Air Quality Consultants

Deriving NO_2 from NO_x for Air Quality Assessments of Roads - Updated to 2006

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Client	Defra	Principal Contact	Dr Janet Dixon (Defra)

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Report Prepared By:	Prof. Duncan Laxen, Dr Ben Marner and Sally Donovan

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Air Quality Consultants Ltd
23 Coldharbour Road, Bristol BS6 7JT Tel: 0117 974 1086
12 Airedale Road, London SW12 8SF Tel: 0208 673 4313
aqc@aqconsultants.co.uk

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1 Introduction

1.1 Predicting the air quality impacts of road traffic relies on air quality models. These models predict the dispersion and dilution of primary pollutants, translating emissions in grammes per second into concentrations in microgrammes per cubic metre. These road traffic concentrations are then added to the local background to give the total concentrations, which decline as a function of distance from the road. Complications arise in the case of pollutants that undergo chemical transformation in the atmosphere. This applies in the case of nitrogen oxides (NO_x) (the sum of nitric oxide (NO) and nitrogen dioxide (NO_2)). Traditionally it has been assumed that approximately 95% NOx is emitted in the form of NO, which is then transformed in the atmosphere to form NO_2, principally by reaction with ozone[1]. Reaction with ozone thus changes the proportion of NO_2 within NO_x and there is the added complexity of background NO and NO_2 mixing with freshly emitted NO and NO_2. There is recent evidence that the proportion of NO_x emitted as primary NO_2, is increasing in the UK. Prediction of NO_2 concentrations is thus not straightforward.

1.2 The principal interest when assessing NO_x emissions from road traffic is the concentrations of NO_2 at the roadside, as it is NO_2 that is associated with adverse health effects, not the NO_x. Air Quality Consultants Ltd published a report in 2002 setting out a "New Approach to Deriving NO_2 from NO_x for Air Quality Assessments of Roads" (Laxen and Wilson, 2002). The report examined a range of approaches to calculate NO_2 concentrations from NO_x concentrations and derived a new method based on an empirical examination of measurements. The Laxen and Wilson approach was incorporated into the Design Manual for Roads and Bridges air quality screening model, as well as into the Local Air Quality Management Technical Guidance provided to local authorities (LAQM TG(03)). It is thus frequently termed the "TG(03) method" and is widely applied across the UK.

1.3 This report outlines the reasons why the NO_x/NO_2 relationships that applied prior to 2002 might no longer be appropriate. It then examines monitoring data collected since the 2002 report was published and assesses the performance of the TG(03) method. Finally, it sets out an updated method that better fits the more recent measurements. In common with the previous analysis, this study deals exclusively with annual mean datasets.

[1] The actual chemistry is far more complicated and, amongst other things, has to allow for the photolytic decomposition of NO_2 to form NO and ozone, and the development of a photo-stationary state during daylight hours.

2 Reasons for an Updated Approach

2.1 The first Air Quality Expert Group (AQEG) report on "Nitrogen Dioxide in the United Kingdom was published in 2004 (AQEG, 2004). The report noted that urban concentrations of NO_x had declined steadily since the early 1990s, associated mainly with reduced emissions from road traffic. While NO_2 concentrations had also declined, these decreases were not so marked as those of NO_x, so that the NO_2 /NO_x ratio showed an increase. Because the partitioning in the atmosphere between NO and NO_2 changes as the concentration of NO_x falls, an increase in NO_2/NO_x would be expected. However, the magnitude of the observed upward trend in the ratio was inconsistent with previous understanding of the NOx and NO_2 partitioning, indicating that additional changes were taking place.

2.2 AQEG revisited this issue in 2006, presenting new monitoring data from London over the period up to 2005 which showed greater than anticipated increases in the annual mean NO_2/NO_x concentration ratio at most kerbside, roadside and urban background sites (AQEG, 2006). Increases were also observed at a number of Automatic Urban and Rural Network (AURN) roadside and kerbside sites outside London and at a few urban background and urban centre sites. There were also, however, a significant number of sites outside of London where no clear trend was observed. The data suggested that trends in London were different from those elsewhere in the UK.

