this source.

7.4.3 Industrial sources with substantially increased emissions

There are several sources in Glasgow that are potentially significant emitters of SO_2, as detailed previously. However, these were considered fully both in the previous round of review and assessment and, in some cases, independent assessments, which concluded that exceedences of the objectives were not likely to be caused by these sources. Since the emissions from these locations have not increased significantly since then, *there is no need for any further assessment*.

7.4.4 Areas of domestic coal burning

There are no areas of Glasgow where 'significant' domestic coal burning takes place, when according to the Technical Guidance, 'significant' is taken to mean:

"*any area of about 500 x 500m where there may be more than 100 houses burning solid fuel as their primary source of heating."*

It is therefore considered that *there will be no requirement to progress to a Detailed Assessment* of SO_2 regarding domestic coal burning.

7.4.5 Small boilers > $5MW_{(thermal)}$

There is the risk of exceedences of the 15-minute objective around large (>5MW) boiler plants, as these can produce high short-term concentrations in the local area. Although such boilers are unlikely to lead to exceedences of the 15-minute objective individually, especially with regulations that limit the sulphur content of fuel oil to 1%, there may be a problem in an area with multiple sources.

There are not believed to any such processes within Glasgow city boundaries that emit sufficient quantities of SO_2, or which may act in combination with other sources to lead to exceedences of the SO_2 objective.

7.4.6 Shipping

Large ships, such as cross-Channel ferries or cruise ships, often use fuel oil which has a high sulphur content, and if there is a large amount of shipping traffic in the area around a port, there will be a risk of exceedences of the 15-minute objective. However, there is currently on average three freight ships a week visiting Glasgow, with an average draft of 1500 tonnes. Consequently, it is considered unlikely that this volume of traffic would cause any exceedences of the SO_2 objective. Therefore, *there is no requirement* to progress to a Detailed Assessment of SO_2 for this source.

7.4.7 Railway locomotives

Diesel and coal-fired railway locomotives can potentially emit large quantities of SO_2, and if these engines are stationary while running for 15-minute periods or more, then there is a risk of exceedences of the 15-minute objective. Locations where this is likely to occur include stations, depots and junctions. For this to be an issue in terms of public exposure, there must be, according to the Technical Guidance, a potential for:

"regular *outdoor exposure of members of the public within 15m of the stationary locomotives".*

It is considered unlikely that there will be any locations where diesel trains have their engines running for extended periods *and* where there is potential exposure for the public. Even in locations like Glasgow Central and Queen Street stations, where engines may idle occasionally, the areas where the public would wait are more than 15m from the locomotive engines. In addition, the potential exists for locomotive engines running at rail depots; however, such sites are not generally accessible to the public.

A new automatic air quality monitoring station has recently been installed in Queen Street Station to test for SO_2 and particulates. Initial raw data are suggesting that SO_2 will not a problem at this location.

It is thus considered that *there will be no requirement* to proceed a Detailed Assessment at these locations.

7.5 Conclusions

Monitoring of SO_2 using automatic and active samplers has indicated that there were no exceedences of the 24-hour mean or 1-hour mean objective at any of Glasgow's monitoring sites in 2003-2005.

However, assessment of the maximum 24-hour mean SO_2 concentrations reported at the 8-port bubbler locations did show means in excess of 80 μgm^{-3} in recent years, e.g. at Baillieston.

In light of this, a co-location study was carried out at Glasgow 1 (St. Patrick's School) to assess bubbler performance. The results of this study last year (as reported in the 2005 Detailed Assessment) showed that the 8-port bubblers were consistently overestimating ambient concentrations. It is considered that the exceedences are not true exceedences and that the bubblers have overestimated concentrations in these locations.

8.0 Update and Screening of PM_{10}

8.1 Introduction

Concentrations of fine particles (PM_{10}) were last considered in Glasgow during the Detailed Assessment and Progress Report of 2005. It was considered in both these reports that there would be exceedences of the air quality objectives for PM_{10} at locations across the city.

In both reports, it was suggested that there required to be further monitoring carried out at these locations prior to declaration of one or more AQMAs. Glasgow City Council is currently going through the process of purchasing three TEOM/FDMS units for this purpose, with the assistance of a grant from the Scottish Executive. These should be operational from the start of 2007.

The current air quality objective for PM_{10} has recently been tightened up in Scotland. The new objectives and targets dates for compliance are given in the table below:

Averaging period	**Air Quality objective (µg/m^3)**	**Number of permitted exceedences**	**Compliance date**
24-hour	50	7	31 Dec 2010
Annual mean	18	n/a	31 Dec 2010

Table 8.1 NAQ objectives for PM_{10}

8.2 Sources of PM_{10}

There are several different sources which contribute to PM_{10} concentrations in the UK. These can be split into three distinct categories:

- *Primary particles* are those which are produced directly through combustion. Sources include road transport, power generation and industrial processes;
- *Secondary particles* are formed through chemical reaction in the atmosphere. These mainly comprise sulphates and nitrates and can travel considerable distances from their source;
- *Coarse particles* have a variety of sources and include resuspended dust from road traffic, construction works and sea salt.

In Glasgow, the main source of PM_{10} emissions is road traffic, with the National Atmospheric Emissions Inventory (NAEI) estimating that this source accounts for just over half of all emissions. Other sources include residential and commercial combustion, industrial combustion and other industrial processes. The following graph gives a breakdown of emissions from the Glasgow boundary:

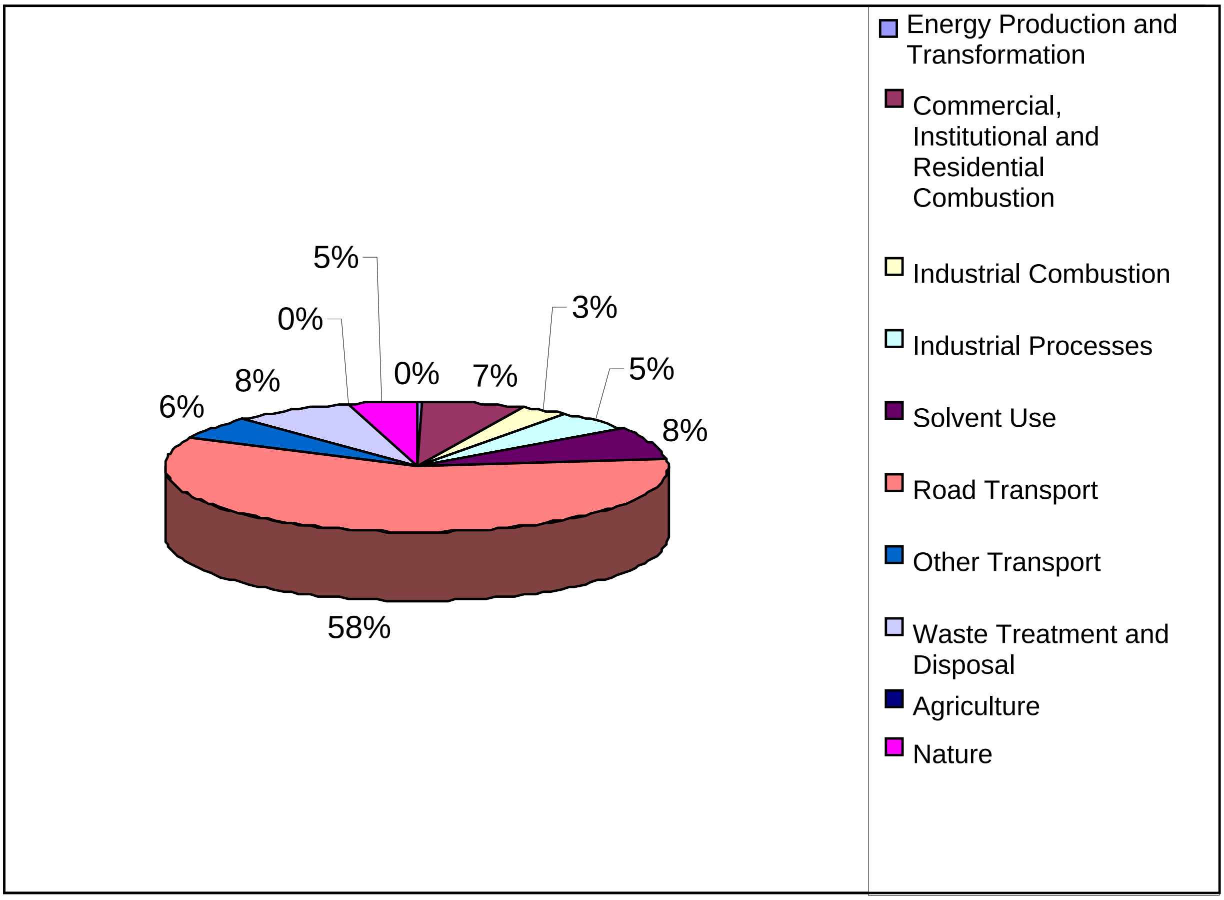


Figure 8.1 Sources of PM_{10} in Glasgow, 2003 (NAEI)

A significant contribution to PM_{10} levels in Glasgow will come from sources outwith the city boundary. Long distance transport from regional sources, and sources in Europe, make up a large portion of background concentrations, which are outside the control of local authorities.

Background concentrations of PM_{10} are available on the national air quality website (http://www.airquality.co.uk/archive/laqm/tools/php?tool=background). Some typical backgrounds are given below:

Grid reference		**Location**	**Background PM_{10} 2001 (µg/m^3)**
Easting	**Northing**		
258890	665540	city centre	20.3
259460	669520	North	17.5
257600	660560	South	18.0
264360	664041	East	18.7
252200	669640	West	17.0

Table 8.2 Background PM_{10} concentrations

Reductions in emissions of the three types of particles will be controlled independently from each other. Primary particles will be governed by legislation on such areas as vehicle emission standards and combustion processes; secondary particles will largely be governed by controls on power generation, SO_2 and NO_x emissions from industry and transport; while coarse particles are uncontrolled, and would not be expected to decline.

There are likely to be areas where road traffic sources are particularly significant. These would be locations including the city centre, where volumes of traffic are high, the motorways which run through the city, and congested arterial routes and junctions.

There are several industrial sites which are potentially large emitters of PM_{10}; these are identified in Table 8.3 below.

Name	Process	Location
A Cohen	Non-ferrous metals	254298, 664460
United Distillers	Grain drying	259155, 666710

Table 8.3 Industrial sources of PM_{10}

These processes were addressed during the previous Update and Screening Assessment in 2003, and the conclusion was reached that they would not result in any exceedences of the air quality objectives for PM_{10}. However, due to the new objectives to be met in Scotland, these locations may have to be considered once again.

8.3 Monitoring methodology

8.3.1 Monitoring equipment and locations

There are currently seven sites which measure PM_{10} using Tapered Element Oscillating Microbalance (TEOM) analysers in Glasgow. However, results from these instruments are not directly comparable to the air quality standards, which are based on measurements made with gravimetric samplers. Measurements from TEOM samplers are found to underestimate gravimetric samplers by between 15-30% and so a correction factor must be applied to TEOM results. The guidance advice on what this factor should be is,

"Measurements of PM_{10} concentrations carried out using a TEOM or β-attenuation instrument, operated with a heated manifold, should be adjusted by multiplying data by 1.3 to estimate gravimetric concentrations."

The factor of 1.3 has been applied to all monitored PM_{10} data in Glasgow.

Two of the automatic monitors are part of the AURN run by the Scottish Executive and DEFRA. These are:

Glasgow Centre (St. Enoch)
This site is in St Enoch Square, an open, pedestrianised area in the centre of Glasgow (2589434 665027). It is around 20m from Argyle Street which has a traffic flow of approximately 20,000 vehicles per day. The site is classed as an urban centre site.

Glasgow Kerbside (Hope Street)
This is positioned at the southern end of Hope Street adjacent to Central Station (258696 665166) close to the junction with Argyle Street in a street canyon. It is a kerbside site with its inlet less than 1m from the road. Traffic flow here is more than 25,000 vehicles per day.

Glasgow City Council independently operates another five air quality monitoring units which measure PM_{10}. These are described below:

Glasgow 1 (St .Patrick's Primary School)
This unit (Groundhog) has been permanently located at St Patrick's Primary School (257925, 665487) just west of the M8 motorway. Despite data capture problems initially, the unit is giving enough data to estimate the annual mean concentration of PM_{10} now.

Glasgow 2 (Byres Road)
This unit (Rollalong) has been permanently located at the junction of Byres Road and University Avenue (256553, 665487) since 2004.

Glasgow 3 (Waulkmillglen Reservoir)
A unit which monitors background concentrations is located at Waulkmillglen reservoir (252520, 658095), just outside the south-east boundary of Glasgow.

Glasgow 4 (Battlefield Road)
This unit has been in operation since May 2005 and is located at the junction of Battlefield Road and Holmlea Road on the south side of the city. (258425, 661375). Data for the full calendar year of 2006 will be ratified and reported on in future Review & Assessment Reports.

Glasgow 5 (Queen Street Station)
A new unit went into operation (March 2006) in Queen Street Station (259229, 665698). This has specifically been set up to monitor particulate pollution from diesel trains on the upper level of the station. Not enough data has been received from it to be included in this report, but will be included in future review & assessment reports.

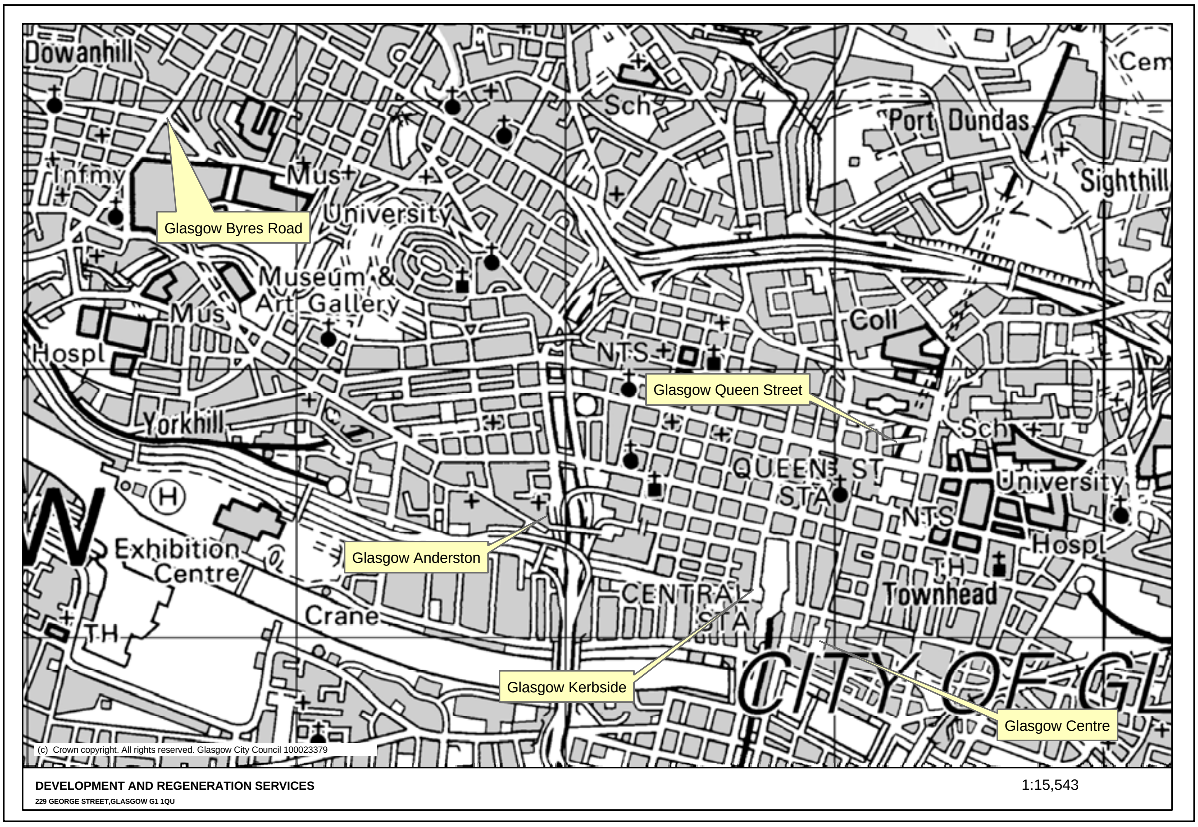


Figure 8.2 Locations of automatic monitoring sites for PM_{10}, except the background site.

The stations at Battlefield and Waulkmillglen are located some distance to the south of the city centre.

8.3.2 Public exposure

When assessing concentrations of pollutants, the guidance is clear that the only sites that should be considered are those which represent relevant exposure against the objective.

For the annual mean objective this means considering all background and roadside locations up to the building façade of properties such as residencies, schools, hospitals and other buildings where the public may visit or remain for long periods. The objective would not apply at building facades of offices or other places of work where members of the public do not have regular access, or at kerbside locations where public exposure is likely to be short. The 24-hour PM_{10} objective will apply at all locations the annual mean objective applies, and also gardens of residential properties. It should not apply at kerbside sites or any other locations where public exposure would be expected to be short term.

For the automatic monitoring sites in use in Glasgow, this means that Glasgow Centre will be compared to both the annual and 24-hour objectives. Glasgow Kerbside does not represent a location with relevant exposure for either objective, although the results will still be presented for completeness.

Data from the remaining sites is relevant and will be compared to the annual and 24-hour objectives. Although Waulkmillglen is not located where there are receptors, it is included as a background level for the city.

8.3.3 Projected PM_{10} Concentrations

It is possible to make projections of PM_{10} concentrations using monitored data, to estimate whether the objectives will be breached in 2005 or 2010. However, making predictions of changing particle concentrations over time is complex, due to the different types of particles, primary, secondary and coarse, being governed by different sources.

In order to estimate total PM_{10} levels in the future, the three particle components must be considered individually. Estimates of the changes in primary and secondary particle concentrations can be made, and the coarse component added to this. A table of the correction factors is given below.

