2008 Detailed Assessment of Air Quality for the London Borough of Sutton

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take part, take pride

Sutton

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Executive Summary

This is the Detailed Assessment of air quality for the London Borough of Sutton ("the Council"). This assessment fulfils the Council's next step of the Local Air Quality Management (LAQM) process and is required as a result of the findings of recent Council's reports.

The Council previously designated parts of its area as an Air Quality Management Area (AQMA) based on its findings that the government's annual mean nitrogen dioxide (NO_2) objective might be exceeded, specifically close to major roads with nearby residences representing relevant public exposure. This included parts of Carshalton, Wallington, Cheam and Beddington. The purpose of this report is therefore to provide an accurate re-assessment of the likelihood of the objective being exceeded across the Borough at these and other locations with relevant exposure.

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

The Council's monitoring results for its continuous site at Wallington and non-continuous sites in Cheam and Sutton indicated that the 2005 annual mean objective for NO_2 was exceeded for all recent years monitored (since 2003 in the report).

The new modelling predictions for the Borough were undertaken using 2003 meteorology. These showed that the annual mean NO_2 objective was exceeded for the 2010 base case scenario close to the centre of the major and other selected roads. This included roads that are outside of the designated AQMA. The area exceeding the objective also overlaps the facades of buildings thereby representing potential relevant exposure.

As a result of these findings, the Council is recommended to undertake the following actions for the statutory objective relating to annual mean nitrogen dioxide.

For the existing AQMA:

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

2. Maintain the designation of the AQMA.

For the other areas examined in the report and identified as exceeding the objective with relevant exposure:

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

4. Confirm that there is relevant exposure in the area predicted to exceed and if confirmed extend the designation of the AQMA.

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1.1 Overview to Detailed Assessment

This is the 2008 Detailed Assessment of nitrogen dioxide (NO_2) for the London Borough of Sutton. The report fulfils the statutory requirement for this, the Council's next step, of the Local Air Quality Management (LAQM) process.

1.2 Background

Local air quality management forms a key part of the Government's strategies to achieve the air quality objectives under the Air Quality (England) Regulations 2000 and 2002. Previous Council reports identified that the government's annual mean NO_2 objective has been exceeded in parts of the Borough not previously assessed as such. As a result the Council needed to undertake a Detailed Assessment for NO_2 in its area.

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

Table 1 NO_2 air quality objectives relevant to this Detailed Assessment report

Concentration	Objective	Measured as	Date to be achieved by
40 $\mu g\ m^{-3}$	Not to be exceeded	Annual mean	31-Dec-05
200 $\mu g\ m^{-3}$	Not to be exceeded more than 18 times in a year.	Hourly mean	31-Dec-05

1.3 Progress with Local Air Quality Management – London Borough of Sutton Council

The Council previously designated Air Quality Management Areas (AQMA) in parts of its area for both NO_2 and PM_{10} during earlier rounds of air quality review and assessment. This was along major roads that run through the Borough, including the A232 and A237. Beddington Lane in the north east of the Borough was also designated an AQMA for PM_{10} as a result of the Council's most recent Detailed Assessment of the industrial activities in this area.

The Air Quality Management Areas consist of the following sections of main roads, and which are shown in blue in Figure 1 below:

- B272 Beddington Lane/Hilliers Lane from Croydon Road (A232) north to borough boundary

- A237 Manor Road/Woodcote Road from Croydon Road (A232) south to borough boundary
- B271 Stafford Road from Woodcote Road east to borough boundary
- B278 Wrythe Lane/West Street from Rosehill south to A232 in Carshalton
- A232 Cheam Road/Carshalton Road/Pound Street/Acre Lane/Croydon Road from Cheam Village east to borough boundary
- B2230 Brighton Road/Grove Road/Sutton Park Road/St Nicholas Way/Throwley Way/Chalk Pit Way/Sutton Court Road/High Street/Angel Hill/Rose Hill from Cedar Road to Rosehill roundabout
- A2043 Central Road/Cheam Common Road from A24 London Road west to borough boundary.

Figure 1 L.B of Sutton AQMAs

2 Monitoring results

2.1 Updated NO_2 results

This section provides an update of the Council's NO_2 monitoring programme. The Council undertakes monitoring of NO_2 using both automatic high quality continuous monitoring analysers and diffusion tubes across its area.

The long-term continuous analysers operate at the following sites:

Carshalton Ecology Centre (Sutton 3) - a suburban background site in Carshalton. This site opened in May 1995.

Woodcote Road, Wallington (Sutton 4) - a kerbside site that started operating in July 2002.

Beddington Lane, Beddington (Sutton 5) – an industrial site close to the roadside that opened in December 2005.

A further automatic site will be installed and opened close to Worcester Park during 2008.

The sites are all part of the London Air Quality Network and therefore the standards of QA/QC are similar to those of the government's AURN sites. Regular calibrations are carried out, with subsequent data ratification undertaken by the ERG at King's College London. In all cases the data are fully ratified.

The results of the monitoring at the automatic sites are given in Table 2.

Table 2 NO_2 continuous monitoring in Sutton (2003 – 2007)

LAQN site		2003	2004	2005	2006	2007
Sutton 3	Annual mean	-	*36*	30	30	33
(Suburban)	No of hours >200 µg m^{-3}	-	*0*	0	0	2
	Data capture %	-	*24*	92	99	97
Sutton 4	Annual mean	**70**	**80**	**83**	**78**	***83***
(Kerbside)	No of hours >200 µg m^{-3}	**39**	**131**	**189**	**100**	***264***
	Data capture %	100	93	99	100	*54*
Sutton 5	Annual mean	-	-	-	*38*	37
(Industrial)	No of hours >200 µg m^{-3}	-	-	-	*0*	7
	Data capture %	-	-	-	*74*	97

(Note – bold exceeds objective; italics < 90% data capture)

The results from the continuous monitoring sites indicate that the annual mean and hourly mean objectives for NO_2 have been easily exceeded for all years at the Sutton 4 site. This site is located at the kerbside of the A237 in Wallington, between a pelican crossing and bus stop. It is also within the existing AQMA.

Concentrations at the Sutton 3 suburban background site in Carshalton met the objectives, as did NO_2 concentrations at the site in Beddington Lane, although concentrations at the latter were higher and approached the annual mean standard. The Sutton 3 site is not within an AQMA, although the Sutton 5 site on Beddington Lane is within an AQMA. The site was designated an AQMA as a result of the high PM_{10} in this area.

As reported in the 2006 Updating and Screening Assessment, the Council also undertook a programme of monthly diffusion tube monitoring of NO_2, supplied by Bureau Veritas and analysed by Gradko. The method of preparation was 50% triethanolamine (TEA) in acetone as absorbent.

The Council however has not undertaken a local co-location study and therefore a locally derived bias adjustment factor was not available, instead default factors obtained from Defra helpdesks were used. These factors were obtained from the Review and Assessment website (http://www.uwe.ac.uk - March 2008 version).

These bias factors indicated that the diffusion tubes measurements were less than the continuously monitored concentrations at the same location for the period from 2003 to 2006 inclusive. In 2007 the diffusion tube measurements exceeded those monitored continuously.

Year	Bias adjustment factor
2003	1.11
2004	1.10
2005	1.10
2006	1.01
2007	0.93

The NO_2 monitoring was undertaken at locations that represented relevant public exposure. These are given in Table 3.

Table 3 Details of the diffusion tube sites

Site	Address
ST32	Lab at Alcorn Close, Sutton
ST33	Sutton Police Station, Carshalton Road, Sutton
ST36	Site of former Paynes Poppets, Croydon Road
ST37	Robin Hood Junior School, Thorncroft Road, Sutton
ST38	Devonshire Primary School, Devonshire Ave, Sutton
ST40	Washateria, 38 High Street, Cheam
ST41	Benhill Road Allotments, Benhill Road, Sutton

The locations of the sites other than the background (ST37, 38 and 41) sites are given below.

The Alcorn Close (ST32) site is located about 25m from the centre of the A217 Oldfields Road (see Figure 2.) The Alcorn Road site represents background exposure, albeit it is not far from a busy road in the Borough. There are residential buildings that are set closer to the road than the diffusion tube site some 600m to the south.

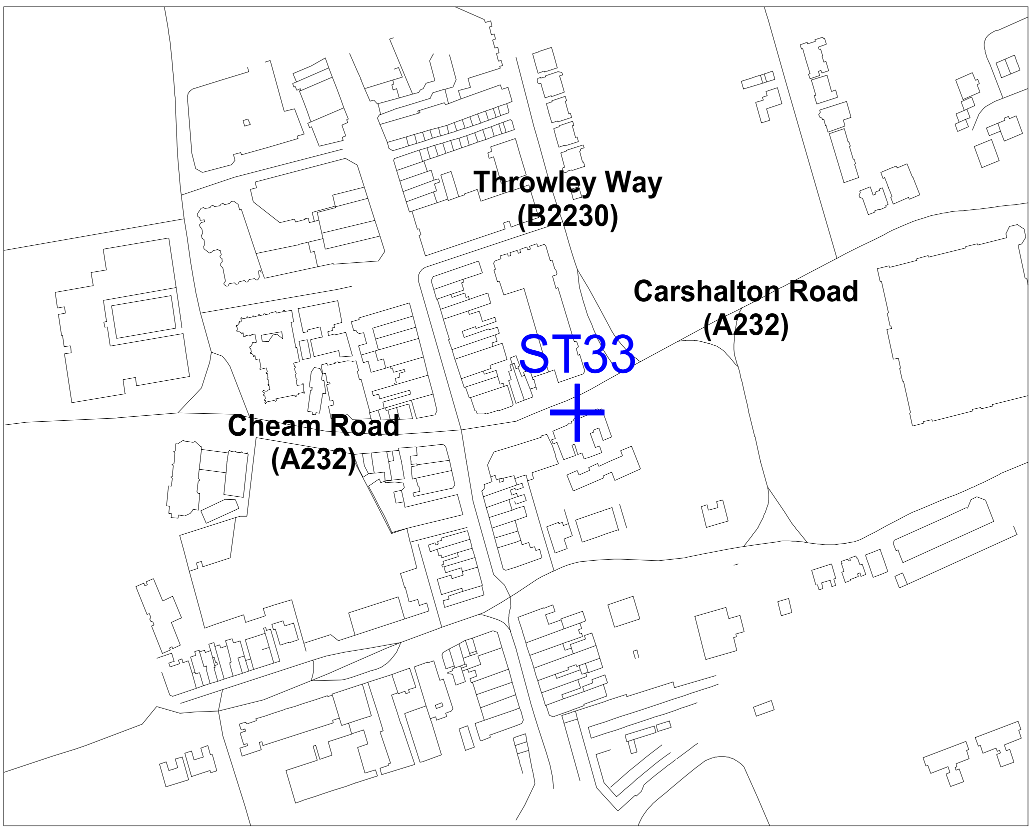
Figure 2 ST32 diffusion tube site.

