Air Quality Consultants

TRL

Nitrogen Dioxide Concentrations in and Around Golders Green Bus Station, Barnet

Document Control

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1 Introduction

1.1 The London Borough of Barnet Council has measured concentrations of nitrogen dioxide within and around Golders Green bus station. These measurements have shown a likelihood that the Government's air quality objective for 1-hour mean nitrogen dioxide concentrations is being exceeded within the bus station. The Council has therefore commissioned Air Quality Consultants Ltd (AQC) and TRL to model concentrations within and around the bus station in order to identify the extent of the exceedence and provide details of which emission sources are contributing to the observed levels. This report sets out the methods and results of this modelling study.

2 Policy Context

Objectives

2.1 The Air Quality Strategy (Defra, 2007a) provides the policy framework for air quality management and assessment in the UK. It provides a set of air quality standards and objectives to protect human health. The 'standards' are set as concentrations below which effects are unlikely even in sensitive population groups, or below which risks to public health would be exceedingly small. They are based purely upon the scientific and medical evidence of the effects of an individual pollutant. The 'objectives' set out the extent to which the Government expects the standards to be achieved by a certain date. They take account of economic efficiency, practicability, technical feasibility and timescale. The objectives for use by local authorities are prescribed within the Air Quality Regulations, 2000 (Stationery Office, 2000) and the Air Quality (England) (Amendment) Regulations 2002, (Stationery Office, 2002). The relevant objectives for this report are provided in Table 1.

Table 1: Relevant Air Quality Objectives

Pollutant	Time Period	Objective
Nitrogen Dioxide	1-hour mean	200 $\mu g/m^3$ not to be exceeded more than 18 times a year
	Annual mean	40 $\mu g/m^3$

Local Air Quality Management

2.2 The Air Quality Strategy also sets out how the different sectors: industry, transport and local government, can contribute to achieving the air quality objectives. Local authorities are seen to play a particularly important role. The strategy describes the Local Air Quality Management (LAQM) regime that has been established, whereby every authority has to carry out regular reviews and assessments of air quality in its area to identify whether the objectives have been, or will be, achieved at relevant locations, by the applicable date. If this is not the case, the authority must declare an Air Quality Management Area (AQMA), and prepare an action plan which identifies appropriate measures that will be introduced in pursuit of the objectives.

Relevant Exposure

2.3 The air quality objectives only apply where members of the public are likely to be regularly present for the averaging time of the objective. For the annual mean objective, relevant exposure is mainly limited to residential properties, schools and hospitals. The 1-hour objective applies at these locations as well as at any outdoor location where a member of the public might reasonably be expected to stay for 1 hour or more.

Percentiles

2.4 Table 1 shows that the 1-hour objective is breached if there are more than 18 hours in a year with a concentration greater than 200 $\mu g/m^3$. Put another way, in a situation in which measurements or predictions are made during every hour of a year, if the 18th highest measurement is greater than 200 $\mu g/m^3$, the objective is exceeded; if it is smaller than 200 $\mu g/m^3$ the objective is achieved. Typically, however, measurements[1] do not cover every hour in a year[2]. Data are thus commonly expressed as percentiles. The 18th highest measurement in a full year's worth of data is the 99.79th percentile. Thus, if the 99.79th percentile is greater that 200 $\mu g/m^3$, the objective is breached; when it is below 200 $\mu g/m^3$, the objective is likely to be achieved.

1 Measured concentrations and also the meteorological data needed to model concentrations.
2 Since instruments occasionally malfunction

3 Study Area

3.1 Figure 1 shows Golders Green bus station and its surroundings. The bus station is one of the busiest in London. It is situated next to Golders Green underground station and Transport for London (TfL) lists 25 routes that serve the bus station. In addition, the bus station is a major stop for National Express coaches, being the second stop out of London Victoria for a number of routes including those to Scotland, the North of England and Stansted Airport.

3.2 The bus station lies immediately north of the busy A502 (North End Road) and the entrance to the bus station forms a part of the junction of the A502 (North End Road / Golders Green Road) with the A598 (Finchley Road). This junction is particularly complex. Owing to the position of the roundabout and the structure of the one way system around it, west-bound vehicles must travel south along Finchley Road, regardless of their ultimate destination (see Figure 1). Since the entrance to the bus station is on the roundabout, while the exit is on North End Road, buses approaching the station from the west must travel to the end of North End Road and go around the roundabout before they can enter the bus station. Similarly, buses exiting the station and travelling westward or northward must exit onto North End Road and rejoin the roundabout.

3.3 The junction is surrounded by shops and businesses, but there are residential flats above several of these. Locations with residential exposure are identified in Figure 1. Passengers on long-distance coach journeys may wait for 1 hour or more, and the area within the bus station with this exposure is also shown in Figure1.

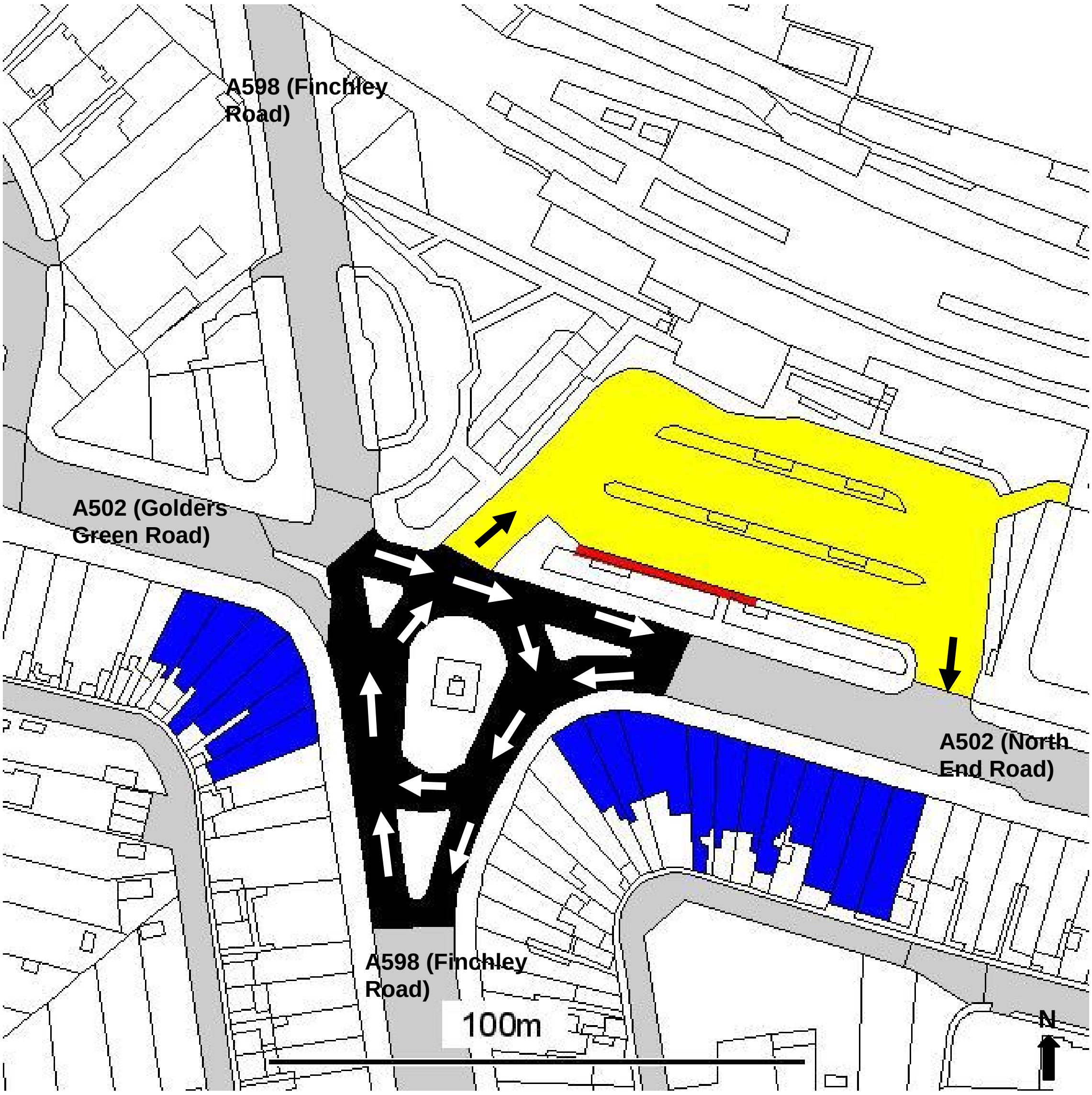

Figure 1: Map of Golders Green Bus Station and Junction. Bus station = yellow; Junction = black; key roadways = grey; residential exposure (flats above shops) = blue; relevant exposure to the 1-hour objective within the bus station = red

4 Methodology

4.1 LB Barnet has operated an automatic monitor within the bus station, as well as a network of nitrogen dioxide diffusion tubes in and around the bus station. The methodology and results are presented in the Council's Detailed Assessment (LB Barnet, 2008). These measurements do not directly form a part of this modelling study, but the modelling draws heavily on the measured data.

4.2 This study has been carried out in two parts. The first was carried out by TRL and involved generating hour-by-hour emissions data for the buses and coaches within the bus station. The methodology and detailed results are given in Appendix 1. The second part of the study was carried out by AQC and involved using the data generated by TRL, along with traffic data for local roads, to model ambient pollutant concentrations. This methodology is given in Appendices 2 to 4.

5 Results

Measurements

5.1 As explained in the methodology section, LB Barnet deployed an automatic monitor and diffusion tubes in and around the bus station. The locations of these monitors are shown in Figure 2. The measurements are summarised in Table 2. Further details are given by LB Barnet (2008).

Table 2: Summary of Recent Nitrogen Dioxide Monitoring Carried out in and around the Bus Station

		Period Mean Concentration ($\mu g/m^3$)	Number of Measured Exceedences of 200 $\mu g/m^3$ as a 1-hour mean
Long -Term Diffusion Tubes (October 06 - September 07)			
1	**Golders Green Bus Station (triplicate tubes)**	82.8	n/a
2	**North End Road**	67.9	n/a
Short -Term Diffusion Tubes (March 08 - June 08)			
3	**624 Finchley Road**	59	n/a
4	**Alliance and Leicester, 877 Finchley Road**	68	n/a
5	**Flightcentre, 17 Golders Green Road**	59	n/a
6	**Lloyds TSB, 2B Golders Green Road**	63	n/a
7	**rear of Golders station Green bus**	70	n/a
8	**North End Road**	71	n/a
9	**12 North End Road**	87	n/a
Automatic Monitor (Feb 08 - August 08)			
10	**Automatic Monitor**	74.3	42
Objective		**40 as an annual mean**	**18 during a full calendar year**

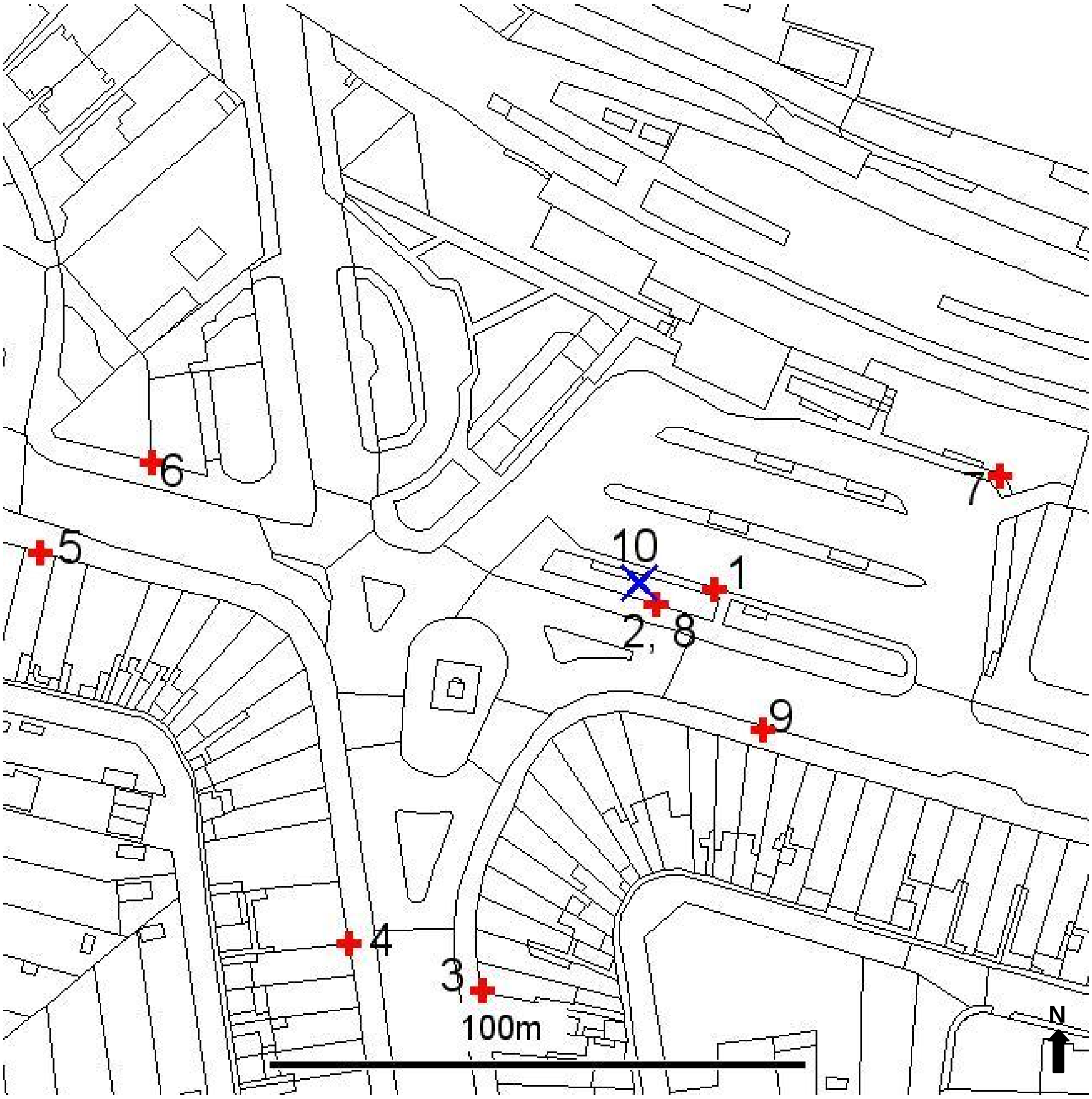

Figure 2: Monitoring Locations in and Around the Bus Station (red = diffusion tubes; blue = automatic monitor; Numbers relate those listed in Table 2)

Predicted Concentrations

5.2 Predicted annual mean concentrations of nitrogen dioxide during 2008 in and around the bus station are shown in Figure 3. The level of the annual mean objective was exceeded across almost the whole of this area (only those locations not coloured in Figure 3 were not predicted to be exceeding this objective). The highest annual mean concentrations are around the entrance and exit to the bus station, rising to above 170 μg/m^3 at the entrance. Concentrations above 90 μg/m^3 were predicted across most of the bus station and along some of the nearby road carriageways. It should be noted that the line of elevated concentrations along North End Road on the approach to the roundabout is centred on the bus lane and not the main carriageway. Figure 4 extends the view shown in Figure 3 to cover a wider area. It shows that the area of predicted exceedence of the annual mean objective becomes smaller with increasing distance from the bus station and the junction.