Year	Correction factor	
	Secondary PM_{10}	Primary PM_{10}
2005	0.909	0.907
2006	0.886	0.890
2007	0.864	0.870
2008	0.841	0.850
2009	0.818	0.843
2010	0.795	0.815

Table 8.4 – Correction factors to predict 2005 PM_{10} annual means

While it is not possible to estimate the number of exceedences of the PM_{10} 24-hour objective in the same manner as above, there is a relationship between the annual mean concentration and the number of exceedences of the 24-hour objective. This relationship was established by examination of results from AURN sites between 1997 and 2001, and is represented in Technical Guidance LAQM.TG(03).

8.4 Update and Screening of PM_{10}

The Update and Screening Assessment of PM_{10} will consider the sources, locations and data separately, in the form of a checklist. For PM_{10} there are 12 steps, which are listed below and then addressed in the following section in turn:

- Monitoring data outside an AQMA;
- Monitoring data within an AQMA;
- Busy road and junctions;
- Road with high flows of buses and/or HGVs;
- New roads constructed or proposed since first round of review and assessment;
- Roads close to the objective during the second round of review and assessment;
- Road with significantly changed traffic flows;
- New industrial sources;
- Industrial sources with substantially increased emissions;
- Areas with domestic solid fuel burning;
- Quarries, landfill sites, opencast coal, handling of dusty cargoes at ports, etc;
- Aircraft.

8.4.1 Monitoring data outside/within an AQMA

As there has been no AQMA declared for PM_{10}, all monitoring locations will be considered together. Four of the sites are located in the city centre and three are located elsewhere, (Byres Road, Waulkmillglen and Battlefield). While there is no relevant exposure at Glasgow Kerbside, this site is also included for completeness.

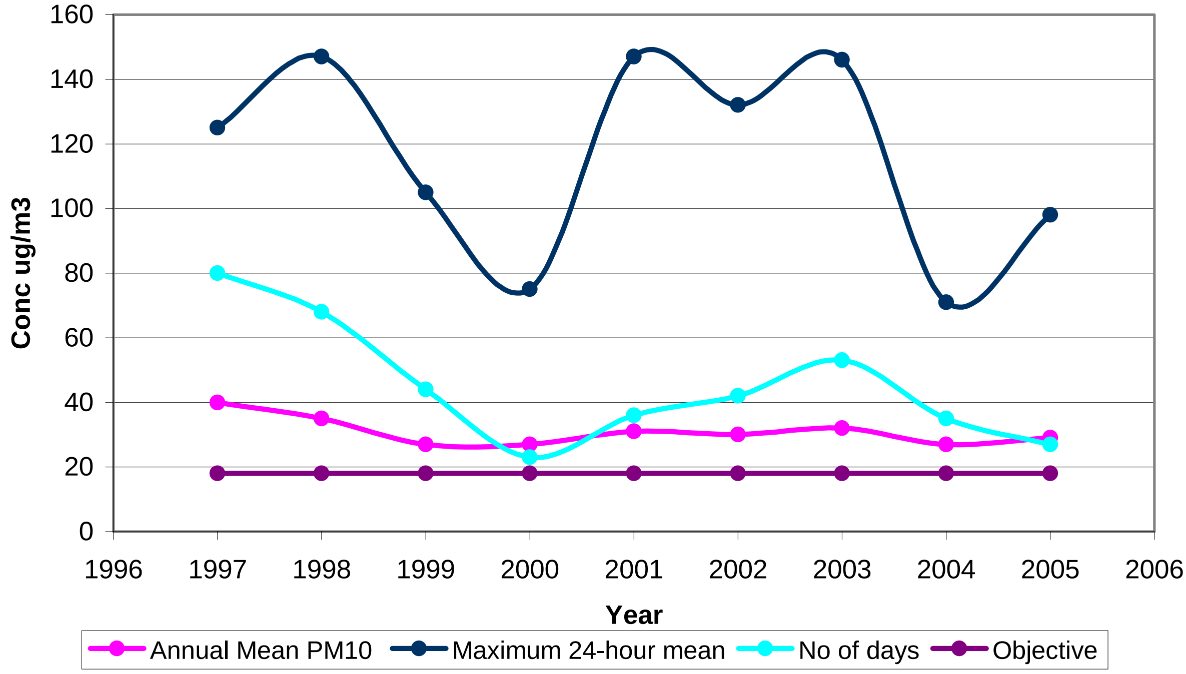


Figure 8.4 Results of monitoring at Glasgow Kerbside
(All results of [PM_{10}] are presented as gravimetric concentrations)

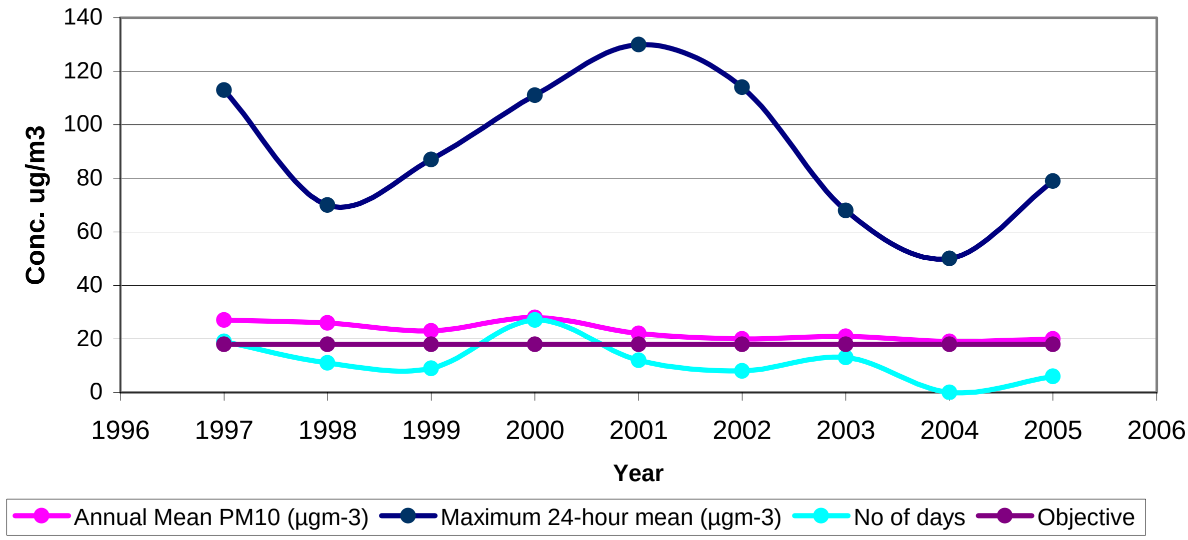


Figure 8.5 Results of monitoring at Glasgow Centre

The remaining four automatic monitoring stations are non-AURN and the results of monitoring in 2005 are as follows:

Station	Data Capture	Annual Mean PM_{10}	Maximum 24 hour mean	No of days > 50µg/m^3
Glasgow Anderston	54.6	15	44	1
Byres Road	84.9	21	54	8
Waulkmillglen	91.4	10	38	0

Table 8.5 non-AURN PM_{10} results

The relationship between the annual mean and the number of exceedences of the 24-hour mean described in 8.3.3 is used to estimate the number of exceedences in 2006 and 2010. These are given below in Table 8.6

Location	**Predicted number exceedences of 24hr objective in 2006 (μg/m^3)**		**Predicted number exceedences of 24hr objective in 2010(μg/m^3)**	
	Base Year 2000	**Base Year 2002**	**Base Year 2000**	**Base Year 2002**
Glasgow Centre	15	2	11	1
Glasgow Kerbside	13	20	9	16
Byres Road	3	0	2	0
Glasgow Anderston	0	0	0	0

Table 8.6

Monitoring in city centre locations indicates that there are exceedences of the 2010 air quality objectives.

The Detailed Assessment for 2005 stated that there will be requirement to declare an AQMA for the city centre at the very least. This will be carried out towards the end of 2006. It also stated that there required to be further monitoring of PM_{10} outwith the city centre and this will commence in 2007 when the three new TEOM/FDMS units are operational.

8.4.2 Busy roads and junctions

It is possible that high concentrations of PM_{10} are present at busy roads and junctions, and such locations should be investigated for exceedences. These should be assessed against the 2010 objectives.

The guidance advises that 'busy' road and junctions should be inspected, where 'busy is defined as,

"Roads and/or junctions with more than 5,000 vehicles per day (AADT), where the background in 2010 is expected to be above 15μg/m^3."

"Roads and/or junctions with more than 10,000 vehicles per day (AADT), where the background in 2010 is expected to be below 15μg/m^3."

Some of the busiest road and junctions in Glasgow are found within the city centre. The Detailed Assessment of 2005 assessed a number of these and came to the conclusion that the 2010 annual mean objective for PM_{10} isn't likely to be met at several locations within the city centre. It is therefore intended to declare the city centre AQMA for PM_{10} as well as NO_2.

Busy roads and junctions outwith the city centre also require to be assessed. The 2005 Detailed Assessment identified potential exceedences at various locations through dispersion modelling, but concluded that monitoring was required to verify the results of the model. This will be carried out through the use of the three new TEOM/FDMS units as detailed previously.

BMT Cordah recently carried out further dispersion modelling on behalf of the Council and the results indicated that many busy roads and junctions will fail to meet the 2010 annual mean objective. The estimated 2010 concentrations obtained were higher than those predicted in the 2005 Detailed Assessment. Dispersion modelling can give varying results and it is important that monitoring data are available to verify model outputs.

Given that potentially most main roads and busy junctions in Glasgow could fail to meet the 2010 objective, there is the possibility that the entire road network, or the entire city of Glasgow, would need to be declared as an AQMA for PM_{10}.

Therefore, it is considered important that a sufficient amount of monitored data for PM_{10} is available to provide a more detailed and accurate picture of PM_{10} concentrations in Glasgow before making decisions on the declaration of further AQMAs outwith the city centre.

Therefore, it is proposed that *there is no requirement* to a Detailed Assessment for these sources at the present time, on the basis that monitoring will be carried out and a Detailed Assessment carried out at a later date.

8.4.3 Roads with high flows of buses and/or HGVs

At locations where there are a particularly high proportion of heavy goods vehicles and buses, which are large emitters of PM_{10}, there is a possibility of elevated PM_{10} concentrations. These locations should be considered individually, with the following criteria set out in the guidance. The guidance notes that,

"*If the flow of HGV's is below 2000 vehicles per day then you do not need to proceed further."*

Traffic flow data shows that the stretch of road with the highest number of heavy vehicles is part of the M8, with an average of 1845 heavy vehicles per day. The highest non-motorway heavy vehicle flow is just over 500 vehicles per day.

Since relevant flow is low, it is considered that *there is no requirement* for a Detailed Assessment at this type of location.

8.4.4 New roads constructed or proposed since last round of Review and Assessment

M74 Extension - Following a Public Local Enquiry, an appeal in the Court of Session against the Roads Orders has been withdrawn. Timescales for starting and completing the project are unclear at the present time. However, if construction were to start in the current year, the road should be open to traffic by 2010.

The road will be constructed in connection to the proposed East End Regeneration Route.

The M74 extension was considered in the 2005 Detailed Assessment. Modelling work previously undertaken on the project by consultants ERM revealed that there may be exceedences of PM_{10} objectives close to the road at some locations along the route. To supplement this, the Council's Land Services are undertaking some PM_{10} monitoring along the route of the proposed road and this monitoring is expected to continue during and after construction. This should provide a more accurate picture of the impacts of the road with respect to PM_{10} and this will inform whether further detailed analysis is required and whether the road, or part of the road, needs to be incorporated into an AQMA.

Therefore, *there is no requirement* to proceed to a Detailed Assessment for this road at the present time.

East End Regeneration Route - This is to provide a connection between the Polmadie Road junction on the new M74 link at its southern end and the M80/M8 at its northern end. The Planning Application was signed off on 9th November 2005 and the Draft CPO published on 13 September 2005. CPO objections are currently being considered. The road should be completed by 2008/09.

Dispersion modelling studies have predicted that this road will have a neutral effect on emissions and concentrations of PM_{10}. However, some localised improvements in air quality are predicted due to reduced traffic congestion and the provision of improved public transport facilities.

As with the M74 extension, monitoring will provide a more accurate picture of the impacts of the road with respect to PM_{10} and this will inform whether further detailed analysis is required. It is the intention to carry out monitoring at relevant locations once the road development has been completed. Therefore, *there is no requirement* to proceed to a Detailed Assessment for this road at the present time.

Finnieston Street Road Bridge - the bridge, which links the north and south banks of the river between Finnieston Street and Govan Road, opened to traffic in September 2006. It has four lanes; two lanes dedicated to public transport and two for private and commercial traffic, with additional pedestrian and cyclist paths.

An assessment of the impact on air quality from the bridge was carried out as part of the planning process. The DMRB (Design Manual for Roads and Bridges) model was used to carry out the initial air quality assessment. The assessment concluded that the construction of the bridge will not have a significant effect on the air quality of the local area. Also, due to the conservative nature of the DMRB model it states that a further air quality study using a detailed model such as ADMS-Roads is not required.

However, it is proposed that monitoring of PM_{10} is carried out at relevant locations near to the bridge in order to provide a clearer picture of its impact on PM_{10}. Should monitoring reveal exceedences, or potential exceedences, of air quality objectives, further assessment using accurate traffic flow data can be undertaken to supplement the monitored data.

Consequently, it is considered that *there is no requirement to proceed to a Detailed Assessment* for the Finnieston Street Road Bridge at the present time.

8.4.5 Roads close to the objectives during the first round of Review and Assessment

This section addresses the changes to the emission factors in 2002. It applies only to locations where results were close to but just below the 2004 objective and for which AQMAs were not declared. The new factors might make a difference if locations were predicted to be close to the objective during the first round of review and assessment.

The 2005 Detailed Assessment considered such roads and identified potential exceedences within the city centre. Therefore, since it was considered 'highly likely' that that parts of the city centre would fail the 2010 annual mean objective, it was concluded that PM_{10} must be added to the existing AQMA for NO_2.

The 2005 Detailed Assessment also considered through dispersion modelling that several other locations outwith the city centre could potentially fail the 2010 objective, but concluded that monitoring was required to verify the results of the model prior to any further AQMAs being declared for PM_{10}. This will be carried out through the use of the three new TEOM/FDMS units as detailed previously.

BMT Cordah recently carried out further dispersion modelling on behalf of the Council and the results indicated that many busy roads across the city will fail to meet the 2010 annual mean objective. The estimated 2010 concentrations obtained were higher than those predicted in the 2005 Detailed Assessment. Dispersion modelling can give varying results and it is important that monitoring data are available to verify model outputs.

Given that there is the potential for many main roads in Glasgow to fail the 2010 objective, there is the possibility that the entire road network, or the entire City of Glasgow, would need to be declared as an AQMA for PM_{10}.

Therefore, it is considered important that a sufficient amount of monitored data for PM_{10} is available to provide a more detailed and accurate picture of PM_{10} concentrations in Glasgow before making decisions on the declaration of further AQMAs outwith the city centre.

Therefore, it is proposed that *there is no requirement* to a Detailed Assessment for these roads at the present time, on the basis that monitoring and a Detailed Assessment will be carried out at a later date.

8.4.6 Roads with significantly changed traffic flows

Those roads which were previously at risk of exceeding the objectives may be subject to higher concentration of pollutants if these has been a 'large' increase in traffic flow, which is defined by,

"*A 'large' increase can be taken to be greater than 25% in AADT traffic flow."*

The road network in Glasgow has not undergone any major changes since the last Update and Screening Assessment in 2003 that could lead to such a significant increase in traffic flow.

Consequently, it is considered that *there is no requirement* to proceed to a Detailed Assessment at these locations.

8.4.7 New industrial sources / industrial sources with substantially increased emissions

Industrial sources do not make a significant contribution to annual mean concentrations, but they can be important in terms of the 24-hour objective, particularly in the area surrounding the source. Since Stage III, there have been no new industrial sources in Glasgow, and no existing sources have substantially increased their emissions, defined in the guidance as,

"A 'substantial' increase can be taken to be one greater that 30%."

This has remained the situation since the Update and Screening Assessment of 2003. In the Detailed Assessment of 2005 it was proposed to introduce a monitoring programme to assess ambient concentrations of PM_{10} at locations in the vicinity of the industrial sources in the city. This has not yet commenced, but will be carried out in conjunction and consultation with SEPA.

8.4.8 Areas of domestic solid fuel burning

In areas where domestic solid fuel is still in widespread use, there can be a problem with PM_{10} concentrations. Potential problems can exist in any area of about 500 x 500 m with more than 50 houses burning solid fuel as their primary source of heating.

There are no areas in Glasgow that would come within this definition, since the entire city is now covered by Smoke Control Areas. It is considered that *there is no requirement* to a Detailed Assessment for these locations.

8.4.9 Quarries/landfill sites/ opencast coal/ handling of dusty cargoes at ports etc

There are several other sources which may be significant for PM_{10}, mainly through fugitive sources, i.e. dust. It is thought that dust emissions contain around 20% PM_{10}.

The guidance on dealing with these sources is to identify potential sources, and then determine whether there are dust concerns at the facility. This assessment should be based on dust complaints about the facility, or a visual inspection indicating significant dust.

The only potential sources which Glasgow contains within its boundaries are landfill sites, of which there are several. The only site that the Council has received complaints about is Paterson's Tip, in the east of the city. There have been no other complaints received regarding dust, nor is dust considered an issue, at any other site.

The complaints regarding Paterson's have also not concerned dust, but mainly smell. There is a working group concerned with Paterson's, of which Glasgow City Council is an active participant, to address all issues surrounding Paterson's. Monitoring for metals and dust has been carried out close to the site and has not revealed any concerns.

Therefore, it is considered that *there is no requirement* to proceed to a Detailed Assessment for these sources.

8.4.10 Aircraft

While aircraft are not considered significant sources of PM_{10} emissions, they may make a contribution close to the source.

Guidance suggests establishing whether there is relevant exposure within 500 m of the airport boundary. Glasgow International Airport is located some distance outwith the city boundary, and so for this reason, it is considered that *there is no requirement* to proceed to a Detailed Assessment for this source.

