A1.1. Summary

A1.1.1   This appendix describes the methods used to estimate the concentrations of NO_2, and PM10 for the time scales required by the NAQS. Many of the techniques described have been used for work on behalf of the DETR e.g. evaluation of local transport measures in tackling NAQS objectives, as well on behalf of the Government Office for London e.g. Meeting air quality targets in London.

A1.1.2   London is unique in the UK in having such a comprehensive network of high quality air pollution monitoring sites. The number of monitoring locations for NO_X and NO_2 has increased dramatically during the 1990s: in 1990 there were 4 sites, whereas in 1999 there were around 41 sites, with several more to be added later this year.

A1.1.3   Thus there are sufficient monitoring data available in London to justify considering London in isolation and to build 'ambient data models' for the prediction of current and future concentrations of PM10, NO_X and NO_2. This has led to the development of London specific 'pollution climate mapping' for the prediction of annual average background concentrations.

A1.1.4   London-specific pollution climate mapping produces reliable estimates of PM10 and NO_X at background locations in London. The approach adopted for London is different in several important respects compared with national mapping. The most significant difference is that a 5x5 km^2 area cannot account for the difference between the local background concentration and the underlying rural concentration, as other areas of high emissions surround the area itself.

A1.1.5   London's measurements have also shown that there is a distinct difference between NO_X-NO_2 relationships at roadside and background locations: roadside concentrations of NO_2 are always lower than background concentrations for a particular concentration of NO_X. This difference reflects important atmospheric chemistry, which occurs over both small spatial (metres) and temporal (seconds to minutes) scales. That is, it takes time to convert NO to NO_2 away from a road. The predictions made within this document have included this important difference in the modelling method used.

A1.1.6   The prediction of the peak hour value of NO_2 at a location is problematic. Under such conditions it is unreasonable to expect dispersion model predictions to be accurate (+/- 100 % or more). The approach taken considers the NO_X-NO_2 relationships at different monitoring sites and explores how the peak NO_2 concentration is likely to change as NO_X concentrations reduce.

A1.1.7   Predictions from Part A processes, i.e. large industrial plant, have been made using both the ADMS and AERMOD stack models. The predictions are for the NAQS objectives for NO_2 and PM10.

A1.1.8   For the predictions of the present NAQS PM10 objective as well as the Daughter Directive SEIPH have developed the receptor modelling technique described in Airborne Particles Expert Group (APEG, 1999). The model predicts daily average PM10 concentrations for 1995 to 1997 in the particle fractions, primary, secondary and coarse. The model was developed using measurements from the London AURN, from sites within the London Network, rural measurements from the EMEP acid rain monitoring network and black smoke measurement from London.

A1.1.9   The approaches developed here are simple, robust, accurate and transparent and avoid many of the drawbacks of conventional dispersion modelling. The approaches are therefore ideally suited for use in support of the Review and Assessment process.

A1.2. Prediction of Background PM10 and NO$_X$ Concentrations

A1.2.1   SEIPH has made predictions of PM10 and NO$_x$ at background locations i.e. greater than 50m from a major road, based on 'pollution climate mapping'. This approach was originally conceived by Stedman (Stedman, 1998). For NO$_x$ however, the approach developed by SEIPH is fundamentally different.

A1.2.2   The technique, suggested by Stedman, assumes that a 5 x 5 km area accounts for the difference between the measured concentration at a location and the underlying rural concentration. This is likely to be satisfactory for most of the landmass of the UK, but is unlikely to be appropriate for large urban areas such as London. The reason for this is that each 5 x 5 km^2 area is surrounded by many others, which also have relatively high emissions and therefore contribute to an additional background concentration. This is reflected when plotting the emissions versus concentration for London, shown in Figure A1.1, which does not go through the origin. The formulation used here is therefore:

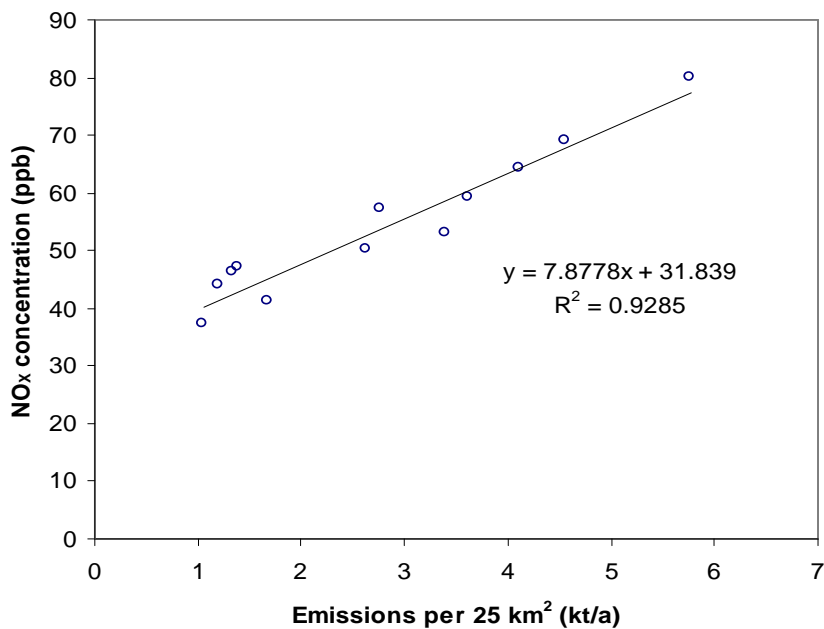*Estimated concentration = rural map + other London contribution + k* x *emissions* (kTonnes per 25 km^2 per year)

y = 7.8778x + 31.839
R^2 = 0.9285

Figure A1.1 Emissions per 25 km^2 Versus NO$_X$ Concentration (1996)

A1.2.3   For predictions in future years each part can be changed independently. For example, in 2005 it has been assumed that the rural NO$_X$ concentration reduces in line with national NO$_X$ emissions (50 %). The 'other London contribution' has been reduced in line with expected reductions in ground-level sources of NO$_X$ in London as a whole (52 %). The 5x5 km area is simply reduced in line with the emissions change in that area.

A1.2.4   The mapping approach has not been used for predictions of NO$_2$, as its relationship with NO$_X$ is non-linear. Predictions of NO$_2$ are described below.

SEIPH Environmental Research Group, Kings College London

A1.3. Prediction of Concentrations in the Vicinity of Roads

A1.3.1 **CAR International**

A1.3.2 The dispersion element of the CAR international model has been used for the prediction of the annual average 'fall off' in concentration of NO_x and PM10 from roadside locations. This is added to the predictions of 'pollution climate mapping' to give a total concentration.

A1.3.3 Before the CAR model was written a literature review of existing models was carried out. It was found that most models are limited to open highway situations and are poor at dealing with street canyons, which are common in cities. The CAR model has been derived from wind tunnel experiments of streets to investigate the flow around different configurations of street layout. Hence the model relies on actual measurements of pollutant concentrations in the city being considered and is therefore potentially more useful from the point of view of air quality management. CAR is calibrated each year against the Dutch National Air Quality Monitoring Network. The model is used by the Netherlands local authorities in the implementation of national air quality decrees and for traffic and environmental planning activities. Whilst the central government uses the model for the evaluation of existing policies and new policy proposals i.e. forecasting.

A1.3.4 The principal advantages of the model are:

- It is based on extensive wind tunnel modelling experiments, which are the most appropriate way of assessing flow around complex street canyons in urban areas. This is a pragmatic approach to a very complex problem, which provides a better alternative than other approaches such as computational fluid dynamics.
- It considers the full range of street canyon configurations (see below).
- It has been extensively tested and validated by two large and well-respected Dutch research establishments: TNO and RIVM. Furthermore, it is "calibrated" against real data, annually.