2.3 AQEG explained that historically, the proportion of NO_x emitted as primary NO_2 was of the order of approximately 5%. In the current vehicle fleet however, this percentage could be far greater, with values in the range 20 – 70% for some modern diesel cars. The report showed that heavy duty vehicles and buses produce a smaller proportion of primary NO_2, but that the fitting of certain types of diesel particulate filters to buses can substantially increase the fraction of NO_2 in vehicle exhaust gases.

2.4 The AQEG report presented analyses showing that the observed increases in the NO_2/NO_x concentration ratio could be explained by increases in primary NO_2 emissions over the period up to 2005. This increase could be due to the increased penetration of Euro-III diesel vehicles fitted with oxidation catalysts and/or to the fitting of catalytically regenerative particle traps to London vehicles. It was suggested that the reason why the NO_2/NO_x ratio had been affected more in London than in other UK cities might be associated with the widespread retrofitting of catalytically regenerative particle filters to London buses.

2.5 Other possible explanations for the observed changes in the NO_2/NO_x concentration ratio were also investigated, including increases in the background concentration of O_3, and were ruled out. It was not however possible to eliminate the effect of direct emissions of nitrous acid (HONO), although direct NO_2 emissions were considered to provide the more plausible explanation.

2.6 AQEG presented data for London indicating that following a step change in primary NO_2 between 2002 and 2004, further increases are expected to be smaller. Increases elsewhere in the UK might persist in the future as the rest of the UK “catches up” with London.

3 Source Data and General Approach

3.1 The Laxen and Wilson report collated annual mean data from AURN sites and also from those operated by the Transport Research Laboratory (TRL) on behalf of the Highway's Agency. They also included data from Salford MBC. Their dataset extended from 1999 to 2001. Monitoring data from the London Air Quality Network (LAQN) was used to test the approach, but not to formulate the method.

3.2 This current study has collated data from the AURN, the Highways Agency, and the LAQN[2]. In addition, in order to define trends near to motorways and dual carriageways with fast-moving traffic, data were obtained from a number of local authorities[3]. Measured annual mean concentrations of both NO_x and NO_2 during 2003, 2004, 2005 and 2006 have been examined[4]. Industrial and airport sites have been excluded from the dataset. Only datasets with at least 90% data capture were included. In addition, datasets were also excluded where the annual mean NO_x data capture differed by more than 2% from the annual mean NO_2 data capture (which occurs in some ratified datasets). The 2006 data are only partially ratified, but this is unlikely to introduce significant error to the analysis. At the time that this study was conducted, no data were available from the Highways Agency sites for 2006. The sites included for 1999 to 2001 are those reported by Laxen and Wilson (2002). The sites from which the 2003 to 2006 data were taken are listed in Appendix 1. Data from background sites are shown in Figure 1 but excluded from all subsequent figures and analyses, so that this study focuses on roadside and kerbside locations.

3.3 In common with the previous study, the site classification provided by the network administrators was not always followed. Several sites (for example London Hillingdon, which is classified as Suburban) are close to busy roads and thus behave as roadside sites. They have thus been reclassified for this current analysis. Details of these reclassifications are given in Appendix 1.

3.4 Using the precise grid coordinates of each site, background concentrations were taken from the national maps (available from www.airquality.co.uk). This current study has used the background maps published in 2006 (which use a base year of 2004) (factored to the appropriate year) for the 2003 - 2006 datasets. The background concentrations used by Laxen and Wilson have been used

[2] Data were thus downloaded from: www.airquality.co.uk; www.trl.co.uk; and www.londonair.org.uk respectively.

[3] South Bucks (Gerrard's Cross - M25); Rushmore (Medway Drive, Farnborough - M3); Gravesham (A2); South Cambs (Barr Hill and Impington - A14); data were received from Salford MBC (M60) too late to be included in the main analysis but are shown in Appendix 3.