9.0 References

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Appendix 1 BMT Cordah Dispersion Modelling Study

BMT Cordah Limited
ENVIRONMENTAL CONSULTANCY
AND INFORMATION SYSTEMS

LAQM Dispersion Modelling Study

A Report for Glasgow City Council

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CONTENTS

Table Contents List

Figure Contents List

Appendices

1 INTRODUCTION

BMT Cordah Ltd was commissioned by Glasgow City Council to undertake a dispersion modelling study of atmospheric emissions at various locations in Glasgow to support the Council's continuing work in fulfilling its requirements under the Local Air Quality Management (LAQM) regime. The locations assessed were:

- Glasgow City Centre;
- West End Corridor; and
- Springburn Road;

Glasgow City Centre

BMT Cordah was requested to assess the area declared as an Air Quality Management Area (AQMA) in 2003 in order to examine whether air quality levels remain above National Air Quality Strategy (NAQS) objectives, and to consider some potential action plan measures and their potential effect on air quality.

West End Corridor

BMT Cordah was requested to assess an area described as the west end corridor. The corridor encompasses the area to the west of Glasgow City Centre (adjacent to the AQMA boundary), to north of the river Clyde. The northern extent of the assessment area was assumed to be Great Western Road and the western boundary at the Clyde Tunnel/Anniesland Cross corridor.

The assessment area included the new Finnieston Bridge development and the proposed Queen's Dock II, Pacific Quay and Glasgow Harbour developments. The focus of the modelling study was to determine the potential effect of these developments on local air quality.

Springburn Road

BMT Cordah was requested to consider the road traffic emissions on Springburn Road (A803), particularly, close to the boundary with the East Dunbartonshire Council administrative area. Springburn Road becomes Kirkintilloch Road within East Dunbartonshire, which was declared an AQMA by East Dunbartonshire Council in 2005. The East Dunbartonshire Council AQMA extends to the Glasgow City Council boundary.

In order to undertake the air dispersion modelling studies BMT Cordah was required to update the Glasgow atmospheric emissions inventory for the city centre area and to produce a second inventory for emissions in the west end. This report presents the results of the emissions inventory compilation as well as the findings of the dispersion modelling study in each of the three areas considered. The dispersion modelling studies were conducted using the modelling software package ADMS Urban (version 2.2) whilst the emissions inventories were compiled using the associated EMIT (version 2.2) software package.

For the purposes of the assessment all PM_{10} concentrations are presented as gravimetric values and all NO_X as NO_2 unless otherwise stated.

1.1 LAQM framework

The Environment Act 1995[1] and subsequent Regulations requires Local Authorities to regularly review and assess local air quality in their area. Local authorities are required to assess measured or predicted air quality levels in their area against air quality objectives for seven pollutants contained within the National Air Quality Strategy (NAQS)[2]. The objectives for these pollutants are presented in Table 1.

Table 1 National Air Quality Strategy objectives, µg/m³

Pollutant	Air Quality Objective			To be achieved by
	Concentration	Measured as	Permitted Exceedences/ Equivalent percentile	
Benzene	16.25 µg/m³	running annual mean	-	31.12.03
	3.25 µg/m³	running annual mean	-	31.12.10
1,3-butadiene	2.25 µg/m³	running annual mean	-	31.12.03
Carbon monoxide (CO)	10 mg/m³	running 8 hour mean	-	31.12.03
Lead	0.5 µg/m³	annual mean	-	31.12.04
	0.25 µg/m³	annual mean	-	31.12.08
Nitrogen dioxide (NO_2)	200 µg/m³	1-hour mean	18 Exceedences 99.79th percentile	31.12.05
	40 µg/m³	annual mean	-	31.12.05
Particulate (PM_{10})	50 µg/m³	24-hour mean	35 Exceedences 90.4th percentile	31.12.04
	40 µg/m³	annual mean	-	31.12.04
	50 µg/m³	24-hour mean	7 Exceedences 98th percentile	31.12.10
	18 µg/m³	annual mean	-	31.12.10
Sulphur dioxide (SO_2)	125 µg/m³	24-hour mean	3 Exceedences 99th percentile	31.12.04
	350 µg/m³	1-hour mean	24 Exceedences 99.7th percentile	31.12.04
	266 µg/m³	15-minute mean	35 Exceedences 99.9th percentile	31.12.05

1.2 Air quality in Glasgow

Like all large urban areas in the UK, emissions from road traffic are responsible for a significant portion of ambient NO_2 and PM_{10} concentrations in Glasgow. Glasgow City Council's Stage IV Review and Assessment report[3] attributed more than 70% of total NO_x ($NO+NO_2$) to road traffic sources.

In 2002, Glasgow City Council declared an AQMA in the city centre (Figure 1) as a result of predicted exceedences of the annual mean NO_2 air quality objective. The Council produced an Air Quality Action Plan[4] in 2004 outlining proposed measures that could be implemented to reduce NO_2 concentrations. The Action Plan focussed on reducing road traffic emissions in recognition of the significant contribution made by road traffic to NO_2 concentrations in Glasgow City Centre.

1 Environment Act 1995 (c.25), ISBN 0105425958, The Stationary Office, 1995.
2 Air Quality Strategy for England, Scotland, Wales and Northern Ireland, DEFRA January 2000.
3 LAQM Stage IV Review and Assessment, Glasgow City Council, October 2003.
4 LAQM Action Plan, Glasgow City Council 2005.

Monitoring of NO_2 in the West End of the city has also indicated potential exceedences of the NO_2 annual mean objective, particularly around the heavily trafficked Byres Road and Dumbarton Road area. The Council are currently undertaking a consultation exercise with the intention of declaring a second AQMA in this area in the near future. The proposed new developments in the west end are likely to have a significant impact on traffic movements in this area and hence on air quality.

The proposed new developments include the Glasgow Harbour and Queens Dock II projects, which are large mixed residential and commercial developments along the north bank of the River Clyde from the Scottish Exhibition and Conference Centre (SECC) to the Clyde Tunnel. The developments will generate additional traffic from both commuters (both into and out of the development) and customers accessing the leisure and commercial facilities on each development.

Additionally, the Finnieston Bridge is scheduled to open in 2006. The Finnieston Bridge provides local vehicle access across the River Clyde between the eastern side of the SECC site (Queens Dock II) and the Pacific Quay development to the south of the development. The Pacific Quay development includes both the Glasgow Science Centre and the new BBC Scotland offices and studios, as well as residential development. The road network around the Finnieston Bridge has been designed to minimise the flow of through traffic using the bridge.

The locations of each of the proposed developments are displayed in Figure 2.

The third location where there is a potential to exceed air quality objectives for NO_2 is at the junction of Springburn Road and Colston Road in the north of Glasgow, just inside the boundary with East Dunbartonshire. East Dunbartonshire Council undertook a detailed air quality assessment of road traffic emissions in the area in 2005 and have subsequently declared an AQMA in Bishopbriggs extending to the boundary with Glasgow. The dispersion modelling study is required for the Glasgow side of the boundary to determine whether an AQMA is also required on the Glasgow side of the boundary.

2 EMISSIONS INVENTORIES

Inventories were compiled of emissions in the city centre and in the west end corridor area in 1km grid squares. Outside of these grid squares the inventories used data obtained from the National Atmospheric Emissions Inventory (NAEI). The inventories were compiled using the atmospheric emissions database package EMIT[5].

The emissions inventories were compiled using both 'calculated' emissions and published emissions data. The inventory considered emissions from:

- road traffic;
- commercial and domestic combustion;
- industrial emissions; and
- other miscellaneous sources.

The source data used to compile the inventories are described in Section 2.1 to 2.4 with further detail provided in Appendix 1.

2.1 Road traffic emissions

Emissions from road traffic were calculated using the equation:

$$Total\_emissions = \sum activity\_rate \times emissions\_factor$$

The activity rate for road traffic is defined by the type of vehicle, the engine type and the speed of the vehicle. The emissions factors were obtained from nationally published data based on emissions standards and testing undertaken by vehicle manufacturers. The emissions factor database is built into EMIT.

EMIT makes a number of assumptions regarding the age and type of vehicles on a road based on the year under consideration and the type of road. For example, it is assumed that in future years there will be newer cars with improved engine technology and therefore reduced emissions. Another assumption is that the percentage of each type of vehicles varies between different roads, i.e. there is a higher percentage of large HGVs on motorways than would be found on an urban road.

The database therefore produces a large matrix calculation of the type of vehicle, engine size, speed and related emissions factor for each permutation. The emissions are calculated as a mass emission per distance travelled i.e. g/km/s.

Vehicle flow data were provided by Glasgow City Council for 2005 and 2010. The flow data were based on traffic model predictions that were calibrated against traffic count data. The traffic flow data provided peak flows which were interpolated to an annual average daily traffic (AADT) flow using diurnal traffic count data. No specific data were available on the percentage of HGVs in the total traffic flow. Glasgow City Council advised a standard HGV flow of 8.6%, which provided good

[5] EMIT Atmospheric Emissions Inventory Toolkit, version 2.2, Cambridge Environment Research Consultants, February 2006.

agreement with recorded count data. Further detail on the road traffic flow data is provided in Appendix 1.

In the city centre the inventory included all roads, outside the city centre the inventory included all major trunk roads and other roads in the west end for which traffic flow data were available. An allowance for road traffic emissions on roads for which no traffic flow data were available was made on a grid square basis using data obtained from the NAEI. The roads explicitly included in the emissions inventory are displayed in Figure 3.

2.2 Commercial and domestic emissions

No local data were available for emissions from commercial and domestic sources. The NAEI calculates emissions from domestic and commercial sources on a grid square basis based on the fuel consumption in that grid square. In the absence of local data the study utilised the NAEI emissions data.

Emissions from commercial and domestic sources were assumed to remain constant between 2005 and 2010.

2.3 Industrial emissions

No large regulated industrial processes are located within Glasgow City Centre or the West End Corridor. There are however two industrial processes located on the outskirts of the City Centre, namely United Distillers at Port Dundas and Allied Distillers in the Gorbals. The locations of each industrial process in relation to the city centre are displayed in Figure 3. Annual emissions data for each process were obtained from public records held by the Scottish Environment Protection Agency (SEPA).

Emissions from small non-regulated and fugitive industrial sources were accounted for on a grid square basis utilising data obtained from the NAEI.

Emissions from industrial sources were assumed to remain constant between 2005 and 2010.

2.4 Other emissions

Emissions from other miscellaneous sources not categorised under each of the other categories such as rail traffic, construction and shipping emissions were included in the inventory on a grid square basis. Emissions data for these other sources were obtained from the NAEI.

3 EMISSION INVENTORY TOTALS

3.1 City Centre (AQMA)

The inventory of city centre emissions included road traffic emissions from both city centre roads and the M8 motorway, combustion generated emissions from commercial and residential premises and industrial emissions. The city centre area was extended to include the whole of the 1km^2 grid squares which constitute part of the AQMA. It should be noted that not all road traffic emissions are accounted for in certain grid squares as they were outside the areas of consideration.

The NO_X and PM_{10} emissions totals for each grid square, as well as the relative contributions of each source to the total emissions are presented in Tables 2 and 3. The results are presented graphically in Figures 4 and 5.

The figures demonstrate the influence of the motorway on total emissions with the highest emission grid squares following the motorway around the north of the city centre and across the river south of the city centre. The emission squares to the north-west and south-east of the city centre are influenced by industrial emissions.

The contribution of each emission source to the total NO_X emission varies from grid square to grid square as demonstrated in Charts 1 and 2. The total emission from grid squares outside the city centre but encompassing the motorways e.g. grid CC1, is dominated by road traffic emissions (>90%). Within the city centre, however, the emissions totals indicate that emissions from commercial and domestic sources can contribute over 40% of the total emissions. Previous assumptions were that commercial and domestic emissions were insignificant in comparison to road traffic emissions therefore the inventory results indicate that this is not the case. The commercial and domestic emissions are influenced by the high number of hotels and large office buildings within the grid square.

If all city centre grid squares are taken together, as demonstrated in Chart 3, then road traffic emissions account for 70% of the total NO_X emission. Commercial and domestic emissions account for 19% of total NO_X emissions.

Chart 1 Contribution of each source to total NO_X emission, Grid CC1

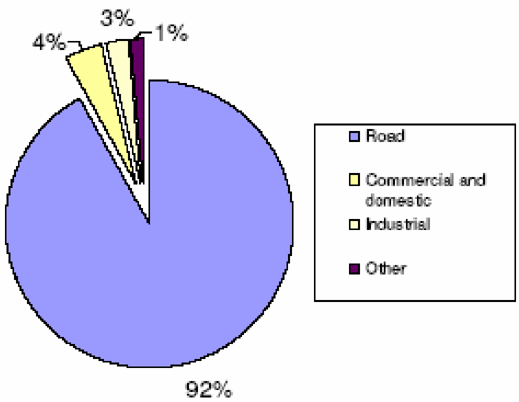


Table 2 City centre NO_X emissions totals

Identifier	Grid Reference	Specified Road Traffic Emissions (te/yr)		Non-specified Roads (te/yr)	Commercial and domestic emissions (te/yr)	Industrial Emissions (te/yr)		Other Emissions (te/yr)	Total (te/yr)
		Main Roads	Motorways			Point	Grid		
CC1	257000, 664000	0	9.16	134.84	6.45	0	3.98	1.98	156.41
CC2	257000, 665000	0.06	21.87	34.67	15.38	0	3.74	3.09	78.81
CC3	257000, 666000	0	0.83	29.16	19.65	0	2.78	1.35	53.77
CC4	258000, 664000	9.82	4.58	24.70	9.08	0	1.35	3.04	52.57
CC5	258000, 665000	32.36	29.6	37.21	81.75	0	8.19	4.09	193.20
CC6	258000, 666000	5.43	58.8	35.79	12.60	0	1.20	0.80	114.62
CC7	259000, 664000	10.08	0	22.52	12.83	0	1.93	1.55	48.91
CC8	259000, 665000	26.51	0	0	41.70	0	2.23	3.28	73.72
CC9	259000, 666000	5.34	59.20	45.46	7.58	49.2	2.23	7.82	176.83
CC10	260000, 664000	0	0	20.00	6.41	0	3.02	3.02	32.45
CC11	260000, 665000	10.96	30.83	110.21	10.73	0	18.30	5.19	186.22
CC12	260000, 666000	0	21.34	29.66	5.33	0	0.93	1.91	59.17

Table 3 City centre PM_{10} emissions totals

Identifier	Grid Reference	Specified Road Traffic Emissions (te/yr)		Non-specified Roads (te/yr)	Commercial and domestic emissions (te/yr)	Industrial Emissions (te/yr)		Other Emissions (te/yr)	Total (te/yr)
		Main Roads	Motorways			Point	Grid		
CC1	257000, 664000	0	0.28	7.44	0.11	0	3.98	0.63	12.44
CC2	257000, 665000	0	0.68	3.08	0.23	0	3.74	1.70	9.43
CC3	257000, 666000	0	0.03	2.03	0.37	0	2.78	0.99	6.20
CC4	258000, 664000	0.36	0.14	1.98	0.16	0	1.35	0.42	4.41
CC5	258000, 665000	1.19	0.91	5.00	1.78	0	8.19	0.93	18.00
CC6	258000, 666000	0.20	1.82	3.92	0.24	0	1.20	0.65	8.03
CC7	259000, 664000	0.36	0	1.89	0.25	0	1.93	0.50	4.93
CC8	259000, 665000	0.98	0	0.73	0.91	0	2.23	1.05	5.90
CC9	259000, 666000	0.19	1.81	4.31	0.16	0	18.80	2.93	28.20
CC10	260000, 664000	0	0	1.26	0.09	0	3.02	1.17	5.54
CC11	260000, 665000	0.39	0.94	7.13	0.20	0	18.30	1.99	28.95
CC12	260000, 666000	0	0.65	2.35	0.18	0	0.93	0.92	5.03

Chart 2 Contribution of each source to total NO_X emission, Grid CC5

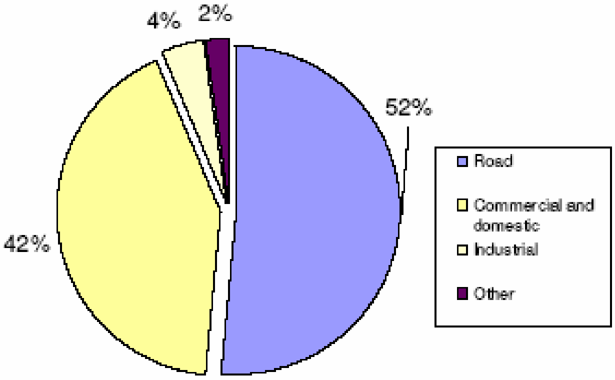
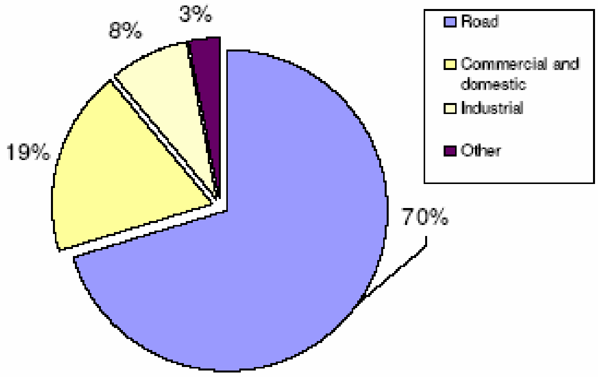
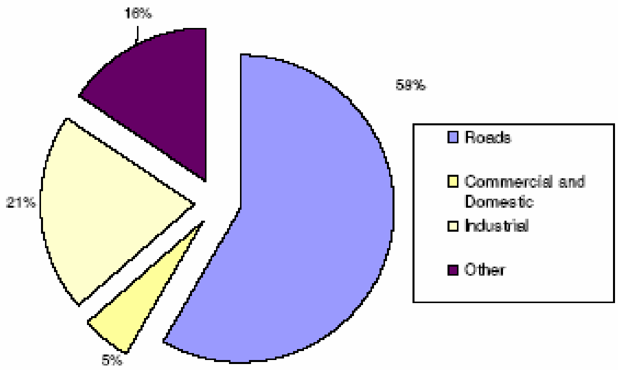


Chart 3 Contribution of each source to total NO_X emissions, all city centre grids



The contribution of each emission source to the total PM_{10} emissions is similar to that of NO_X. Outside the city centre road traffic emissions contribute over 80% of total PM_{10} emissions, whilst in the city centre emissions from other sources (including construction/industrial, commercial and domestic and other miscellaneous sources) contribute around 40% of total PM_{10} emissions. A breakdown of the total PM_{10} emission across all city centre grid squares is presented in Chart 4.