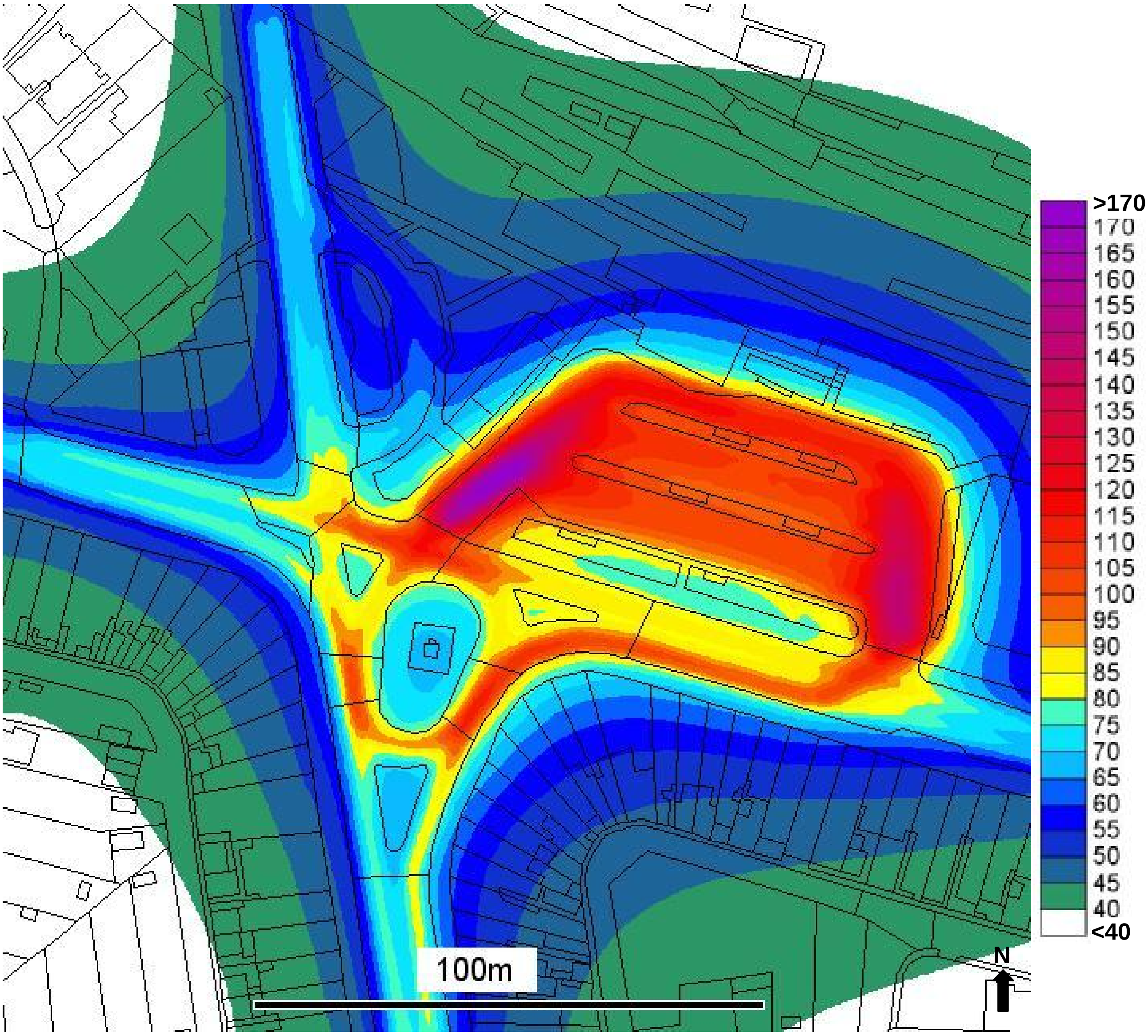

Figure 3: Predicted Annual Mean Nitrogen Dioxide Concentrations around Golders Green Bus Station in 2008 (mg/m³)

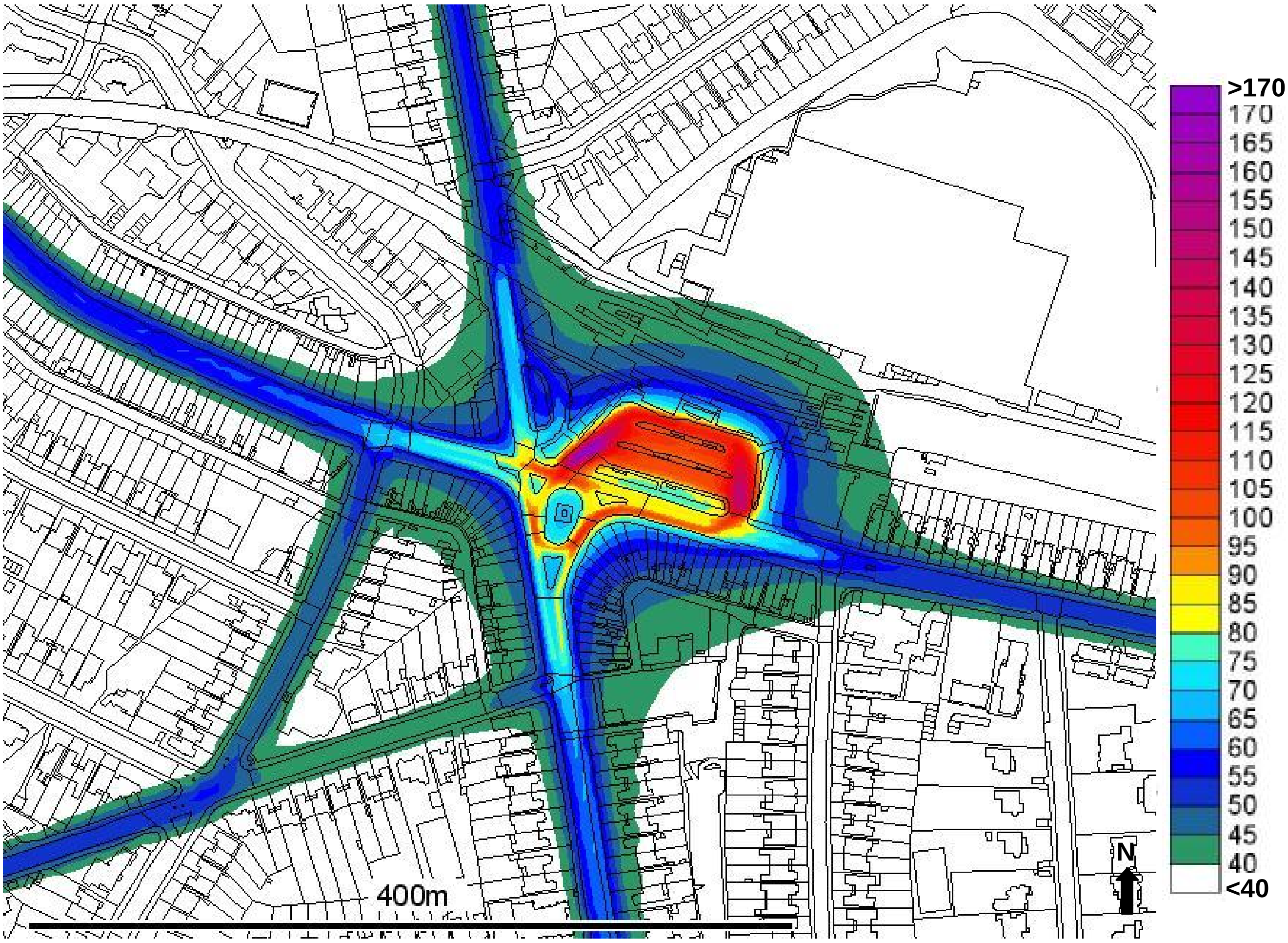

Figure 4: Predicted Annual Mean Nitrogen Dioxide Concentrations In the Wider Area around Golders Green Bus Station in 2008 (μg/m^3)

5.3 Predicted 99.79th percentiles of 1-hour mean nitrogen dioxide concentrations during 2008 are shown in Figure 5. The model results indicate that the level of the 1-hour objective was exceeded across most of the area shown in the Figure and only not exceeded in those areas which are not coloured. The highest predicted percentile concentrations are near to the exit and entrance to the bus station, as well along road carriageways. Figure 6 shows the same information for a wider area. It indicates that the only buildings at which the 1-hour objective was exceeded are those immediately surrounding the junction, but that the level of the objective was exceeded along the pavement of Finchley Road (South) as well as within the main road carriageways.

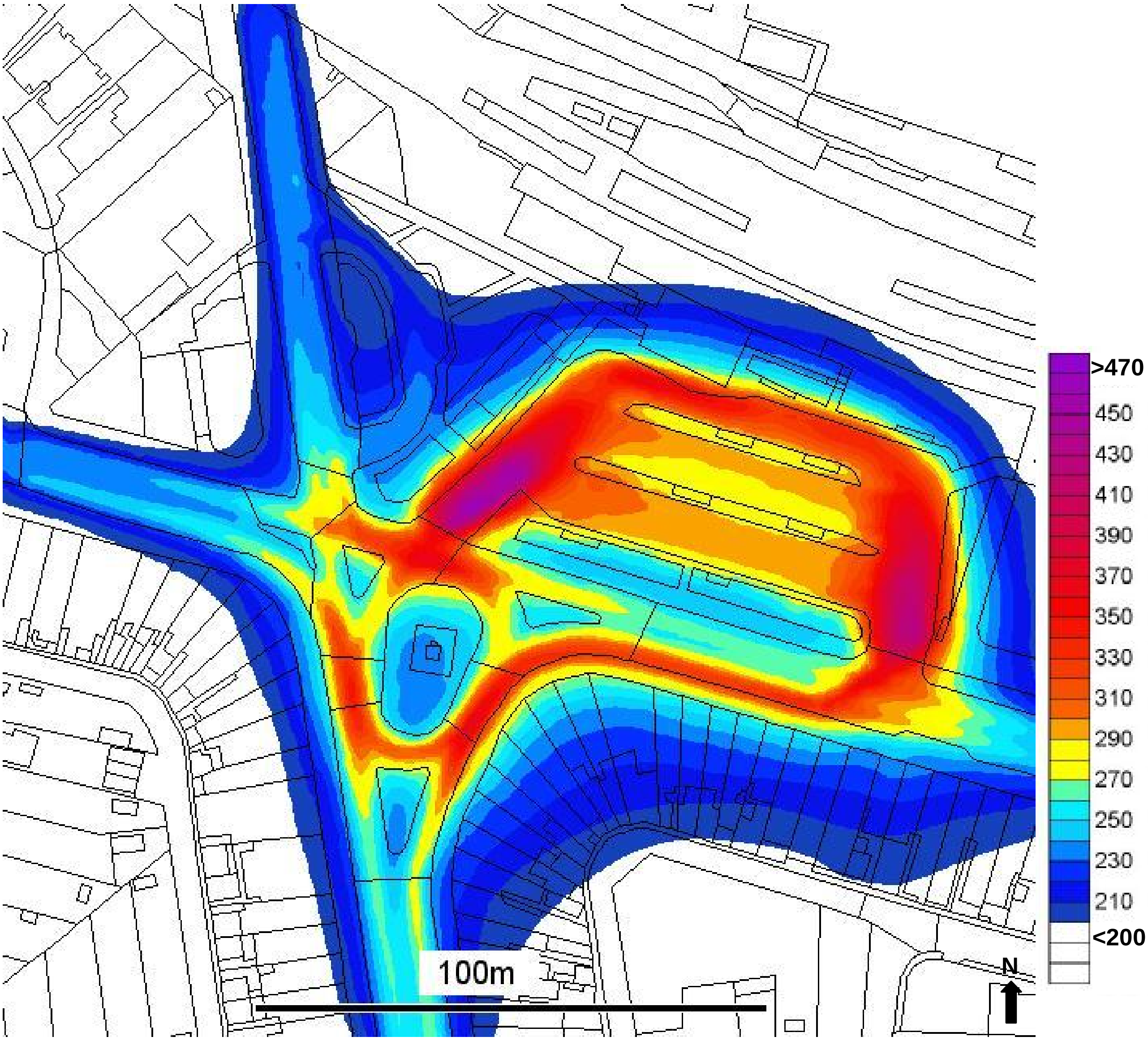

Figure 5: Predicted 99.79th Percentiles of 1-hour Mean Nitrogen Dioxide Concentrations around Golders Green Bus Station in 2008 (mg/m³)

5.4 A comparison of Figure 5 with Figure 3 shows that the contour of 1-hour objective exceedence (i.e. the edge of the coloured area) is very approximately equivalent to the annual mean 50 $\mu g/m^3$ contour. This is somewhat different from national guidance issued in 2003 that the 1-hour objective is unlikely to be exceeded unless the annual mean concentration is greater than 60 $\mu g/m^3$ (Laxen and Marner, 2003) which was recently corroborated by Cook (2008) using more recent measurements. Figure A4.1 in Appendix 4 is taken from Cook (2008). It shows that in recent years, a relatively large number of monitoring sites have recorded exceedences of the 1-hour objective when the annual mean has been less than 50 $\mu g/m^3$. Cook (2008) concluded that these occurrences all related to unusual sites or to episodic conditions during 2007. The relationship between the annual mean nitrogen dioxide concentration and exceedences of the 1-hour objective within and around the bus station is thus not inconsistent with national observations[3].