[4] Data for 2002 were not included as they were not considered to be recent enough for deriving new trends. These 2002 data were not considered by Laxen and Wilson. This analysis does not require continuity of data.

for the 1999-2001 datasets which were taken from a previous publication of the national maps. For motorway and fast-traffic dual-carriageway sites, the approach given in TG(03) was used to avoid double-counting local emissions in the background concentrations. For each site, values of "road-NO_x" and "road-NO_2" were calculated by subtracting the predicted background concentration from the measured concentration.

3.5 A straightforward approach has been used to test the NO_2/NO_x relationships. This predicts the total annual mean NO_2 concentration as the sum of the predicted background-NO_2 (taken from the national maps) and the predicted road-NO_2 (calculated from NO_x). The approach thus simulates a modelling study, except that the NO_x concentration comes from measurements rather than modelling.

3.6 For convenience, and to provide sufficiently large datasets, the 1999 to 2001 data are grouped into a single dataset (following the approach of Laxen and Wilson (2002)). Similarly, the 2003 and 2004 data are aggregated into a single dataset, as are the 2005 and 2006 data. The analysis presented below indicates relatively little variation in NO_2/NO_x ratios between 2003 and 2006 and so isolating the data by individual year is unlikely to have altered the conclusions.

4 Changing NO_2/NOx Ratios

4.1 Figure 1A reproduces Figure 1 from the Laxen and Wilson report. It shows the NO_2/NO_x ratio across all sites during the period 1999 to 2001. Figure 1B shows the same data for 2003 and 2004, while Figure 1C shows the data for 2005 and 2006. The selection of sites in each Figure is slightly different (as discussed above), but most of the sites included in Figure 1A are also included in Figures 1B and 1C.

4.2 The pattern shown by background sites at low concentrations is very similar across all three plots, but the curve for roadside sites was steeper in 2003 and 2004 than in 1999-2001. This means that high NO_x concentrations tended to be associated with higher NO_2 concentrations in the 2003 and 2004 dataset. For example, in 1999-2001, a NO_x concentration of 200 µg/m^3 was associated with NO_2 concentrations between approximately 40 µg/m^3 and 75 µg/m^3. In 2003 and 2004, the same NO_x concentration was associated with NO_2 concentrations between approximately 55 µg/m^3 and 80 µg/m^3. This progression continues into the 2005 and 2006 dataset, so that NO_2 concentrations associated with NO_x concentrations of 200 µg/m^3 range from around 60 µg/m^3 to 85 µg/m^3.

4.3 Defining this trend statistically is problematic, since as noted in section 2, the key factor that is changing (i.e. the NO_2/NO_x ratio) would be expected to change year-by-year in any event simply because of the non-linearity of the NO_2/NO_x curve. Figure 2 plots a power law trend line to each of the three datasets described above (including both roadside and background sites). This shows how the general pattern has changed in recent years.