Chart 4 Contribution of each source of total PM_{10} emissions, all city centre grids



3.2 West End Corridor

Similar to the city centre, the grid square emission totals for the west end corridor varied from area to area but were strongly influenced by road traffic emissions, particularly around the M8 motorway and Clydeside Expressway. The total NO_X and PM_{10} emissions are presented graphically in Figures 6 and 7.

Figures demonstrate that the highest emissions occur around the Byres Road/Dumbarton Road area. The contribution of each emission source to the total NO_X and PM_{10} emissions for this area are presented in Charts 5 and 6.

Chart 5 Contribution of each emission source to total NO_X emissions, Byres Road/Dumbarton Road area

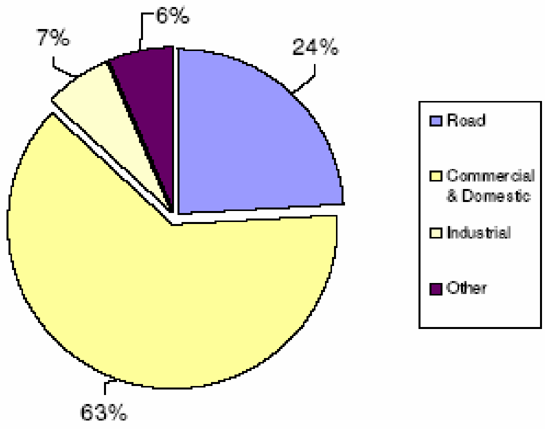
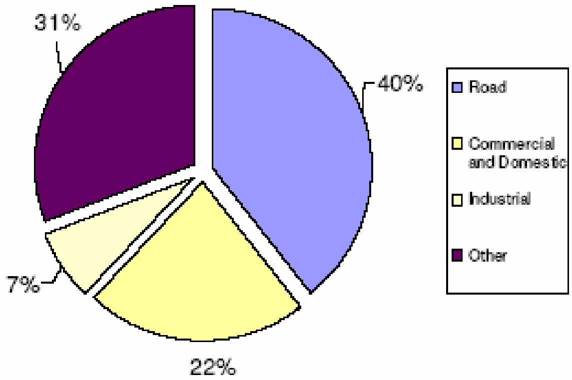


Chart 6 Contribution of each emission source to total PM_{10} emissions, Byres Road/Dumbarton Road area



Non-road traffic related sources contribute the majority of emissions in the Byres Road/Dumbarton Road area. The contribution of commercial and domestic emissions will be influenced by emissions from the university and hospital buildings in the grid square. There is also a high housing density within the grid square. Emissions from other sources including natural sources contribute a high proportion of total PM_{10} emissions.

When all west end grids are considered the influence of road traffic emissions on the total emission increases. The relative contribution of each source type to the total NO_X and PM_{10} emissions are presented in Charts 7 and 8.

Chart 7 Contribution of each emission source to total NO_X emissions, all West End corridor grid squares

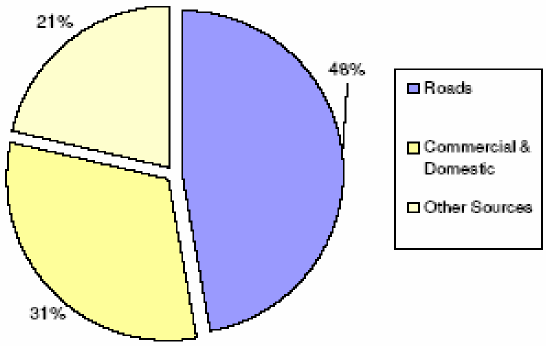
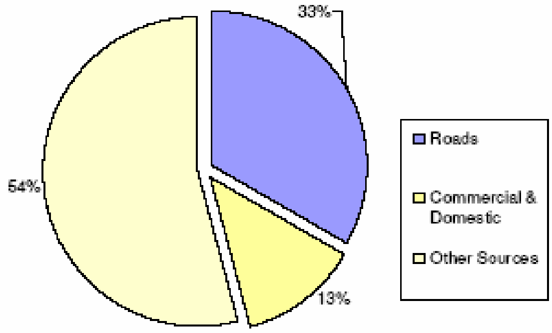


Chart 8 Contribution of each emission source to total PM_{10} emissions, all West End corridor grid squares



The predominant source of NO_X emissions in the west end corridor is from road traffic accounting for nearly 50% of all emissions. Commercial and domestic emissions also account for a large proportion of all emissions at 31%. The contribution from traffic sources accounts for a third of all PM_{10} emissions. Non road traffic and commercial and domestic emission sources are predominant in the west end corridor.

The influence of road traffic on total emissions in the west end is significant, however is less than that within the city centre.

3.3 Future emissions

To allow dispersion modelling predictions for future years to be undertaken both the city centre and west end corridor emission inventories were projected forward to 2010. The emissions from non-road traffic sources were assumed to be constant. Road traffic emissions were assumed to change based on changes to emission standards and traffic growth projections assuming no changes are made to current road traffic movements (This represents the "Do Nothing" scenario).

For city centre grid squares NO_X emissions from road traffic sources are predicted to reduce by approximately 20% between 2005 and 2010 based on the Do Nothing scenario. PM_{10} emissions are predicted to reduce by 27%. The reduction in road traffic emissions on the motorway is greater, however the predictions do not account for changes in traffic flows resulting from the M74 extension.

In the west end corridor grid squares, NO_X emissions from road traffic are predicted to reduce by approximately 23% between 2005 and 2010. PM_{10} emissions are predicted to reduce by approximately 32%.

4 DISPERSION MODELLING STUDY

The dispersion modelling studies each followed a two-staged approach. Modelling predictions were initially undertaken for the base year (2005). The modelling predictions were verified against monitoring data and the modelling input parameters adjusted to customise the model to local conditions and optimise performance and accuracy. Having established a baseline model predictions were undertaken for 2010 based on predicted future traffic flow and calculated emissions data.

Further information on the emissions data used in the modelling study is provided in Appendix 1. Modelling assumptions and selected model input parameters are documented in Appendix 2.

4.1 Glasgow City Centre (AQMA)

The modelling predictions for the city centre included the following emission sources as itemised in the emissions inventory:

- road traffic emissions;
- commercial and domestic emissions; and
- other emission sources including railway, industrial and natural.

The model also accounted for the influence of transboundary sources from areas adjacent to the AQMA.

Traffic flow emissions were included explicitly for each road in the city centre and the surrounding motorway as discussed in Section 2. Emissions from commercial and domestic and 'other' sources were accounted for as area grid sources. The emissions were assumed to be evenly distributed across the grid squares.

Modelling predictions were undertaken for the base year (2005) based on the emissions data compiled in the inventory. The modelling predictions were verified against local monitoring data. Iterations of the baseline modelling were undertaken testing the sensitivity of the model to various input parameters. The input parameters were adjusted to optimise model accuracy and the final modelling prediction adjusted to account for any systematic over or under prediction.

Future modelling predictions were undertaken based on the future emissions inventory. The study also included modelling predictions of pollutant concentrations for other scenarios including the effect of reducing the emissions of the bus fleet (minimum Euro 3) and by introducing a low emissions zone (all vehicles Euro 3 standard minimum) in the city centre AQMA.

4.2 West End Corridor

As with the city centre, modelling predictions were undertaken for the base year (2005) based on the emissions data compiled in the inventory. The modelling predictions were then verified against local monitoring data and iterations of the baseline modelling were undertaken testing the sensitivity of the model to various input parameters. Future modelling predictions were undertaken for the west end based on future emissions inventory data. The future inventory data assumed that the Glasgow Harbour, Queens Dock II and the Finnieston Bridge developments were all complete.

4.3 Springburn Road

Modelling predictions of NO_2 and PM_{10} concentrations for Springburn Road were undertaken using traffic flow data provided by both Glasgow City Council and East Dunbartonshire Council. Modelling predictions were undertaken for the base year (2005) and 2010. The traffic flow data used for the 2010 modelling predictions was obtained assuming a 2% year on year traffic growth.

Modelling predictions were verified against available monitoring data and modelling predictions adjusted where appropriate to account for systematic model over or under prediction.

5 DISPERSION MODELLING RESULTS

5.1 City Centre (AQMA)

A contour plot of the predicted annual average NO_2 concentration in the city centre for 2005 is presented in Figure 8. The predicted concentrations have been adjusted following the results of the model verification exercise. For the purposes of the assessment it is considered likely that the NAQS annual mean objective will be exceeded in areas where the predicted concentration exceeds 45μg/m^3 based on the systematic over-prediction of the model.

The contour plot indicates that the highest concentrations are experienced alongside the M8 motorway between Charing Cross and the Kingston Bridge, with concentrations exceeding 80μg/m^3 predicted at roadside locations on North Street, Newton Street and St Georges Road. Concentrations exceeding 80μg/m^3 are also predicted at the busiest road junctions in the city centre.

Concentrations exceeding 55μg/m^3 are predicted at kerbside locations on most streets in the city centre, with higher concentrations predicted on streets defined as street canyons.

Based on modelling predictions the NO_2 annual mean objective was exceeded across most of the city centre in 2005.

A contour plot of the predicted 99.79th percentile of 1-hour mean NO_2 concentrations is presented in Figure 9. No adjustments have been made to the predicted 1-hour concentrations. Based on the model over-prediction identified by the verification exercise it is considered that the NAQS 1-hour mean objective will be exceeded only where the predicted concentration exceeds 240μg/m^3. Based on predicted levels the hourly mean objective will be exceeded at roadside locations on North Street, Newton Street and at Charing Cross.

Modelling predictions of NO_2 concentrations in 2010 (Figures 10 and 11) indicate a fall in annual average NO_2 concentrations of approximately 5μg/m^3. The footprint of the area predicted to exceed the annual mean objective level in 2010 is reduced from 2005 levels, however exceedences of the objective are still predicted alongside most roads. The hourly mean concentration is predicted to exceed the objective levels close to the motorway between Charing Cross and the Kingston Bridge only.

Contour plots of predicted annual average PM_{10} concentrations in 2005 and 2010 are presented in Figures 12 and 13 respectively. The model verification study indicated that PM_{10} concentrations were under-predicted by the model, however this is based on measurements at two monitoring sites only. No adjustment to predicted concentrations has been made as the magnitude of the model under-prediction is unknown.

The predicted annual mean PM_{10} concentrations in 2005 indicate that it is unlikely that the 2004 PM_{10} objective of 40μg/m^3 will be exceeded, even allowing for the model under-prediction, except in areas of no public exposure close to the M8 between Charing Cross and the Kingston Bridge. Predicted annual average PM_{10} concentrations in 2010 are lower than those predicted in 2005. Predicted PM_{10} concentrations will however exceed the more stringent 2010 annual mean objective of 18μg/m^3 across most of the city centre.

Modelling predictions indicate that it is unlikely that the 24-hour mean objective will be exceeded in either 2005 or 2010 except at roadside locations alongside the M8 between Charing Cross and the Kingston Bridge.

5.2 West End Corridor

A contour plot of the predicted annual mean NO_2 concentrations in 2005 is presented in Figure 14. The predicted levels have been adjusted following the results of the model verification exercise. The results of the modelling study indicate that the annual mean NO_2 objective level will be exceeded on or close to the following roads:

- Sauchiehall Street;
- Dumbarton Road;
- Argyle Street;
- Byres Road;
- University Avenue;
- Woodlands Road;
- Great Western Road;
- Anniesland Cross;
- Balshagray Avenue;
- Hyndland Road;
- Finnieston Street; and
- Maryhill Road.

Predicted annual average NO_2 concentrations also exceed the NO_2 objective level alongside the Clydeside Expressway.

The contour plot of predicted NO_2 concentrations in 2010 (Figure 15) indicates a reduced footprint of NO_2 concentrations above the objective level, even allowing for the proposed west end developments. Typically, non-roadside NO_2 concentrations are reduced by approximately 5µg/m^3. The number of roads with predicted exceedences of the objective is reduced, however exceedences of the objective are still predicted on Balshagray Avenue; Dumbarton Road; Great Western Road; Hyndland Road; Byres Road; Finnieston Street; Maryhill Road; Woodlands Road and alongside the Clydeside Expressway.

A contour plot of the predicted 99.79th percentile of 1-hour mean concentrations is presented in Figure 16. The contour plots indicate that the 1-hour mean objective level is unlikely to be exceeded except on feeder roads close to Charing Cross/M8 motorway e.g. Great Western Road, Sauchiehall Street and St. Vincent Street. NO_2 concentrations exceeding the objective are also predicted on Balshagray Road between the Clyde Tunnel and Anniesland Cross. Predictions of hourly mean concentrations in 2010 indicate that there will be no exceedences of the NO_2 hourly mean objective.

Contour plots of predicted annual average PM_{10} concentrations in 2005 and 2010 are presented in Figures 17 and 18 respectively. The model verification study indicated that PM_{10} concentrations were under-predicted by the model, although that is based on data from one monitoring site only. No adjustment to predicted concentrations have been made.

The predicted annual mean PM_{10} concentrations in 2005 indicate that it is unlikely that the 2004 PM_{10} objective will be exceeded, even allowing for the model under-prediction. Predicted annual average PM_{10} concentrations in 2010 are typically 2-3µg/m^3 lower than those predicted in 2005. Predicted PM_{10} concentrations will, however, exceed the more stringent 2010 annual mean objective at locations close to all roads in the west end.

Modelling predictions indicate that there is potential for exceedence of the 24-hour mean objective of 50µg/m^3 in 2010 (Figure 19) locations close to most roads in the west end.

5.3 Springburn Road

A contour plot of the predicted annual average NO_2 concentration around Springburn Road in 2005 is presented in Figure 20. The model verification exercise indicated that the model was over-predicting NO_2 concentrations in comparison to measured levels, however no adjustments have been made to the predicted levels as the magnitude of the over-prediction was unknown. The modelling predictions indicate that the highest NO_2 concentrations occur at the boundary between Glasgow and East Dunbartonshire. The highest predicted annual mean NO_2 concentrations at this area are below the NAQS objective level, even allowing for the model over-prediction.

A contour plot of the predicted 99.79th percentile of hourly mean NO_2 concentrations is presented in Figure 21. The highest predicted 99.79th percentile of hourly mean concentrations is below the NAQS objective of 200µg/m^3.

The predicted annual mean PM_{10} concentrations in 2010 (Figure 22) are below the NAQS objective levels, however the model was identified as under-predicting PM_{10} concentrations by as much as 40%. Based on this level of under-prediction, the annual mean PM_{10} concentration may be higher than the objective level of 18µg/m^3 across most roadside locations within the Glasgow City boundary. Modelling predictions (Figure 23) indicate that it is unlikely that the 98th percentile of 24-hour mean concentrations will exceed the NAQS objective level of 50µg/m^3.

6 ACTION PLAN FUTURE SCENARIOS

Glasgow City Council requested that two further modelling scenarios be considered within the city centre AQMA which would form part of the ongoing Council air quality Action Plan.

The first scenario considered the implications to local air quality of the proposed Scottish Executive initiative of regulating bus emissions. The initiative would require all buses to conform to the Euro 3 vehicle emission standard.

The second scenario considered the implementation of a low emission zone where all vehicles were required to conform to Euro 3 emissions standards.

The two scenarios considered did not allow for any change in traffic flow levels resulting from the implementation of the schemes. The scenarios considered the assumed 2010 traffic flow levels with all vehicles with emissions poorer than Euro 3 considered to be of Euro 3 standard.

The results of the assessments are discussed in Sections 6.1 and 6.2.

6.1 Scenario 1 – Bus emission regulation

The assessment considered all buses to be of Euro 3 standard. The standard fleet assumption for an urban environment in 2010 is that buses with emissions poorer than Euro 3 account for 20% of the total bus/HGV traffic flow.

The reduction in emissions between Euro 2 and Euro 3 standards for buses is approximately 30% of NO_X and PM_{10} emissions.

Modelling predictions were undertaken for defined points in the city centre based on the standard 2010 assumed traffic flow and the amended 2010 traffic flows with all buses as Euro 3 standard. The results are presented in Table 4.

Table 4 Effect of bus emissions regulation on ground level pollutant concentrations

Location	Annual average NO_2 Concentration (µg/m^3)			Annual Average PM_{10} Concentration (µg/m^3)		
	Base 2010	Regulated 2010	Difference	Base 2010	Regulated 2010	Difference
Hope Street	64	64	0.5	22	22	0.2
Cochrane Street	51	51	0.1	20	20	0.0
Argyle Street	63	63	0.5	22	22	0.2
George Square	66	65	0.8	23	22	0.3
Union Street	68	67	0.7	23	22	0.2
Bath Street	68	68	0.4	22	22	0.1
St Vincent Street	80	79	1.1	25	25	0.4
Renfield Street	65	64	0.5	22	21	0.1
Gordon Street	56	56	0.1	20	20	0.0

The difference in predicted concentrations varies between roads, however in general terms the reduction in annual average NO_2 concentrations is between 0.5-1µg/m^3. The reduction in concentration is greater at areas of higher predicted concentrations. The reduction in annual average PM_{10} concentrations follows a similar pattern, with the reduction in concentration around 0.2-0.3µg/m^3.

The traffic flow data input to the model assumed a standard percentage of HGV/buses across all city centre roads as no specific data were available. Furthermore, the study assumed a standard proportion of buses in the total HGV/bus flow. The number of buses on certain roads e.g. Hope Street or Union Street, may therefore have been underestimated. The reduction in pollutant concentrations may therefore be greater on these roads.