(Note – blue cross indicates d/t site)

The ST33 site is located 8m to the south of the centre of the A232 Carshalton Road in Sutton. (See Figure 3 for the location of the site). The site is located to close buildings used for office and commercial uses.

The area is dominated by slow moving traffic, particularly at peak periods, with queuing at the junctions. The ST33 site is on the Sutton one-way system and is approximately 30m from the signal-controlled junction with Throwley Way.

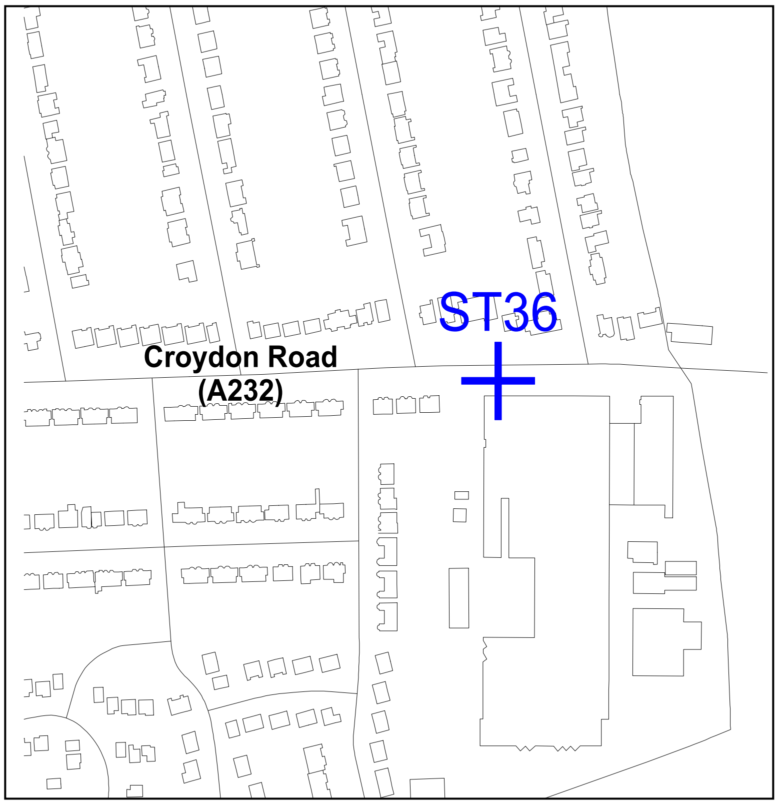
Figure 3 ST33 diffusion tube site.



(Note – blue cross indicates d/t site)

The ST36 site is located in the east of the Borough, close to the administrative boundary with Croydon. It is a roadside site with the diffusion tube site located approximately 8m to the south of the road centre. It is representative of exposure along this road, which includes residential buildings.

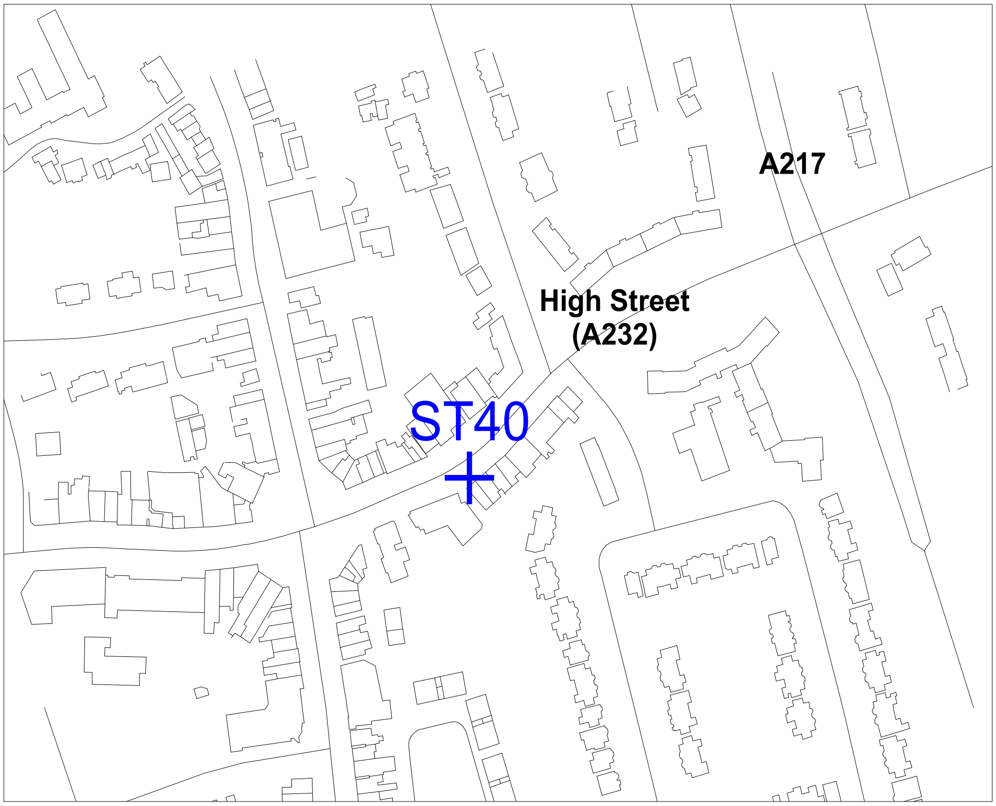
Figure 4 ST36 diffusion tube site



(Note – blue cross indicates d/t site)

The ST40 site is located on the southern side of the High Street in Cheam, approximately 7m from the road centre line. It is located about 170m west of the A217 and 80m to the east of the crossroads with The Broadway and Station Road. The roads close to the site are frequently congested throughout the day. It is representative of relevant exposure in the area, which includes both residential and commercial uses.

Figure 5 ST40 diffusion tube site



The three remaining sites ST37, ST38 and ST41 (not shown in this report) are all at background locations. This ST37 site is located close to the main centre of Sutton and consequently has the highest concentrations of the three sites. The biased adjusted result for the sites are given below and for the years reported, there was full data capture for all sites.

Table 4 Bias adjusted diffusion tube monitoring results (2003 - 2007)

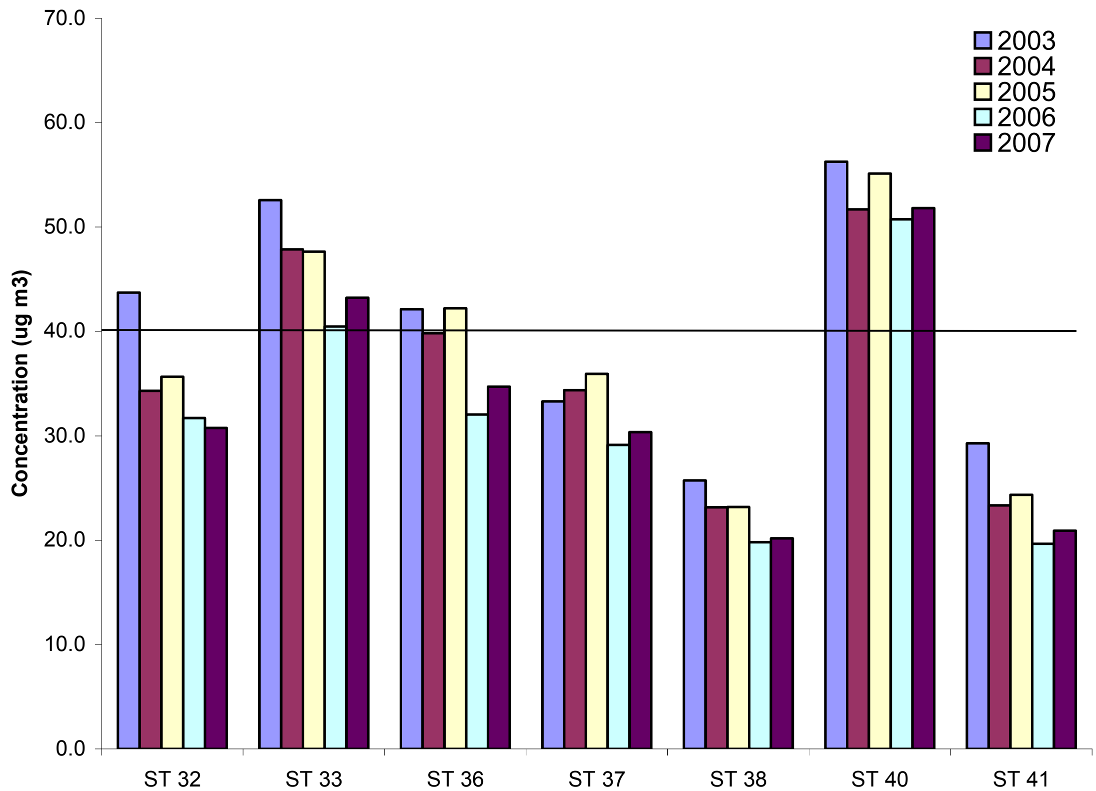
Site code	2003	2004	2005	2006	2007
ST 32	**43.7**	34.3	35.7	31.7	30.7
ST 33	**52.6**	**47.9**	**47.7**	**40.5**	**43.2**
ST 36	**42.1**	39.8	**42.2**	32.1	34.7
ST 37	33.3	34.4	35.9	29.1	30.4
ST 38	25.7	23.1	23.2	19.8	20.2
ST 40	**56.3**	**51.7**	**55.1**	**50.7**	**51.8**
ST 41	29.3	23.3	24.4	19.7	20.9

(Note: bold indicates exceeds objective)

The results indicated that the annual mean objective of 40 $\mu g\ m^{-3}$ was exceeded at both ST33 and ST40 sites for all years during the monitoring period shown. (Note - the unbiased monthly results are given in Appendix C). There was however interannual variation between years, with the annual mean concentrations highest in 2003 and lowest in 2006 for these two sites.