The CAR model is also able to model many different street canyon configurations:

- Roads in open terrain;
- Broad roads with buildings on both sides;
- Street canyon with buildings on both sides;
- Street with Buildings on one side;
- Basic street type, i.e. a "typical" urban road which exhibits a mix of those configurations

The basic street type has been used in this report.

A1.3.5 **Model Validation**

A1.3.6 CAR has been validated against measurements made in streets by the Dutch National Air Quality Monitoring Network. The average, relative, differences between the calculated and measured values are -3±9 % for CO, 8±19 % for NO_X, and 6±9 % for NO_2. However these values have been calculated using data from the same monitoring stations used to calibrate the model in the first instance and can therefore be considered as minimum errors. Based on measured data from 10 streets in Amsterdam differences were found of -10±12 % for 98th percentile of CO and 6±10 % for 98th percentile NO_2. The results indicate that the accuracy of the model is well within the limits set by the Dutch air quality decrees (30 % at 70 % confidence level).

A1.4. Predictions of NO₂ at Background and Roadside Locations

A1.4.1 A new approach based on the use of ambient data in London has been used to make predictions of annual mean NO_2 at background and roadside locations.

A1.4.2 A useful way of viewing the resulting non-linear relationship between NO_X and NO_2 is to place the NO_X concentrations into different bins e.g. 0-5 ppb, 5-10 ppb…etc. and calculate the corresponding mean NO_2 concentration for each bin. Derwent and Middleton (1996) have done this for a site in central London. It is also possible to summarise the frequency of occurrences of NO_X and NO_2 into the same bin sizes. The mean NO_2 is then calculated by 'multiplying' the two curves together and dividing by the number of readings. This is a useful way of summarising the data and results in less than 1 % inaccuracy when annual mean concentrations of NO_2 are estimated for current day concentrations.

A1.4.3 Derwent has shown through trajectory modelling in London that points move down the NO_X-NO_2 curve as NO_X concentrations reduce (Derwent, 1999). Assuming that this is the case, then recalculating the frequency distribution allows for the assessment of the effects of reductions in NO_X. Figure A1.2 shows the three components of this approach for the Ealing roadside site. First, the familiar NO_X-NO_2 relationship shows that NO_2 concentrations increase at first with increasing NO_X, and then begins to level out. The frequency distribution for NO_X in 1997 peaks at about 60 ppb i.e. most NO_X concentrations are around 60 ppb. The new frequency distribution for a 50 % reduction in NO_X peaks at about 30 ppb. Recalculating the annual mean NO_2 for the Ealing site shows that a 50 % reduction in NO_X reduces the annual mean NO_2 from 33 ppb to 23 ppb, a reduction of 30 %.
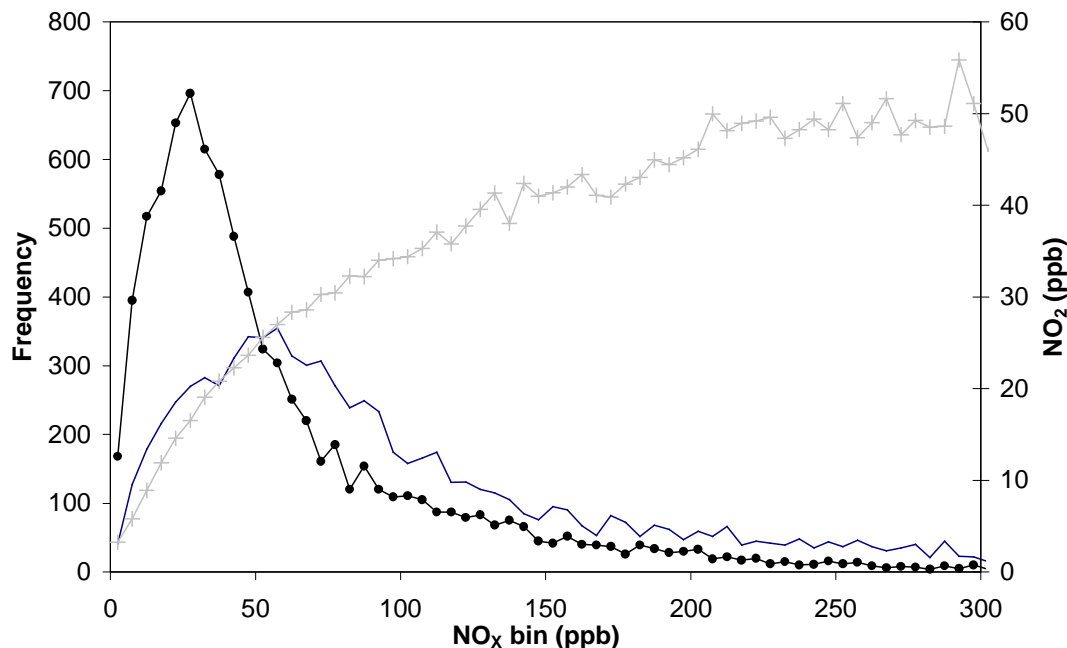

Figure A1.2 Ealing Roadside NO_X and NO_2 Relationships (1997)

A1.4.4 New NO_X-NO_2 points can therefore be generated for different NO_X reductions e.g. from 10 to 80 % reduction, for background and roadside sites. A relationship between NO_X and NO_2 can therefore be determined, which is based on considerably more data, for roadside and background locations for different years.

SEIPH Environmental Research Group, Kings College London

A1.4.5 **NOₓ-NO₂ Relationships at Background and Roadside Locations**
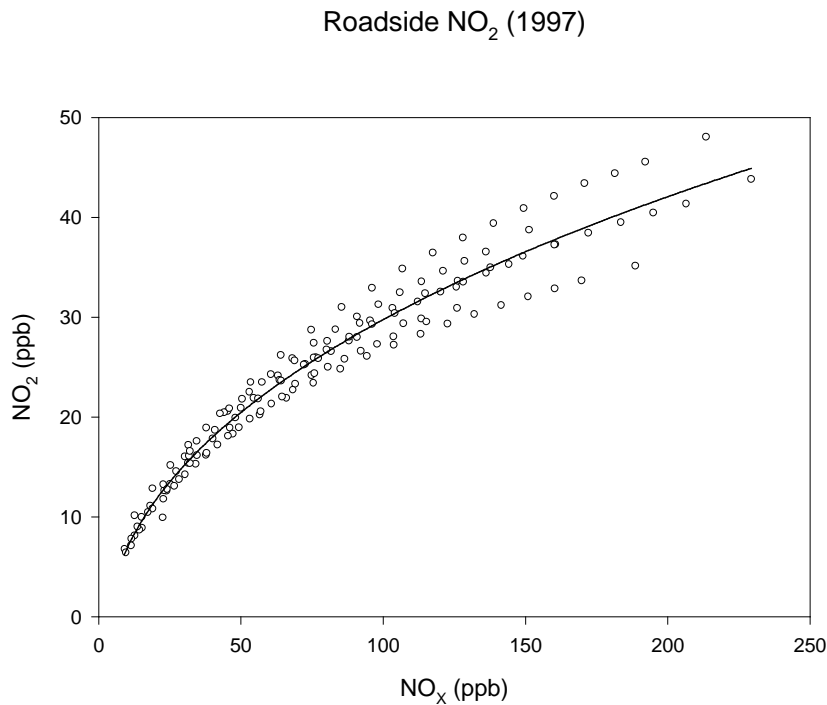
Roadside NO$_2$ (1997)

Figure A1.3 NO$_X$-NO$_2$ Relationship at Roadside Locations (1997)

A1.4.6 Figure A1.3 shows how the extra NO$_X$ and NO$_2$ data points, calculated using the method described above, move down the curve towards zero NO$_X$. This process has been repeated for 1996 and 1997. For 1996 13 background and 8 roadside sites were used. Points were generated at 5 % intervals of NO$_X$ reductions, from 10 to 80 %. Therefore a total of 195 points are generated for background and 120 points at roadside. More sites were available for the analysis of 1997 data: 21 at background, including sites from the Kent Network, and 12 at roadside.