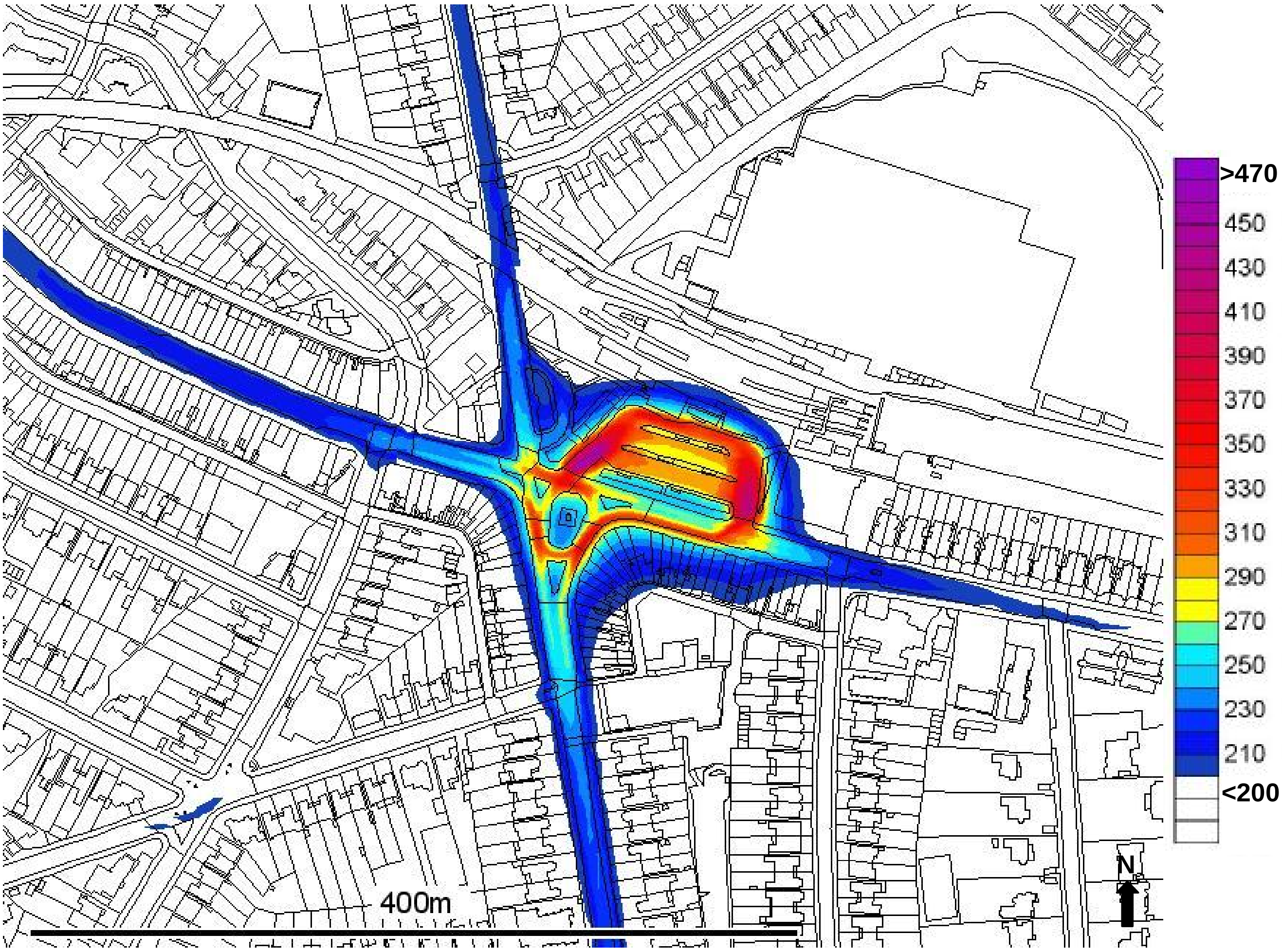

Figure 6: Predicted 99.79th Percentiles of 1-hour Mean Nitrogen Dioxide Concentrations in the Wider Area around Golders Green Bus Station in 2008 (μg/m^3)

5.5 Figure 7 shows seven locations that have been chosen to represent worst-case exposure to the annual mean and daily mean objectives. Receptors 1 to 3 represent those residential properties that will experience the highest annual mean concentrations (compare Figures 1 and 3) while Receptors 4 to 7 represent locations in and around the National Express bus stand where passengers may wait for 1-hour or more. It should be noted that the annual mean objective does not apply at the bus stand, but the results are included for information purposes. Table 3 sets out

[3] Cook (2008) cautioned that the analysis should be repeated in the future in order to ascertain whether conditions in 2007 (when numerous 1-hour exceedences at relatively low annual mean concentrations were measured) were an isolated event or part of a long-term trend. This has not yet been done.

the predicted annual mean concentrations, the predicted 99.79th percentiles of 1-hour nitrogen dioxide concentrations, and the modelled the number of exceedences of 200 μg/m^3 as a 1-hour mean concentration across the 8731 hours of valid data[4]. There were 161 exceedences of 200 μg/m^3 at Receptor 4 within the bus station, and 61 exceedences at residential Receptor 2.

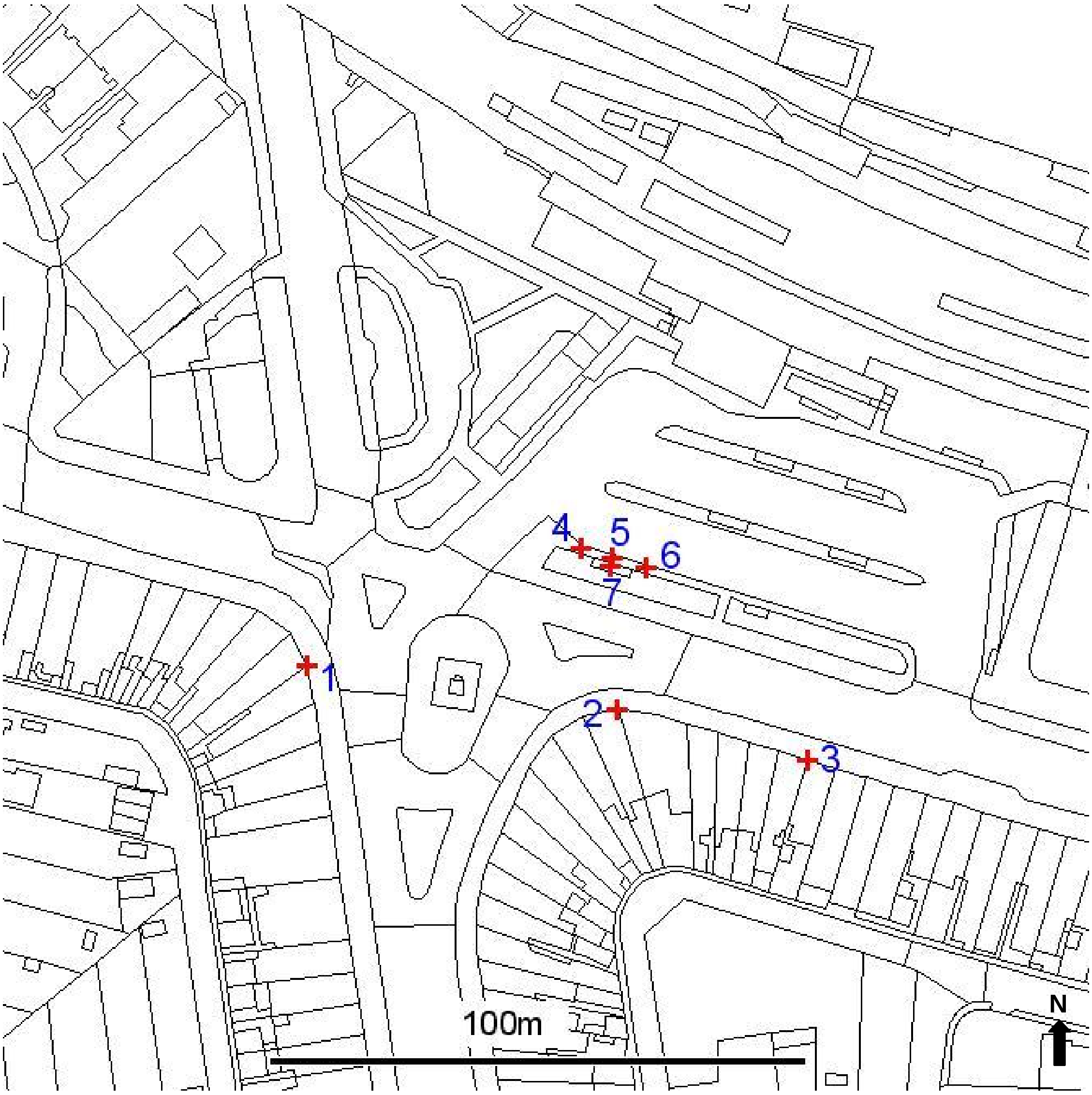

Figure 7: Receptor Locations

[4] i.e. 99.39% of the 8784 hours in this leap year.

Table 3: Predicted Annual Mean Nitrogen Dioxide (NO_2) Concentrations, 99.79th Percentiles of 1-hour Mean Concentrations, and the Number of 1-Hour Exceedences at Seven Receptors in 2008 ($\mu g/m^3$)

Receptor	Annual Mean NO_2	99.79th Percentiles of 1-hour Mean NO_2 Concentrations	Number of Exceedences of 200 $\mu g/m^3$ (Out of 8731 valid hours of data)
1	53	217	28
2	67	247	61
3	60	240	47
4	92	284	161
5	88	277	141
6	86	270	128
7	84	260	111

Source Apportionment

5.6 Table 4 sets out the relative contribution from each vehicle type to the total annual mean nitrogen dioxide concentration at each receptor. It also shows the relative contribution from the local background (i.e. that part of the concentration that does not come from local emissions). The data in Table 4 are shown graphically in Figure 8. The local background makes up approximately half the total concentration at the three residential receptors and between 30% and 40% within the bus station. Buses make up between 23% and 38% of the total concentration at the residential receptors, with other vehicles making up between 10% and 16%. Within the bus station, buses make up more than half of the total concentration at each receptor, with other vehicles contributing no more than 10%.

Table 4: Relative Contribution of Different Sources to the Total Predicted Annual Mean Nitrogen Dioxide Concentration at Seven Receptors

R	background	cars and m/c	taxis	LGVs	rigid HGVs	artic HGVs	buses on roads	buses in station	Bus total	Non-bus local vehicle total
1	61%	8%	1%	2%	4%	1%	14%	9%	**23%**	**16%**
2	48%	7%	1%	2%	3%	0.5%	23%	15%	**38%**	**14%**
3	53%	5%	1%	2%	2%	0.4%	19%	18%	**36%**	**10%**
4	33%	5%	1%	2%	2%	0.3%	9%	48%	**57%**	**9%**
5	34%	5%	1%	2%	2%	0.3%	9%	47%	**56%**	**9%**
6	35%	5%	1%	1%	2%	0.3%	10%	46%	**56%**	**9%**
7	37%	5%	1%	2%	2%	0.3%	10%	43%	**53%**	**10%**

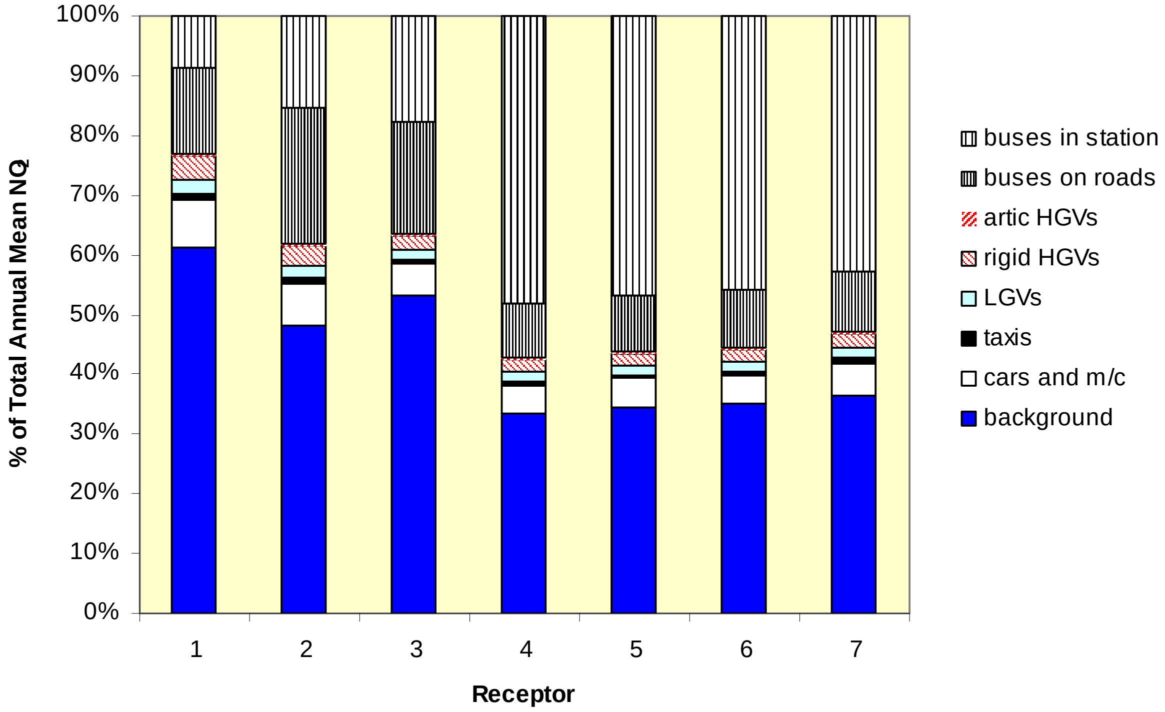

Figure 8: Relative Contribution of Different Sources to the Total Predicted Annual Mean Nitrogen Dioxide Concentration at Three Receptors

5.7 Table 5 and Figure 9 show the average contribution of each vehicle class to the local component of NOx concentrations[5] during every hour when the 1-hour mean concentration was greater than 200 µg/m^3. At the receptors within the bus station, buses account for more than 90% of the local concentration component during the hours when the air quality standard is exceeded. At the residential receptors, buses account for between 53% and 78% of this total.