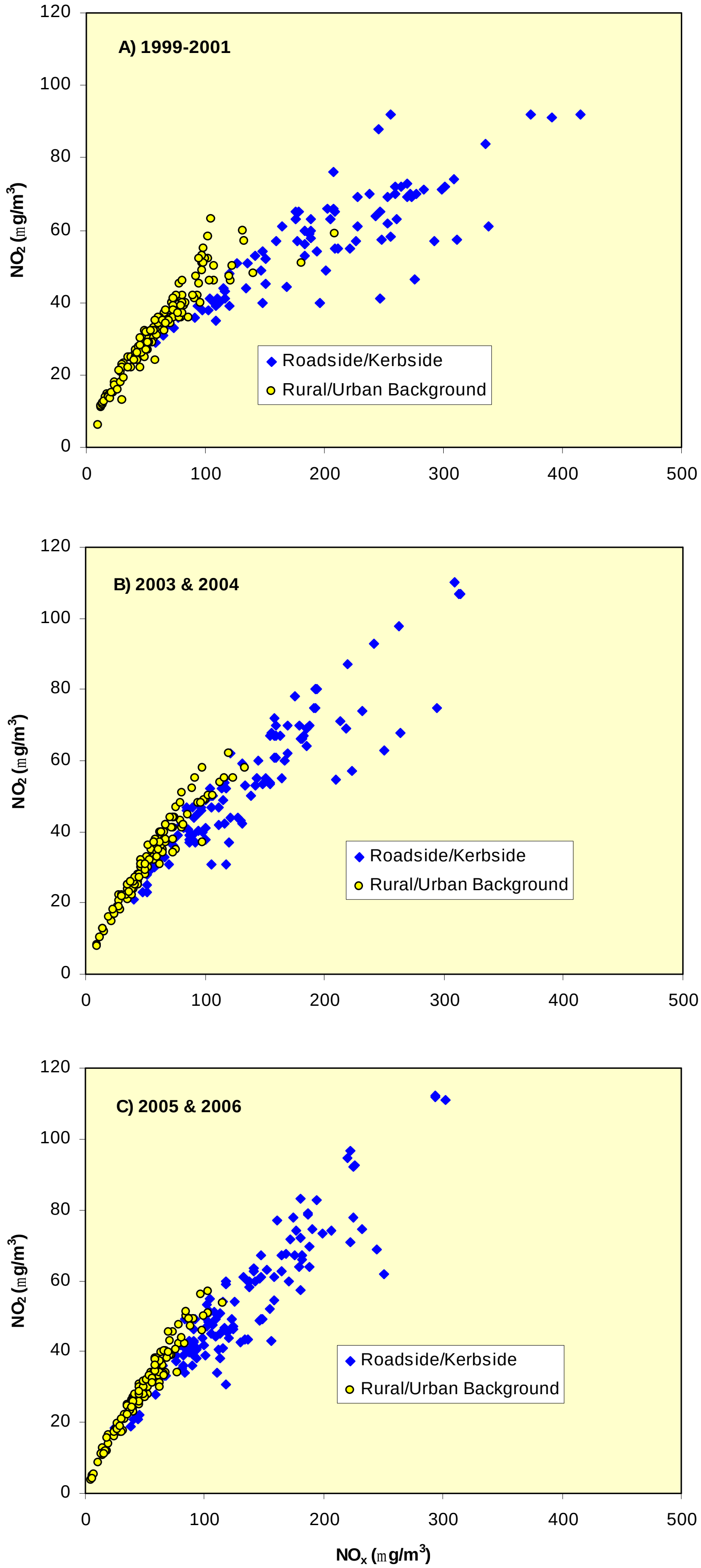

Figure 1 Annual Mean NO_2 / NO_x from Nation-Wide Sites in A) 1999-2001; B) 2003 and 2004; and C) 2005 and 2006

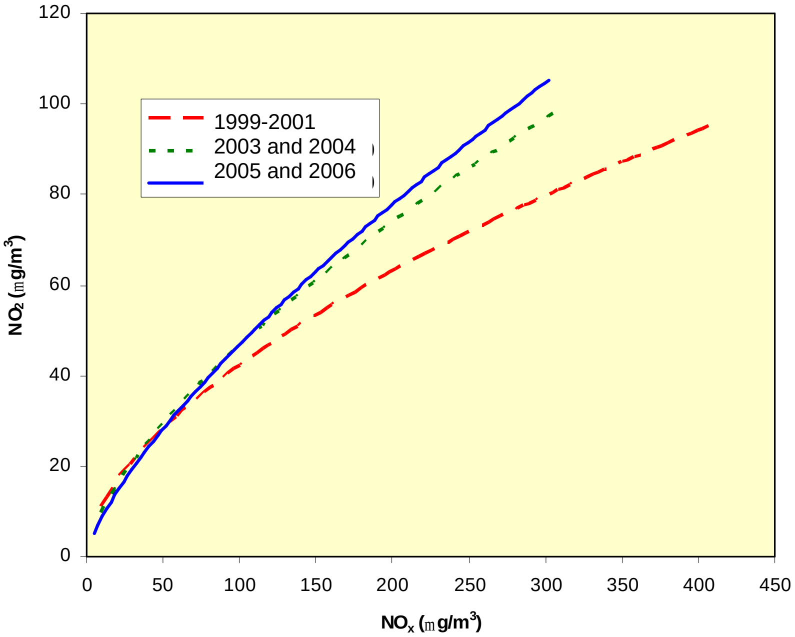

Figure 2 Approximate (power law) NO_2/NO_x Curves Fitted to 1999-2001; 2003 & 2004; and 2005 & 2006 Measurements.