Concentrations at all sites (other than ST37) were higher in 2003 than other years. This is similar to findings elsewhere nearby. Concentrations in London during 2003 were higher as a result of the meteorology during the year which was conducive the formation of NO_2 and other pollutants (ERG, 2003). The lowest concentrations arose in 2006 for six of the seven sites, with concentrations varying between sites for other years. This variation in concentration between years may partly be explained by changes in local emissions of pollutants, variation in meteorology between years or a combination of both.

Figure 6 Bias adjusted annual mean concentrations for the Sutton diffusion tube sites (2003 – 2007)



3 Predictions of NO_2 in the L.B of Sutton

3.1 Outline of modelling developments

The Detailed Assessment incorporates:

- Major roads on an exact geographic basis to allow an improved assessment of exposure;
- Predictions plotted on OS base maps;
- An estimate of model uncertainty.

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

The model was empirically developed for urban areas and has been previously used for modelling assessments by the Council as part of its local air quality management responsibilities. Details of the model validation are given in Appendix B.

The traffic data used for the modelling were obtained from the London Atmospheric Emissions Inventory 2004; these include details of flows for the base case scenario modelled in 2010, which incorporates a prediction of the impact of the London Low Emission Zone (LEZ), as well as incorporating the likely effect of the Congestion Charging Zone. (The L.B of Sutton is however outside of the CCS area).

The area modelled was extended to include the whole Borough.

3.2 Annual mean NO_2 ($\mu g\ m^{-3}$) in 2010

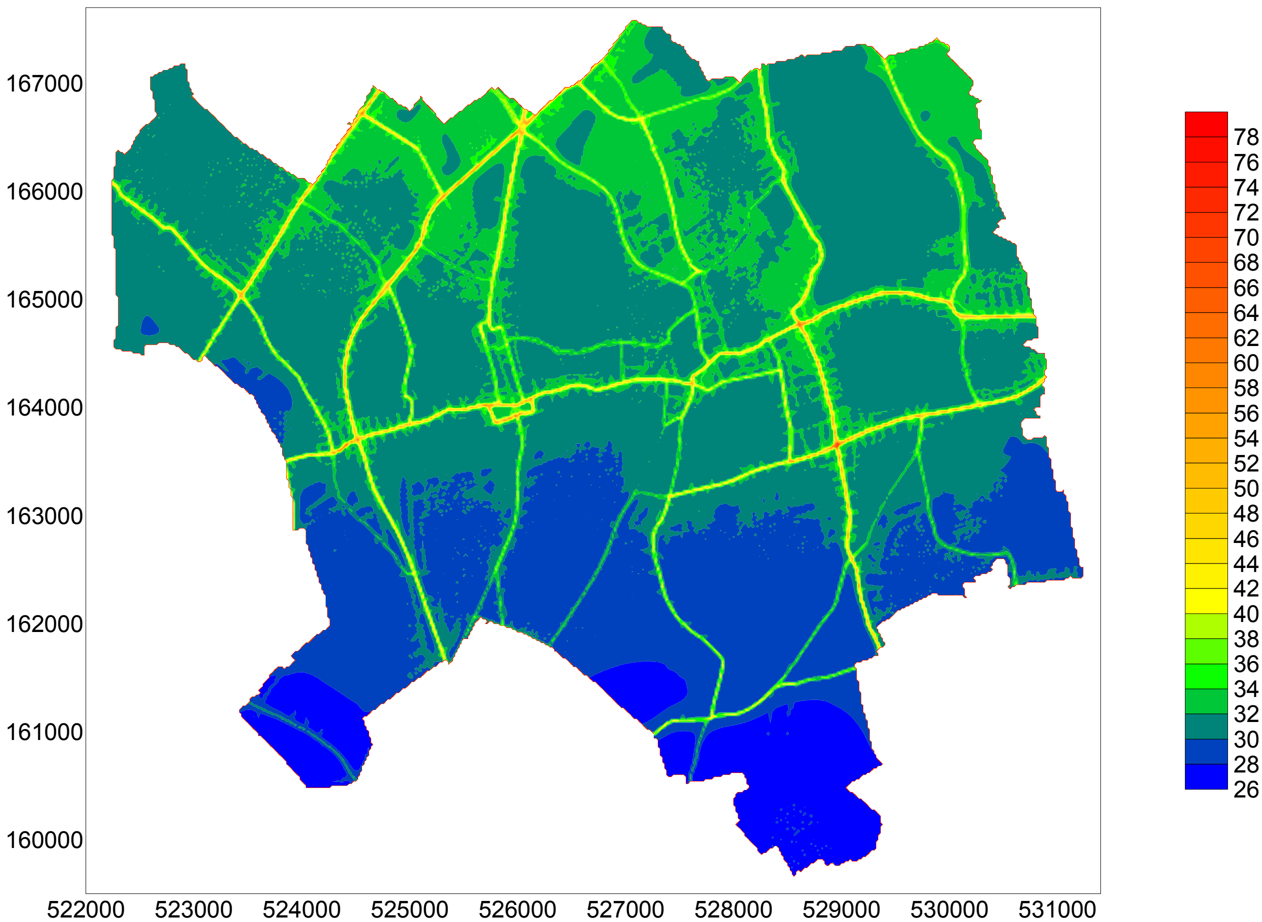
The predicted annual mean concentrations for the above mentioned 2010 base case, assuming that the meteorology of the year 2003 was repeated, are shown in Figure 7. This meteorological year was modelled as it represents a year when high pollutant concentrations arose as a consequence of the hot summer and prolonged photochemical episodes. Thus it provides some certainty that those years where exceedences are more likely are considered.

The locations of the roads are modelled to a high degree of accuracy and in this case it is within 1m. This enables the concentration contours to be plotted with OS Landline data[1], which gives details of individual buildings and allows easy estimation of the exposure of the local population to concentrations above the AQS objective. The pollution contours also show the rapid fall off in concentration to the background from the road. In the plot only those areas coloured yellow to orange/ red exceed the air quality objective.

3.3 Predictions of NO_2 using 2003 meteorology

The 2010 base case predictions confirmed that the annual mean air quality objective was exceeded along the major roads modelled in the Borough. The area that exceeded was mostly close to the centre of roads. The area that exceeded however also overlapped the façades of nearby relevant buildings with potential public exposure. Further detail of these predictions is provided in the next sections of the report.

Figure 7 Predicted annual mean NO_2 ($\mu g\ m^{-3}$) for 2010 base case (with 2003 meteorology)



(Note – blue cross indicates diffusion tube site)

The main sections of roads in the Borough where the annual mean objective is exceeded includes the A24, A217, A232, A237, A297, A2043, plus parts of B271, B272, B278, B279, B2230, Middleton Road, Green Wrythe Lane, Gander Green Lane, Stanley Park Road.

3.4 Comparison with L. B Sutton monitored results

As reported earlier the Council undertakes monitoring of NO_2 using both continuous and non-continuous monitoring. The monitored results were given in the previous section. The monitoring results indicate that the annual mean objective was exceeded at its roadside monitoring sites; including the Sutton 4 automatic site in Wallington and the ST 33 and 40 diffusion tube sites in Sutton and Cheam town centres for all years reported. The objective was also exceeded at the ST 36 roadside site near Beddington in 2003 and 2005. In 2004, 2006 and 2007 the objective was met at the site, albeit in 2004 annual mean was only just met.

The monitoring results at the Council's background sites indicate that the objective was met for all years reported, apart from the ST32 site near Rosehill that exceeded the objective in 2003 only. The sites that met the objective include the automatic Sutton 3 and 5 sites in Carshalton and the north end of Beddington Lane, plus the diffusion sites at ST32, 37, 38 and 41 (near Rosehill, Sutton town centre (both ST 37 and 38) and Benhilton respectively).

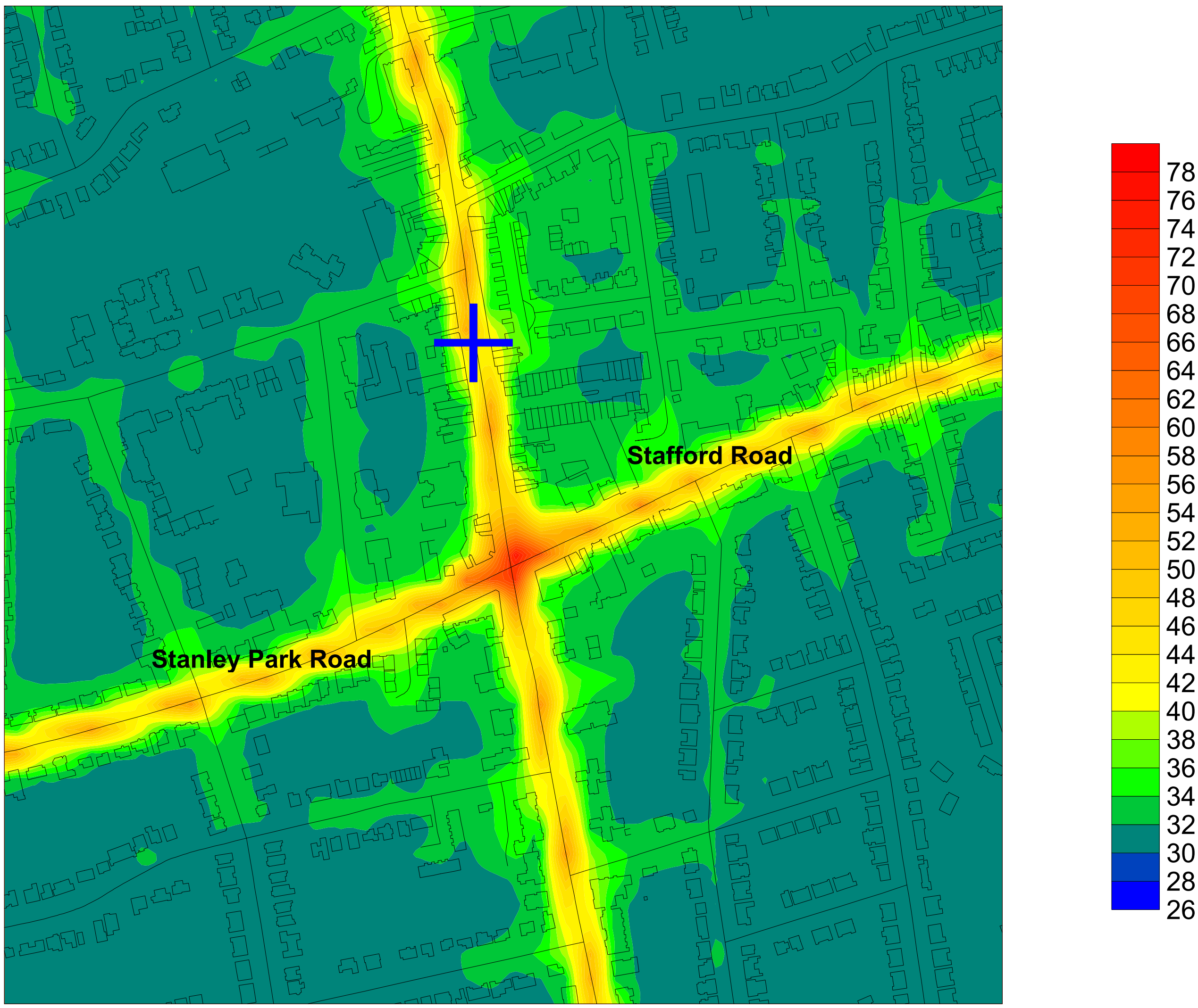
Close ups of the predictions for the mainly roadside sites where the annual mean objective has been exceeded are shown below.