[5] i.e. the total hourly NOx minus the hourly background NOx.

Table 5: Average Relative Contribution of Different Sources to the Local Component of Predicted Hourly-Mean Nitrogen Oxides Concentration During Each Hour when the Nitrogen Dioxide Concentration was Predicted to be Greater than 200 μg/m³ at Seven Receptors

R	cars and m/c	taxis	LGVs	rigid HGVs	artic HGVs	buses on roads	buses in station	Bus total	Non-bus local vehicle total
1	25%	4%	7%	11%	1%	37%	16%	**53%**	**47%**
2	16%	2%	4%	7%	1%	40%	30%	**70%**	**30%**
3	12%	2%	3%	5%	1%	38%	40%	**78%**	**22%**
4	7%	1%	2%	3%	0.4%	10%	77%	**87%**	**13%**
5	7%	0.9%	2%	3%	0.4%	9%	78%	**87%**	**13%**
6	6%	0.9%	2%	3%	0.3%	9%	79%	**88%**	**12%**
7	8%	3%	2%	3%	0.4%	11%	75%	**85%**	**17%**

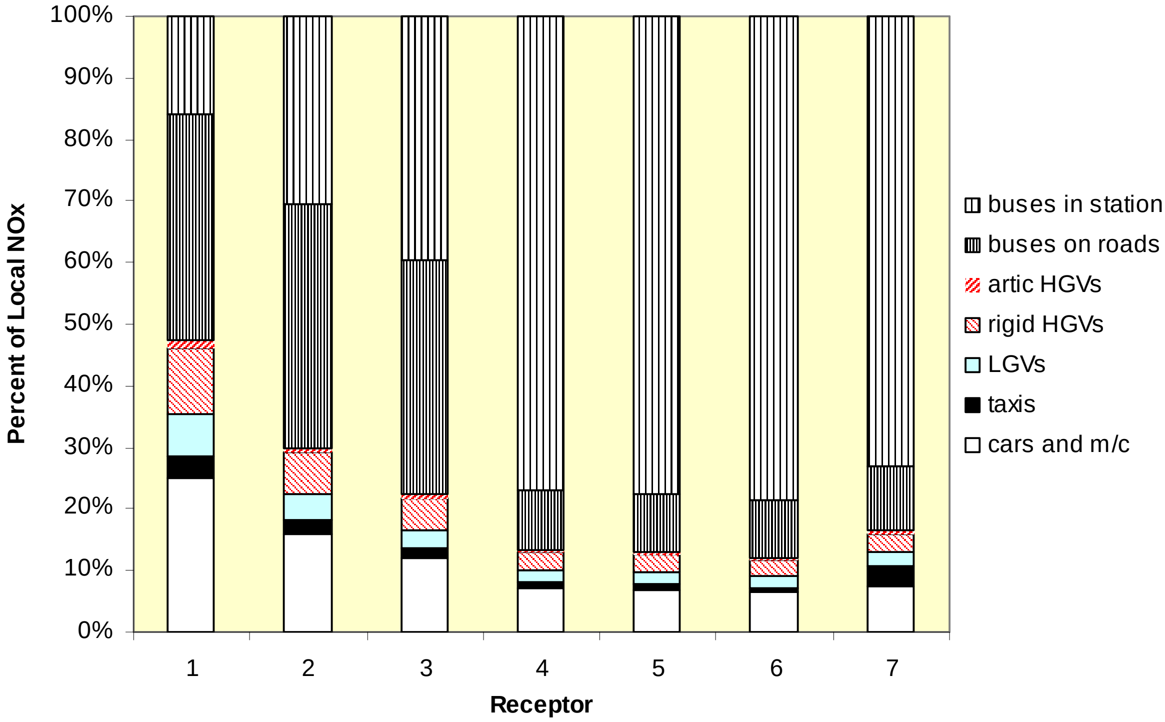

Figure 9: Average Relative Contribution of Different Sources to the Local Component of Hourly-Mean Nitrogen Oxides Concentration During Each Hour when the Nitrogen Dioxide Concentration was Predicted to be Greater than 200 μg/m³

6 Summary and Conclusions

6.1 A detailed study has been carried out to estimate hour-by-hour emissions profiles of nitrogen oxides from buses within Golders Green bus station. The results, along with traffic data held on the London Atmospheric Emissions Inventory, have been used to model annual mean and 1-hour mean concentrations of nitrogen dioxide in and around the bus station. The results have been verified against measurements, including those made with an automatic monitor within the bus station.

6.2 The results show that the annual mean objective for nitrogen dioxide is being exceeded at all residential properties near to roads in this area. Furthermore, the 1-hour objective is being exceeded within the bus station and also at premises around Golders Green junction.

6.3 A source apportionment study has shown that emissions from buses accounted for more than half of the total annual mean nitrogen dioxide concentration at the worst-case location. Bus emissions also accounted for nearly 90% of the local contribution to nitrogen oxides concentrations at the worst-case location during those hours when the 1-hour nitrogen dioxide standard was breached.

7 References

Boulter P G and McCrae I S (2009). ARTEMIS: Assessment and reliability of transport emission models and inventory systems – final report. PPR350. TRL Limited, Wokingham.

Cook (2008) Analysis of the relationship between annual mean nitrogen dioxide concentration and exceedences of the 1-hour mean AQS Objective.

Laxen and Marner (2003) Analysis of the Relationship Between 1-Hour and Annual Mean Nitrogen Dioxide at UK Roadside and Kerbside Monitoring Sites.

LB Barnet, 2009 Review and Assessment of Air Quality in the London Borough of Barnet Detailed Assessment March 2009

Rexeis M, Hausberger S, Riemersma I, Tartakovsky L, Zvirin Y and Erwin C (2005). Heavy-duty vehicle emissions. Final Report of WP 400 in ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems); DGTREN Contract 1999-RD.10429; University of Technology, Graz; report no. I 02/2005/Hb 20/2000 I680.

Stationery Office (2000) Air Quality Regulations, 2000, Statutory Instrument 928.

Stationery Office (2002) Air Quality (England) (Amendment) Regulations, 2002, Statutory Instrument 3043.

8 Appendix 1: Emissions within the Bus Station

This Appendix was written by McCrae I S and Barlow T J. Energy, Emissions and Air Pollution Team, TRL, Wokingham, RG40 3GA.

TRL were contracted by Air Quality Consultants to provide a best estimate of emissions associated with the bus activity within Golders Green bus station. The conventional way of allocating emissions to traffic links is to identify the flows and average speeds, and to use these (combined with fleet characteristics) as inputs to an average speed emission model, such as that contained within Volume 11 of the Design Manual for Roads and Bridges.

At the Golders Green bus station, buses enter from the west and generally take one of three routes, labelled A to C in Figure A1.1. Various designated bus stands (servicing specific bus routes) are located along the apex of these three routes. All vehicles exit the bus station to the east. However, in contrast to the entrance, the exit is controlled by a signalised junction.

It is evident that within a bus station, the driving characteristics are very specific. Not surprisingly the buses enter the bus station at a relatively low speed and move to their allocated bus stop. In some instances these in-coming buses need to wait until the bus in front has cleared the bus stop, and thus the journey into the bus station can be interrupted by periods of slow speeds and idling. Once at the bus stop, the buses wait to collect passengers and may either operate at idle or switch of their engines. Once passenger loading has been completed (and in accordance with the timetable), buses will pull away from their bus stops and proceed to the bus station exit.

To identify bus movements in and out of the bus station, a review was undertaken using the timetables published by TfL[6] and National Express[7]. For each bus stop within the bus station, an activity matrix was derived, using the example tabular structure shown in Table A1.1. For each bus stop, the bus number was noted from the arrival time and the departure time. These data were produced for a typical weekday and individually for a Saturday and a Sunday.

The timetable data does not provide information on engine operation, whilst buses are waiting at the bus stops. For example, it can be noted from Table A1.1 that the bus service 401 arrived at bus stop GA at 16:04, and then departed at 16:06. However, it was unclear if the driver switched off the engine at the bus stop, or left the vehicle at idle. Advice given to London Transport drivers is to switch off engines when stationary at bus stops for more than a few minutes.

[6] TfL information available at: http://www.tfl.gov.uk/tfl/gettingaround/maps/buses/pdf/goldersgreen-2098.pdf, and http://journeyplanner.tfl.gov.uk/user/XSLT_SEL_STT_REQUEST?sessionID=0&language=en&mode=line&linePreSel=tfl:25:*&linePreSel=tfl:63:*)

[7] National Express timetable “Golders Green to and from Towns, Cities and Airports”. Leaflet number TGOL/52v1.

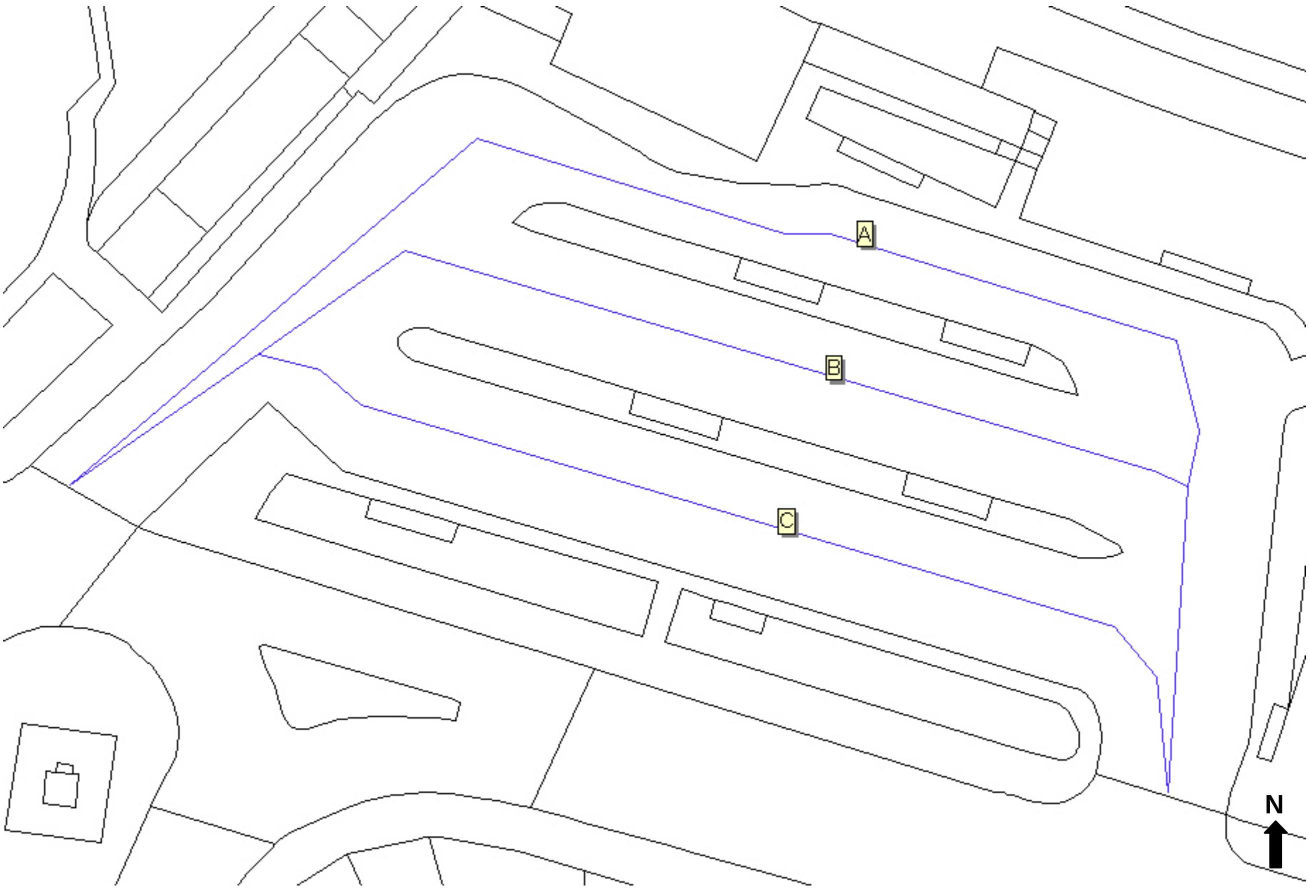

Figure A1.1: Golders Green bus station showing the three bus routes.

To identify the proportion of idling times at the bus station, a site survey was undertaken by TRL staff for several hours on the 15 December, recording where buses were stopping, and timing how long they were at the stops. Attempts were made to record the amount of time that buses where stationary, but with their engines on. The latter proved difficult to confirm, without the need to walk in and out of the buses at the bus stops. This presented additional hazards to the survey staff that were not initially included in the site survey risk assessment. Given this information, a second survey was undertaken on the 27 January to record more idling times. This was done by observation and timings with a stop-watch.

Table A1.2 provides a summary of the route characteristics for each of the routes through the bus station. To simplify the modelling procedure, it was decided to allocate the bus stop location to the mid-point of each of the three routes. This was largely due to the fact that there were too many locations where buses could stop, and it was noted during the site surveys that the buses did not always stop precisely at their designated bus stops.

Figure A1.2 and A1.3 show the derived driving profile through the bus station, expressed in terms of time and distance, respectively. These profiles were estimated, as no direct measurements were possible within this project. It may be noted that constant speeds (20 km/h) were assumed into and out of the bus station, with uniform rates of deceleration and acceleration on the approach and exit from the bus stop. Typical rates of acceleration and deceleration where selected from TRLs database and knowledge of real world driving characteristics

Table A1.1: Derivation of bus activity data, as extracted from published timetables. This shows an example for a selected time period, and only 4 bus stops.

	Bus stop			
Time	GA	GB	GC	GD
XX:XX				
16:00				
16:01			46	
16:02			46	15
16:03			46	15
16:04	401			15
16:05	401			15
16:06	401	123		15
16:07		123		15
16:08		123		15
16:09		123		15
16:10		123	27	15
16:11	401		27	15
16:12	401		27	15
16:13	401		27	15
16:14				15
16:15				15
16:16				
XX:XX				

Table A1.2: Distances of routes through bus station (assuming a stop mid way through).