5 Performance of the TG(03) Method

5.1 The approach set out in Section 3 has been used to predict NO_2 concentrations from measured NO_x concentrations using the TG(03) method. Figure 3A plots the predicted NO_2 concentrations against the measured concentrations in 1999 and 2001[5]. The plot is essentially a reproduction of Figure 5 in Laxen and Wilson (2002), except for the inclusion of the LAQN sites and a classification according to whether the site is within or outside of Greater London. The plot shows that aside from inevitable scatter around the 1:1 line, the TG(03) approach fits the 1999 to 2001 dataset reasonably well.

5.2 Figure 3B shows the same plot for the 2003 and 2004 dataset[6]. The points in Figure 3B clearly tend to fall below the 1:1 line, showing that the TG(03) method is tending to under-predict concentrations. This is the case across the full range of measured NO_2 concentrations but is particularly prominent at high concentrations, all of which are within Greater London. On average, the degree of under-prediction is more than 20%.

5.3 Figure 3C repeats this analysis with data from the period 2005 and 2006. As above, the majority of the data lie below the 1:1 line across the full range of measured concentrations, with very few over-predictions. The most significant under-predictions occur at the highest concentrations and within Greater London. There are even greater divergences from the measured values in the 2005 and 2006 dataset than is apparent in 2003 and 2004, but the average under-prediction for 2005 and 2006 is slightly less, although still greater than 20%.

5.4 TG(03) recommends that model results are verified against measurements. It is often the case that model results require an initial adjustment of predicted road-NO_x and a secondary adjustment of NO_2. Applying this secondary adjustment acknowledges and corrects for inadequacies in the TG(03) NO_x to NO_2 calculation (for the year of the verification). The implications of this current study for assessments which have verified against NO_2 measurements (and not just NO_x) and which do not project far into the future will thus be minimal. However, the results presented here do suggest that any modelling study that has verified against NO_x without an additional check against measured NO_2 might have under-predicted NO_2 concentrations by, on average, 20%. Appendix 2 sets out a case study to demonstrate this point.

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5 Using the background mapping that was available at that time.

6 Using the latest (2006) background maps.

5.5 The TG(03) method is also incorporated in the Design Manual for Roads and Bridges (DMRB) screening model (versions issued in 2003). The increase in the proportion of primary NO_2 emissions is one of the reasons cited by the review and assessment helpdesk website[7] in its advice to local authorities to verify the results of the DMRB model against monitoring data wherever possible. Without verification and adjustment, the current DMRB model is likely to under-predict NO_2 concentrations by an average of 20% because of its reliance on the TG(03) NOx/NO_2 relationship.