3.5 Sutton 4 in Wallington

The Sutton 4 site is located within the Council's designated AQMA, close to the kerbside of Woodcote Road in Wallington, which is a busy street with both shops and residences. The monitoring equipment is sited on a section of pavement between a pelican crossing and a bus stop.

A close up of the area is shown in Figure 8, which shows that the A237 along Woodcote Road in Wallington is predicted to exceed the annual mean objective in 2010, both north and south of the marked position of the monitoring site. It is also predicted that the objective is exceeded at facades of buildings along Stanley Park Road and Stafford Road (the B271). Both Stanley Park Road and Stafford Road are outside of the designated AQMA (see Figure 1).

Figure 8 Predicted annual mean NO_2 at Sutton 4 site in Wallington ($\mu g\ m^{-3}$)



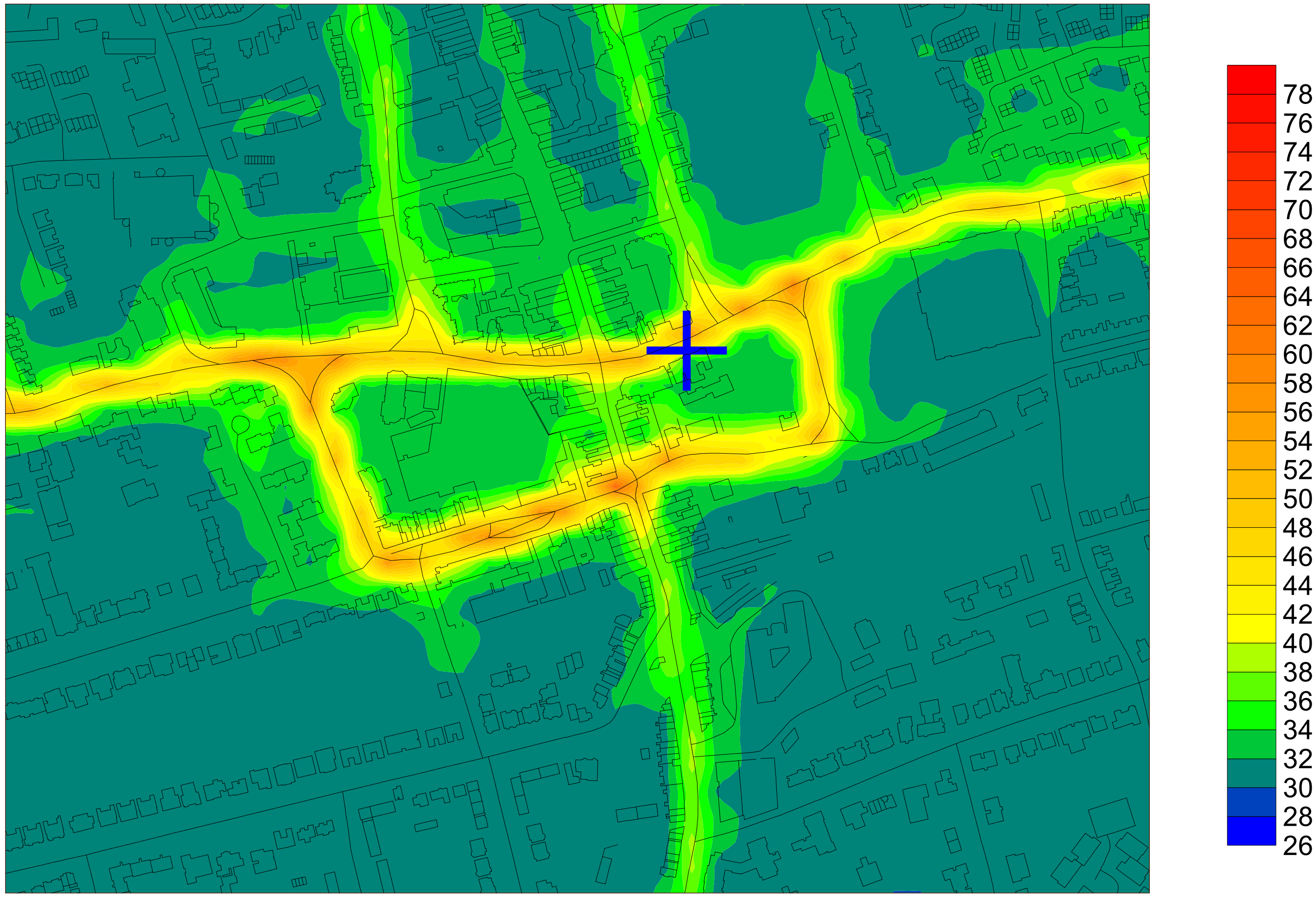
(Note – Sutton 4 site is marked with blue cross)

3.6 ST33 site in Sutton

This diffusion tube site is located close to the Sutton town centre at the roadside. It is not within the designated AQMA, as relevant public exposure was not identified here. The monitoring location is on the one-way system road layout in Sutton (the A232 Carshalton Road section). The predicted concentrations for the area are shown in Figure 9.

This close up shows that the whole of the one-way system and A232 beyond (both east and westwards) is within an area that has building facades that are predicted to exceed the annual mean objective.

Figure 9 Predicted annual mean NO_2 at ST 33 site in Sutton ($\mu g\ m^{-3}$)



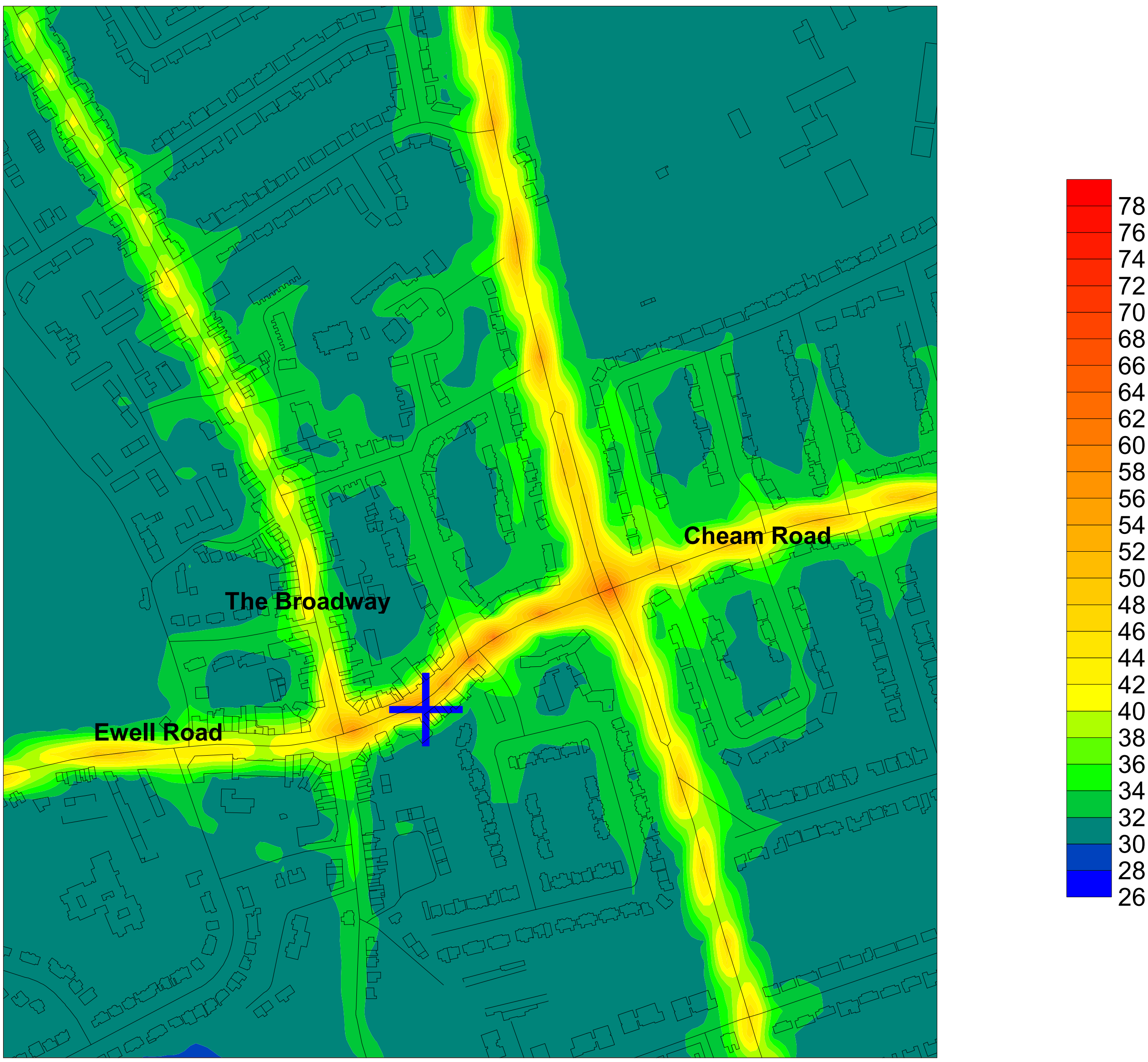
(Note – ST33 site is marked with blue cross)

3.7 ST40 site in Cheam

The diffusion tube site is located on the southern side of the A232 High Street in Cheam, which is a busy shopping and residential area. It is located within the designated AQMA.