Each curve was fitted using a third order log function:

$$NO_2 \text{ (ppb)} = A + B\,[\ln(NO_X)] + C[\ln(NO_X)]^2 + D[\ln(NO_X)]^3$$

Where A, B, C and D are constants.

A1.4.7 As a check on whether the curve fit was influenced by the sites chosen, the same sites in 1996 were chosen for the 1997 analysis, which showed that there was very little difference when additional sites were added. The sites from the Kent Network were also removed from the 1997 data and again very little difference in the fit equation was seen.
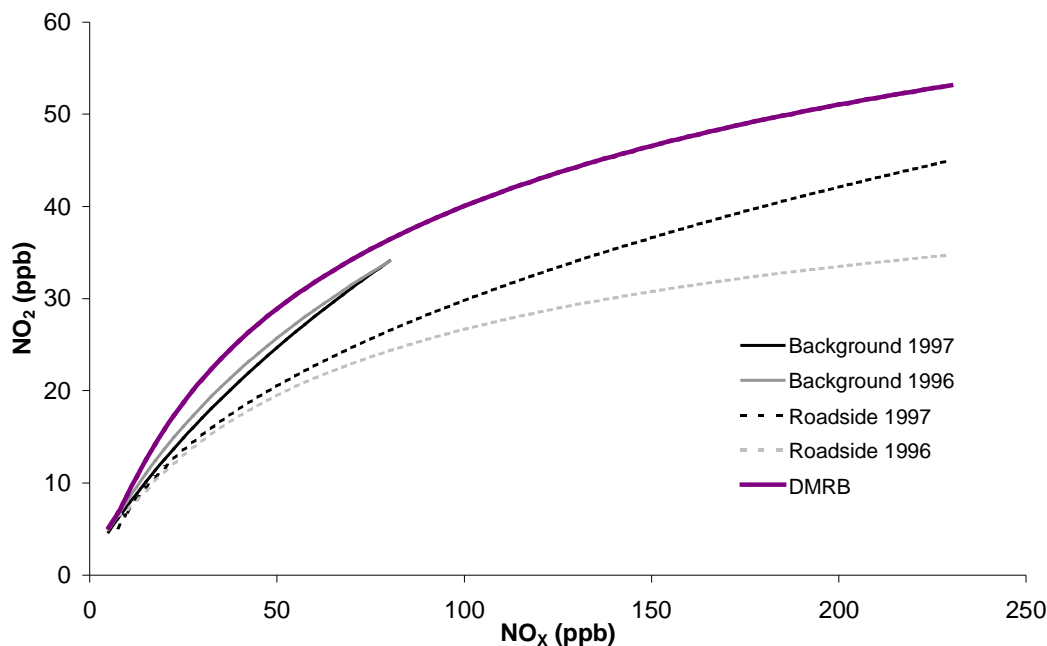
Figure A1.4 NO_X-NO_2 Relationships at Roadside and Background Locations for 1996 and 1997

A1.4.8 Figure A1.4 shows the fit lines for 1996 and 1997. Several important features can be observed:

- The background and roadside points fall onto two distinctly different curves. Background NO_2 concentrations are always predicted to be higher than roadside concentrations for a particular concentration of NO_X. This is intuitively correct as very little time is given for the conversion of NO to NO_2 at roadside locations. It is also encouraging to note that even when points are 'artificially' generated, the distinct differences, as a result of atmospheric chemistry, are still observed between the two location types. For example, reducing NO_X concentrations at a central London background location such as Bloomsbury by 50 % (taking the NO_X concentration to that of background sites Greenwich or Bexley), results in a NO_2 concentration, which is very similar to Greenwich or Bexley. Similarly, reducing NO_X concentrations at a busy roadside site in London at some point results in similar NO_2 concentrations to less busy roadside sites - not a background site.

- The background curves are very close to being linear, which reinforces the original assumption used in pollution climate mapping that the background NO_2 concentration varies linearly with emissions. Nevertheless, they are curved enough to affect the NO_2 concentration predictions around 21 ppb, which tend to be higher using the non-linear approach. The difference is around 1 ppb, but is enough to significantly affect the number of roads, which are estimated to exceed 21 ppb in London.

- The background lines for 1996 and 1997 are in very close agreement.

- Roadside NO_2 concentrations in 1997 are generally higher, which is in agreement with measurement data, which shows 1997 to be a tougher year for NO_2.

- A comparison has been made with the NO_X-NO_2 relationship used in the DMRB methodology. A comparison in London shows the DMRB methodology predicts significantly higher NO_2 concentrations at background and roadside locations. It appears therefore that the DMRB methodology produces very conservative estimates of NO_2.

SEIPH Environmental Research Group, Kings College London

- The mapping approach used by SEIPH has been revised to take account of these findings. Mapping is now only used for predictions of NO_X and not NO_2. NO_X can be more easily related to changes in emissions than NO_2. NO_2 is calculated directly from the predicted NO_X concentration. This change has improved the robustness and transparency of the approach.

A1.4.9 An advantage of this approach is that it is easy to apply and reflects complex chemical reactions that occur over metres and seconds. Such a distinction between concentrations on this scale would not be possible through Normal modelling techniques such the use of trajectory models, which tend to rely on kilometre grid square averages.

A1.4.10 Figure A1.5 shows how well the mapping approach predicts annual mean NO_X concentrations for background sites in London. It shows that the technique provides consistently good predictions across the entire London area. Using the NO_2 non-linear function, the annual mean NO_2 can be predicted as shown in Figure A1.6. Again, the predictions are very good: almost all are within 10 % of the measured values. Predictions of NO_2 at roadside locations have been made for 1996 and 1997 based on the LTS traffic model (Figure A1.7). In general there is good agreement between measured and predicted values. The technique has also been used in the Monte Carlo study, described in appendix 4, where it is applied to a number of roadside locations in London.
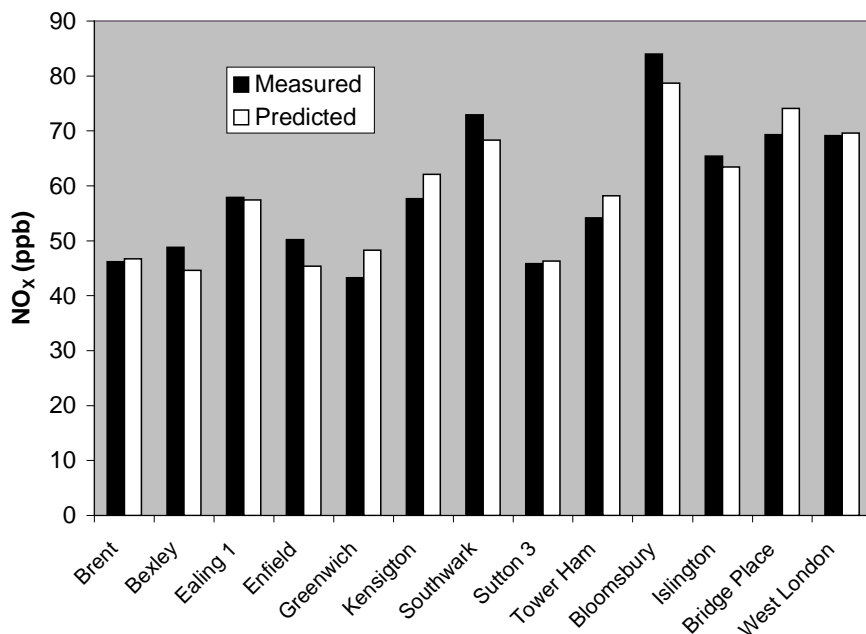