The proposed measure would therefore have a positive effect on air quality within the AQMA, however to achieve compliance with NAQS objectives additional measures would be required.

6.2 Scenario 2 – Low emission zone

The scenario considered all road traffic on city centre roads to be of Euro 3 standard or better. The net effect of introducing the low emission zone on vehicle emissions is presented in Table 5.

Table 5 Variation in city centre road traffic emissions for Low Emission Zone

	Base inventory 2010 (te/yr)	Low Emissions Inventory 2010 (te/yr)	Difference (te/yr)	Difference (%)
Total NO_X emission	73.88	62.77	11.11	15%
Total PM_{10} emission	2.34	2.19	0.15	6.5%

The effect of the low emission zone scenario would be to reduce NO_X emissions by 15% and PM_{10} emissions by 6.5%.

The revised road traffic emissions were input to a dispersion modelling study. Modelling predictions were undertaken for defined points in the city centre based on the standard 2010 assumed traffic flow and the revised road traffic emissions. The results are presented in Table 6.

Table 6 Effect of low emission zone on ground level pollutant concentrations

Location	Annual average NO_2 Concentration ($\mu g/m^3$)			Annual Average PM_{10} Concentration ($\mu g/m^3$)		
	Base 2010	LEZ 2010	Difference	Base 2010	LEZ 2010	Difference
Hope Street	64	59	5	22	19	3
Cochrane Street	51	48	3	20	18	2
Argyle Street	63	59	4	22	19	3
George Square	66	61	5	23	20	3
Union Street	68	63	5	23	20	3
Bath Street	68	62	6	22	20	2
St Vincent Street	80	70	10	25	22	3
Renfield Street	65	59	6	22	19	3
Gordon Street	56	53	3	20	18	2

Modelling predictions indicate that the implementation of a low emission zone in the city centre would reduce ground level NO_2 concentrations by between 3-10$\mu g/m^3$, with the highest decreases in concentration experienced on the busiest roads. The equivalent reduction in the annual average PM_{10} concentration would be 2-3$\mu g/m^3$.

The predicted concentrations reported in Table 6 have not been adjusted to account for the systematic model over-prediction. Based on the magnitude of reduction in predicted concentrations it is likely that the low emission zone would significantly reduce the footprint of areas of predicted concentrations exceeding NAQS objectives in 2010.

7 CONCLUSIONS

7.1 City centre

The emissions inventory indicated that road traffic emissions were the predominant emission source in the city centre, although commercial and domestic emissions form a significant proportion of total emissions, particularly of NO_X.

Dispersion modelling predictions of annual average NO_2 concentrations in 2005 indicate that concentrations are substantially above the NAQS annual mean objective level of 40µg/m^3 and that the requirement of an AQMA remains valid. Dispersion modelling predictions of NO_2 concentrations in 2010 based on no changes to traffic flow (other than constant traffic growth) indicates that annual average NO_2 concentrations will fall by approximately 5µg/m^3 and that the footprint of areas predicted to exceed the objective will be reduced, however there will still be large areas of the city centre in which the objective will be exceeded in 2010.

Modelling predictions indicate that the hourly mean NAQS objective for NO_2 will not be exceeded in the city centre.

Modelling predictions of PM_{10} concentrations in the city centre indicate that the annual mean objective will be widely exceeded in 2010.

The proposed regulation of bus emissions will have a positive effect on air quality in the city centre, however the predicted reduction in pollutant concentrations is insignificant in comparison to the necessary reduction in pollutant concentrations required. Additional action plan measures would therefore be required.

The modelling studies considered the effect of designating a low emission zone in the city centre. Modelling predictions indicate that a low emission zone would have a positive effect on local air quality with reductions in ground level annual average NO_2 concentrations of up to 10µg/m^3 achieved. Annual average PM_{10} concentrations are predicted to be reduced by 2-3µg/m^3. Based on the magnitude of reduction in predicted concentrations it is likely that the low emission zone would significantly reduce the footprint of areas of predicted concentrations NAQS objectives in 2010.

7.2 West end corridor

The inventory of city centre emissions demonstrates that road traffic is the predominant emission source, however the contribution of commercial and domestic sources is significant in areas of high density housing or close to large scale municipal and institutional buildings.

Modelling predictions of pollutant concentrations in the west end indicate that NO_2 concentrations will exceed the annual mean objective level along the corridors of the busiest roads in the wend end. Modelling predictions indicate that NO_2 concentrations will improve in future years, however there will still be areas with annual average NO_2 concentrations above the NAQS objective of 40µg/m^3.

A localised area of hourly mean NO_2 concentrations exceeding the 1-hour mean NO_2 objective was predicted close to the M8 motorway junctions. Predicted concentrations in 2010 indicate that the 99.79th percentile of hourly mean NO_2 concentrations will be below 200µg/m^3.

Modelling predictions indicate that PM_{10} concentrations in 2010 will exceed both the annual mean and 24-hour mean NAQS objectives in the corridors of most roads in the west end.

7.3 Springburn Road

Modelling predictions of pollutant concentrations on Springburn Road, close to the boundary with East Dunbartonshire Council indicate that it is unlikely that NO_2 concentrations will be above either the annual mean or hourly mean NAQS objectives at receptors within the Glasgow boundary.

Modelling predictions indicate that PM_{10} concentrations may be above the annual mean objective level in 2010, but that the 98th percentile of 24-hour mean PM_{10} concentrations will be below the objective level.

8 RECOMMENDATIONS FOR FURTHER WORK BY GLASGOW CITY COUNCIL

During the compilation of the emissions inventory and the dispersion modelling study a number of areas were identified where improvements could be made to inventory or modelling data or where further studies were required. It is anticipated that these improvements will allow the Council to obtain better understanding the existing air quality situation and will aid future action planning measures.

The road traffic flow data used in the study were provided by Glasgow City Council Land Services. The flow data was based on traffic modelling predictions for 2005 from modelling undertaken in 2003. The flow data was provided as a total flow with a number of assumptions provided to allow the vehicle classifications to be identified. The study therefore assumed a constant percentage of HGVs/buses on all roads. This assumption may underestimate the number of HGVs and/or buses on some roads. Predicted traffic flows for 2010 were obtained allowing for a standard growth on all roads.

It is recommended that the traffic flow data should be refined by commissioning new traffic modelling studies which can be calibrated based on 2006 traffic flows (it is understood that Land Services will commission this work later in 2006). The modelling predictions should, if possible, include for a more detailed split in vehicle classifications. The modelling should also predict traffic flows in 2010 (or other agreed year) based on traffic management and air quality action plan measures planned for Glasgow. Some traffic models (e.g. Saturn) allow air quality emissions data to be provided for roads based on vehicle emissions (similar to EMIT) but can also simulate the effect of congestion and traffic queuing on emissions. Where possible the traffic modelling should include for these emissions data as they would improve the road traffic emissions inventory.

One of the main areas of uncertainty in the modelling study was in estimating emissions from non-road traffic sources in the city. The study utilised data provided by the NAEI which is calculated on a "top-down" calculation methodology i.e. assumptions on grid emissions are made based on overall fuel use in a square kilometre (for example) rather than an aggregate of emissions from individual sources.

To improve the emissions inventory of non-road sources a survey of commercial and domestic emissions should be undertaken. Outside of the AQMA the inventory could continue to include an element of 'grid emissions', however large municipal, commercial and institutional building emissions should be explicitly included. To improve the dispersion modelling predictions the more significant commercial and institutional emissions should be treated as individual point sources.

Lastly, the modelling study considered the influence of other areas of the city on air quality levels in the city centre and west end. It is recommended that the emissions inventories and dispersion modelling studies should, initially, be extended to include the areas to the south of the River Clyde and subsequently to include the whole city. The inventory and model outside the AQMA and areas close to the AQMA do not require to be as detailed as within the AQMA.

Appendix 1

Emissions Inventory

The emissions inventory was compiled using the emissions database package EMIT. EMIT allows emissions data to be entered directly for an emissions source or emissions can be calculated based on in-built emissions factors and specified activity data (e.g. road traffic flows).

The source data used to compile the atmospheric emissions inventory are described below.

Road traffic data

Glasgow City Council Land Services Department commissioned a city wide traffic modelling study in 2000. The study used the traffic model, Saturn, to predict traffic flows and speeds on all major road links in the city. The study included all main roads in the city and all minor roads in the city centre. The Saturn modelling predictions were extensively validated against measured traffic flows in 2003. The validated model was used to predict traffic flows in 2005. The model output provided traffic flow data defined in Passenger Carrier Units (PCUs) for AM peak, intermediate and PM peak periods.

The roads which were included in the emission inventory were digitised using GIS software allowing the road geometry to be identified. The digitised roads which were included in the emissions inventory are shown in Figure 3. For the city centre inventory, all roads have been included with the M8 motorway forming the extent of the area to the west and the north, the river Clyde to the south with the area extending east to the High Street and M8 on-ramps at the Glasgow Royal Infirmary.

The base inventory was created using the predicted 2005 traffic flows.

Vehicle Flows - PCUs to AADT

The vehicle traffic flows provided by the Saturn predictions were converted to an AADT flow for three vehicle classes; motorcycles, light vehicles and heavy vehicles. The PCU traffic flows were converted into AADT flows using the factors provided in Table A.1.

Table A.1 PCU to AADT traffic flow conversion factors

Vehicle Class	Percentage of fleet	PCU conversion factor
Motorcycle	0.5	0.4
Light vehicle	91.0	1
Heavy vehicle	8.6	2

The vehicle fleet breakdown figures were provided by Glasgow City Council Land Services department for a previous emissions inventory in 2004[6]. No updated figures were available from the Council. Recent transport assessments for new developments in Glasgow provide similar estimates of vehicle fleet breakdown to the 2004 Council figures. The air quality assessment for the Finnieston Bridge reported a traffic flow of 7% HGVs, whilst the Glasgow Harbour transport assessment quoted a flow of 9% HGVs using the Clydeside Expressway, 10% HGVs on Dumbarton Road during the morning peak and 6% HGVs during the evening peak. It is considered that the original value of 8.6% heavy vehicles is a good estimate of the percentage of heavy vehicles using the whole road network for the entire day.

The PCU factor was determined from previous communication with the transport consultants who conducted the SATURN modelling[7]. The PCU factor is used to convert the PCU flow into a AADT flow. The AM and PM peak flows and the intermediate flow were converted to traffic flows by

[6] Glasgow City Council Atmospheric Emissions Inventory, BMT Cordah report GLC-003, 2004
[7] MVA and Glasgow City Council personal communication

factoring the PCU flows by the relevant PCU factors. The individual vehicle type flows were aggregated to give an overall traffic flow.

National Road Traffic Statistics 2003[8] indicate that the AM and PM peak flows each account for approximately 8% of daily traffic flow. The overall traffic flows were determined by adding the AM and PM peak flows and multiplying them by a factor of 6.25. The individual vehicle classification flows provided in Table 2 were used to determine the AADT for each vehicle class.

Diurnal flow variation

The diurnal variations in traffic flow were determined from automatic traffic count data. The diurnal variation assumed in the study is presented in Table A.2.

Table A.2 Diurnal variation in traffic flow

Time	Ratio of AADT flow		
	Weekday	Saturday	Sunday
00:00	1.3	2.6	3.1
01:00	0.7	2.2	2.6
02:00	0.6	2.0	2.2
03:00	0.6	1.7	2.0
04:00	0.5	1.0	1.4
05:00	0.9	0.9	0.9
06:00	2.7	1.4	1.1
07:00	6.0	2.5	1.8
08:00	7.7	3.9	2.2
09:00	6.5	4.8	3.1
10:00	5.6	5.5	4.6
11:00	5.6	6.4	6.1
12:00	5.8	7.2	7.2
13:00	6.0	7.3	7.9
14:00	6.0	7.1	7.8
15:00	6.3	6.4	7.5
16:00	7.0	6.4	7.3
17:00	7.0	6.6	6.8
18:00	6.1	5.7	5.9
19:00	5.0	5.1	5.2
20:00	3.8	4.0	4.4
21:00	3.2	3.3	3.4
22:00	2.9	3.2	3.1
23:00	2.1	2.9	2.4

Vehicle Emissions

The AADT traffic flows for each link of road were input to EMIT to calculate the atmospheric emissions for that road link. The emissions per road were calculated using the default emission factors contained within the EMIT database. The emissions factors are reported for a number of vehicle sub-categories of engine emissions standards. The emissions factors are calculated as grams of pollutant emitted per vehicle per kilometre travelled and are sensitive to the average speed of the vehicles.

The vehicle engine type is assumed from default vehicle fleet compositions. The composition corresponds to the percentage of vehicles of each fleet corresponding to default European engine classifications. The composition of each vehicle type is built into the EMIT database for each year i.e.

[8] Transport Statistics Bulletin, Road Traffic Statistics 2003. Department for Transport 2004.

in 2010 the vehicle fleet in Glasgow will contain a higher percentage of 'cleaner' engines than in 2005 as new vehicles adopt cleaner technology.

Road geometry and street canyons

Road geometry data required for dispersion modelling include the road width, road elevation and building heights if the road is to be treated as a street canyon. Street canyons generate turbulence, which can result in different concentrations on different sides of the street depending on the alignment of the street to wind direction. Often, elevated pollutant concentrations are found in street canyons as dispersion is reduced. ADMS Urban contains a street canyon module which simulates the effect of street canyons on pollutant dispersal.

For street canyons the road width was entered as the distance between buildings on either side of the road, for other roads the width was assumed to be the distance between the two kerbs. The model uses the road width information to calculate the traffic generated turbulence.

The geometry and vertices of each road were digitised using GIS software and recorded in the inventory. The elevation of the roads was estimated based on site visits. Similarly, building heights for the purposes of identifying street canyons were estimated based on site visits.

Future traffic flows

Projections of future traffic flows were made assuming a standard 2% year on year growth figure. The growth figure was assumed to be constant across all vehicle types.

Commercial and domestic emissions

Emissions from commercial and domestic sources were obtained from the NAEI. Emissions data were obtained on a grid square basis and entered directly into the inventory.

The NAEI calculates emissions from commercial and domestic sources based on fuel consumption data and calculated emissions factors.

Industrial emissions

There are two SEPA-regulated emission sources adjacent to the city centre, namely United Distillers at Port Dundas to the north of the city centre and Allied Distillers at the Gorbals to the south-east of the city centre. Emissions data for each source were obtained from measured data reported in SEPA public records.

Emissions data for non-regulated industrial sources were obtained from the NAEI. The emissions were obtained on a grid square basis and entered directly into the inventory. Emissions from the regulated point sources were disaggregated from the grid emissions data.

Other emissions

Emissions data from other sources, such as railway emissions, emissions from construction sources and natural emissions amongst others, were obtained from NAEI. The emissions data were obtained on a grid square basis and entered directly into the emissions inventory.

Appendix 2

Dispersion Modelling Parameters and

Sensitivity Analyses

A. Model Input Data

Dispersion modelling was undertaken using the model ADMS Urban (version 2.2). The parameters used in the modelling study were selected based on the local situation or were selected following sensitivity analyses.

Meteorological data

The study utilised meteorological data for the most recently available year, 2005, measured at the closest UK meteorological office site at Bishopton (Glasgow Airport). The site is located approximately 20 kilometres north-west of Glasgow City Centre.

A wind rose of the measured 2005 meteorological data is provided in Figure 24. The wind rose shows that the predominant wind direction in 2005 was north-westerly, with significant periods of westerly, south-westerly and easterly winds.

Surface roughness

The interaction of wind flow with the earth's surface generates turbulence, influencing pollutant dispersion. The strength of this turbulence is dependent on the land use, with built-up areas generating more turbulence than open countryside. The modelling study assumed a surface roughness length of 1m.

Monin-Obukhov length

The Monin-Obukhov length is used to characterise the stability of the atmosphere. The modelling study assumed a Monin-Obukhov length of 30m.

Grid depth

The depth of the grids for grid emission sources (all non-road emissions) was varied as part of the sensitivity analyses. The sensitivity analyses considered grid depths of 40m, 50m and 75m.

In general terms, the higher the grid depth assumed then the greater the allowance for mixing and dispersion. A low grid depth assumes all emissions are released and are recirculated in an area close to ground level, thus dispersion is reduced. The sensitivity analysis confirmed the premise with lower ground level concentrations predicted with the higher grid depths.

Grid source emissions in the city centre are influenced by emissions from commercial and domestic sources. The emission point for commercial and domestic emissions is likely to be at roof height. Within the city centre the height of commercial buildings are generally above 50m. The study therefore assumed a mixing depth of 50m within the city centre.

Outside of the city centre the height of buildings are generally lower. A grid mixing depth of 40m was applied outside of the city centre.

Chemistry scheme and background concentrations

The modelling study utilised a chemistry scheme to simulate the secondary formation of NO_2 in the atmosphere. The chemistry scheme requires data for background NO_2, NO and O_3 concentrations.

Background pollutant concentration data for 2005 were obtained from Glasgow City Council's background monitoring station at Waulkmillglen Reservoir. The monitoring station is situated upwind of the greater Glasgow urban area and as such measures the true background pollutant concentration. There were some gaps in the monitoring data. Where such gaps existed substitute data were entered from periods of similar meteorological conditions EXPLAIN WHY.

Modelling predictions were also undertaken using background concentration data from the urban background monitoring station at Glasgow Centre.

Sensitivity analyses of the model chemistry schemes was included. The model has three chemistry schemes:

- NO_X-NO_2 correlation scheme;
- Chemical Reaction Scheme; and
- Chemical Reaction Scheme with trajectory model.

Both the city centre and west end corridor will be influenced by emissions from adjacent grid squares therefore it was deemed necessary to include the trajectory model with the chemistry scheme.

B. Sensitivity Analysis

The sensitivity of the modelling predictions was tested by varying model input parameters. Due to time restrictions, the modelling predictions were conducted for a single month of meteorological data for a limited number of receptor points. A neutral month, June was selected for the modelling predictions.