The close up of predicted concentrations of the area, confirms that the annual mean objective is exceeded at building facades in the High Street. In addition some building facades are predicted to exceed in the Broadway (A2043) close to the junction with the High Street and along Ewell Road and Cheam Road (A232). These locations (apart from Cheam Road) are not within the designated AQMA.

Figure 10 Predicted annual mean NO_2 at ST 40 site in Cheam ($\mu g\ m^{-3}$)



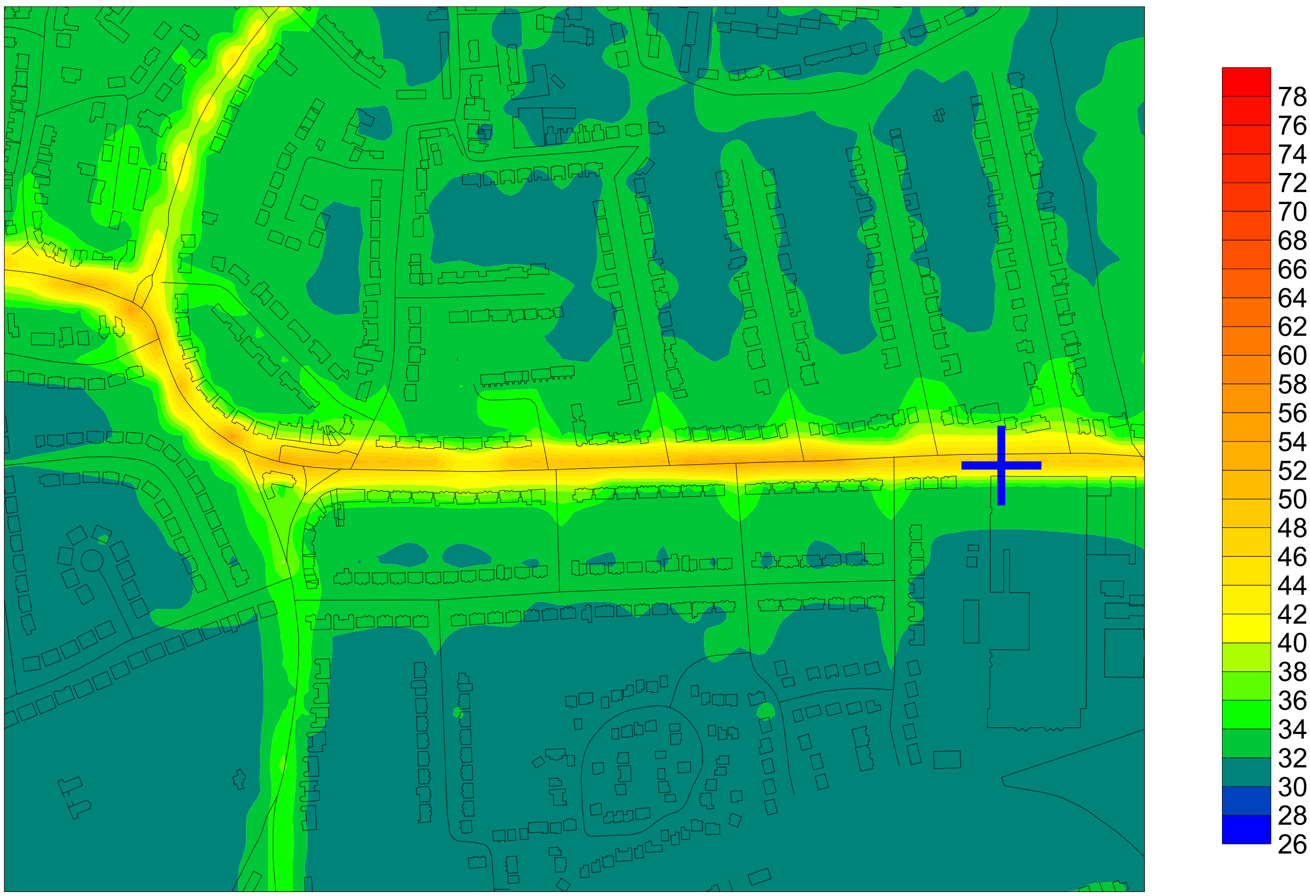
(Note – ST40 site is marked with blue cross)

3.8 ST36 site in Beddington

This diffusion tube site is located on the south side of the A232 Croydon Road. The site is within the designated AQMA.

The predictions for 2010 confirm that the annual mean objective is exceeded at building facades along this road.

Figure 11 Predicted annual mean NO_2 at ST 36 site in Beddington ($\mu g\ m^{-3}$)



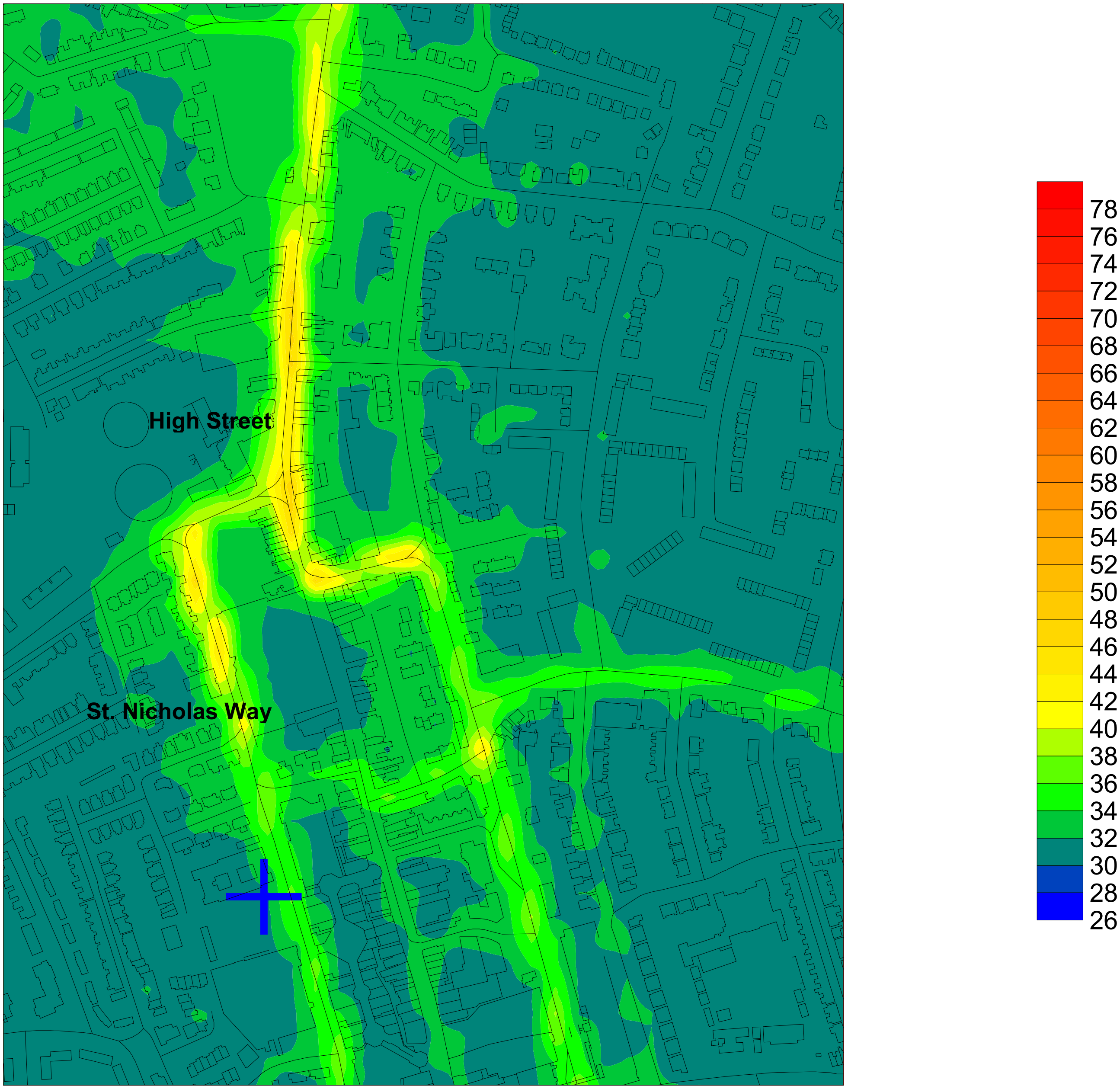
(Note – ST36 site is marked with blue cross)

3.9 ST37 site in Sutton

This site is located at a primary school near the Sutton town centre. The diffusion tube is located near a busy road and bus stop. It is not within the designated AQMA.

The predictions indicate that adjacent to the monitoring site the annual mean objective is met. Further north along St. Nicolas Way (B2230), which is a one-way street, and High Street (B2230) the annual mean objective is exceeded at the façade of buildings.