Figure A1.5 Predicted and Measured NO_X Concentrations at Background Locations in London (1997)
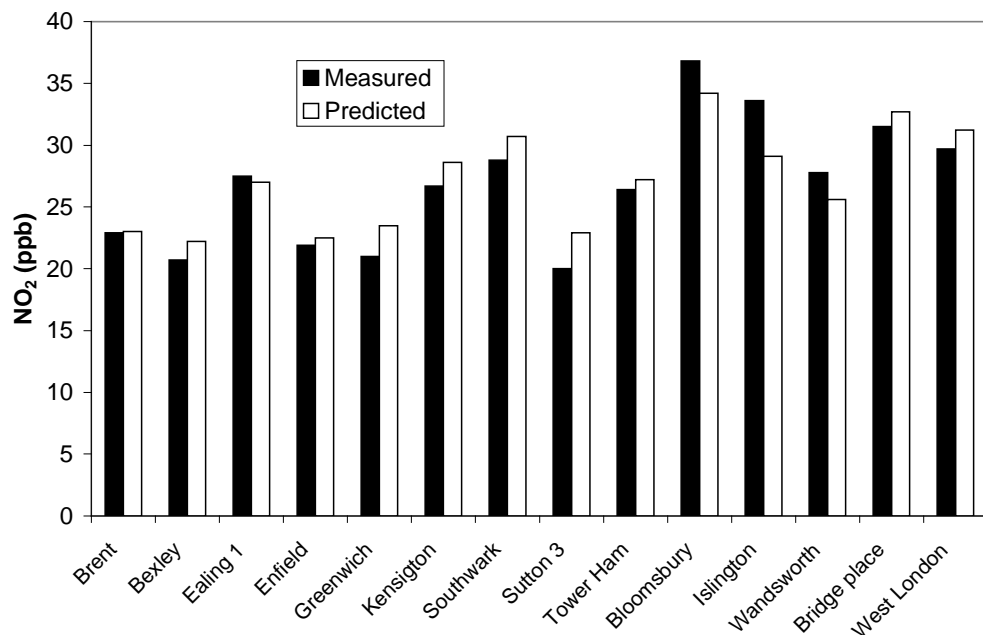
Figure A1.6 Predicted and Measured NO$_2$ Concentrations at Background Locations in London (1997)
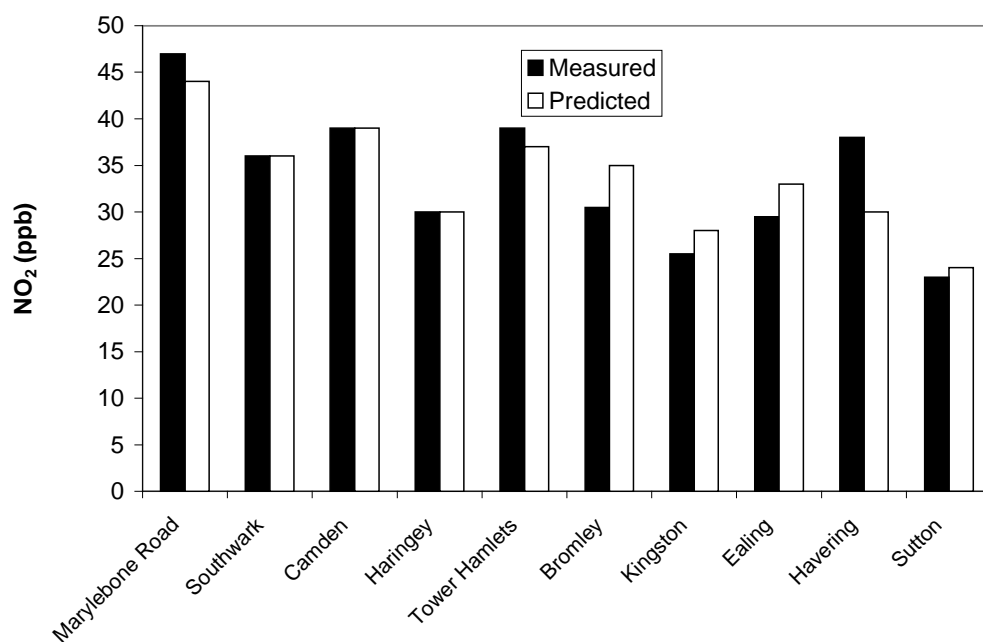

Figure A1.7 Measured and Predicted NO$_2$ at London Roadside Locations (1997)

A1.4.11 *Important note* - Predictions at road junctions have not been modelled specifically for this study for the following reasons:

1) the high degree of complexity involved with modelling a road junction, which requires an understanding of acceleration and deceleration of vehicles, associated emission factors, geometry of the junction in question

2) the results of our work for the Government Office for London indicate that junctions are less important for both NO$_2$ and PM10, than for CO.

SEIPH Environmental Research Group, Kings College London

A1.4.12 Estimates of NO_2 concentrations have been made at background locations on a 1-km^2 basis, as described above. An analysis of the monitoring data shows that there is an order in the NO_X-NO_2 curves generated for each monitoring site. Those sites in central London have consistently higher NO_2 concentrations for a particular NO_X concentration. This might be expected, as air travelling to central London must travel on average over the largest distances and over the path of highest emissions compared with any other area. Furthermore, air arriving at central London will have had more time for atmospheric chemistry to occur, converting NO_X to NO_2. For this reason our predictions suggest that at central London background locations a NO_X concentration as low as 30-33 ppb may be required to meet the 21 ppb objective. For inner London an analysis of the monitoring data suggest that a NO_X value of around 36 ppb will be required to meet the objective.

A1.4.13 The estimation of background NO_2 concentrations has been refined to take account of the analysis above. Based on an analysis of the monitoring data, three different curves have been used, broadly consistent with areas covered by central, inner and outer London. The NO_X-NO_2 curve at London Bloomsbury is used for a distance of 4 km from the centre. The centre is defined as the centre of the City of London, located at (532500, 180500). Between 4 and 8 km the curve at Kensington and Chelsea is used, and beyond 8 km the Teddington curve is used.

A1.5. Fall-off in NO_2 Concentration Away From a Road

Note: This appendix contains extracts of a report written on behalf of the Department of Environment, Transport and the Regions (DETR), entitled: ***NO_2 Model and Measurement Profiles from a Major Road in London.***

A1.5.1 **Summary**

A1.5.2 The available literature indicates that NO_2 concentrations decrease rapidly away from the road centreline, and reach a maximum value at the road centreline.

A1.5.3 Measurements show that there are seasonal differences in the gradient of NO_2 away from a road. In wintertime, there is a smaller difference between roadside and background concentrations, compared with summertime. This is attributed to increased thermal mixing in summer resulting in rapidly decreasing concentrations away from a road, and increased photochemical reactions.