Route	In length (m)	Out length (m)	Total length (m)
A	104	91	195
B	87	80	167
C	79	69	148

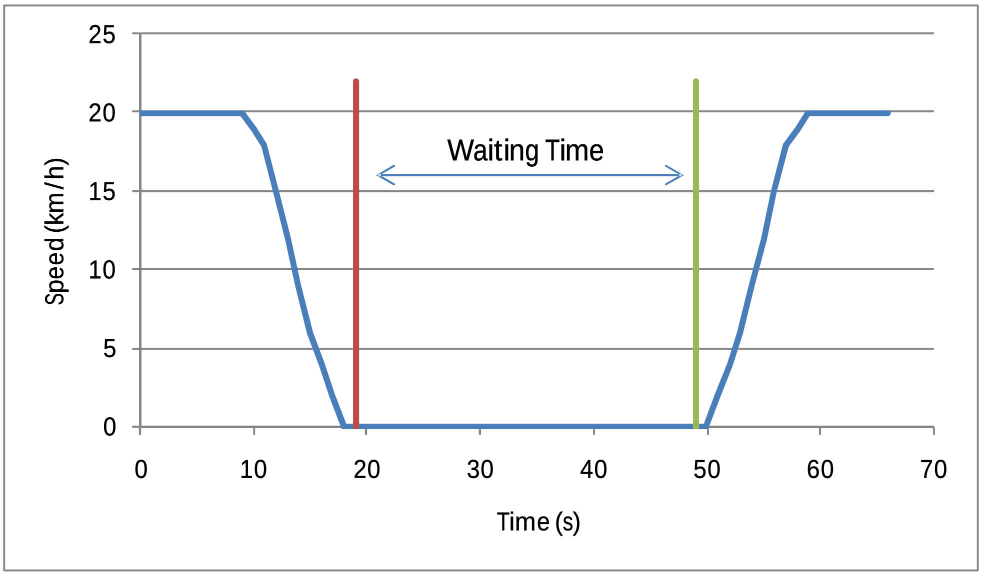

Figure A1.2: Speed profile through bus station (time based).

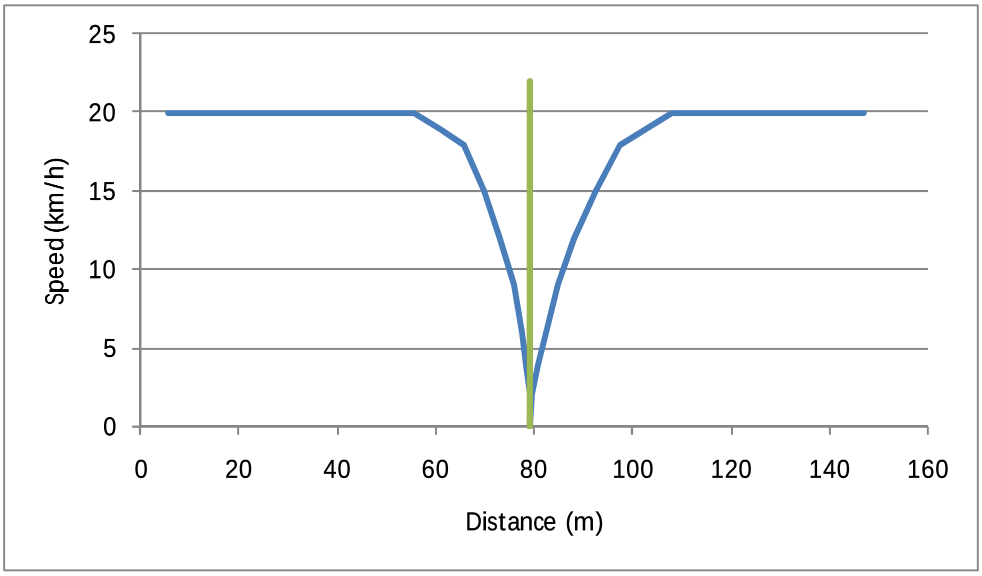

Figure A1.3: Speed profile through bus station (distance based).

The ARTEMIS project (Boulter and McCrae, 2009) and the COST Action 346[8] provided a great deal of insight into the emission behaviour of modern vehicles. One of the main outputs of ARTEMIS and the COST Action was the development of a range of emission databases and models. One of the resulting tools - PHEM (Passenger car and Heavy-duty Emission Model) - estimates fuel consumption and emissions based on the instantaneous engine power demand and engine speed during a driving pattern specified by the user (Rexeis *et al.*, 2005).

[8] http://www.cordis.lu/cost-transport/src/cost-346.htm

The main inputs to PHEM are a user-defined driving pattern and a file describing vehicle characteristics. For every second of the driving pattern PHEM calculates the actual engine power demand based upon vehicle driving resistances and transmission losses, and calculates the actual engine speed based upon transmission ratios and a gear-shift model. The engine power and speed are then used to reference the appropriate emission (and fuel consumption) values from steady-state engine maps. The emission behaviour over transient driving patterns is then taken into consideration by 'transient correction functions' which adjust the second-by-second steady-state emission values according to parameters describing the dynamics of the driving pattern.

The emissions associated with each bus moving through the bus station were subsequently estimated using the PHEM instantaneous emission model. Inputs to this model were the driving profiles through the bus station, which are converted on a second-by-second basis into emissions of carbon monoxide (CO), oxides of nitrogen (NO_X), hydrocarbons (HC), particulate matter (PM), carbon dioxide (CO_2) and fuel consumption (FC).

One further input to the modelling procedure is knowledge of the fleet characteristics by emission standard and body type. Table A1.3 provides bus and coach fleet characteristics, extracted from published national data sources.

Table A1.3: Fleet composition used in the analysis.

	Euro level					
Vehicle	**0**	**I**	**II**	**III**	**IV**	**V**
Single Decker	**0.00%**	**0.00%**	**48.92%**	**40.31%**	**10.76%**	**0.00%**
Double/Bendy	**0.00%**	**0.00%**	**29.42%**	**65.57%**	**5.01%**	**0.00%**
Coach	**4.62%**	**5.71%**	**24.15%**	**42.62%**	**22.90%**	**0.00%**

Based on the results of the field surveys, typical idling times are noted in Table A1.4.

Table A1.4: Typical bus idling times.

Vehicle	**Idling time (s)**
Single Decker	**57.4**
Double/Bendy	**57.4**
Coach	**125.6**

An example of the PHEM based emission estimates for a Euro V coach are shown in Table A1.5.

Table A1.5: Example of the PHEM emissions (Euro V coach).

Route	Phase	Units	Dist	FC	NOx	CO	HC	PM	CO2
A	In run	g	104.17	38.59	0.446	0.032	0.007	0.008	*122.41*
	Out run	g	93.06	74.30	0.794	0.052	0.008	0.011	*235.70*
	Total	g	197.22	112.89	1.240	0.084	0.015	0.018	*358.12*
B	In run	g	87.50	31.52	0.367	0.027	0.006	0.007	*99.97*
	Out run	g	81.94	69.58	0.742	0.048	0.007	0.010	*220.75*
	Total	g	169.44	101.10	1.109	0.075	0.013	0.016	*320.72*
C	In run	g	81.94	29.16	0.341	0.025	0.005	0.006	*92.50*
	Out run	g	70.83	64.87	0.689	0.044	0.007	0.009	*205.79*
	Total	g	152.78	94.03	1.030	0.069	0.012	0.015	*298.28*
All	Idling	g/s		1.56	0.025	0.001	0.000	0.000	*4.96*

These emissions were generated for each vehicle type (single decker, double/bendy and coach) and for each Euro standard (0 to V). Knowing the typical idling time (from Table A1.4) the typical emissions for vehicle & Euro standard along each route was determined. Using the fleet composition from Table A1.3, the emissions for each Euro standard were weighted by their proportion in the fleet and summated to derive typical emissions for each vehicle type, as shown in Table A1.6.

Table A1.6: Emissions by vehicle type and route through bus station.

	Emissions (g)	FC	NO_X	CO	HC	PM	CO_2
Route_A	Single Decker	136.59	4.710	1.123	0.332	0.101	430.70
	Double/Bendy	158.28	5.489	1.465	0.376	0.123	498.86
	Coach	298.04	10.592	1.883	0.619	0.195	940.99
Route_B	Single Decker	126.47	4.441	1.041	0.302	0.091	398.81
	Double/Bendy	146.62	5.201	1.359	0.340	0.112	462.13
	Coach	286.24	10.223	1.795	0.587	0.186	903.79
Route_C	Single Decker	120.38	4.281	0.988	0.283	0.086	379.60
	Double/Bendy	139.59	5.029	1.289	0.319	0.105	439.99
	Coach	279.15	10.003	1.740	0.569	0.181	881.43

Bus activity data are shown for a typical weekday, and separately for a Saturday and a Sunday in Tables A1.7 to A1.9. By multiplying the hourly number of buses by the appropriate emissions factor and summating by route through the bus station, the total hourly emissions for each link were calculated, as listed in Tables A1.10 to A1.18.

Table A1.7: Hourly timetabled bus activity – weekday.

	Stop	GA	GA	GA	GB	GB	GC	GD/GE/GF	GG	GH	GH	GI
	Route	A	A	A	A	A	C	C	C	B	B	B
	Vehicle	DD	DD	DD	SD	SD	DD	Coach	SD	DD	DD	DD
	Bus	260	210	102	226	245	328	Natl Expr	13	83	183	240
00:00	01:00	1	5	3	3	1	4	0	0	3	1	3
01:00	02:00	0	3	0	1	0	0	0	0	2	0	1
02:00	03:00	0	0	0	0	0	0	0	0	2	0	0
03:00	04:00	0	0	0	0	0	0	0	0	2	0	0
04:00	05:00	0	0	0	1	0	1	0	0	3	0	0
05:00	06:00	3	2	0	3	3	4	1	3	3	3	0
06:00	07:00	5	4	5	5	5	12	2	6	9	5	4
07:00	08:00	4	6	6	5	8	10	2	10	6	6	5
08:00	09:00	5	6	6	6	6	10	3	7	8	4	4
09:00	10:00	5	6	6	5	6	10	0	6	7	5	5
10:00	11:00	4	6	6	5	6	10	2	6	8	4	5
11:00	12:00	5	6	6	5	6	10	2	6	7	5	4
12:00	13:00	5	6	6	5	6	10	2	6	8	5	5
13:00	14:00	4	6	6	5	6	10	2	6	7	4	4
14:00	15:00	5	6	6	5	6	10	1	6	8	5	5
15:00	16:00	4	6	6	5	6	10	4	6	7	4	5
16:00	17:00	5	6	6	5	6	10	3	6	8	5	4
17:00	18:00	4	6	6	5	6	10	2	6	7	5	5
18:00	19:00	5	6	6	5	6	10	4	6	7	4	4
19:00	20:00	5	6	6	4	6	6	2	4	5	4	5
20:00	21:00	4	6	6	4	5	6	3	5	5	4	3
21:00	22:00	4	5	5	3	5	6	1	5	4	4	3
22:00	23:00	4	5	5	3	5	6	1	4	4	4	3
23:00	00:00	4	5	5	3	5	6	0	4	3	4	3
Total		85	113	107	91	109	171	37	108	133	85	80

Table A1.8: Hourly timetabled bus activity – Saturday.

	Stop	GA	GA	GA	GB	GB	GC	GD/GE/GF	GG	GH	GH	GI
	Route	A	A	A	A	A	C	C	C	B	B	B
	Vehicle	DD	DD	DD	SD	SD	DD	Coach	SD	DD	DD	DD
	Bus	260	210	102	226	245	328	Natl Expr	13	83	183	240
00:00	01:00	1	5	3	3	1	4	0	0	3	1	3
01:00	02:00	0	3	0	1	0	0	0	0	2	0	1
02:00	03:00	0	0	0	0	0	0	0	0	2	0	0
03:00	04:00	0	0	0	0	0	0	0	0	2	0	0
04:00	05:00	0	0	0	1	0	1	0	0	3	0	0
05:00	06:00	3	2	0	3	3	4	1	3	2	3	0
06:00	07:00	3	4	4	4	3	6	2	4	4	3	2
07:00	08:00	4	4	4	3	4	6	2	6	5	4	3
08:00	09:00	5	4	5	5	5	8	1	6	6	5	3
09:00	10:00	5	6	6	5	6	7	0	6	7	5	5
10:00	11:00	5	6	6	5	6	8	2	6	7	5	5
11:00	12:00	5	6	6	5	6	7	2	6	5	5	4
12:00	13:00	5	6	6	6	6	8	2	6	7	5	5
13:00	14:00	5	6	6	5	6	7	2	6	7	5	5
14:00	15:00	5	6	6	5	6	8	1	6	6	5	4
15:00	16:00	5	6	6	5	6	7	4	6	7	5	5
16:00	17:00	5	6	6	5	6	8	3	6	7	5	4
17:00	18:00	5	6	6	5	6	7	4	6	6	5	5
18:00	19:00	5	6	6	5	6	8	4	5	5	4	4
19:00	20:00	4	6	6	3	5	6	2	4	5	4	3
20:00	21:00	4	5	5	3	5	6	3	5	4	4	3
21:00	22:00	4	5	5	3	5	6	1	5	4	4	3
22:00	23:00	4	5	5	3	5	6	1	4	4	4	3
23:00	00:00	4	5	5	3	5	6	0	4	3	4	3
Total		86	108	102	86	101	134	37	100	113	85	73

Table A1.9: Hourly timetabled bus activity – Sunday.