Figure 12 Predicted annual mean NO_2 at ST 37 site in Sutton ($\mu g\ m^{-3}$)

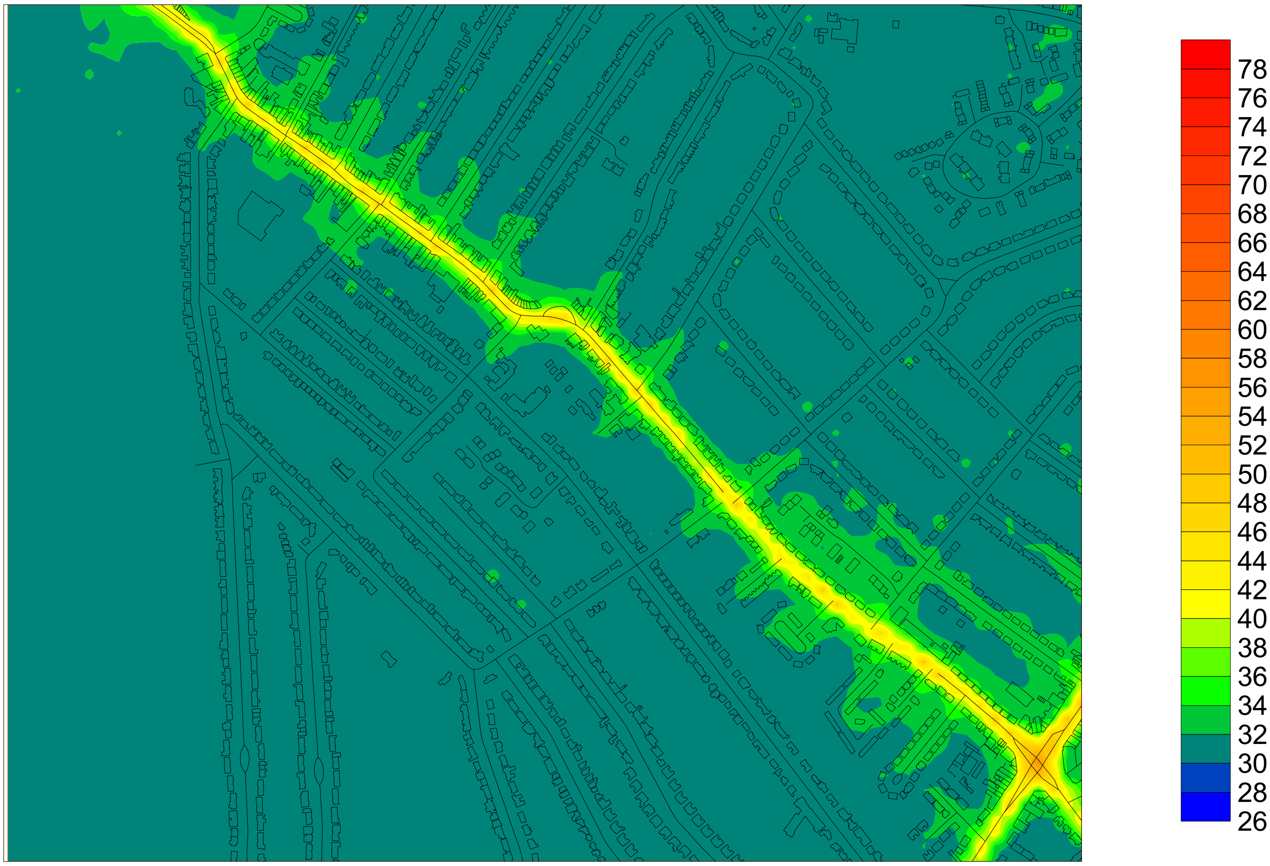


(Note – ST37 site is marked with blue cross)

3.10 Predictions near Worcester Park

The Council is currently installing a new site in the Worcester Park area. The site will be located close to the roadside, representing relevant exposure.

Figure 13 Predicted annual mean NO_2 at Worcester Park ($\mu g\ m^{-3}$)



The predictions show that concentrations along the A2043 are predicted to exceed the annual mean objective. The area is within the designated AQMA.

4 Conclusion

This report fulfils the requirements of the Defra guidance for the Detailed Assessment. The Detailed Assessment incorporates recent monitoring results and improved modelling techniques, plus an improved treatment of emissions using the most recent locally available traffic data from the LAEI 2004.

The continuous monitoring results from the Sutton 4 site at Wallington and the bias corrected NO_2 monitoring results for the diffusion tube sites near Cheam and Sutton town centres indicated that roadside locations monitored exceeded the annual mean objective for all the years reported. The annual mean concentrations monitored at the diffusion tube sites at Alcorn Close near the A217 and A232 Croydon Road also exceeded the objective in 2003.

New updated modelled predictions were made to determine concentrations across the Borough for 2010, using 2003 meteorology. The model was validated against continuous sites in the LAQN and overall these agreed reasonably well with the monitored results (see Appendix B). In view of this the modelling predictions were not corrected using a verification factor (this was based on TG03 guidance).

The modelled predictions indicated that concentrations exceeded the annual mean objective close to the centre of major roads across the Borough. The area predicted to exceed the objective also overlapped the front facades of buildings with relevant exposure along the some of the roads modelled.

Previously the Council designated parts of its area as an AQMA for the annual mean nitrogen dioxide objective. This report confirms that these areas are still predicted to exceed the objective. In addition further areas outside the designated AQMA exceed the objective. These areas are considered to include relevant exposure (based on the TG03 guidance).

In view of these findings the Council will need to designate an AQMA in these areas.

5 Recommendations

The Council is recommended to undertake the following actions, for the statutory objective relating to annual mean nitrogen dioxide:

For the existing AQMA:

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

2. Maintain the designation of the AQMA.

For the other areas examined in the report and identified as exceeding the objective with relevant exposure:

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

4. Confirm that there is relevant exposure in the area predicted to exceed and if confirmed designate an AQMA.

Appendix A

Model Development

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

A combined modelling-measurement approach is used to predict air pollution, based on the use of a kernel modelling technique to describe the initial dispersion. This relates to a set of model concentration fields that were produced using an emissions source of unity: 1 g s^{-1} (point sources), or 1 g m^{-3} s^{-1} (volume sources) or a 1 g km^{-1} s^{-1} (road sources). It assumes that the contribution of any source to total air pollution concentrations can be determined by applying the model concentration field and adjusting for the source strength, so long as each source exhibits similar emissions characteristics. Each kernel was created using hourly meteorological data but was applied to the emissions sources as an annual mean. As such details of individual hours performance is implicit within the model. The modelling method was chosen as a reasonable goal given the limitations of a number of key inputs, as well as enabling more detailed spatial information and computational efficiency. As such the modelling system reflects a consistent approach with the LAEI emissions, which are only expressed as annual average values, as well as the limitations of meteorological data in London, which is confined to a single location, the Heathrow meteorological station.

The model approach assumes two main source types: 1) road and gas sources which at nearby locations require detailed treatment, and 2) the combined emissions from more distant locations including all source types which are modelled as shallow volume sources of varying dimension. The contribution of each source was then calculated through multiple regressions as described below.

Treatment of road sources in the model

The road network around each monitoring site in London (all site types) was modelled in a detailed way. Each road link was split into 10 m lengths based on geographically accurate Ordnance Survey road centre line data. This approach allowed the roads to be represented in a geographically accurate way. This is very important for sites close to roads where strong concentration gradients exist. For dual carriageways, each side of the road was modelled separately, to reflect the important separation of two or more lanes of traffic and the varying separation distance between carriageways. This approach essentially recognises a larger degree of pre-mixing for wider roads. Roads were modelled in this way to 500m from each monitoring site, thus covering a 1km^2 area around the site. The ADMS roads model was used for this purpose (CERC 2003) plus the OSPM model v5.0.64 where street canyons exist (Berkowicz 2000, Berkowicz 2002).

The dispersion kernels held within the model were created using hourly meteorological data and a unit emissions source. However to reflect the change in emissions during both weekdays and weekends an average emissions profile was applied to the model. This was based upon the average emissions calculated for all major roads in London and reflects not only the hourly weekday profiles but also the relative change between weekday and weekends, especially Sunday, when there are large reductions in the numbers of HGVs.

Treatment of gas combustion sources in the model

Gas combustion sources were separated out into individual points and located at 50m intervals throughout the minor road network, set back from the road by 20m to approximate actual location. Associated with each of these sources was a specific release height. For example for larger commercial sources the height varies by location and reflects both the building heights in London as well as their location. These sources in the London Borough of Sutton were mostly modelled at low heights, apart from commercial buildings in Sutton itself, which were modelled as high.

Treatment of sources not within the immediate vicinity of a receptor point

All sources (including those treated explicitly, e.g. roads, rail and gas) more than 500m from each site were modelled as shallow volume sources using the ADMS 4 (CERC 2004) model. Different volume heights were assumed, depending on the characteristics of each source type. It was assumed that road transport emissions were released into a volume 2 m deep and all other sources were released into a 50 m deep volume, apart from the emissions from large (Part A) industrial processes, for which specific emissions data were available. It should be noted however that Part A sources give a very small contribution to annual mean NO_X.

Multiple regression

For each location the model makes predictions based upon:

- The local road sources, split into 10m sections for the 500m x 500m around the site (including major and minor roads);
- The local gas combustion sources, split into 50m sections for the 500m x 500m around the site;
- All the other sources outside this area (2465 km^2), using shallow volume sources (2 m volume height for roads or 50 m volume height for other sources);
- A constant value (intercept D), which represents the contribution from outside London.

A multiple regression was then undertaken in the form:

$$C_M = A.E_{ROAD} + B.E_{OTHER} + C.E_{GAS} + D$$

Where A, B and C are constants to be derived through multiple regression, D was assumed to be the rural contribution of NO_X taken from measurements, E_{ROAD} was the contribution made from the nearby road network, E_{OTHER} the contribution from other sources and roads further than 500 m from each site and E_{GAS} was the contribution from nearby domestic and commercial gas sources. C_M was the annual mean NO_X concentration at a monitoring site. Once the analysis was complete predictions are made for receptor locations, other than at monitoring sites, so long as the values E_{ROAD}, E_{OTHER} and E_{GAS} can be calculated.

Approximately 30 monitoring sites throughout London were used in this multiple regression. Subsequently a further model evaluation was undertaken using approximately 50 - 60 NO_X sites. This gives confidence that the model works well at all sites in London and not just at those that were part of its development.

Annual mean NO_2 vs. NO_X relationships

The ERG toolkit model uses specially derived relationships for the conversion of annual average NO_X to NO_2 (Carslaw et al, 2001). The curves were created by combining the NO_X frequency distribution and the relationship between hourly average NO_2 and NO_X for any measurement site and for any year. The method uses all the hourly measurements of NO_X and NO_2 for each curve and hence reflects the different regimes in which nitric oxide (NO) is converted to NO_2. The resulting NO_x to NO_2 relationship describes the main features of NO_x chemistry, first the NO_x -limited regime where NO_2 concentrations increase rapidly with NO_x and second the O_3-limited regime where a change in NO_X concentration has little effect on the concentration of NO_2. A third and final regime also exists where, once again NO_x and NO_2 increase pro-rata, related to extreme wintertime episodes.