7 www.uwe.ac.uk/aqm/review

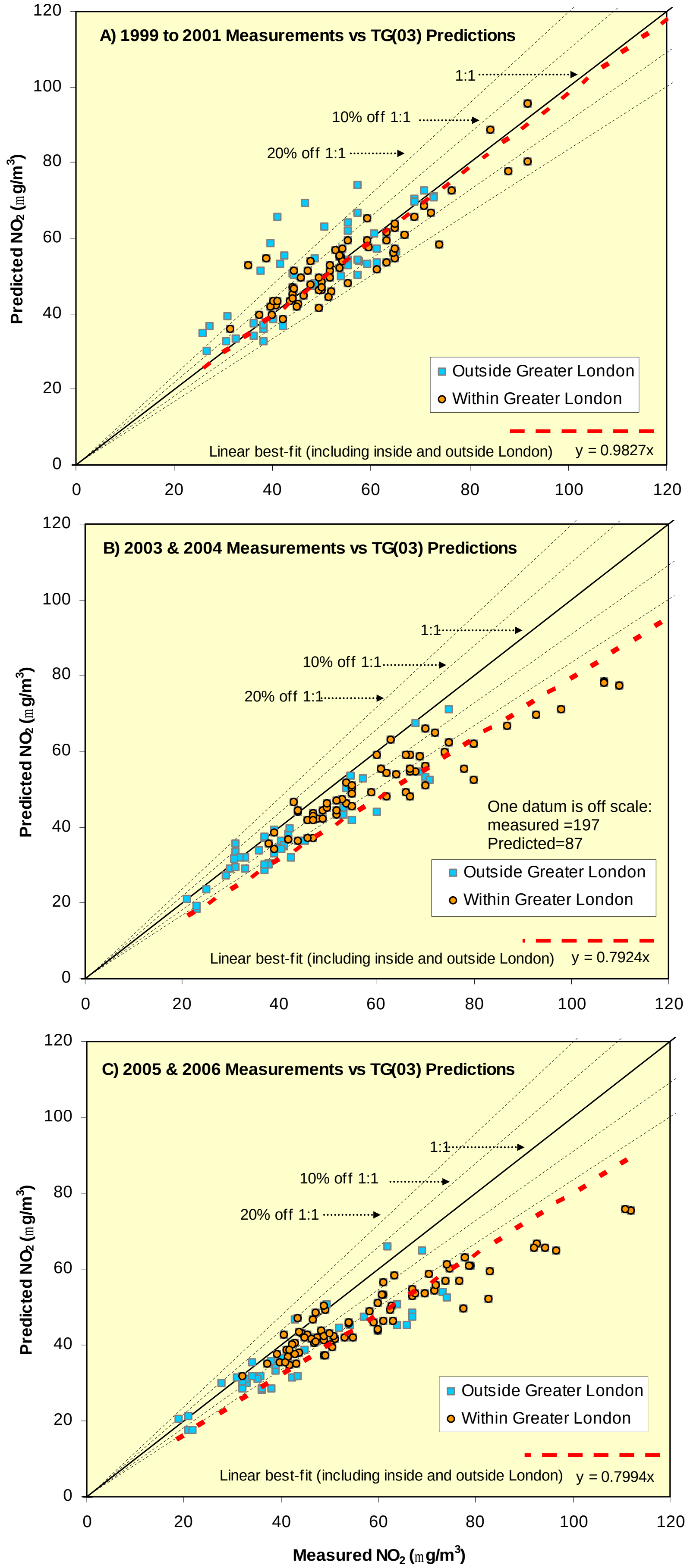

Figure 3 Predicted NO_2 Using the TG(03) Method vs Measured NO_2 in A) 1999-2001; B) 2003 & 2004; and C) 2005 & 2006.

6 An Updated Method

6.1 The approach described by Laxen and Wilson (2002) and incorporated in TG(03) is based on an idea proposed by Stedman *et al.* (2001) which involved splitting roadside NO_2 into two components, 1) a background component brought into the area from outside and 2) a component directly related to the fresh NO_x emissions. The Stedman approach is thus to add background-NO_2 to the road-NO_2 (derived from road-NO_x), to give total-NO_2. The Laxen and Wilson adaptation of this approach allows for a variable contribution to be made by road-NO_x to road-NO_2, reflecting the decreasing amount of ozone available to oxidise NO to NO_2 at higher NO_x concentrations.

6.2 The approach implies that a proportion of NO_x is emitted directly as primary NO_2 and that some of the NO emissions are rapidly converted to NO_2 to give a fixed proportion of NO_2 within the fresh road-NO_x (albeit at the annual mean level). This proportion is dependent on the total-NO_x concentration, this acting as a surrogate for the amount of available ozone. There is then assumed to be no further conversion of fresh NO to NO_2, just a mixing of background NO and NO_2, and road traffic NO and NO_2 in the near-road environment. In this simplified model, the ratio of NO_2 to NO_x will thus vary with distance from the road due to the mixing process, not chemical transformation. Over a longer time period there is further chemical conversion of NO to NO_2 until concentrations are determined by the photo-stationary state at background locations.