A1.5.4 Diffusion tube measurements at a central London location for a typical road suggests that NO_2 falls to background locations within about 15 m of the road centreline.

A1.5.5 SEIPH's approach to calculating the fall-off in concentration agrees very well with these findings.

A1.5.6 **Introduction**

A1.5.7 The prediction of background and roadside NO_X and NO_2 concentrations is challenging. In the case of NO_2, concentrations are determined by complex atmospheric reactions, driven by ambient ozone concentrations. The prediction of roadside concentrations in urban areas is particularly challenging given the complex dispersion involved.

A1.5.8 Many approaches can be used to predict concentrations of NO_2: simple dispersion models, empirical models, wind tunnel modelling and trajectory modelling. In the context of the National Air Quality Strategy, robust and reliable techniques are required in which all the assumptions are clearly identified.

A1.5.9   **Fall-Off in NO$_2$ Concentration Away From a Road**

A1.5.10 Laxen and Noordally (1987) used NO$_2$ diffusion tubes at a central London location to determine vertical and horizontal distributions of NO$_2$ away from a typical urban street. The principal roads investigated were York Road with a traffic flow of 48,000 vpd, and roads around Mansion House carrying between 22,000 and 33,000 vpd. They found that concentrations of NO$_2$ were highest along the road centreline and decreased rapidly away from the street falling to background concentrations within about 15 m from the centre of the road. Along York Road the fall-off in concentration was established in a gap between buildings. Results for a 'true' street canyon without such gaps may be different. However, given the complex morphology of streets in urban areas, where very few 'true' street canyons exist, these results are probably typical of that expected in an urban area.

A1.5.11 The results from this experiment provide an opportunity for comparing SEIPH's predicted results with measurements. A road in central London with a traffic flow of 50,000 vpd was chosen and the fall-off in NO$_2$ concentration predicted. SEIPH's approach, which makes use of the CAR model for the fall-off in concentration away from a road, assumed the road to be type 2 i.e. a typical urban street. Figure A1.8 compares the excess NO$_2$ concentration i.e. the NO$_2$ concentration above background for the study. The SEIPH approach compares remarkably well with the measurements, although further comparisons would be required to gain full confidence in the findings presented here.
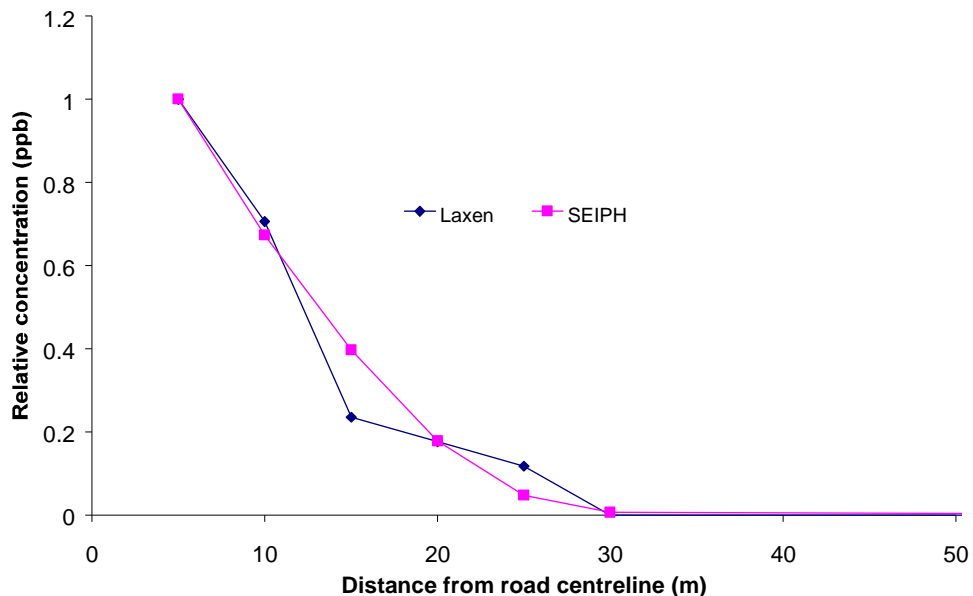

Figure A1.8 : Excess NO$_2$ Concentration Away From a Typical Urban Street in London

A1.6. Prediction of Peak Hour NO$_2$

A1.6.1   The prediction of the peak hour value of NO$_2$ at a location is problematic. The events that lead to such high concentrations are characterised by low wind speeds and by low vertical mixing. These conditions are generally considered to be outside the valid regime of dispersion models, which work best under typical "average" conditions i.e. wind speeds of 5 m/s and day-time conditions. Peak hour events also tend to be associated with the accumulation and re-circulation of pollution as a result

SEIPH Environmental Research Group, Kings College London

of a stagnated air mass; events, which conventional dispersion models cannot replicate. An added complexity to the dispersion in urban areas is the presence of buildings, and additional chemical reactions forming NO_2. Under such conditions it is unreasonable to expect dispersion model predictions to be very accurate (+/- 100 % or more).

A1.6.2   An alternative approach however can be used, based on monitoring data. This approach considers NO_X-NO_2 relationships at different monitoring sites and explores how the peak NO_2 concentration is likely to change as NO_X concentrations reduce and the highest hourly concentrations 'fall down' their individual curves.
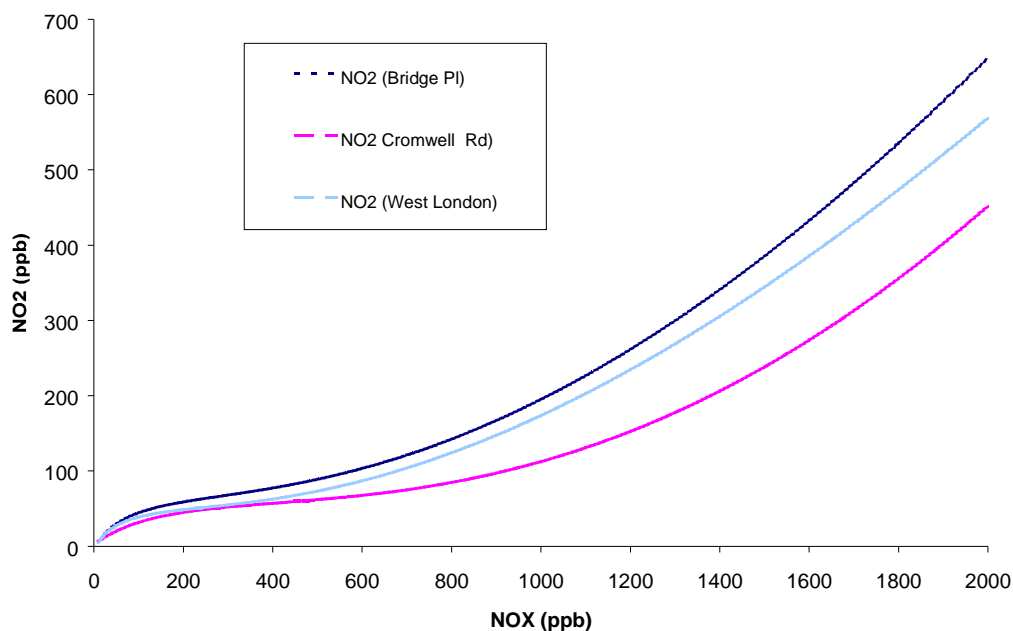

Figure A1.9 NOx-NO_2 Relationships at three London Sites 1991 - 1997

A1.6.3   Figure A1.9 represents an average NO_X-NO_2 relationship for three sites in London. The data are summarised from the years 1991 to 1997. December 1991 is included in the data and represents the period, which gave the highest recorded hourly NO_2 concentration. During these cold and still winter time episodes, often associated with fog, the reaction between NO and O_2 becomes significant and is the cause of the steep section of the curve. This is evident at NO_X concentrations greater than 1000 ppb.