From these a second set of curves was produced that summarises the frequency of hourly NO_X concentrations in different NO_X bins. The first curve (0% NO_X reduction) was the actual frequency distribution for the site and year being processed. Further curves were produced to determine the annual average NO_2. Based on these cures that reduce the NO_X concentrations towards the 80% NO_X reduction were produced. These curves reflect both a reduction in emissions and also the increased number of hours in the year that exist within the NO_X-limited regime. The method used to create the annual average NO_2 from NO_X concentrations thereby accounts for changes in future emissions.

Future concentrations of NO_2 also depend on emissions of vehicle primary NO_2, which are increasing rapidly. To include this effect a new NO_X-NO_2 relationship was derived based on the NO_X increment above a background site.

The NO_X-NO_2 curve for the increment above background takes the form:

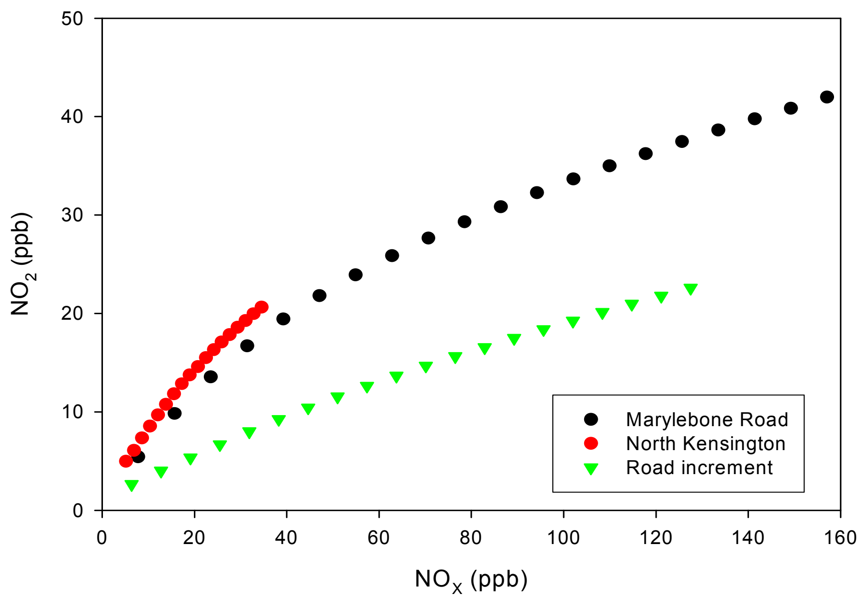
$$NO_2 = y_0 + A_1*(1 - \exp(-NO_X /t_1)) + A_2*(1 - \exp(-NO_X /t_2))$$

where y_0, A_1, t_1, A_2 and t_2 are constants. The equation above was based on an analysis of Marylebone Road where the mean primary NO_2 emissions fraction was estimated to be 9.5 % of NO_X (Carslaw and Beevers, 2005a). From this a more general case, where the primary NO_2 % by volume (primary nitrogen dioxide [NO_2 (p)]) is known, the equation above can be re-written:

$$NO_2 = [NO_2\ (p)/100 – 0.095] + y_0 + A_1*(1 - \exp(-NO_X /t_1)) + A_2*(1 - \exp(-NO_X /t_2))$$

Tests have been undertaken for London roadside sites using the background and incremental NO_X and NO_2 equations plus knowledge of the primary NO_2 % by volume. The estimated primary NO_2 % by volume was taken from Carslaw and Beevers (2005a) and varied by site across the range 3.9 % (Hillingdon) to 23.4 % (Redbridge). The results have an R^2 value of 0.98. The conclusion reached is therefore that using this approach a very good annual mean NO_2 concentration can be predicted at roadside locations if the model produces good estimates of NO_X and there is some knowledge of the primary NO_2 value. The hierarchy of NO_x and NO_2 relationships is summarised in Figure 14 below.

Figure 14 NO_x and NO_2 Relationships in 2002 in London



Treatment of Emissions

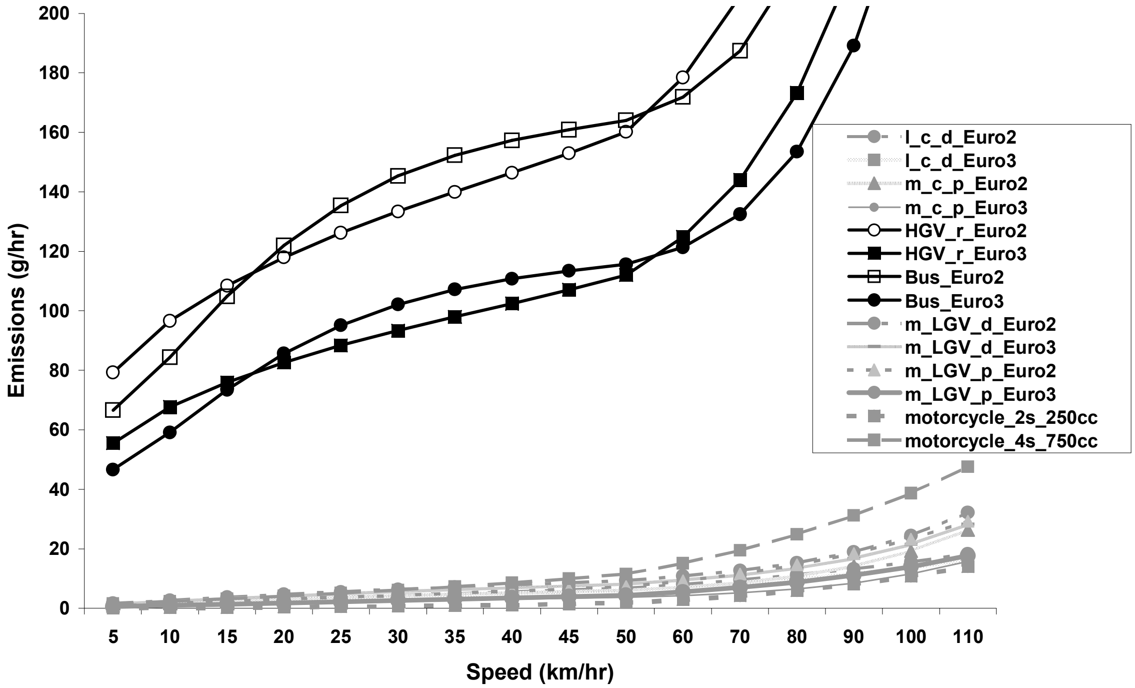
The model has used the latest detailed emission factors released by Defra. These are applicable down to a speed of 5 km/hr, although factors at this speed are highly uncertain.

The effect of low speeds on NO_x emissions from different vehicle types can be by multiplying the g/km results for different average speeds by speed the emissions and then expressed in g/hr. A sample of the g/hr vehicle emissions for Euro 2 and 3 vehicles is summarised in Figure 15 below. It shows that as LGV (petrol and diesel), cars (petrol and diesel) and motorcycles increase their speed so the emissions increase steadily and are at a maximum at 110 km/hr. This increase in emissions is related to the additional work, which is being done by the engine.

It is important to note however, that for these vehicle types the g/hr emissions approaches zero at 5 km/hr. Also plotted in black are rigid HGVs, and buses in the Euro 2 and 3 technology categories. These vehicles contrast significantly with the cars, LGVs and motorcycles by showing emissions up to a factor 40 times greater than for smaller vehicles at very slow speeds. It is therefore these specific vehicle types, which provide the majority of the emissions close to road junctions.

However since comparatively little work has been carried out on emissions from heavy vehicles, the emission factors derived at such slow speeds should be treated with considerable caution.

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



Appendix B

Model Validation and Uncertainty Estimates

A comprehensive validation exercise was undertaken for the ERG Air Pollution Toolkit at measurement sites in London and the southeast and this is presented below (see Figure 16). This was split into 2 stages, first a calibration exercise to factor the background, gas and roadside contributions to reflect measurements at approximately 30 NO_X sites throughout London. These factors were generated using a multiple regression approach described above for both 2003 and 2004. The next stage was a further test of model performance through the addition of another 20-30 sites. All comparisons with measurements (obtained using continuous chemiluminescence oxides of nitrogen (NO_X) analysers) were made using fully ratified data and data capture rates in excess of 75%, for the year.