6.3 Laxen and Wilson calculated the variable proportion of road-NO_2 in the fresh road-NO_x from an analysis of the ratio of road-NO_2/road-NO_x against total-NO_x at roadside monitoring sites. Road-NO_x and road-NO_2 were calculated as described in Section 3. Figure 4A reproduces Figure 4 from the Laxen and Wilson report. It plots the road-NO_2/road-NO_x ratio against total-NO_x. The best fit line in Figure 4A, which is described by Equation 1, lies at the heart of the TG(03) method.

Equation 1 (TG(03) Method):

$$\text{Road-}NO_2 = (-0.068 \times \ln(\text{Total-}NO_x) + 0.53) \times \text{Road-}NO_x$$

6.4 Figures 4B and 4C show the same data for 2005 and 2006, separating out those sites outside Greater London (Figure 4B) and those within Greater London (Figure 4C). In each case, an updated best-fit line is also shown. As noted previously, there is a clear shift between the earlier dataset and the most recent ones, with the best-fit line entirely below a 0.3 NO_2/NO_x ratio in 1999-2001[8]; straddling 0.3 in 2005 and 2006 outside Greater London; and almost entirely above 0.3 in

8 i.e. showing that NO_2 never made up more than 30% of road-NOx at roadside sites.

2005 and 2006 within Greater London[9]. The plots also show clearly how different the overall trends are within and outside of Greater London.

6.5 Because of the large differences between Figures 4B and 4C, it is considered appropriate to generate different relationships for sites outside and within Greater London. The line which best fits the 2005 and 2006 data from sites outside Greater London (as shown in Figure 4B) is described by Equation 2. The line which best fits the 2005 and 2006 data from sites within Greater London (as shown in Figure 4C) is described by Equation 3. Substituting the appropriate equation into the TG(03) method gives an updated approach which is based on the same assumptions and processes, but uses the most recent (2005 and 2006) data, and is tailored according to whether the site is within or outside of Greater London. This analysis has focused on the 2005 and 2006 relationship and 2003-2004 equations have not been developed. The significance of this is discussed later.

Equation 2 (sites outside Greater London):

$$\text{Road-NO}_2 = (-0.0719 \times \text{Ln}(\text{Total-NO}_x) + 0.6248) \times \text{Road-NO}_x$$

Equation 3 (sites within Greater London):

$$\text{Road-NO}_2 = (-0.0413 \times \text{Ln}(\text{Total-NO}_x) + 0.5225) \times \text{Road-NO}_x$$

9 i.e. showing that NO_2 always made up more than 30% of road-NOx at roadside sites.