A1.6.4   Between 1991 and 2005 the reduction of emissions of NO_X (approximately 50 %) will significantly reduce the highest hourly concentrations. The effect, described by Derwent (1999), will be for a point to follow the curve down towards the flat section, reducing the NO_2 concentrations.

A1.6.5   This method provides the most robust way of firstly, estimating the concentration during wintertime episodes and secondly predicting the future change expected through reduction in the emissions of NO_X.

Table A1.1 Measured and Predicted Highest Hourly NO$_2$ in London

	Measured Concentration 12th Dec 91	Measured Concentration 13th Dec 91	Measured Concentration 12th Dec 91	Measured Concentration 13th Dec 91	Predicted Concentration
	NO$_X$	NO$_X$	NO$_2$	NO$_2$	NO$_2$
Bridge Place	1566	1567	342	423	418
Cromwell Road	1708	1654	341	382	334
West London	1555	1511	323	388	369

A1.6.6 **Table A1.1** presents a number of important points:

- The highest concentrations are at the background sites of West London and Bridge Place. This is likely to be because of the increased period available for the oxidation of NO to take place, at these locations;
- The difference between concentrations of NO$_2$ for the same NO$_X$ prediction at Bridge Place. This is 81 ppb NO$_2$ for a 1 ppb change in NO$_X$ concentration, which clearly identifies the difficulty of predicting such events;
- The reasonable predictive capability of the NO$_X$-NO$_2$ relationships.

A1.6.7 A further point to note, from the measurements at Cromwell Road, is that the highest hourly measurement of NO$_X$ of 1746 ppb does not coincide with the highest hourly measurement of NO$_2$, it gives instead, 166 ppb. This occurred on the 15th December, during the break up of the episode. Dispersion models would be unable to predict such an event.

Table A1.2 Predicted Highest Hourly NO$_2$ in London in 1991 and 2005

	Predicted Concentration 1991	Predicted Concentration 2005
Bridge Place	418	139
Cromwell Road	334	90
West London	369	117

A1.6.8 Predictions of future concentrations have shown that at roadside and background sites in central London, the highest hourly concentration of NO$_2$ is not predicted to exceed the NAQS objective in 2005. However because of the uncertainty of predictions of this objective and the proximity of the Bridge Place prediction to 150 ppb (< 10 %), it must be considered possible to exceed this objective in central London. This is considered unlikely in outer London.

A1.7. Prediction of NO$_2$ Concentrations from Industrial Processes

A1.7.1 Emissions data for the modelled Part A industrial processes were taken from the London Atmospheric Emissions Inventory release 2a (LAEI). This data set includes stack parameters and emissions data for Part A processes within the M25, and data for some of those processes outside the M25 whose emissions may impact upon London.

A1.7.2 Data for some potentially significant processes were not available from the LAEI, and data were therefore obtained from the Environment Agency through personal communication and their website at http://www.environment-agency.gov.uk/ your_env/. Although less detailed than the LAEI data, emissions rates could still be calculated for the processes as a whole, but not for multi-flued stacks and multiple stacked processes. A summary of the data used in these assessments can be seen in appendix 2. The NO$_2$ concentrations were predicted using the ADMS Urban model.

A1.7.3   **Model Results**

A1.7.4   Modelling was carried out for base years 1996 and 1997 at a range of locations across London. Hourly sequential meteorological data were used from the London Weather Centre. Valid data were available for 97 % of hourly values during 1996 and 94 % of values in 1997. Monitoring data were checked against meteorological data for both 1996 and 1997 to see whether any periods of invalid meteorological data coincided with any peak hourly NO_2 concentrations at the sites in Table A1.3. This was not the case for either of the years and therefore we can be confident that the worst case meteorological conditions have been taken into account when modelling these concentrations.

A1.7.5   It has been assumed that the emissions from each process are released continuously where data on operational periods was not available (operational hours = 8760/annum). Where these data were available, the emissions were calculated according on the operational time.

$$\text{Emission rate (g / s)} = \frac{\text{Emission (kg)} \times 1000}{\text{Operation (hours)} \times 3600}$$

Table A1.3 Modelled NO_2 Concentrations for 1996 and 1997

Site	1996 (ppb)		1997 (ppb)	
	Annual mean	Peak hourly	Annual mean	Peak hourly
Bexley 1	0.4	8.0	0.6	2.1
Bloomsbury	0.5	4.3	0.7	2.4
Sutton 1	0.5	3.2	0.5	3.1
Ealing 1	0.6	3.8	0.5	3.5
Greenwich 4	0.4	6.9	0.6	2.5
Brent 1	0.8	3.8	1.0	3.8
Tower Ham. 1	0.5	4.9	0.6	2.4
Ken. & Chel.	0.5	5.0	0.6	3.3

A1.7.6   The model predicts annual average and maximum 1 hour mean concentrations of NO_x that were subsequently converted to annual average and maximum 1 hour mean concentrations of NO_2 by dividing the NO_x concentration by 5.   This is consistent with NAQS guidance on industrial processes (TG4).

A1.7.7   Table A1.3 shows that the contribution from industrial point source emissions to the annual mean concentration of NO_2 is insignificant compared to the contribution from traffic sources. Even accounting for the fact that the dispersion model under predicts, the impact of industrial sources in London provides < 5 % of the annual average NO_2 in all cases.

A1.7.8   Further modelling of the maximum 1 hour mean concentration was undertaken for the east London area shown in Figure A1.10 below. This was to ascertain whether or not the locations and results in Table A1.3 were representative of London as a whole and specifically of the east Thames region.
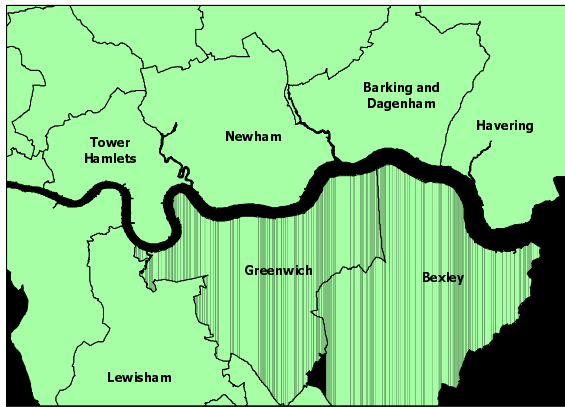
Figure A1.10 Extent of area modelled for maximum 1 hour mean concentrations of NO_2