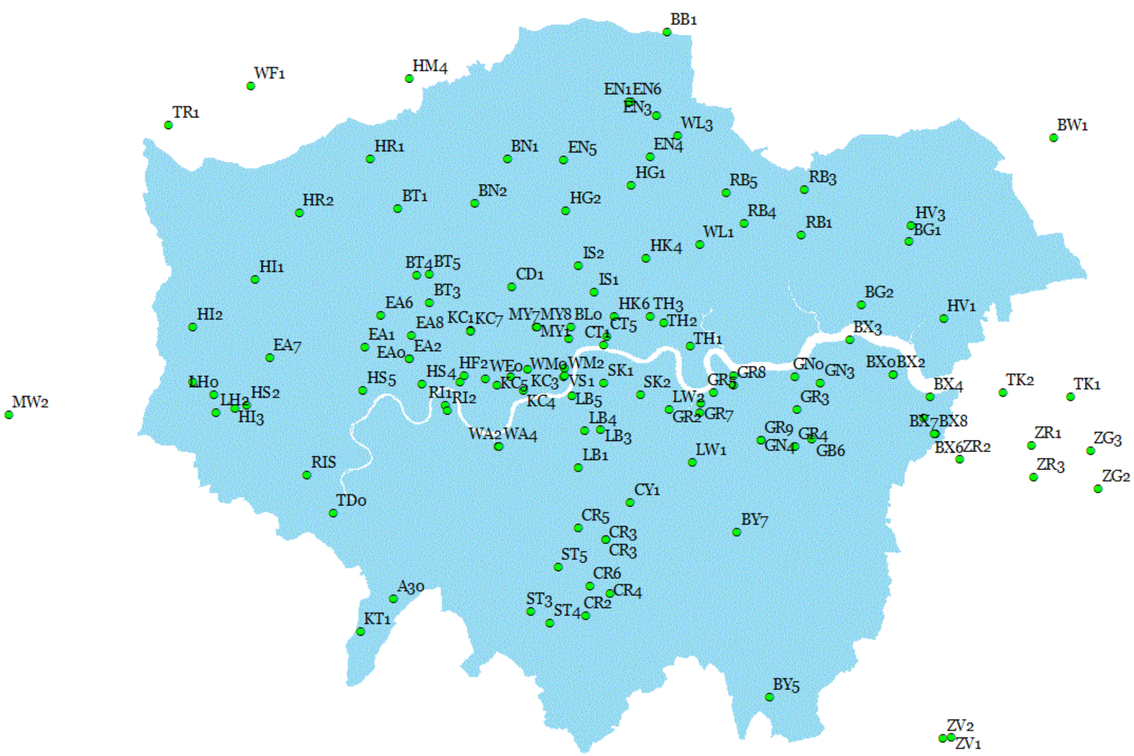


Figure 16 Air pollution monitoring sites in London

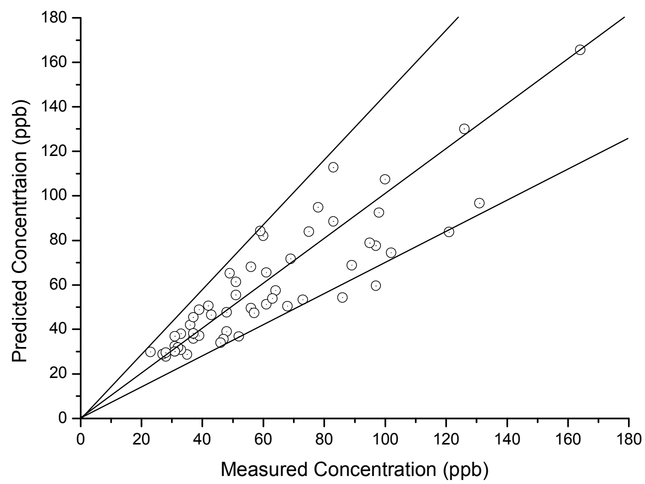
From this analysis a number of model performance statistics have been used to test the ability of the model to replicate measured data across London. These include the root mean square (RMS) error, the fractional bias (FB) and the residual frequency (predicted-measured), for each pollutant and year combination. These are summarised in Table 5.

Table 5 Annual Mean NO_x and NO_2 (ppb) validation results for 2003 and 2004

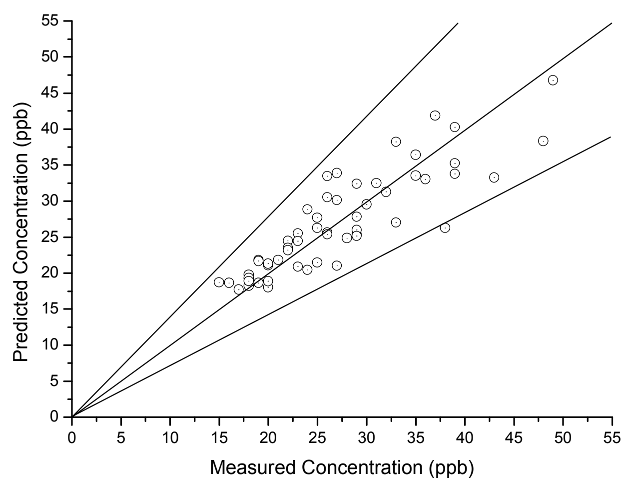
Pollutant	Year	Number of sites	Measured average & error[2]	Model average & ± RMS error	Model Fractional Bias
NO_X (ppb)	2003	56	61.4 ± 6.1	58.9 ± 14.6	-0.03
NO_X (ppb)	2004	52	53.8 ± 5.4	52.3 ± 12.3	-0.02
NO_2 (ppb)	2003	56	27.6 ± 2.8	27.4 ± 3.9	0
NO_2 (ppb)	2004	52	25.0 ± 2.5	25.0 ± 3.7	0.02

The measured versus modelled results are also shown below along with a 1:1 line and two lines showing ± 30% error, typically used when describing model performance.

Nitrogen Oxides (NO_X) 2003 (ppb)

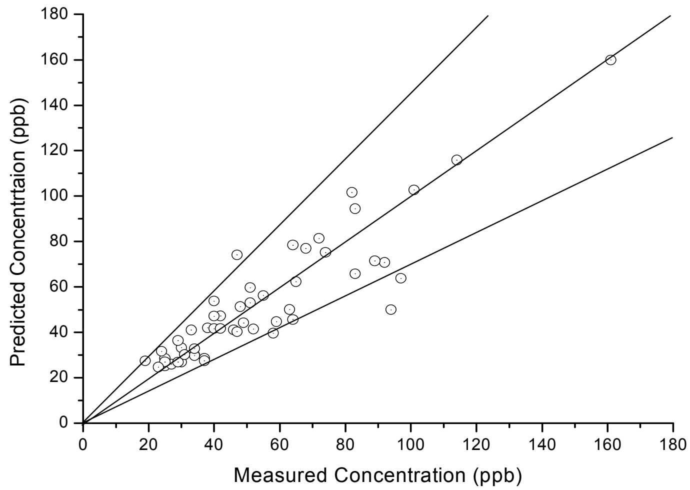


Nitrogen Dioxide (NO_2) 2003 (ppb)

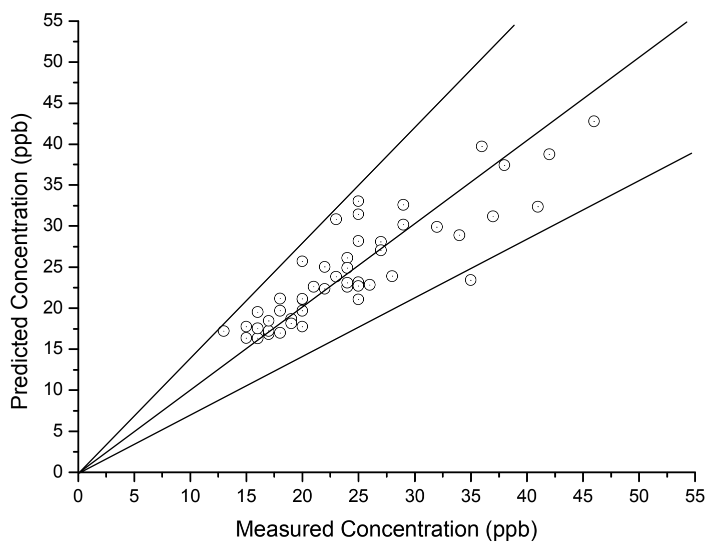


[2] Measurement error is assumed to be ± 10% (2 σ). These estimates are described in (ERG, 2002).

Nitrogen Oxides (NO_X) 2004 (ppb)



Nitrogen Dioxide (NO_2) 2004 (ppb)



The first was that across all sites and for both years the average modelled and measured NO_X agree to within 2.5 ppb. For NO_2 the maximum difference between model and measured averages was 0.2 ppb. RMS error results also indicate good model performance and for annual mean NO_X, annual mean NO_2, average values are: ± 25 % and ± 15% across all years. The fractional bias results indicate that the model is relatively free from bias.

Overall the model performed very well with the average modelled and measured predictions showing close agreement.

Appendix C

Monthly NO_2 diffusion tube measurements

All results are unbiased and expressed in µg m^{-3}.

Table 6 Monthly monitoring results for L.B of Sutton sites (2005 to 2007)

Site ref	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
2005												
ST 32	25.65	32.04	30.03	38.29	32.48	35.93	33.61	18.62	28.14	43.13	38.02	33.08
ST 33	37.42	54.92	44.41	46.65	38.80	46.66	40.04	27.35	47.68	51.86	40.07	44.10
ST 36	38.34	39.91	40.00	38.29	29.44	39.95	32.65	32.71	37.69	44.18	48.88	38.69
ST 37	28.47	39.37	39.08	32.09	25.20	28.29	28.05	29.47	27.91	33.55	43.02	37.61
ST 38	23.01	20.81	26.42	19.84	13.26	17.68	17.03	17.68	17.97	21.05	30.75	27.29
ST 40	45.00	51.91	51.92	52.43	52.86	49.59	51.52	44.02	38.39	57.22	54.28	52.33
ST 41	21.41	29.92	25.79	23.10	14.46	17.68	12.58	19.09	18.31	25.52	29.16	28.71
2006												
ST 32	40.75	39.33	26.63	17.68	32.64	35.54	40.20	25.17	33.99	33.00	29.67	22.14
ST 33	51.53	48.89	33.75	41.10	37.81	42.90	46.89	27.64	38.96	39.55	40.42	31.38
ST 36	42.86	39.10	34.10	39.13	30.28	29.30	3.73	34.14	28.03	31.65	37.17	31.35
ST 37	38.90	37.17	31.32	27.36	23.59	24.85	28.88	22.58	20.56	26.05	15.31	49.43
ST 38	31.19	28.57	17.71	14.53	15.95	15.63	12.22	15.40	16.18	16.53	21.23	30.26
ST 40	56.60	56.81	42.85	44.25	45.84	54.32	65.94	47.64	55.18	51.60	40.89	40.94
ST 41	30.61	26.01	17.89	14.69	15.67	17.04	16.89	15.17	14.60	18.60	22.76	23.66
2007												
ST 32	24.07	31.94	34.53	34.67	28.47	36.89	26.81	30.56	30.03	43.47	36.75	38.56
ST 33	35.03	47.99	47.62	48.21	44.27	51.99	36.71	48.74	30.71	62.15	54.64	49.76
ST 36	29.67	34.95	40.60	40.53	36.39	32.48	26.58	33.27	36.39	46.53	48.30	42.28
ST 37	26.65	36.62	36.86	37.45	26.73	25.54	22.07	28.61	24.35	43.47	42.08	41.32
ST 38	18.38	21.41	23.77	25.52	16.11	16.61	13.58	16.72	17.72	30.28	31.78	28.44
ST 40	40.97	58.92	58.80	58.34	52.49	56.80	54.33	54.12	35.04	74.95	62.31	61.49
ST 41	21.08	27.27	24.50	25.75	16.29	16.91	14.40	16.99	16.37	29.10	32.32	28.92

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