	Stop	GA	GA	GA	GB	GB	GC	GD/GE/GF	GG	GH	GH	GI
	Route	A	A	A	A	A	C	C	C	B	B	B
	Vehicle	DD	DD	DD	SD	SD	DD	Coach	SD	DD	DD	DD
	Bus	260	210	102	226	245	328	Natl Expr	13	83	183	240
00:00	01:00	1	5	3	3	1	4	0	0	3	1	3
01:00	02:00	0	3	0	1	0	0	0	0	2	0	1
02:00	03:00	0	0	0	0	0	0	0	0	2	0	0
03:00	04:00	0	0	0	0	0	0	0	0	2	0	0
04:00	05:00	0	0	0	0	0	1	0	0	3	0	0
05:00	06:00	3	0	0	0	0	4	1	3	2	0	0
06:00	07:00	3	0	4	1	1	4	2	4	2	2	0
07:00	08:00	3	4	4	2	3	4	2	4	3	2	2
08:00	09:00	3	4	3	3	4	5	1	5	4	3	2
09:00	10:00	4	5	5	4	5	6	0	4	5	4	2
10:00	11:00	4	5	5	3	5	6	2	5	5	3	3
11:00	12:00	4	6	5	3	5	6	2	4	5	4	3
12:00	13:00	4	6	5	3	5	6	2	5	4	4	3
13:00	14:00	4	6	5	3	5	6	2	5	4	4	3
14:00	15:00	4	6	5	3	5	6	1	4	5	4	3
15:00	16:00	4	6	5	3	5	6	4	5	4	4	3
16:00	17:00	4	6	5	3	5	6	3	5	5	4	3
17:00	18:00	4	6	5	3	5	6	4	4	5	4	3
18:00	19:00	5	6	5	3	5	6	3	5	5	4	3
19:00	20:00	4	5	5	2	5	6	2	4	4	4	4
20:00	21:00	4	5	5	3	6	6	2	5	4	4	3
21:00	22:00	4	5	5	3	5	6	1	5	4	4	3
22:00	23:00	4	5	5	3	5	6	1	4	4	4	3
23:00	00:00	4	5	5	3	5	6	0	4	3	4	3
Total		74	99	89	55	85	112	35	84	89	67	53

Table A1.10: Hourly emissions - weekday for Route A.

Time		Emissions (g)					
Hour start	Hour start	FC	NO_X	CO	HC	PM	CO_2
00:00	01:00	1970.9	68.244	17.675	4.710	1.513	6212.5
01:00	02:00	611.4	21.178	5.517	1.459	0.471	1927.3
02:00	03:00	0.0	0.000	0.000	0.000	0.000	0.0
03:00	04:00	0.0	0.000	0.000	0.000	0.000	0.0
04:00	05:00	136.6	4.710	1.123	0.332	0.101	430.7
05:00	06:00	1611.0	55.707	14.062	3.871	1.221	5078.5
06:00	07:00	3581.9	123.951	31.737	8.582	2.734	11291.0
07:00	08:00	4308.2	149.060	38.036	10.330	3.283	13580.8
08:00	09:00	4329.9	149.839	38.378	10.373	3.306	13649.0
09:00	10:00	4193.3	145.129	37.255	10.041	3.205	13218.3
10:00	11:00	4035.0	139.640	35.790	9.665	3.082	12719.4
11:00	12:00	4193.3	145.129	37.255	10.041	3.205	13218.3
12:00	13:00	4193.3	145.129	37.255	10.041	3.205	13218.3
13:00	14:00	4035.0	139.640	35.790	9.665	3.082	12719.4
14:00	15:00	4193.3	145.129	37.255	10.041	3.205	13218.3
15:00	16:00	4035.0	139.640	35.790	9.665	3.082	12719.4
16:00	17:00	4193.3	145.129	37.255	10.041	3.205	13218.3
17:00	18:00	4035.0	139.640	35.790	9.665	3.082	12719.4
18:00	19:00	4193.3	145.129	37.255	10.041	3.205	13218.3
19:00	20:00	4056.7	140.419	36.131	9.709	3.105	12787.6
20:00	21:00	3761.8	130.220	33.544	9.001	2.880	11858.0
21:00	22:00	3308.7	114.531	29.491	7.918	2.533	10429.6
22:00	23:00	3308.7	114.531	29.491	7.918	2.533	10429.6
23:00	00:00	3308.7	114.531	29.491	7.918	2.533	10429.6
Total		75594.1	2616.259	671.364	181.030	57.770	238291.5

Table A1.11: Hourly emissions - weekday for Route B.

Time		Emissions (g)					
Hour start	Hour start	FC	NO_X	CO	HC	PM	CO_2
00:00	01:00	1026.3	36.406	9.510	2.380	0.782	3234.9
01:00	02:00	439.9	15.603	4.076	1.020	0.335	1386.4
02:00	03:00	293.2	10.402	2.717	0.680	0.223	924.3
03:00	04:00	293.2	10.402	2.717	0.680	0.223	924.3
04:00	05:00	439.9	15.603	4.076	1.020	0.335	1386.4
05:00	06:00	879.7	31.205	8.152	2.040	0.670	2772.8
06:00	07:00	2639.1	93.616	24.455	6.121	2.011	8318.3
07:00	08:00	2492.5	88.415	23.097	5.781	1.899	7856.2
08:00	09:00	2345.9	83.214	21.738	5.441	1.788	7394.0
09:00	10:00	2492.5	88.415	23.097	5.781	1.899	7856.2
10:00	11:00	2492.5	88.415	23.097	5.781	1.899	7856.2
11:00	12:00	2345.9	83.214	21.738	5.441	1.788	7394.0
12:00	13:00	2639.1	93.616	24.455	6.121	2.011	8318.3
13:00	14:00	2199.3	78.013	20.379	5.101	1.676	6931.9
14:00	15:00	2639.1	93.616	24.455	6.121	2.011	8318.3
15:00	16:00	2345.9	83.214	21.738	5.441	1.788	7394.0
16:00	17:00	2492.5	88.415	23.097	5.781	1.899	7856.2
17:00	18:00	2492.5	88.415	23.097	5.781	1.899	7856.2
18:00	19:00	2199.3	78.013	20.379	5.101	1.676	6931.9
19:00	20:00	2052.7	72.812	19.021	4.761	1.564	6469.8
20:00	21:00	1759.4	62.410	16.304	4.081	1.341	5545.5
21:00	22:00	1612.8	57.210	14.945	3.741	1.229	5083.4
22:00	23:00	1612.8	57.210	14.945	3.741	1.229	5083.4
23:00	00:00	1466.2	52.009	13.586	3.401	1.117	4621.3
Total		43692.5	1549.859	404.871	101.339	33.292	137713.8

Table A1.12: Hourly emissions - weekday for Route C.

Time		Emissions (g)					
Hour start	Hour start	FC	NO_X	CO	HC	PM	CO_2
00:00	01:00	558.4	20.115	5.158	1.275	0.418	1760.0
01:00	02:00	0.0	0.000	0.000	0.000	0.000	0.0
02:00	03:00	0.0	0.000	0.000	0.000	0.000	0.0
03:00	04:00	0.0	0.000	0.000	0.000	0.000	0.0
04:00	05:00	139.6	5.029	1.289	0.319	0.105	440.0
05:00	06:00	1198.6	42.961	9.863	2.694	0.856	3780.2
06:00	07:00	2955.6	106.036	24.883	6.663	2.130	9320.4
07:00	08:00	3158.0	113.103	26.257	7.158	2.264	9958.8
08:00	09:00	3076.0	110.263	25.033	6.877	2.188	9701.4
09:00	10:00	2118.2	75.973	18.823	4.888	1.560	6677.5
10:00	11:00	2676.5	95.979	22.304	6.025	1.921	8440.4
11:00	12:00	2676.5	95.979	22.304	6.025	1.921	8440.4
12:00	13:00	2676.5	95.979	22.304	6.025	1.921	8440.4
13:00	14:00	2676.5	95.979	22.304	6.025	1.921	8440.4
14:00	15:00	2397.3	85.976	20.564	5.456	1.740	7559.0
15:00	16:00	3234.8	115.985	25.785	7.163	2.282	10203.2
16:00	17:00	2955.6	105.982	24.045	6.594	2.102	9321.8
17:00	18:00	2676.5	95.979	22.304	6.025	1.921	8440.4
18:00	19:00	3234.8	115.985	25.785	7.163	2.282	10203.2
19:00	20:00	1877.3	67.302	15.170	4.184	1.332	5921.2
20:00	21:00	2276.9	81.586	17.899	5.036	1.598	7182.2
21:00	22:00	1718.6	61.580	14.418	3.898	1.237	5419.4
22:00	23:00	1598.2	57.299	13.430	3.615	1.151	5039.8
23:00	00:00	1319.0	47.296	11.689	3.046	0.970	4158.4
Total		47199.0	1692.364	391.611	106.155	33.820	148848.4

Table A1.13: Hourly emissions - Saturday for Route A.

Time		Emissions (g)					
Hour start	Hour start	FC	NO_X	CO	HC	PM	CO_2
00:00	01:00	1970.9	68.244	17.675	4.710	1.513	6212.5
01:00	02:00	611.4	21.178	5.517	1.459	0.471	1927.3
02:00	03:00	0.0	0.000	0.000	0.000	0.000	0.0
03:00	04:00	0.0	0.000	0.000	0.000	0.000	0.0
04:00	05:00	136.6	4.710	1.123	0.332	0.101	430.7
05:00	06:00	1611.0	55.707	14.062	3.871	1.221	5078.5
06:00	07:00	2697.2	93.353	23.974	6.458	2.062	8502.3
07:00	08:00	2855.5	98.843	25.438	6.834	2.185	9001.2
08:00	09:00	3581.9	123.951	31.737	8.582	2.734	11291.0
09:00	10:00	4193.3	145.129	37.255	10.041	3.205	13218.3
10:00	11:00	4193.3	145.129	37.255	10.041	3.205	13218.3
11:00	12:00	4193.3	145.129	37.255	10.041	3.205	13218.3
12:00	13:00	4329.9	149.839	38.378	10.373	3.306	13649.0
13:00	14:00	4193.3	145.129	37.255	10.041	3.205	13218.3
14:00	15:00	4193.3	145.129	37.255	10.041	3.205	13218.3
15:00	16:00	4193.3	145.129	37.255	10.041	3.205	13218.3
16:00	17:00	4193.3	145.129	37.255	10.041	3.205	13218.3
17:00	18:00	4193.3	145.129	37.255	10.041	3.205	13218.3
18:00	19:00	4193.3	145.129	37.255	10.041	3.205	13218.3
19:00	20:00	3625.2	125.510	32.420	8.669	2.780	11427.3
20:00	21:00	3308.7	114.531	29.491	7.918	2.533	10429.6
21:00	22:00	3308.7	114.531	29.491	7.918	2.533	10429.6
22:00	23:00	3308.7	114.531	29.491	7.918	2.533	10429.6
23:00	00:00	3308.7	114.531	29.491	7.918	2.533	10429.6
Total		72393.9	2505.625	643.580	173.331	55.351	228202.7

Table A1.14: Hourly emissions - Saturday for Route B.

Time		Emissions (g)					
Hour start	Hour start	FC	NO_X	CO	HC	PM	CO_2
00:00	01:00	1026.3	36.406	9.510	2.380	0.782	3234.9
01:00	02:00	439.9	15.603	4.076	1.020	0.335	1386.4
02:00	03:00	293.2	10.402	2.717	0.680	0.223	924.3
03:00	04:00	293.2	10.402	2.717	0.680	0.223	924.3
04:00	05:00	439.9	15.603	4.076	1.020	0.335	1386.4
05:00	06:00	733.1	26.004	6.793	1.700	0.559	2310.6
06:00	07:00	1319.6	46.808	12.228	3.061	1.005	4159.1
07:00	08:00	1759.4	62.410	16.304	4.081	1.341	5545.5
08:00	09:00	2052.7	72.812	19.021	4.761	1.564	6469.8
09:00	10:00	2492.5	88.415	23.097	5.781	1.899	7856.2
10:00	11:00	2492.5	88.415	23.097	5.781	1.899	7856.2
11:00	12:00	2052.7	72.812	19.021	4.761	1.564	6469.8
12:00	13:00	2492.5	88.415	23.097	5.781	1.899	7856.2
13:00	14:00	2492.5	88.415	23.097	5.781	1.899	7856.2
14:00	15:00	2199.3	78.013	20.379	5.101	1.676	6931.9
15:00	16:00	2492.5	88.415	23.097	5.781	1.899	7856.2
16:00	17:00	2345.9	83.214	21.738	5.441	1.788	7394.0
17:00	18:00	2345.9	83.214	21.738	5.441	1.788	7394.0
18:00	19:00	1906.1	67.611	17.662	4.421	1.452	6007.7
19:00	20:00	1759.4	62.410	16.304	4.081	1.341	5545.5
20:00	21:00	1612.8	57.210	14.945	3.741	1.229	5083.4
21:00	22:00	1612.8	57.210	14.945	3.741	1.229	5083.4
22:00	23:00	1612.8	57.210	14.945	3.741	1.229	5083.4
23:00	00:00	1466.2	52.009	13.586	3.401	1.117	4621.3
Total		39733.8	1409.435	368.188	92.157	30.276	125236.4

Table A1.15: Hourly emissions - Saturday for Route C.

Time		Emissions (g)					
Hour start	Hour start	FC	NO_X	CO	HC	PM	CO_2
00:00	01:00	558.4	20.115	5.158	1.275	0.418	1760.0
01:00	02:00	0.0	0.000	0.000	0.000	0.000	0.0
02:00	03:00	0.0	0.000	0.000	0.000	0.000	0.0
03:00	04:00	0.0	0.000	0.000	0.000	0.000	0.0
04:00	05:00	139.6	5.029	1.289	0.319	0.105	440.0
05:00	06:00	1198.6	42.961	9.863	2.694	0.856	3780.2
06:00	07:00	1877.3	67.302	15.170	4.184	1.332	5921.2
07:00	08:00	2118.1	75.864	17.146	4.750	1.503	6680.4
08:00	09:00	2118.1	75.918	17.985	4.819	1.531	6679.0
09:00	10:00	1699.4	60.887	14.955	3.931	1.246	5357.6
10:00	11:00	2397.3	85.921	19.725	5.388	1.712	7560.4
11:00	12:00	2257.7	80.893	18.436	5.069	1.608	7120.4
12:00	13:00	2397.3	85.921	19.725	5.388	1.712	7560.4
13:00	14:00	2257.7	80.893	18.436	5.069	1.608	7120.4
14:00	15:00	2118.1	75.918	17.985	4.819	1.531	6679.0
15:00	16:00	2816.0	100.899	21.917	6.207	1.969	8883.3
16:00	17:00	2676.4	95.924	21.466	5.957	1.893	8441.8
17:00	18:00	2816.0	100.899	21.917	6.207	1.969	8883.3
18:00	19:00	2835.2	101.646	22.218	6.242	1.988	8943.7
19:00	20:00	1877.3	67.302	15.170	4.184	1.332	5921.2
20:00	21:00	2276.9	81.586	17.899	5.036	1.598	7182.2
21:00	22:00	1718.6	61.580	14.418	3.898	1.237	5419.4
22:00	23:00	1598.2	57.299	13.430	3.615	1.151	5039.8
23:00	00:00	1319.0	47.296	11.689	3.046	0.970	4158.4
Total		41071.2	1472.054	335.996	92.093	29.267	129531.9

Table A1.16: Hourly emissions - Sunday for Route A.