The results of the sensitivity analysis are presented in Table A.3. The following sensitivity analysis runs were performed:

- chemistry scheme and background concentration file;
- depth of grid source emissions;
- Monin-Obukhov length; and
- variations in grid source emissions.

Table A.3 Results of model sensitivity analysis, Glasgow City Centre, NO_2

Receptor	Period mean monitored concentration (µg/m³)	Predicted concentration dispersion model (µg/m³)									
		Chemistry Scheme Analysis				Grid Depth			Monin-Obukhov length		
		No Chemistry		NOx – NO_2 Correlation		75m	50m	40m	70m	50m	40m
		Waulkmillglen	Glasgow Centre	Waulkmillglen	Glasgow Centre						
Glasgow Centre AURN	33	45	-	75	76	58	66	66	65	66	66
Glasgow Kerbside AURN	63	49	-	81	93	67	73	73	72	73	73
Argyle Street PDT	57	51	-	84	96	69	75	75	75	75	75
Union Street PDT	67	53	-	86	98	73	79	79	78	79	79
Broomielaw PDT	24	42	-	68	79	73	77	76	76	76	76
Gordon Street PDT	54	43	-	73	84	55	62	62	62	62	62

Table A.4 Results of model sensitivity analysis, Glasgow City Centre, PM_{10}

Receptor	Period mean monitored concentration (µg/m³)	Predicted concentration dispersion model (µg/m³)									
		Chemistry Scheme Analysis				Grid Depth			Monin-Obukhov length		
		No Chemistry		NOx – NO_2 Correlation		75m	50m	40m	70m	50m	40m
		Waulkmillglen	Glasgow Centre	Waulkmillglen	Glasgow Centre						
Glasgow Centre AURN	20	-	-	18	29	12	13	13	13	13	13
Glasgow Kerbside AURN	29	-	-	20	31	14	15	15	15	15	15

The sensitivity analysis indicated that the model is insensitive to variations in the Monin-Obukhov length. The variations to the selection of chemistry scheme, background concentrations and depth of grid emissions are however important.

Modelling predictions using Glasgow Centre background concentration data are higher than those using the Waulkmillglen data. It is likely that using the Glasgow Centre data will include some element of double counting, therefore predicted concentrations will be overestimated. The final modelling predictions were therefore undertaken using Waulkmillglen background concentrations.

As has been previously mentioned, the influence of emissions from adjacent grid squares on air quality levels in the city centre (and west end) is important, therefore the model utilised the CRS+Trajectory chemistry scheme.

The depth of grid emissions has an influence on predicted concentrations. Whilst the 75m grid depth gave predicted concentrations closer to measured levels it was felt that this was an overestimate of the grid depth. A 50m grid depth was assumed as discussed earlier in the report due to building heights across the city centre.

It was evident from the sensitivity analysis results that the modelling predictions were substantially over-predicting NO_2 concentrations. The modelling study utilised as accurate input data as was possible for all sources with the exception of the grid emissions data for commercial and domestic emissions obtained from the NAEI. The emissions inventory demonstrated that commercial and domestic emissions comprised a large proportion of emissions in certain areas, particularly in the city centre. Analysis of modelling predictions of vehicle emissions only indicated that the predicted concentrations were of a correct order of magnitude. It was therefore concluded that the likely cause of model over-prediction was the commercial and domestic emissions.

The commercial and domestic emissions were treated as area grid sources, whereas in reality they will be from a series of point sources emitted at height with thermal buoyancy which will aid dispersion. Treating the emissions as grid emissions will therefore underestimate the dispersion of the emissions, thus over-predicting ground level concentrations. To negate this affect the commercial and domestic emissions were reduced by 25% in the final model runs, rather than adjusting the final modelling predictions by a large percentage.

The assumptions made following the city centre sensitivity analysis were also applied to the west end and Springburn Road dispersion modelling studies.

C. Final Modelling Input Data

The final input data used in the modelling studies are summarised in Table A.5.

Table A.5 Final model input data

Modelling Parameter	City Centre Model	West End Model	Springburn Road Model
Chemistry scheme	CRS+Trajectory	CRS+Trajectory	CRS+Trajectory
Background concentration data	Waulkmillglen 2005	Waulkmillglen 2005	Waulkmillglen 2005
Meteorological data	Bishopton 2005	Bishopton 2005	Bishopton 2005
Surface roughness	1m	0.5m	0.5m
Monin-Obukhov length	30m	30m	30m
Grid depth	50m	10m	10m

D. Model Verification Study

The final base modelling predictions were compared against monitoring data to determine the relative accuracy of the predictions.

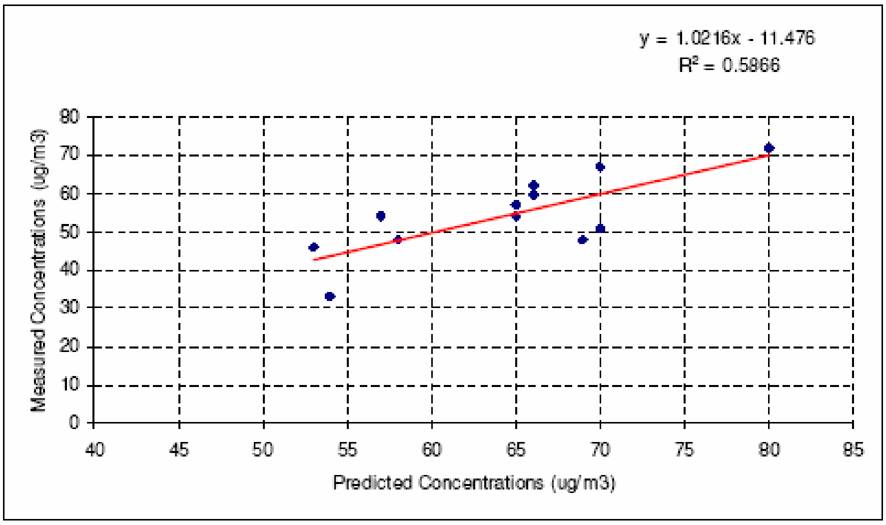
City Centre

The ground level NO_2 and PM_{10} concentrations predicted by the base model at monitoring locations are presented in Table A.6. The monitored concentrations are presented for comparison. The results are presented graphically in Chart A.1.

Table A.6 Predicted NO_2 and PM_{10} concentrations at monitoring sites

Monitoring Location	Predicted NO_2 Concentration ($\mu g/m^3$)	Measured NO_2 Concentration ($\mu g/m^3$)	Difference (%)	Predicted PM_{10} Concentration ($\mu g/m^3$)	Measured PM_{10} Concentration ($\mu g/m^3$)	Difference (%)
Centre AURN	54	33	39%	18	21	-17%
Kerbside AURN	66	62	6%	21	29	-38%
Chambers AURN	53	36	13%	-	-	-
Argyle St	65	57	12%	-	-	-
George Square	69	48	30%	-	-	-
Union St	70	67	4%	-	-	-
Bath St	70	51	27%	-	-	-
St Vincent St	80	72	10%	-	-	-
Renfield St	65	54	17%	-	-	-
Gordon St	57	54	5%	-	-	-
High St	58	48	17%	-	-	-
Hope St North	66	60	9%	-	-	-

Chart A.1 Predicted vs Monitored NO_2 Concentrations ($\mu g/m^3$)



On average the model was found to over-predict city centre annual average NO_2 concentrations by 16% or based on the regression analysis by approximately 11µg/m^3. Analysis of the data indicates that the modelling predictions were closer to measured levels at the areas of higher measured concentration. The model demonstrated less spatial variation in concentrations than indicated by the measurements. The observations indicated that it is likely that the model is overestimating the effect of grid emissions or the effect of secondary pollutant formation, thus resulting in a higher 'background concentration' for the city centre. Correspondingly, the model is underestimating the impact of road traffic emissions at hot-spot locations, possibly as a result of not taking congestion fully into account in the emissions inventory.

The final modelling predictions were adjusted to account for the model over-estimation. It was considered more appropriate to reduce the modelling predictions by 16% rather than a fixed concentration level as following the fixed level approach would give a disproportionate effect on some receptor locations.

The model was found to under-predict PM_{10} concentrations by up to 40%. The under-prediction may occur as the model may not fully account for regional pollution episodes resulting from transboundary sources or localised fugitive or recirculated emissions, as well as the increased emissions from traffic congestion.

West End

The ground level NO_2 and PM_{10} concentrations predicted by the base west end model at monitoring locations are presented in Table A.7. The monitored concentrations are presented for comparison. It should be noted that the monitoring sites in the west end are more dispersed than in the city centre. The results are presented graphically in Chart A.2.

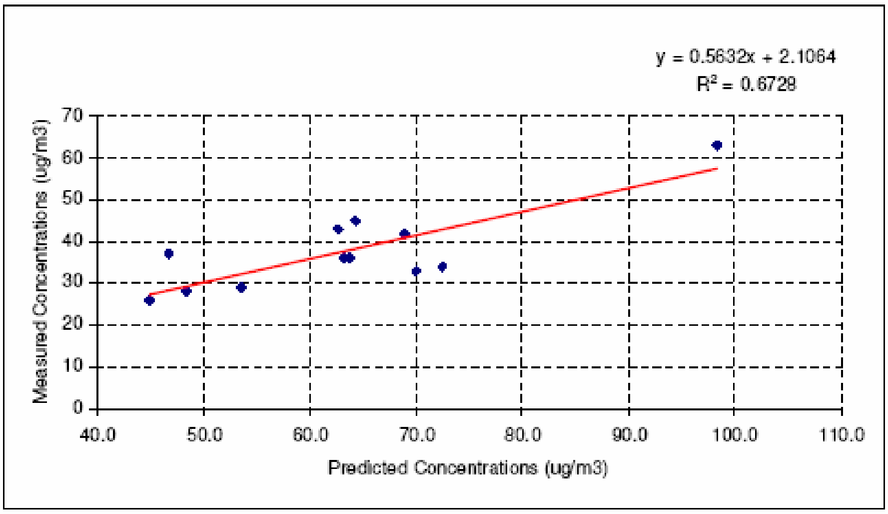
Table A.7 Predicted NO_2 and PM_{10} concentrations at west end monitoring sites

Monitoring Location	Predicted NO_2 Concentration (µg/m^3)	Measured NO_2 Concentration (µg/m^3)	Difference (%)	Predicted PM_{10} Concentration (µg/m^3)	Measured PM_{10} Concentration (µg/m^3)	Difference (%)
ByresRd AUTO	64	36	44%	20.4	23	-13%
Anniesland Cross	69	42	39%	-	-	-
Balshagary Ave	70	33	53%	-	-	-
Dumbarton Rd	63	43	31%	-	-	-
North St	98	63	36%	-	-	-
Byres Rd	64	45	30%	-	-	-
Queen Mag Dr	63	36	43%	-	-	-
Finnieston St	47	37	21%	-	-	-
Napeirshall St	73	34	53%	-	-	-
Castle St Partick	54	29	46%	-	-	-
Broomhill Road	45	26	42%	-	-	-
Lawrence St	49	28	42%	-	-	-

On average the model was found to over-predict the annual mean NO_2 concentrations by 40%. As with the city centre model it is likely that the over-prediction results from the treatment of grid emissions. The modelling predictions were adjusted to account for the over-prediction.

The model was found to under-predict PM_{10} concentrations by 13%. The under-prediction may occur as the model may not fully account for regional pollution episodes resulting from transboundary sources or localised fugitive or resuspended material.

Chart A.2 Predicted vs Monitored West End NO_2 Concentrations ($\mu g/m^3$)



Springburn Road

The ground level NO_2 and PM_{10} concentrations predicted by the base Springburn Road model at monitoring locations are presented in Table A.8. The monitoring data used to verify the model was provided by East Dunbartonshire Council and refers to monitoring data outside of Glasgow. It should be noted that East Dunbartonshire Council apply a different bias correction factor from Glasgow City Council to diffusion tube monitoring results, thus monitored levels are higher than are recorded at equivalent sites in the Glasgow City Council area.

Table A.8 Predicted NO_2 and PM_{10} concentrations at Springburn Road monitoring sites

Monitoring Location	Predicted NO_2 Concentration ($\mu g/m^3$)	Measured NO_2 Concentration ($\mu g/m^3$)	Difference (%)	Predicted PM_{10} Concentration ($\mu g/m^3$)	Measured PM_{10} Concentration ($\mu g/m^3$)	Difference (%)
Bishopbriggs Automatic Site	30	36	-20%	17	23	35%
Bishop 5	20	20	0%	-	-	-
Bishop 6	44	39	11%	-	-	-
Bishop 8	20	21	-5%	-	-	-
Bishop 12	42	29	31%	-	-	-
Bishop 13	49	29	41%	-	-	-

The modelling predictions therefore vary from a 20% under-prediction to a 40% over-prediction. It is believed that there are site specific issues associated with some of the monitoring sites which cannot be replicated by the model (sheltering of monitoring sites and complex building layouts). The monitoring sites closest to the Glasgow City Council boundary indicate that the model over-predicts by between 30-40%.

BMT Cordah Limited
ENVIRONMENTAL CONSULTANCY
AND INFORMATION SYSTEMS

NO_2 Concentrations in Glasgow Street Canyons

A Report for Glasgow City Council

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CONTENTS

Table Contents List

Figure Contents List

1 INTRODUCTION

BMT Cordah Limited has been commissioned by Glasgow City Council (the Council) to undertake a study to investigate nitrogen dioxide (NO_2) concentrations at different heights in urban street canyons. The aim of the study is to determine how NO_2 concentrations change as height above street level increases, and to determine whether Glasgow residents living in busy street canyons may be exposed to NO_2 concentrations which exceed national air quality standards.

Like most large urban areas, Glasgow suffers from poor air quality in many locations, with road traffic being a significant source of atmospheric pollution. Glasgow City Council's Updating and Screening Assessment of air quality, published in 2003, attributed 78% of total nitrogen oxides, (NO_x), emissions to road transport[1].

Under the Environment Act 1995, the Council is required to assess ambient concentrations of NO_2, along with a number of other air pollutants, within its area against air quality objectives defined in the National Air Quality Strategy (NAQS). There are two air quality objectives for NO_2 which are presented in Table 1.

Table 1: NAQS Objectives for NO_2

NO_2 Concentration µg/m^3	Measured as	Permitted Exceedences	Equivalent Percentile
40µg/m^3	Annual mean	0	na
200µg/m^3	1 hour mean	18	99.79th

Monitoring of NO_2 conducted by the Council over a number of years has indicated that the NAQS objectives for NO_2 have been exceeded at numerous locations across the City Centre. In 2002, the Council declared the city centre an Air Quality Management Area (AQMA) for NO_2. The AQMA is displayed in Figure 1.

NO_2 concentrations in the city must be assessed against the NAQS objectives at all locations where members of the public are expected to be regularly present. Technical guidance[2] published to assist local authorities in their assessment of air quality states that the ambient concentration of pollutants should be assessed at *"locations which are situated outside of buildings or other natural or man-made structures, above or below ground, and where members of the public are regularly present"*. Examples of locations where the annual mean objective is assessed include the building facades of residential properties, schools, and libraries. The 1-hour mean objective is also assessed at these locations and any outdoor locations where the public might spend 1 hour or more, such as the pavements of busy shopping streets.

There are very few residential properties at ground level within the Glasgow AQMA, with the majority of residents living in flats above street level. Many of these streets are classed as street canyons having relatively narrow streets compared to the building height. This can lead to increased pollutant concentrations as a result of reduced air dispersion within the canyon. It is of great interest, therefore, to investigate how pollutant concentrations change with height, and to determine whether concentrations which are over NAQS objectives at street level will necessarily lead to exceedences of the objectives at greater heights.

This study investigated NO_2 concentrations at three street canyon locations inside the Glasgow AQMA; namely Hope Street, Montrose Street and Cochrane Street, which are highlighted in Figure 1. NO_2 concentrations were measured at a number of heights over a 6-week period between March and April 2006.

This report begins with a discussion on the various mechanisms which affect pollutant dispersion and concentrations in the urban environment. These mechanisms include street geometry (street width and building height), meteorology and chemistry.

The report also includes a synopsis of atmospheric dispersion modelling techniques in the urban environment. Dispersion models are valuable tools used for the purposes of Local Air Quality Management (LAQM), so their ability to replicate observed pollutant dispersion patterns, including vertical distribution, is of great importance. A comparison is made between measured data and predictions from a commercially available dispersion model.

2 LITERATURE REVIEW

2.1 Urban Geometry and Atmospheric Flow

The elevated concentrations of air pollutants in urban areas as a result of high traffic volume has generated great interest in understanding the processes that govern pollutant dispersion. Understanding how air pollutants disperse within the urban environment can assist public health and environmental protection officers to identify and tackle areas of poor air quality, planners can design new urban developments to generate optimal ventilation and dispersion, and emergency contingency plans can be developed to respond to incidents such as toxic releases in urban areas.

Pollutant dispersion is governed by the complex interaction of atmospheric flow with urban geometry including buildings of varying height, narrow and wide streets, junctions and open areas. To understand these processes, many studies have focussed on dispersion within idealised urban situations, such as the street canyon.

The "classic" street canyon is characterised by a long, straight street, with buildings of identical height on either side. The ratio of building height to street width (H/W) for the classic street canyon is 1, with deeper canyons having ratios of <1 and wider canyons >1. The main features of the classic canyon are well understood. When the above-roof wind direction is perpendicular to the direction of the street, and is of sufficient wind speed, one or more recirculation vortices are generated within the canyon. This has the effect of increasing pollutant concentrations at the leeward side of the street and decreasing concentrations at the windward side of the street. When the above-roof wind direction is parallel to the street, the wind is channelled along the street, and pollutant concentrations at either side of the street are approximately equal. Concentrations are also approximately equal at low wind speeds (<2m/s), as recirculation vortices do not form.