A1.7.9 The meteorological data used were from 29th October to the 3rd November 1997, as this represented a 'worst case' episode for NO_2 throughout London. As in earlier model runs above, the meteorological data used covers all periods of peak NO_2 values monitored in London. The maximum concentration predicted for the peak hour was 8 ppb. This agrees well with the concentrations predicted for the specific points in Table A1.3. The results of the modelling can be seen below in Figure A1.11.
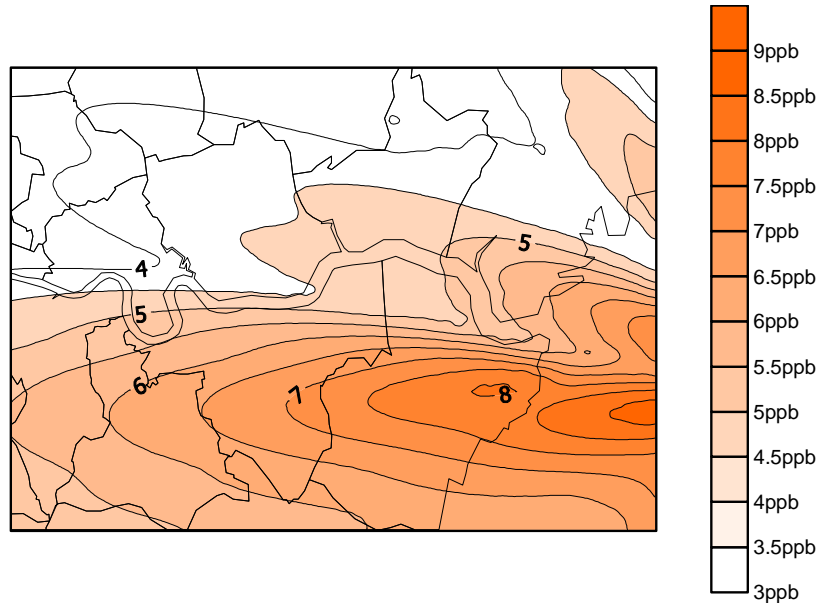

Figure A1.11 Predicted Maximum 1 hour Mean Concentrations of NO_2 over East London

A1.7.10 The model predicts that industrial point source emissions contribute approximately 5% to the maximum hourly mean NO_2 concentration. This contribution can be considered to be small in comparison with the contribution from road traffic sources. However, the model has difficulty in predicting high percentile concentrations accurately and has been known to significantly under-predict these concentrations.

SEIPH Environmental Research Group, Kings College London

A1.8. Prediction of PM10 Concentrations From Industrial Processes

A1.8.1 PM10 concentrations from industrial processes have been predicted using the ADMS Urban model. A selection of the sources in Appendix 2 has been modelled, with only those sources having an emission rate of 1 g/s or greater being chosen.

A1.8.2 **Comparison of Model Results with Measurements**

A1.8.3 Modelling was carried out for base year 1997 at a selection of locations across London. Hourly sequential meteorological data were used from the London Weather Centre. Valid data were available for 94% of values in 1997.

A1.8.4 It has been assumed that the emissions from each process are released continuously (assumption of operational hours = 8760/annum) except where data on operational times were available.

A1.8.5 Table A1.4 shows that the contribution of industrial emission sources of PM10 to the Daughter Directive can be regarded as negligible. Even taking into account the likelihood that the model under predicts pollutant concentrations by a considerable margin, the main focus of concern for PM10 concentrations should be road traffic, transboundary sources of secondary particles and the contribution of coarse fraction particles.

Table A1.4 Contribution of Part A Industrial Sources to PM10 concentrations in 1997

Site	Contribution of Industrial Sources to PM10 Concentrations on Days over 50 μgm^{-3}
Bexley 1	0.03 %
Greenwich 4	0.02 %
Brent 1	0.02 %
Tower Hamlets 1	0.05 %
Kens. & Chel.	0.05 %

A1.9. PM10 Predictions

A1.9.1 SEIPH has adopted and adapted the receptor modelling technique described in Airborne Particles Expert Group (APEG, 1999). The model predicts daily average PM10 concentrations for 1995 to 1997 in the particle fractions, primary, secondary and coarse.

A1.9.2 The model was developed using measurements from the London AURN, from sites within the London Network, rural measurements from the EMEP acid rain monitoring network and black smoke measurement from London.

A1.9.3 The model is consistent with that described in APEG and takes the form described below. It differs in number of respects however, not least of which is its treatment of the coarse particle fraction, which is essential for the correct prediction of the NAQS PM10 objectives and particularly for the prediction of future PM10 concentrations.

PM10 Concentration = A (Black Smoke Concentrations) + B (Rural Sulphate Concentrations) + C (Total PM10 Concentrations)

A = Constant derived from regression analysis

B = Relationship between Rural Sulphate Measurements with TEOM – BS

C = Factor relating the proportion of coarse particles with Total PM10 concentration.

A1.9.4   **Estimating the Secondary Particle Contribution**

A1.9.5   In common with work by APEG, rural sulphate measurements were plotted against the network average TEOM – black smoke measurements made at background locations throughout London. Rural sulphate concentrations have a gradient east–west and north–south in the UK and so the sites most likely to represent London were chosen. These sites were Barcombe Mills (South Coast) and Stoke Ferry (East Anglia). The period chosen was the year 1996 and separate relationships were included for summer and winter.

A1.9.6   **Estimating the Coarse Particle Contribution**

A1.9.7   The coarse fraction particles are an important contributor to the overall PM10 concentration and whilst previous models had used a constant figure throughout the year it was considered important to vary this fraction of PM10 to improve the predictive capability of the model. This was undertaken by relating the fraction of coarse particles, defined in this case as PM10–PM2.5, to the total particle concentration. The data availability of co-located TEOM monitors is not as comprehensive as many other measurements, but it was possible to relate those measurements from the Bexley site for the first and second quarter of 1998. This also allowed factors to be produced for a summer and winter period.

A1.9.8   The assumption that the coarse fraction is the same at every location may not be correct as there are local sources of coarse particles from tyre and brake wear from vehicles and also from the re-suspension of road dust in turbulent vehicle wakes.

A1.9.9   The assumption in the model is that 27.6 % of total PM10 relates to the coarse fraction.   This compares well with the assumption for Ealing, 29.5 % and Bloomsbury, 32.5 % and is therefore a reasonable one, although an underestimate is likely towards the central London area.

A1.9.10 Through the above analysis the process of predicting daily average PM10 concentrations was performed using measurement data from the following monitoring sites:

- The network average black smoke measurements from the London sites;
- The average daily sulphate concentration from Stoke Ferry and Barcombe Mills;
- The network average TEOM concentration from the sites Greenwich, Kensington and Chelsea, Tower Hamlets 1, Bexley, Thurrock and Bloomsbury.

The assumptions for the prediction of individual locations are as follows:

- The concentration of coarse and secondary particles vary daily and by separate relationships for summer and winter;
- The primary particles vary daily and are calculated using a relationship with the London network average black smoke measurements;
- The annual average secondary particle contribution is uniform across London;
- The annual average coarse particle contribution is also uniform across London;
- The difference in average concentration between sites is dominated by locally generated primary particles and therefore relates directly to local particle emissions, mainly from motor vehicles.