Time		Emissions (g)					
Hour start	Hour start	FC	NO_X	CO	HC	PM	CO_2
00:00	01:00	1970.9	68.244	17.675	4.710	1.513	6212.5
01:00	02:00	611.4	21.178	5.517	1.459	0.471	1927.3
02:00	03:00	0.0	0.000	0.000	0.000	0.000	0.0
03:00	04:00	0.0	0.000	0.000	0.000	0.000	0.0
04:00	05:00	0.0	0.000	0.000	0.000	0.000	0.0
05:00	06:00	474.8	16.468	4.394	1.127	0.370	1496.6
06:00	07:00	1381.1	47.846	12.499	3.295	1.065	4353.4
07:00	08:00	2424.0	83.933	21.727	5.794	1.861	7640.9
08:00	09:00	2539.0	87.864	22.509	6.082	1.939	8003.5
09:00	10:00	3445.3	119.241	30.614	8.250	2.634	10860.3
10:00	11:00	3308.7	114.531	29.491	7.918	2.533	10429.6
11:00	12:00	3466.9	120.021	30.956	8.293	2.656	10928.5
12:00	13:00	3466.9	120.021	30.956	8.293	2.656	10928.5
13:00	14:00	3466.9	120.021	30.956	8.293	2.656	10928.5
14:00	15:00	3466.9	120.021	30.956	8.293	2.656	10928.5
15:00	16:00	3466.9	120.021	30.956	8.293	2.656	10928.5
16:00	17:00	3466.9	120.021	30.956	8.293	2.656	10928.5
17:00	18:00	3466.9	120.021	30.956	8.293	2.656	10928.5
18:00	19:00	3625.2	125.510	32.420	8.669	2.780	11427.3
19:00	20:00	3172.1	109.821	28.368	7.585	2.432	9998.9
20:00	21:00	3445.3	119.241	30.614	8.250	2.634	10860.3
21:00	22:00	3308.7	114.531	29.491	7.918	2.533	10429.6
22:00	23:00	3308.7	114.531	29.491	7.918	2.533	10429.6
23:00	00:00	3308.7	114.531	29.491	7.918	2.533	10429.6
Total		60592.5	2097.618	540.992	144.946	46.426	190998.6

Table A1.17: Hourly emissions - Sunday for Route B.

Time		Emissions (g)					
Hour start	Hour start	FC	NO_X	CO	HC	PM	CO_2
00:00	01:00	1026.3	36.406	9.510	2.380	0.782	3234.9
01:00	02:00	439.9	15.603	4.076	1.020	0.335	1386.4
02:00	03:00	293.2	10.402	2.717	0.680	0.223	924.3
03:00	04:00	293.2	10.402	2.717	0.680	0.223	924.3
04:00	05:00	439.9	15.603	4.076	1.020	0.335	1386.4
05:00	06:00	293.2	10.402	2.717	0.680	0.223	924.3
06:00	07:00	586.5	20.803	5.435	1.360	0.447	1848.5
07:00	08:00	1026.3	36.406	9.510	2.380	0.782	3234.9
08:00	09:00	1319.6	46.808	12.228	3.061	1.005	4159.1
09:00	10:00	1612.8	57.210	14.945	3.741	1.229	5083.4
10:00	11:00	1612.8	57.210	14.945	3.741	1.229	5083.4
11:00	12:00	1759.4	62.410	16.304	4.081	1.341	5545.5
12:00	13:00	1612.8	57.210	14.945	3.741	1.229	5083.4
13:00	14:00	1612.8	57.210	14.945	3.741	1.229	5083.4
14:00	15:00	1759.4	62.410	16.304	4.081	1.341	5545.5
15:00	16:00	1612.8	57.210	14.945	3.741	1.229	5083.4
16:00	17:00	1759.4	62.410	16.304	4.081	1.341	5545.5
17:00	18:00	1759.4	62.410	16.304	4.081	1.341	5545.5
18:00	19:00	1759.4	62.410	16.304	4.081	1.341	5545.5
19:00	20:00	1759.4	62.410	16.304	4.081	1.341	5545.5
20:00	21:00	1612.8	57.210	14.945	3.741	1.229	5083.4
21:00	22:00	1612.8	57.210	14.945	3.741	1.229	5083.4
22:00	23:00	1612.8	57.210	14.945	3.741	1.229	5083.4
23:00	00:00	1466.2	52.009	13.586	3.401	1.117	4621.3
Total		30643.4	1086.981	283.953	71.073	23.349	96584.5

Table A1.18: Hourly emissions - Sunday for Route C.

Time		Emissions (g)					
Hour start	Hour end	FC	NO_X	CO	HC	PM	CO_2
00:00	01:00	558.4	20.115	5.158	1.275	0.418	1760.0
01:00	02:00	0.0	0.000	0.000	0.000	0.000	0.0
02:00	03:00	0.0	0.000	0.000	0.000	0.000	0.0
03:00	04:00	0.0	0.000	0.000	0.000	0.000	0.0
04:00	05:00	139.6	5.029	1.289	0.319	0.105	440.0
05:00	06:00	1198.6	42.961	9.863	2.694	0.856	3780.2
06:00	07:00	1598.2	57.245	12.591	3.546	1.122	5041.2
07:00	08:00	1598.2	57.245	12.591	3.546	1.122	5041.2
08:00	09:00	1579.0	56.551	13.128	3.579	1.132	4979.4
09:00	10:00	1319.0	47.296	11.689	3.046	0.970	4158.4
10:00	11:00	1997.7	71.583	16.158	4.467	1.417	6300.8
11:00	12:00	1877.3	67.302	15.170	4.184	1.332	5921.2
12:00	13:00	1997.7	71.583	16.158	4.467	1.417	6300.8
13:00	14:00	1997.7	71.583	16.158	4.467	1.417	6300.8
14:00	15:00	1598.2	57.299	13.430	3.615	1.151	5039.8
15:00	16:00	2556.0	91.589	19.639	5.605	1.779	8063.7
16:00	17:00	2276.9	81.586	17.899	5.036	1.598	7182.2
17:00	18:00	2435.6	87.308	18.651	5.321	1.693	7684.1
18:00	19:00	2276.9	81.586	17.899	5.036	1.598	7182.2
19:00	20:00	1877.3	67.302	15.170	4.184	1.332	5921.2
20:00	21:00	1997.7	71.583	16.158	4.467	1.417	6300.8
21:00	22:00	1718.6	61.580	14.418	3.898	1.237	5419.4
22:00	23:00	1598.2	57.299	13.430	3.615	1.151	5039.8
23:00	00:00	1319.0	47.296	11.689	3.046	0.970	4158.4
Total		35515.9	1272.921	288.337	79.410	25.234	112015.6

Acknowledgements

Thanks to Karen Winkle, Emma Anderson and Hongjun Mao who undertook the site surveys at the Golders Green bus station and to Jenny Price for analysing the bus and coach timetables.

9 Appendix 2: Emissions from Vehicles on Roads

9.1 The road-based movements of buses associated with Golders Green bus station were calculated by AQC using the bus timetable data provided by TRL in Tables A1.7 to A1.9. The routes taken by each TfL bus were identified from the TfL journey planner website[9]. National express buses stopping at the bus station were all assumed to travel along the A502 in both directions. All buses and coaches entering and exiting the bus station were assigned onto the local road network and around the junction depending upon their origin or destination[10].

9.2 Bus and coach data for each link were also taken from the London Atmospheric Emissions Inventory (LAEI). The difference between the link-specific bus and coach movements held in the LAEI and those inferred from the bus timetables were taken to be buses which do not use Golders Green bus station. These buses were assigned around the junction as described below for other vehicle classes.

9.3 Flows of all other vehicle classes were taken from the LAEI dataset, with flows of each separate class of vehicle[11] during 2008 interpolated linearly from those in 2004 and those predicted within the Inventory for 2010. The LAEI treats Golders Green junction as a simple crossroads, and does not provide individual turning movements around the roundabout. So as to provide a more precise prediction of concentrations, turning movements around the junction were estimated from the relative volumes on each link, assuming that the bi-directional flows on each road are equal[12].

9.4 Emissions from each separate vehicle class were then calculated using the emission factor toolkit provided at www.airquality.co.uk assuming average speeds of 20kph around the junction and the link-average speeds held in the LAEI away from the junction[13].

9 http://journeyplanner.tfl.gov.uk/user/XSLT_SEL_STT_REQUEST?sessionID=0&language=en&mode=line&linePreSel=tfl:25:*&linePreSel=tfl:63:*&linePreSel=nrc:90:*&withoutTrains=0

10 i.e. buses leaving the station to travel west simply turn left onto North End Road, but buses travelling north along Finchley Road turn right onto North End Road, and navigate the roundabout before joining Finchley Road northbound - See Figure 1.

11 The LAEI differentiates between the separate vehicle classes listed in Table A3.1.

12 So that, for example, the vehicles entering the junction from the west are assumed to exit southbound, westbound, and northbound apportioned according to the relative volumes of vehicles on each of those exists to the junction.

13 Since the emission factor toolkit does not provide separate emissions for motorcycles, these were grouped together with cars within the model.

9.5 Road-based emissions from buses using the bus station were given a diurnal and weekly profile calculated from the bus timetables. Emissions from all other vehicles were assigned the national diurnal and weekly profile for 2007 published by the Department for Transport (www.dft.gov.uk/pgr/statistics).

10 Appendix 3: Dispersion Modelling Methods

10.1 Modelling was carried out using the ADMS-Roads dispersion model. Movements around the bus station were entered into the model as three line sources with widths which varied along the length of each line set to represent the overall area across which buses regularly move.

10.2 Each separate turning movement around the junction was entered into the model as a separate line source, with all buses assumed to use bus lanes where they are present and no other vehicles assumed to use the bus lanes. The model was run to include each of the sources listed in Table A3.1.

10.3 The model was run using 2008 meteorological data from Northolt. Hour-by-hour background concentrations of nitrogen oxides (NOx) and nitrogen dioxide (NO_2) during 2008 were taken as the average from the three background monitors at Barnet 2 Finchley; Harringey 2 Priory Park; and Brent 7 St Marys[14]. Some of these data were provisional but a visual inspection of each dataset did not highlight any anomalous data.

Table A3.1: Components of the Dispersion Model

Component of Model	Data Source
Buses in station	TRL analysis in Appendix 1
Buses on roads	LAEI (2004 projected to 2008)
Cars and motorcycles	LAEI (2004 projected to 2008)
Taxis	LAEI (2004 projected to 2008)
LGVs	LAEI (2004 projected to 2008)
Rigid HGVs	LAEI (2004 projected to 2008)
Artic HGVs	LAEI (2004 projected to 2008)
Background	Average of hour-by-hour data at: Barnet 2 Finchley; Harringey 2 Priory Park; and Brent 7 St Marys (2008)
Meteorological Data	Northolt (2008)

10.4 The model was first run for the period of the monitoring data. All subsequent model runs were for the full 2008 calendar year.

[14] Data downloaded from www.airquality.co.uk in March 2009.

Model Verification of Period Mean Concentrations

10.5 The model was initially run without including a background file, to predict hour-by-hour concentrations of locally-emitted NOx at the Golders Green automatic monitoring station between 6th February 2008 and 13th August 2008 (i.e the dates of the monitoring). Concurrent datasets were then generated for a) the model results; b) the Golders Green automatic monitor; and c) the background file, by deleting any hours not present in one of the datasets from both of the others[15]. This left 4,455 hours of concurrent data.

10.6 The period mean background NOx concentration was subtracted from the period mean NOx concentration measured at the Golders Green monitor. This value was compared with the modelled period mean NOx concentration as shown in Table A3.2. This showed that the model was under-predicting locally emitted NOx by a factor of 3.1 on average. All modelled NOx concentrations were thus multiplied by 3.1 in order to account for this under-read.

Table A3.2: Comparison of Measured and Modelled Period Mean Locally-Emitted NOx

		Period Mean NOx (mg/m^3)
A	**Total Measured NOx**	149.9
B	**Measured Background NOx**	47.1
C	**Measured locally-emitted-NOx (A - B)**	102.8
D	**Modelled locally-emitted-NOx NOx**	33.1
E	**Adjustment Factor (C/D)**	3.1

10.7 In order to calculate NO_2 concentrations it was necessary to identify the relationship between NOx and NO_2 at the monitoring site. Figure A3.1 compares the hour-by-hour NOx concentrations measured at the Golders Green monitor with the concurrent measurements for NO_2. The red line shows the best-fit relationship which is:

$$NO_2 = \text{Exp}\,(0.8606 \times \text{Ln NOx} + 0.0101) \quad (r^2 = 0.91)$$

10.8 This relationship has been applied to all predicted period mean and annual mean NOx concentrations in order to derive annual mean and period mean NO_2 concentrations.

10.9 In order to check that the predicted NO_2 concentrations accurately reflect measurements, the period mean predictions at the automatic monitoring site have been compared with the period

[15] Different datasets report data as hour beginning and hour ending and this was taken into account.

mean measurements. In addition, the model has been run to predict the 2008 annual mean NO_2 concentration at each of eight diffusion tube sites located around the bus station and Golders Green junction. None of these diffusion tube sites produced data for the 2008 calendar year and so the data have been annualised (see LB Barnet, 2009) but have not been adjusted to reflect year-on-year variations. The results of this comparison are shown in Figure A3.2. The model recreates the automatic measurement very well, but over-predicts concentrations at one of the long-term monitors slightly. The model also under-predicts concentrations at the short-term diffusion tubes sites, but it should be recognised that there will be much more uncertainty in these short-term measurements than in the long-term measurements.