Street canyon effects have been investigated experimentally through various types of studies including physical measurements of pollutant concentrations and wind flow within a canyon, numerical modelling and wind tunnel experiments. The leeward/windward concentration variation has been confirmed in numerous studies including Xie et al[3], who measured CO concentrations in a street canyon in China and found concentrations on the leeward side to be twice the concentration on the windward side. Similar results are observed in studies by Berkowicz et al[4] and Kukkonen et al[5]. This effect has also been noted in wind tunnel tracer experiments such as Chan et al[6] and Sagrado et al[7]

In reality, the flow through an urban area is not idealised. When the above-roof wind direction is not perpendicular or parallel to the street, the vortices which form are more complex. The formation of vortices is also influenced by the uniformity of building heights on both sides of the canyon and the presence of junctions or gaps between buildings. Additionally, turbulence generated by vehicles at ground level can strongly affect pollutant dispersion, particularly at low wind speeds[8,9].

Dobre et al[10] conducted a study at a junction in London where they took flow field measurements at four heights within the streets leading to the junction. They found that actual flows were similar to idealised street canyons despite the irregularity of the junction. For oblique wind directions, the flow within the canyons was linearly related to the parallel and perpendicular components of the above-roof wind direction.

2.2 Modelling

Atmospheric dispersion modelling is an important tool widely used by industry, regulatory bodies and local authorities for air quality impact assessments and local air quality management. As shown above, the processes which govern dispersion in urban areas are complex, requiring large computer processing time and power to run a detailed model within a reasonable time period.

There are some models available that adapt well established Gaussian-type models for urban use by including simplified modules of urban dispersion processes such as the street canyon. Examples of this type of model are ADMS-Roads and ADMS-Urban, developed by Cambridge Environmental Research Consultants (CERC)[11]. These models allow the user to model road sources and specify street canyon geometry. ADMS-Urban is designed to simultaneously model several hundred road sources as would be found in a large urban area.

The street canyon module used by the ADMS programmes is based on a Danish model, the Operational Street Pollution Module (OSPM)[12]. This model simplifies the flow and dispersion within a street canyon to produce a practical use street canyon module. This module has been validated against field measurements in Finland and found to give good agreement against CO and NO_x but not so good agreement against measured NO_2 concentrations[13]. The user enters details of the road traffic emissions on the street, meteorological data, the building-to-building width of the canyon and the height of the buildings (assumed to be uniform on both sides). The model uses these data to calculate a recirculation region, the width of which is dependent on the roof-level wind speed and the canyon height. The concentration within the recirculation region is calculated on a balance of inflow from vehicle emissions within the recirculation region, and outflow as pollutants escape.

A separate study compared the predictions of three simplified street canyons models, including OSPM, against measurements in Belgium[14]. It found that OSPM made good predictions against measured concentrations over long averaging periods (annual mean), while under-predicting against short-term averaging periods or percentile comparisons.

The use of computational fluid dynamics (CFD) to simulate flow and dispersion in urban streets is becoming more common, particularly with increasing computing power currently available. Use of CFD is particularly advantageous as it can be used, for example, in street canyons which have non-uniform building height or where the flow is affected by corners or junctions. While simplified models require such a street canyon to be idealised and would only account for above-roof flow, a CFD model could be inclusive of all these factors, giving a more accurate simulation of pollutant dispersion. Some examples of CFD modelling studies are summarised below.

Dixon et al[15] compared normalised flow and pollutant concentrations from a CFD model to measurements from a typical street canyon in York. The model was successful in reproducing observed flow features including recirculation, corner vortices, channelling and convergence for most wind directions. Modelled concentrations generally over-predicted measurements, attributed in part to the model underestimating vertical velocities and turbulent kinetic energy for some wind directions. The model also made no account of increased traffic emissions during periods of congestion.

Xiaomin et al[16] conducted numerical CFD modelling to investigate how different street canyon configurations affect pollutant dispersion. The study identified three distinct flow regimes within the street canyon which are dependent on the ratios of building height to street width (H/W) and building height ratios on either side of the street (H_1/H_2). These regimes were validated against wind tunnel data, although not against actual real-time measurements of street canyon flows.

Chan et al[17] also identified three dispersion regimes within street canyons, and used CFD to determine the street canyon geometry which resulted in optimal pollutant dispersion. They proposed some rules of thumb which would result in improved ventilation in street canyons including non-uniform building height and a maximum ratio of canyon length to building height to promote best flow regime for dispersion.

Mumovic et al[19] constructed a three-dimensional CFD model of the complex series of streets and street canyons which make up Glasgow's AQMA. They compared its predictions against monitoring data for a number of pollutants at several automatic monitoring sites in Glasgow in order to assess its potential for regulatory use. While initial model runs show satisfactory agreement with actual measurements, the study concludes that this accuracy is dependent on the experience of its users.

2.3 Chemistry

Other than atmospheric flow and dispersion, the most significant process which determines secondary pollutant concentrations, such as NO_2, in urban areas and street canyons is chemical reaction. In an urban area such as Glasgow, the principal source of NO_2 is road traffic, where emissions of total NO_x can include up to 10% NO_2.

Upon emission of NO_x to atmosphere, under typical tropospheric conditions, NO is converted to NO_2 by the following reaction:

$$NO + O_3 \rightarrow NO_2 + O_2 \qquad (1)$$

This process occurs on a time scale of a few seconds to a minute, and is dependent on the ambient concentration of ozone. During daylight hours, NO_2 is converted back to NO through photochemical reaction which also results in regeneration of ozone:

$$NO_2 + h\nu \rightarrow NO + O \qquad (2)$$

$$O + O_2 + M \rightarrow O_3 + M \qquad (3)$$

In typical unpolluted atmospheric conditions, this chemical cycle comes to equilibrium, or a photostationary state, within a few minutes, with the concentrations of NO and NO_2 related to ozone concentration by the following equation:

$$[O_3] = J_2[NO_2]/k_1[NO] \qquad (4)$$

where J_3 is the rate of photolysis of NO_2 and k_2 is the reaction rate of NO with O_3.

In polluted urban air, however, with higher NO_x concentrations, reaction 1, the production of NO_2 and loss of O_3, is dominant. Ozone concentrations in rural areas tend to be higher than concentrations in urban areas as a result of this reaction.

There are other chemical mechanisms that are involved in the conversion of NO to NO_2, one being the reaction of NO with oxygen;

$$2NO + O_2 \rightarrow 2NO_2 \qquad (5)$$

This is a slow reaction at typical background? NO concentrations, and only becomes important at large NO concentrations (500-1000ppb or 260-525$\mu g/m^3$).

As a result of NO_2 destruction by sunlight, there is a seasonal variation in NO_2 concentrations, with higher concentrations in winter than in summer. Kourtidis et al[19] measured VOC, ozone, NO_2 and SO_2 concentrations at a height of 13.5m in Greece. Ozone concentrations were higher in summer than in winter and NO_2 concentrations were higher in winter than in summer. This is explained in part by increased sunlight in summer resulting in NO_2 photolysis and the creation of ozone. Primary pollutant concentrations (VOC and SO_2) were higher in winter than in summer, attributed to increased wind speed and dispersion, and lower traffic volume, in summer.

Xie et al[3] measured CO, NO, NO_2 and O_3 concentrations at different heights on both sides of a street canyon in China. They measured the pollutants at 5m, 15m, 25m and 35m on the leeward side of the canyon, and at 5m, 15m and 35m on the windward side. The results show that ozone and NO_2 concentrations vary with height in different manners on the windward and leeward side of the street. At the windward side, highest ozone concentrations are found at 35m and lowest ozone concentrations at 5m, while highest NO_2 concentrations are found at 5m and lowest NO_2 concentrations are at 35m. This is expected following the chemistry scheme outlined above. At 5m, NO_2 concentrations are greatest due to proximity to the emission source and conversion of NO to NO_2 with consumption of ozone. It is also clear that ozone concentrations peak during the middle of the day, when photolysis of NO_2 is greatest. On the leeward side of the street, however, the vertical profile is more complex. Highest ozone concentrations are still at 35m, with peak concentration during the middle of the day, however, lowest concentrations are found at 25m with concentrations at 5m and 15m higher than at 25m. There is no peak ozone concentration in the middle of the day at 5m, 15m or 25m. NO_2 measurements on the leeward side show lowest concentrations at 35m and highest at 5m, however concentrations at 25m were greater than concentrations at 15m. It seems that the vertical profile of pollutants on the leeward side of the canyon are not as straight forward at the profile on the windward side, and concentrations do not always necessarily decrease as height increases.

Vakeva et al[20] determined that concentrations of CO and NO_x in a street canyon in Finland decreased by a factor of five between street and roof-top levels, while ozone increased by a factor of eight. Laxen and Noordally[21] measured NO_2 concentrations to a height of 20m in a London street canyon, finding a general decreasing trend, although NO_2 concentrations increased between some levels.

Baker et al[22] conducted CFD modelling of reactive pollutants in a street canyon by extending a large eddy simulation (LES) previously validated for wind flow and turbulence in a wind tunnel experiment for non-reactive pollutants. Results were compared against measurements taken by Xie et al[1] and were found to be consistent, with NO and NO_2 concentrations greater on the leeward side of the canyon.

3 GLASGOW AQMA EXPERIMENT DETAILS

Monitoring of NO_2 was carried out using passive diffusion tubes at three locations in Glasgow, namely Hope Street, Montrose Street and Cochrane Street. The locations are shown in Figure 1. The Hope Street and Montrose Street canyons lie on a north-south axis, with Cochrane Street lying east-west.

Hope Street is one of the busiest streets in Glasgow, and experiences frequent traffic congestion. The monitoring location in Hope Street is in a deep street canyon section of the road. Additionally, the street is heavily used by buses and taxis, with frequent queuing of buses and taxis at bus stops and taxi ranks. There is an automatic monitoring site at the southern end of Hope Street, approximately 100m south of the monitoring position, which is part of the Automatic Urban and Rural (monitoring) Network (AURN). Diffusion tubes were deployed at heights of 5m, 10m, 15m, 25m and 35m. The canyon heights on either side of the street at not uniform, with the height of the buildings on the east side (where monitoring took place) reaching approximately 50m, while on the west side, the building heights along the length are irregular, ranging from approximately 20-40m. The buildings directly opposite the monitoring position are around 30m in height.

The sites at Montrose Street and Cochrane Street are located close to each other, near Glasgow City Chambers. The Montrose Street monitoring site is located approximately 30m from the junction with Cochrane Street, and a similar distance to a junction with Ingram Street. All these streets are busy streets, with generally free-flowing traffic although all can be subject to congestion. It is likely that the flow in this area will be complex, with the flow in each street influencing each other. Since Cochrane Street and Montrose Street are perpendicular to each other, it is likely that there will often be recirculation and channelling occurring simultaneously. The diffusion tubes at Cochrane Street were located at 5m and 10m, while at Montrose Street they were located at heights of 5m, 15m, 20m, 25m and 30m. The building heights on both sides of Montrose Street are equal, and are approximately 30m in height. Building heights on Cochrane Street are approximately 20m on either side at the monitoring location, although the heights are irregular along the length of the street.

The diffusion tubes were exposed in three periods of between 10 and 14 days, from 10th March 2006 to 21st April 2006. Tubes were exposed in triplicate with the average concentration of the three tubes used. Diffusion tube monitoring is limited by the need to expose the tubes for long time periods, only allowing the average concentrations over the monitoring period to be obtained. As such, it is not possible to identify any short term trends in NO_2 concentrations, which is unfortunate, as NO_2 concentrations can vary greatly over short time periods, as traffic flow fluctuates and wind direction changes. However, diffusion tubes have the advantage of being readily deployed at numerous locations and heights.

When diffusion tubes are used in terms of LAQM, it is normal practice to apply a bias adjustment factor to the results, calculated by comparing results from diffusion tubes co-located with an AURN monitoring site. The bias adjustment factor is unique to the laboratory that analyses the diffusion tubes, and accounts for any under or over-read compared to automatic monitoring. This factor should be applied to the diffusion tube results before they are compared against NAQS objectives. A bias adjustment factor is not applied to the results in this study, since monitoring occurred over an insufficient time period to allow an accurate factor to be calculated. However, to gain an indication of the diffusion tube performance against a continuous monitoring technique for NO_2, three of the tubes were co-located with the AURN site at Glasgow City Chambers. The results of the diffusion tube/AURN co-location are presented in Table 2, which shows that the diffusion tubes consistently under-estimate concentrations measured by the AURN. The largest difference between diffusion tube and AURN concentrations (36%) occurred during Period 1, when the AURN had its lowest data capture rate. It is likely that this had some impact on the difference between the two measurement methods. Additionally, the AURN data has not been ratified, and could be altered upon ratification.

It is likely, however, that the diffusion tubes under-estimate by an average of around 25%, which is a typical result for diffusion tube/AURN co-location studies[23].

Table 2: Results of co-located diffusion tubes and AURN monitoring

Period	From	To	Diffusion Tube NO_2 Concentration	City Chambers AURN NO_2 Concentration	AURN Date Capture	Difference
1	10/03/06	24/03/06	35.9	56.4	88%	-36%
2	24/03/06	07/04/06	39.7	49.6	99%	-20%
3	07/04/06	21/04/06	32.8	45.3	99%	-28%

4 RESULTS AND DISCUSSION

The results of the diffusion tube monitoring results at the three sites are presented in Table 3 and in Charts 1, 2 and 3.

Table 3: Street canyon diffusion tube monitoring results

Site	NO_2 Concentration (µg/m³)			Height (m)
	Period 1	Period 2	Period 3	
Hope St 1	138.7	116.8	102.9	5
Hope St 2	87.7	73.7	59.2	10
Hope St 3	73.2	65.1	56.1	15
Hope St 5	63.6	48.2	37.7	25
Hope St 7	60.0	57.6	39.6	35
Montrose St 1	49.1	38.8	34.9	5
Montrose St 3	45.3	37.0	30.9	10
Montrose St 4	42.1	34.5	29.9	20
Montrose St 5	35.6	35.8	31.7	25
Montrose St 6	37.1	31.3	31.1	30
Cochrane St 1	42.8	42.3	33.4	5
Cochrane St 2	35.9	39.7	32.8	10

Chart 1: Measured NO_2 Concentrations at Hope Street

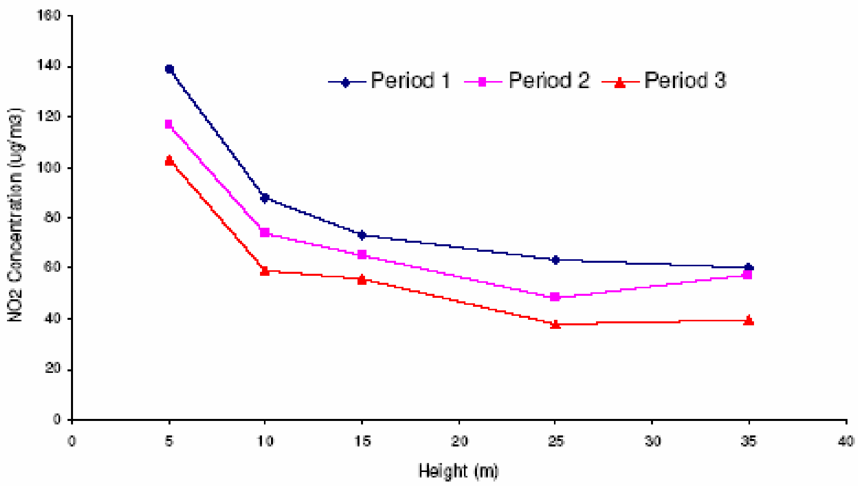


Chart 2: Measured NO_2 Concentrations at Montrose Street

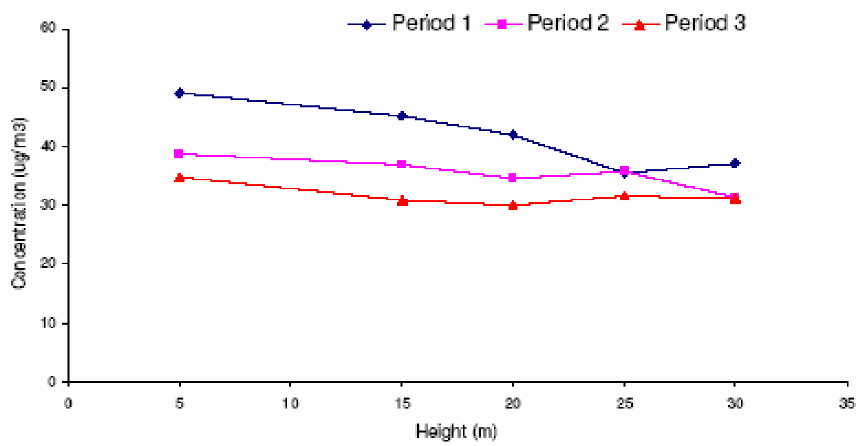
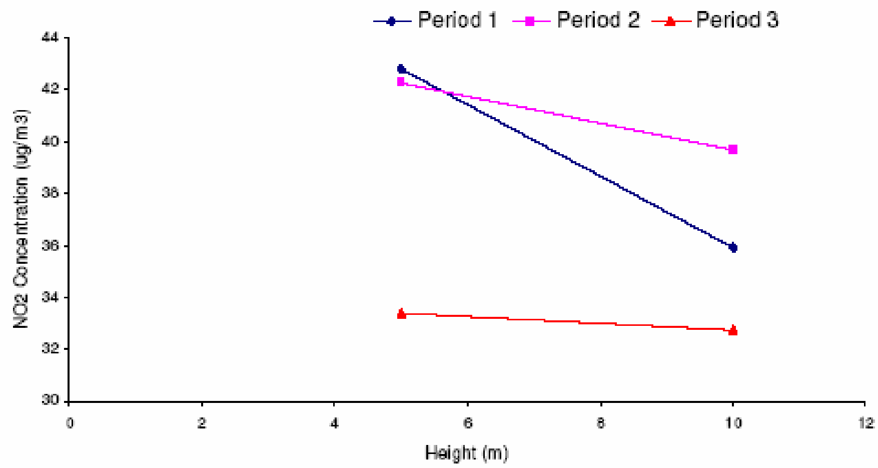


Chart 3: Measured NO_2 Concentrations at Cochrane Street



4.1 Hope Street

Measured NO_2 concentrations were greatest at Hope Street, with mean concentrations of over 100µg/m^3 measured during all three monitoring periods, with the highest measured concentration being 138.7µg/m^3 at 5m during Period 1. Vertical concentration profiles differed slightly between Period 1 and Periods 2 and 3. During Period 1 the largest concentration decrease was 37% between 5m and 10m. The rate of decrease reduced as height increased, with concentration reductions being 17% between 10m and 15m, 13% between 15m and 25m and 6% between 25m and 35m. During Periods 2 and 3, the average decrease was 40% between 5m and 10m, 8% between 10m and 15m and 29% between 15m and 25m. Between 25m and 35m, NO_2 concentrations were observed to increase by 20% during Period 2 and increase by 6% during Period 3.