A1.9.11 **Comparison of Modelled and Measured PM10 Concentrations**

A1.9.12 The results from the model, using the variable coarse concentration and a summer and winter secondary particle relationship provided the most robust predictions. An example of a scatter plot of the results is given below:
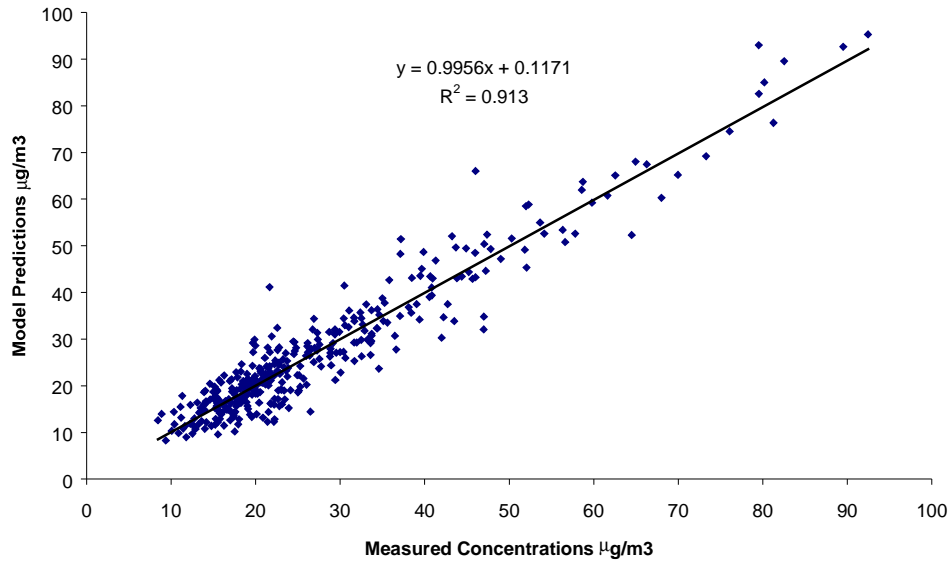
Figure A1.12 Tower Hamlets PM10 Concentrations vs. Model Predictions (Daily Averages 1996)

A1.9.13 Figure A1.12 shows that predictions made for 1996 at the Tower Hamlets site are very good. Further tests were also undertaken for the year 1997 and again the model provided very good agreement with measurements, in this case at the roadside site in Greenwich. It should be noted however that the daily peak concentrations of PM10 become increasingly difficult to estimate at busy roadside sites in central London, for example Marylebone road.   This is due to sensitivity of the model to very high emissions of locally generated particles close to major roads.
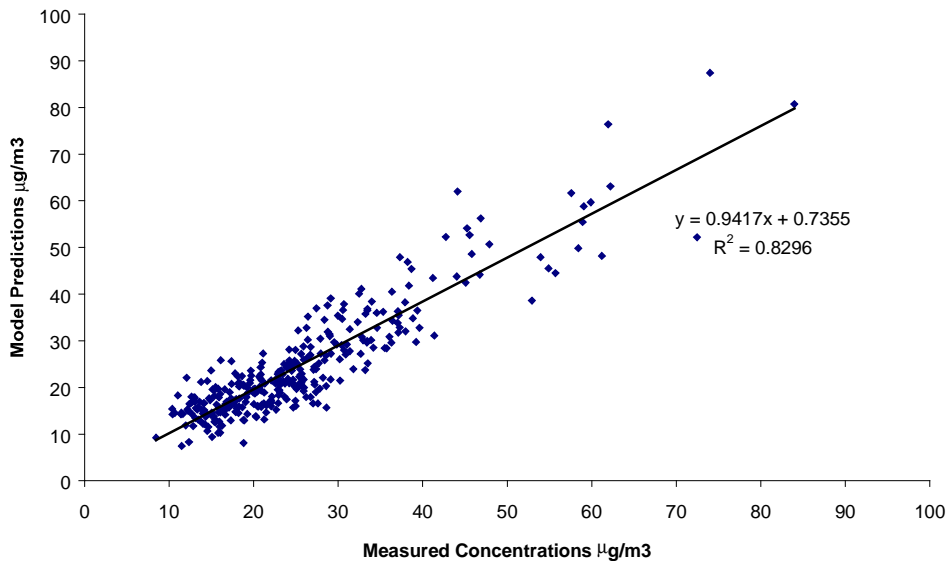

Figure A1.13 Greenwich Roadside PM10 Concentrations vs. Model Predictions (Daily Averages 1997)

A1.9.14 **Comparison with the NAQS PM10 Objectives**

A1.9.15 Predictions have been made of the NAQS objectives and Daughter Directive for 1996 and 1997. Table A1.5 summarises the predictions at background sites in London, for the current NAQS objective. The model provides very good agreement with the measurements with the largest error being a 7 % under prediction at Greenwich.

Table A1.5 Comparison of Modelled and Measured NAQS PM10 concentrations µg/m^3 (1996/7)

Site	TEOM Measurement	Model Prediction	% Difference
1996			
Kensington	78	81	+ 4
Tower Hamlets	80	85	+ 6
1997			
Bexley	76	77	+ 1
Greenwich	71	66	- 7
Kensington	84	82	- 3
Tower Hamlets	84	89	+ 6

A1.9.16 Table A1.6 summarises the model predictions for background and roadside sites in London. Comparisons are made between modelled and measured data, for the proposed NAQS objective and Stage 1 EU Daughter Directive for PM10. The 1997 results also show very good agreement, with the largest error being an over prediction of 4 days at roadside site in Sutton.

Table A1.6 Comparison of Modelled and Measured Daughter Directive PM10 concentrations µg/m^3 (1997) for Roadside and Background

Location	days > 50 µg/m^3 (measured)	days > 50 µg/m^3 (modelled)	days difference between measured and modelled
Roadside			
Camden	86	86	0
Sutton 1	35	39	+ 4
Haringey	50	47	- 3
Kingston	47	50	+ 3
Greenwich 5 *	32	34	+ 2
Background			
Bexley	33	33	0
Greenwich 4	25	24	- 1
Kensington	34	35	+ 1
Tower Hamlets	37	38	+ 1

Note: A full year's data was unavailable for Greenwich 5

A1.9.17 In summary, the background predictions for both the NAQS objective and the background and roadside predictions for the Daughter Directive are in very good agreement with measured data in London. This, in combination with the improved prediction of daily coarse fraction, provides a robust model for the prediction of PM10 in future years. It should be emphasised however that there remain many uncertainties concerning the sources of particles in urban air. In particular, the proportion of coarse particles, which can be attributed to road vehicles as a result of re-suspension, is uncertain. An analysis of particle concentrations at the Marylebone Road and Bloomsbury sites suggests that 50 % of the coarse particle concentration may also be attributable to road traffic sources. It should be noted that this work only considers vehicle exhaust emissions of particles and does not attribute any of the

coarse fraction to them. This assumption may lead to an underestimate of the proportion of PM10 that is attributable to road vehicles.

A1.12 References

1. Report of the Airborne Particles Expert Group (1999) **Source Apportionment of Airborne Particle Matter in the United Kingdom**, Department of the Environment, Transport and the Regions, Jan 99.

2. Stedman J (1996) **Revised High Resolution Maps of Background Air Pollutant Concentrations in the UK: 1996**, Report No AEAT-3133, AEA Technology, 1998.

3. Derwent R G, Middleton D R (1996), **An Empirical Function for the Ratio NO_2:NO_X**, Clean Air, Vol. 26, No. 3/4.

4. Derwent R G (1999) **NO_X and Ozone in the London Routine Column Trajectory Model,** Climatic Research Division, Meteorological Office, For the Department of the Environment, Transport and the Regions.

5. Buckingham et al (1998) **London Atmospheric Emissions Inventory**, London Research Centre.

6. Carslaw D, Beevers S (1999) **NO_2 Model and Measurement Profiles from a Major Road in London,** Department of the Environment, Transport and the Regions, April 99.

7. Carabias M V et al. (1997) **Small-Scale Spatial Variability of Particulate Matter < 10 μm (PM10) and Nitrogen Dioxide**, *Atmospheric Environment* Vol. 31, No. 15, pp. 2243-2247.

8. Derwent R G (1999) **Oxides of Nitrogen and Ozone in the London Routine Column Trajectory Model**, The Meteorological Office, January 1999.

9. Laxen D P H and E Noordally (1987) **Nitrogen Dioxide Distribution in Street Canyons**, *Atmospheric Environment* Vol. 21 No. 9, pp. 1899-1903

Acknowledgements