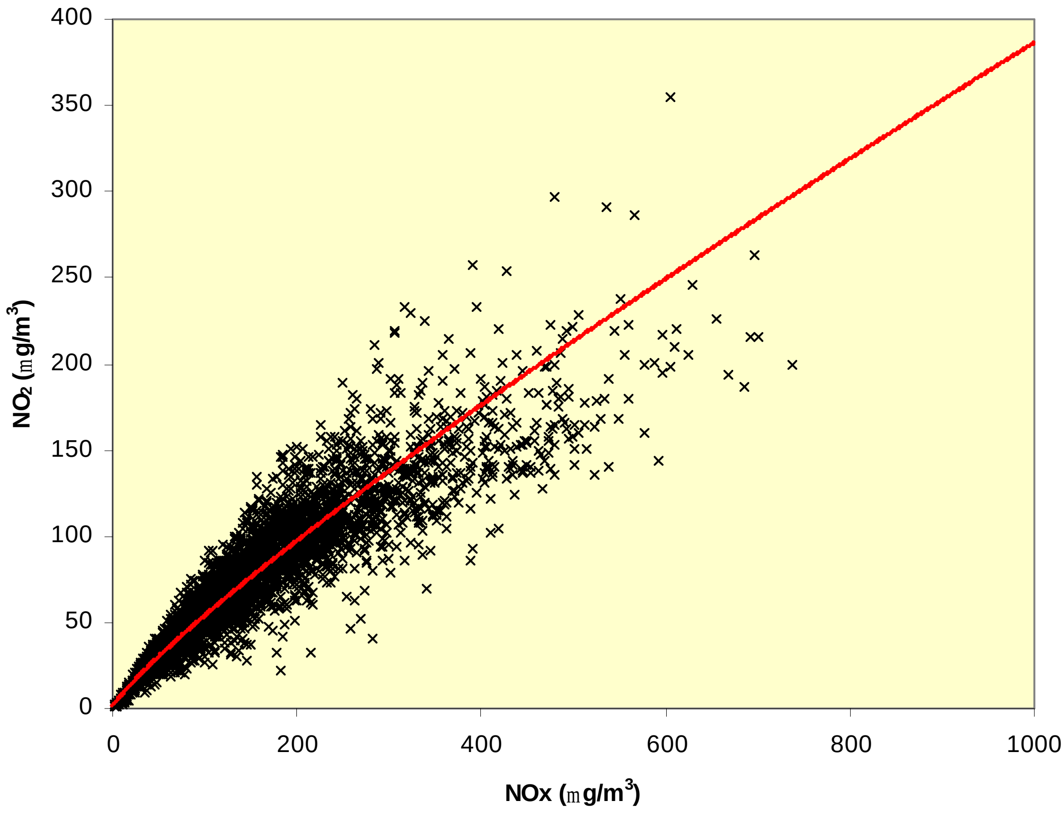

Figure A3.1: Measured Hourly NOx vs Measured Hourly NO_2 at the Golders Green Monitoring Station - red line shows the best fit relationship used in this study

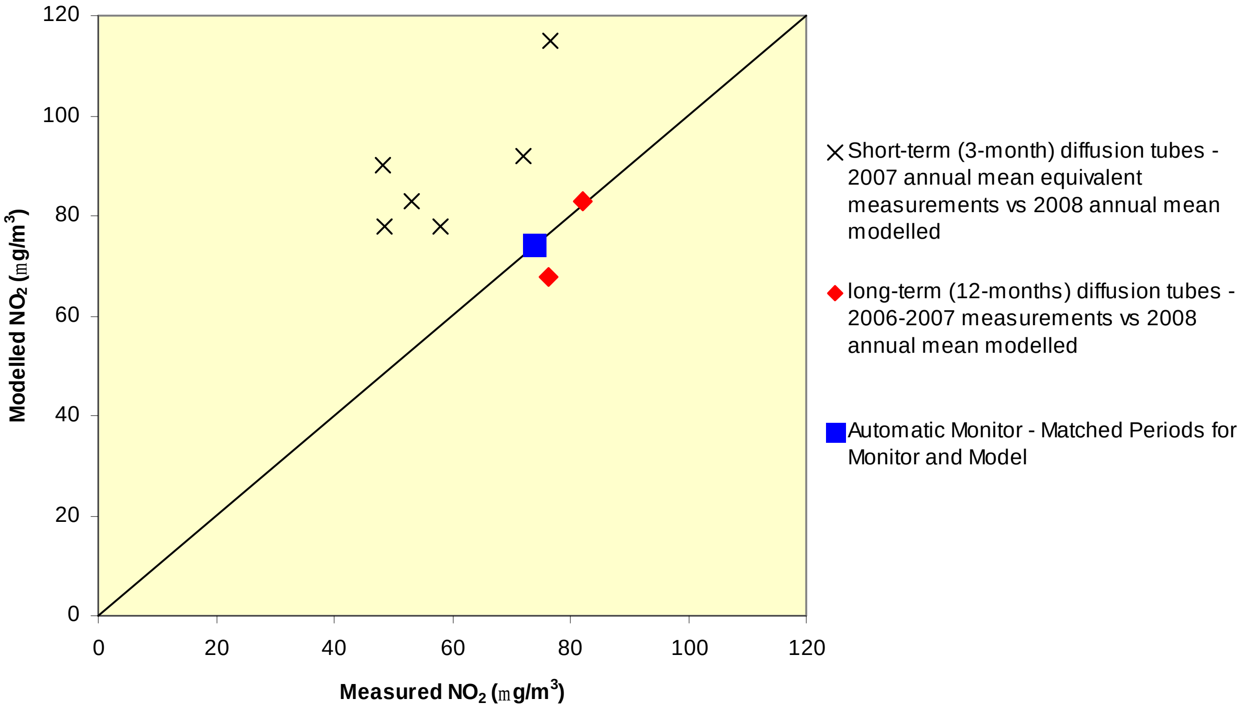

Figure A3.2: Measured vs Modelled Period Mean and Annual Mean Equivalent Data

Model Verification of 99.79th Percentile Concentrations

10.10 The model was run incorporating the NOx adjustment factor (3.1) described above into the model input files and including hour-by-hour background concentrations within the model. The predicted 99.79th percentile of 1-hour NOx concentrations is given in Table A3.3; as is the 99.79th percentile measured concentration over the same period. The model over-predicts this concentration and so all predicted 99.79th percentiles of 1-hour NOx concentrations have been multiplied by 0.65 to correct for this over-read. The 99.79th percentiles of 1-hour NOx concentrations were then converted to 99.79th percentiles of 1-hour NO_2 concentrations using the site-specific NOx to NO_2 relationship shown in Figure A3.1.

Table A3.3: Comparison of Measured and Modelled 99.79th Percentile NOx Concentrations

		Period Mean 99.79th Percentile NOx (mg/m³)
A	**Measured**	628.5
B	**Modelled**	971.1
C	**Adjustment Factor (A/B)**	0.65

11 Appendix 4: Source Apportionment Methodology

Annual Mean Concentrations

11.1 The model was run to predict annual mean local-NOx (i.e. NOx from all sources excluding the background) concentrations from each of the individual emission sources set out in Table A3.1 at the seven receptors shown in Figure 7.

11.2 While most NO_2 is formed by chemical reaction of nitric oxide and ozone, some is emitted directly in vehicle exhausts. This is termed "primary NO_2". Figure A4.1 shows the proportion of primary NO_2 expected to be emitted by each type of vehicle. London buses clearly emit more NO_2 directly than other types of vehicles. The annual mean source apportionment has taken this into account. The NOx to NO_2 calculator (version 1.1) published at www.airquality.co.uk has been used to predict the local-NO_2 concentration associated with each individual NOx source (using the appropriate year, location and the annual mean background NO_2 from the monitoring described above and using the appropriate fNO_2 values listed in the calculator and repeated in Figure A4.1)[16]. The relative contribution of each emission source to the sum of the local-NO_2 from all separate emission sources was then calculated. The relative contribution of local-NO_2 to total NO_2 was calculated by subtracting the background from the total. To retain consistency in the method, the background NO_2 in this instance was calculated from the background NOx using the site-specific NOx to NO_2 relationship given in Figure A3.1.

16 The NOx to NO_2 relationship is not linear and so the road-NO_2 calculated in this way applies to a scenario in which there are no other sources of NOx. It is not appropriate to use these results directly.

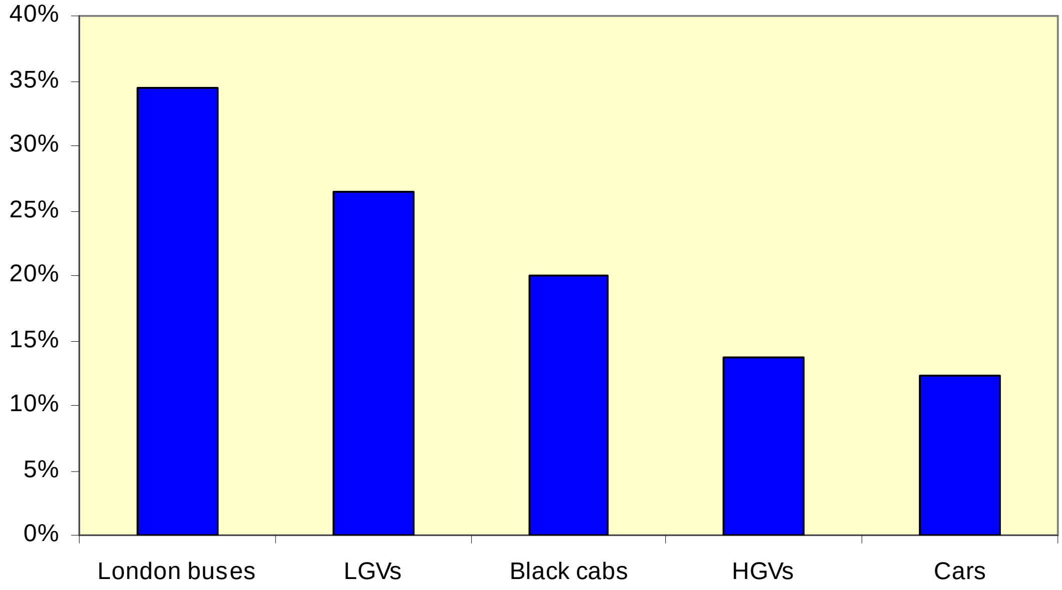

Figure A4.1: Percent of Total NOx Emitted as NO_2 (fNO_2) in 2008[17]

1-Hour Mean Concentrations

11.3 The 99.79th percentile of 1-hour NO_2 concentrations describes the conditions at a single point in time. On an hour-by-hour basis, the relative contribution of different sources to the total NO_2 concentration is highly variable. It is thus not appropriate to provide source apportionment information for a single hour's data. The approach has instead been taken of describing the average contribution of each source to the total concentration during every hour when the concentration was greater than 200 $\mu g/m^3$ (i.e. the air quality standard).

11.4 The model was run to predict hour-by-hour concentrations at the seven selected receptors; first including all emission sources and the hour-by-hour background file; and second for each separate emission source and excluding the background file. The results from the first of these model runs was used to identify which hours experienced an exceedence of the 200 $\mu g/m^3$ standard at each receptor. The emission source specific model outputs for these individual hours were then used to calculate the source apportionment results.

11.5 The relative contribution of each source to local-NOx during each exceedence hour was calculated and these values were then averaged for each site. These data are presented as source

[17] Derived from the data in the NOx to NO_2 calculator published at www.airquality.co.uk.

apportioned local-NOx rather than total NO_2, since it was not practical to take account of differences in primary NO_2 emissions from each source in the hour-by-hour data.

12 Appendix 5: Relationship Between the Annual Mean and the Number of 1-hour Exceedences

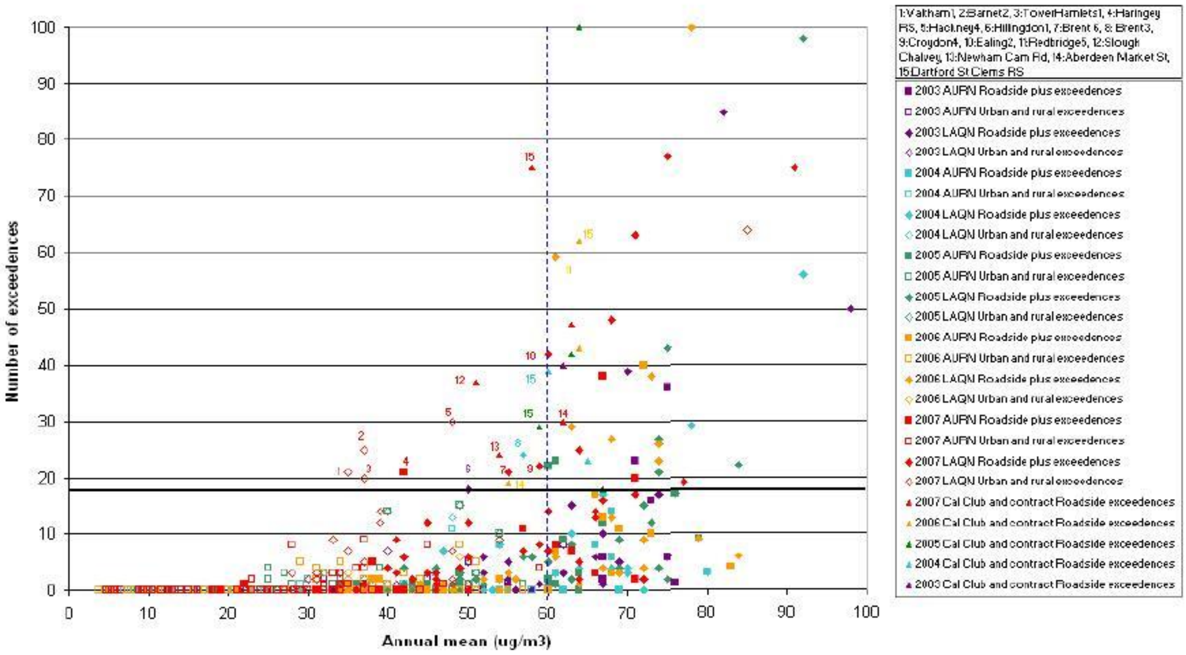

Figure A4.1: The Relationship Between the NO_2 Annual Mean and the Number of Exceedences of the Hourly Objective - Taken from Cook (2008)