4.2 Montrose Street

The vertical NO_2 concentration gradients at the Montrose Street site were similar between the lowest three levels during all measurement periods, with concentrations reducing by an average of 8% between 5m and 15m, and reducing by an average of 6% between 15m and 20m. During Period 1, concentrations reduced by 15% between 20m and 25m, and were observed to increase by 4% between 25m and 30m. During Period 2, concentrations were observed to increase by 4% between 20m and 25m and decrease by 13% between 25m and 30m. Similarly, during Period 3 concentrations were observed to increase by 6% between 20m and 25m, and decrease by 2% between 25m and 30m.

4.3 Cochrane Street

NO_2 concentrations measured at the Cochrane Street monitoring sites decreased between 5m and 10m by 16% during Period 1, 6% during Period 2 and 2% during Period 3.

4.4 Analysis of results

One of the interesting features of the measured NO_2 concentrations is the increase in NO_2 concentration as height increases which are observed at the Hope Street and Montrose Street sites during all measurement periods except Period 1 at Hope Street. At Hope Street, Periods 2 and 3, the increases occurred between 25m and 35m, while the increases at Montrose Street occurred between 25m and 30m during Period 1 and between 20m and 25m during Periods 2 and 3.

It would be expected that the effect of dispersion within the canyon would be to dilute the NO_2 concentration and lead to decreasing concentration with height. The concentration gradient between the lower levels shows NO_2 concentrations decreasing with height, indicating that dispersion and dilution are the dominant factors that determine NO_2 concentrations.

The increases in concentration at some heights could be attributed to the relative rates of chemical reaction taking place at different heights within the canyons. As discussed, the concentration of NO_2 within the canyon depends on the production of NO_2, mainly through the reaction of NO and ozone, and its destruction through photolysis. It is possible that as height increases, the balance of these chemical reaction rates fluctuates. The studies by Xie et al[1] and Vakeva et al[20] measured highest ozone concentrations at roof-level, indicating that there are high ozone concentrations in the atmosphere outside the canyon. Vakeva et al noted that ozone concentrations at roof level were eight times higher than concentrations at street level yet Xie et al found that ozone concentrations at 25m on the leeward side of the canyon were lower than concentrations at 5m and 15m. It is possible that as the ozone enters the canyon it is quickly consumed through reaction with NO, leading to a large NO_2 production. This would explain why the increase is observed near the top of the canyons, as the ozone reacts quickly upon entering the canyon.

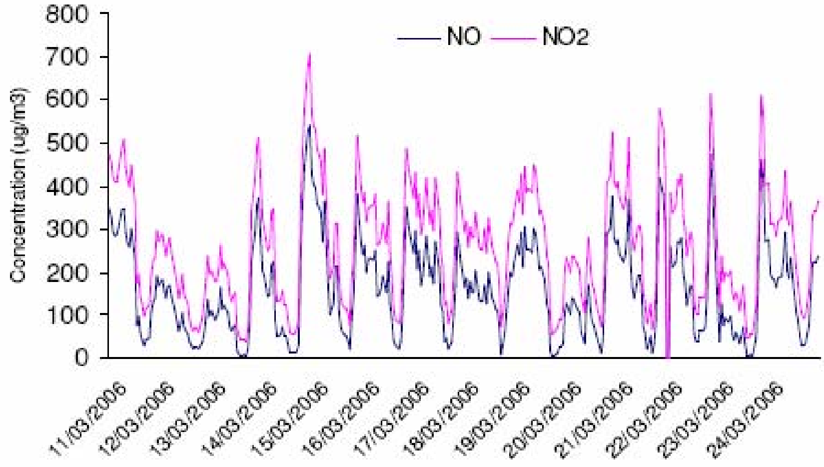
The wind direction during Period 1 was predominantly easterly, compared to predominantly westerly winds during Periods 2 and 3. The Hope Street and Montrose Street canyons lie on a north-south axis, and monitoring took place on the east side of the street. This means that the monitoring locations are on the leeward side of the street when wind direction is easterly and they are on the windward side of the street when the wind direction is westerly. This supports the idea of above-canyon ozone reacting at height as incoming wind and ozone to a canyon is initially carried to the windward side of the canyon, where it can first react with NO rising from street level, leading to NO_2 production. This offers a potential explanation for the observations at Hope Street Periods 2 and 3 and Montrose Street Periods 2 and 3, where the monitoring sites were on the windward side of the canyon. At Hope Street Period 1, the wind direction was such that any incoming ozone might be initially transported to the opposite side of the canyon to where monitoring occurred. The ozone then had to circulate all round the canyon, including the more heavily polluted lower levels, before reaching the monitoring sites at the top of the canyon on the leeward side. There was no increase in NO_2 concentrations observed at the highest levels of Hope Street during Period 1.

Also, during Period 1 meteorological conditions were more stable, with lower wind speeds, leading to high pollutant concentrations in the canyon as a result of reduced dispersion. Chart 4 shows the measured hourly NO, NO_2 and total NO_x concentrations during Period 1 at the Glasgow Kerbside AURN site. Measured NO concentrations were frequently around 500µg/m^3, enough that some of the NO would be converted to NO_2 through reaction with oxygen (Reaction 5). Highest measured NO_2 concentrations in both canyons were during Period 1, likely to be as a result of reduced dispersion due to the meteorological conditions and the monitoring sites being on the leeward side of the street.

Another feature that is apparent is that the decrease in NO_2 concentrations with height is more dramatic at the Hope Street site, with large concentration decreases occurring between levels. Concentration decreases between levels at Montrose Street are significantly less. Possible explanations for this include the geometry of the Hope Street canyon generating increased dispersion than at Montrose Street, the effect of traffic induced turbulence at Hope Street being more significant than at Montrose Street or higher NO_2 concentrations being consumed faster through chemical reaction.

The general vertical profile of NO_2 concentrations in street canyons is for concentrations to initially decrease over the first 20m-30m. There is then an area where NO_2 concentrations increase, likely a result of higher ambient concentrations of ozone which reacts quickly with NO to produce NO_2. This area often occurred between the top two levels where measurements took place. The initial rate of decline in NO_2 concentrations is dependant upon NO_2 concentrations at street level, with the largest decreases occurring in Hope Street where initial concentrations were highest. The results have indicated that NO_2 concentrations decreased by around 40% between heights of 5m and 10m in Hope Street, while at Montrose Street, concentrations between the same two levels decreased by an average of 8%. The observed increase in NO_2 concentrations at around 20m-30m does not result in concentrations being higher than they are at 5m, 10m or 15m. Highest concentrations are measured at 5m, which corresponds to the typical height of a first floor residential dwelling.

Chart 4: NO_2 concentrations measured at Glasgow Kerbside AURN Period 1



5 ATMOSPHERIC DISPERSION MODELLING

An atmospheric dispersion modelling study was conducted to compare the ability of a commercial dispersion model to replicate observed NO_2 concentrations at different heights within the street canyon. The modelling study used the model ADMS-Urban, an urban scale model licensed to Glasgow City Council. In order to conduct modelling, there are a number of input parameters which are required including meteorological data, traffic flow information and background pollutant concentration.

5.1 Emission sources

In this study, only road traffic emissions are explicitly modelled. Information on road sources was supplied by SATURN road traffic modelling conducted by the Land Services department of Glasgow City Council.

ADMS-Urban requires road traffic data in the number of vehicles per hour, vehicle classification (percentages of light and heavy vehicles), and diurnal traffic variation information. The SATURN data provided by Land Services contains traffic flow data in passenger carrier units (PCUs) for AM, PM and intermediate peak hour flows, and average vehicle speed, for all road links in Glasgow city centre. This is converted into Annual Average Daily Traffic (AADT) flows, and then hourly flows for light vehicles, heavy vehicles and motorcycles following the methodology of E_GLC_005[24]. The diurnal flow was calculated based on road traffic count data gathered at a number of locations around the city centre by Land Services. While road traffic flow information has been gathered at all roads in the city centre, only the roads in the immediate vicinity of the monitoring sites are modelled explicitly in this study. Emissions from all other sources are accounted for in the treatment of background pollutant concentrations, discussed in Section 5.5.

5.2 Meteorology

The model requires a minimum input of six meteorological parameters for hourly sequential data. The six parameters used in this study are:

- Surface temperature (ºC);
- Wind speed (m/s);
- Wind direction (degrees from north);
- Relative humidity (%);
- Cloud cover (oktas); and
- Precipitation (mm).

Meteorological data were obtained from a meteorological site located at Bishopton, approximately 10km to the west of Glasgow City Centre. This is the closest meteorological site to Glasgow City Centre that measures all required parameters for ADMS-Urban. Modelling was conducted over short periods of around fourteen days using meteorological data for 2005, the nearest year for which data were available. Modelling was therefore not conducted over the same period that monitoring took place, so modelling and monitoring results are not directly comparable. It is not the intention of this study, however, to make such a comparison, instead this study is investigating whether the observed vertical concentration gradient is replicated by ADMS-Urban, with comparison between actual measured and modelled concentrations considered less important. The periods for which modelling was undertaken are listed in Table 4.

Table 4: Modelling Periods

Period	From	To
M1	1 March 2005	14 March 2005
M2	15 March 2005	31 March 2005
M3	1 April 2005	14 April 2005
M4	15 April 2005	30 April 2005
M5	18 January 2005	7 February 2005

The wind direction during Period M2 and Period M4 was easterly, and so perpendicular to the Hope Street and Montrose Street canyons, with the monitoring sites on the leeward side of the canyon. The Cochrane Street canyon would lie approximately parallel to an easterly wind, and so recirculation vortices should be unlikely to form. During Period M1, M3 and Period M5, wind direction is predominantly north-westerly, oblique to all three street canyons. For an oblique wind, the model calculates the size and strength of the recirculation region based on wind speed and the angle of the wind to the canyon axis.

5.3 Surface roughness

The surface roughness length is used in dispersion modelling in order to characterise the surface of the area being modelled and the frictional effects caused by the interaction between land surface and wind speed. The effect is a key component in the generation of atmospheric turbulence, which influences dispersion patterns. In an urban area, the surface roughness is usually quite large, with numerous buildings of non-uniform height from which the flow generates turbulence. The surface roughness is measured in metres, and the ADMS user guide recommends a surface roughness value of 1m for cities or woodlands. A surface roughness of 1m was used for this study.

Often, meteorological sites are located outside of main conurbations, on areas of flat land, away from the influence of buildings or uneven terrain. The surface roughness will then be smaller than the surface roughness in urban areas. If the surface roughness at the meteorological station used differs to the area where modelling is taking place, both values of surface roughness must be specified. In this case, the meteorological monitoring site is located outside the urban area, with flat topography and agricultural land. A surface roughness length of 0.3m was used, which corresponds to the maximum length for agricultural land specified in the ADMS user guide.

5.4 Chemistry

ADMS contains a number of chemistry schemes which can be used to simulate the chemical reactions that take place between NO, NO_2 and ozone. The chemistry scheme used in this study is the Generic Reaction Scheme (GRS), and simplifies the chemical reactions of NO, NO_2, ozone and hydrocarbons into a series of seven reactions, including reactions (1) and (2) from Section 2.3. Additionally, the GRS also includes reaction (5). The scheme calculates the reactions between emitted pollutants (for example NO, NO_2 or hydrocarbons emitted from road traffic) and background pollutant concentrations. The rate of photochemical reactions is calculated based on the solar radiation strength calculated from cloud cover, time of day and day of the year as specified in the meteorological file.

5.5 Background Pollutant Concentrations

ADMS requires the background concentration of all pollutants which are involved in chemical reactions i.e. NO, NO_2 and ozone background concentrations to be specified. These data can be input either as a constant background concentration, or as measured hourly concentrations, with hourly data being preferred since the rate of chemical reaction depends on the pollutant concentration and the strength of sunlight which will fluctuate hourly. Hourly measured NO, NO_2 and ozone data are available from the Glasgow Centre AURN site, the position of which is highlighted in Figure 1. This site is located in the city centre, but at a distance of approximately 20m from the nearest main road, so it is not directly influenced by road traffic emissions. Concentrations at this site will provide a good indication of typical ambient concentrations throughout Glasgow city centre. Background pollutant data were obtained for periods equivalent to the modelling periods in Table 4.

5.6 Modelling Results

The predicted NO_2 concentrations from the modelling studies for the five modelling periods are presented in Table 5 and Table 6. It is clear that the model does not predict the same vertical concentration profile that was observed. Predicted NO_2 concentrations did not vary much as height increased, generally decreasing by only a few tenths of a microgram between each level. The model does predict some increases in NO_2 concentration with an increase in height, but these are generally predicted to occur at lower levels than was observed. Between heights of 20m-25m, or 25m-30m, concentrations are predicted to either be the same, or slightly lower.

Wind direction was north-westerly in Periods M1, M3 and M5, and easterly during Periods M2 and M3. This would result in recirculation vortices being formed such that during Periods M1, M3 and M5 the monitoring side would be mainly the windward side and concentrations would be expected to be lower than on the opposite side of the street. During Periods 2 and 4, the monitoring side of the street would be the leeward side and concentrations should be greater than concentrations on the opposite side of the street. The model predictions do show higher NO_2 concentrations on the leeward side of the street, with concentrations greater by between approximately 1µg/m^3 and 3µg/m^3.

The modelling predictions of NO_2 concentrations at varying height in street canyons do not show similar concentration profiles as was observed by measured data. As such, there should be caution exercised when using ADMS Urban to make predictions of NO_2 concentrations at different heights in street canyons.

Table 5: Predicted NO_2 concentrations using ADMS Urban – Montrose Street

Height (m)	Predicted NO_2 Concentrations (µg/m³)									
	Period M1		Period M2		Period M3		Period M4		Period M5	
	Monitoring Side	Opposite Side	Monitoring Side	Opposite Side	Monitoring Side	Opposite Side	Monitoring Side	Opposite Side	Monitoring Side	Opposite Side
5	48.7	51.7	39.6	38.1	33.9	35.2	47.3	44.4	53.0	55.6
10	48.5	51.4	39.4	37.9	33.6	34.9	47.1	44.2	52.8	55.4
15	48.3	51.2	39.2	37.7	33.4	34.7	46.8	44.0	52.7	55.3
20	48.2	51.1	39.1	37.7	33.4	34.7	46.7	43.9	52.6	55.2
25	48.1	51.1	39.1	37.6	33.3	34.6	46.7	43.9	52.6	55.1
30	48.1	51.1	39.1	37.6	33.3	34.6	46.7	43.9	52.6	55.1

Table 6: Predicted NO_2 concentrations using ADMS Urban – Hope Street

Height (m)	Predicted NO_2 Concentrations (µg/m³)									
	Period M1		Period M2		Period M3		Period M4		Period M5	
	Monitoring Side	Opposite Side	Monitoring Side	Opposite Side	Monitoring Side	Opposite Side	Monitoring Side	Opposite Side	Monitoring Side	Opposite Side
5	47.3	48.5	36.8	36.2	31.8	32.2	43.3	42.1	52.0	53.0
10	47.3	48.5	36.9	36.3	31.8	32.3	43.4	42.2	52.0	53.0
15	47.3	48.5	36.9	36.2	31.7	32.2	43.3	42.1	52.0	53.0
20	47.3	48.5	36.8	36.2	31.7	32.2	43.3	42.1	52.0	53.0
25	47.2	48.4	36.8	36.2	31.7	32.1	43.3	42.1	52.0	53.0
30	47.2	48.4	36.8	36.2	31.6	32.1	43.2	42.1	52.0	53.0

6 CONCLUSIONS

NO_2 concentrations were measured using passive diffusion tubes at various heights in street canyons in Glasgow. The aim of the study was to determine how NO_2 concentrations varied with height, and to determine whether national air quality objectives would be exceeded at residential properties within street canyons.

The results of the monitoring indicated that dispersion was likely to be the main process affecting NO_2 concentrations in the lowest 20m of the canyon, and concentrations were observed to decrease as height increased. The rate of decline of NO_2 was found to be greatest when the NO_2 concentration at street level was high. In Hope Street, concentrations decreased by an average of 39% between 5m and 10m. In Montrose Street, NO_2 concentrations decreased by an average of 8% between 5m and 15m.

The lowest measurements were taken at 5m, which would be the height of a first floor residential dwelling in a street canyon. Concentrations at this level were observed to be higher than concentrations at any other height, so if measured street level NO_2 concentrations are below the NAQS objectives, it is likely that concentrations at all heights above the street will also be below the NAQS objectives. If measured NO_2 concentrations at street level are over the NAQS objective level, however, then concentrations at residential dwellings above the street canyon, particularly at 5m or 10m, will have the potential to exceed the objectives.

The results also showed that there is an area above 20m where NO_2 concentrations increase as height increases. The exact height where this NO_2 production occurs varies, and it is thought that it is a result of high ozone concentrations entering the canyon reacting with NO at height, producing NO_2. At the heights where NO_2 production occurs, NO_2 concentrations have already declined considerably through dilution and dispersion, and the increase in concentration is observed to be small (2-5%).

A modelling study was undertaken using ADMS-Urban to determine whether the model could replicate the observed vertical profile of NO_2 concentrations. The results of the modelling study indicated that the model does not reproduce the observed NO_2 vertical profile, and that there would be poor confidence is using the model to predict NO_2 concentrations at height.

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