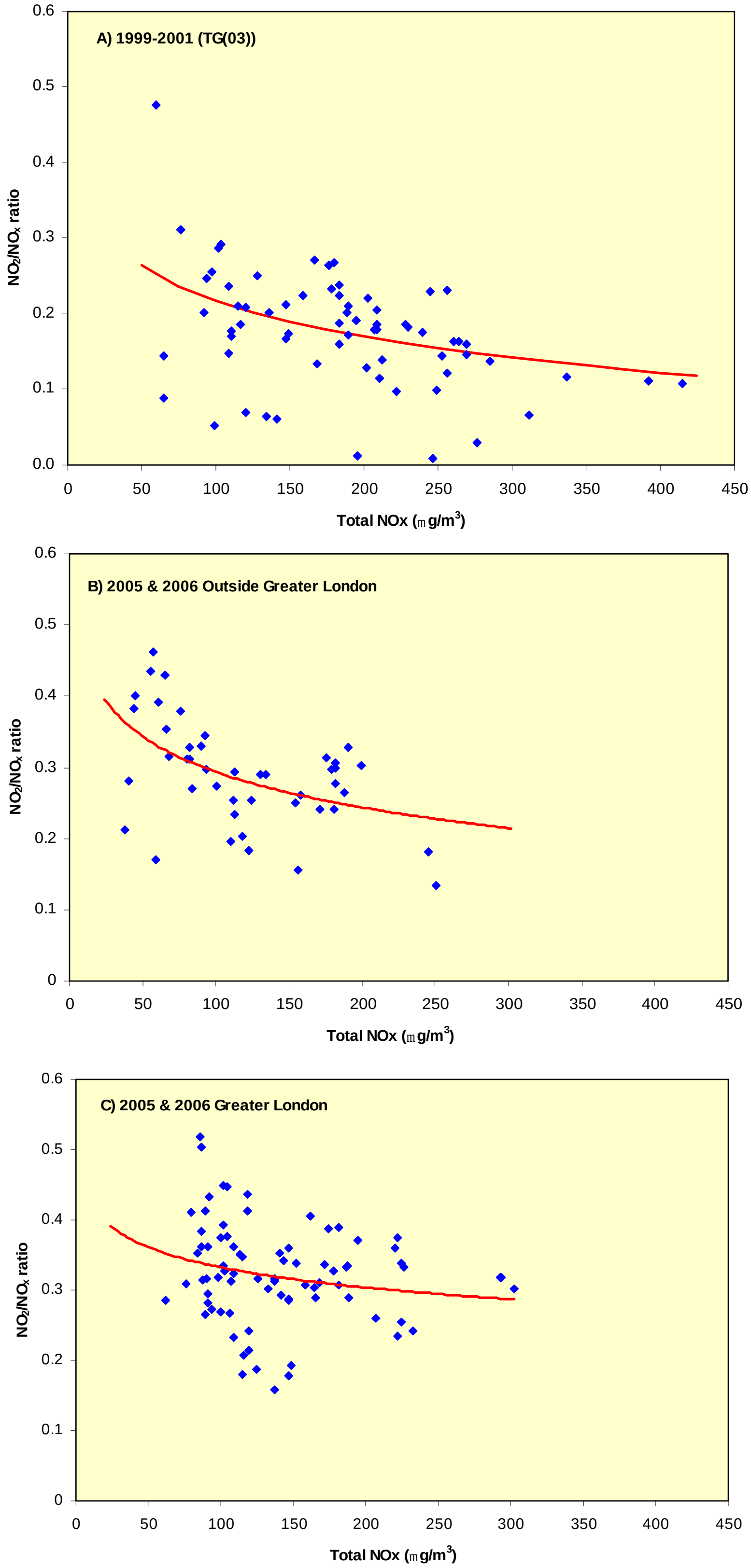

Figure 4 Ratio of Road-NO_2/Road-NOx vs Total-NO_x in A) 1999-2001; B) 2005 and 2006 Outside London; and C) 2005 and 2006 Within London. The Lines Represent Best-Fit Equations

7 Testing the Updated Method

7.1 The approach set out in Section 3 has been used to predict NO_2 concentrations from measured NO_x concentrations using the updated method (i.e. substituting Equations 2 and 3 into the TG(03) method). A separate comparison has been carried out for sites outside and within Greater London.

Sites outside Greater London

7.2 Figure 5A plots the predicted NO_2 concentrations using Equation 2 against the concentrations measured outside Greater London in 1999 and 2001[10]. The updated method is clearly inappropriate for these data, leading to substantial over-predictions. Figure 5B shows the same plot for the 2003 and 2004 dataset[11]. There is still scatter around the 1:1 line, and a tendency to over-predict by, on average, 2%. Figure 5C shows the same plot for the 2005 and 2006 dataset. Again, the data points are scattered around the 1:1 line, this time showing on average, a 1% under-prediction.

7.3 It is considered that an average discrepancy of around 2% is acceptable considering the scatter in the data and other sources of uncertainty. The updated relationship for sites outside Greater London is thus considered appropriate for application to the 2003 to 2006 datasets, but not to data prior to 2003 when the TG(03) relationship continues to perform better. It is, however, noted that the change between Figures 5B and 5C is consistent with a gradual "drift" in NO_x/NO_2 ratios outside of London. As noted previously, the 2006 AQEG report suggests that there might be a period of changing NO_x/NO_2 ratios outside of London, as the rest of the UK "catches up". The change between Figures 5B and 5C suggest that this "drift" is effectively causing the predicted concentrations to diverge from measurements by no more than a few percent per year. It is, however, recommended that this situation is closely monitored and, if necessary, the approach updated in the future.

[10] Using the background mapping that was available at that time.
[11] Using the latest (2006) background maps.

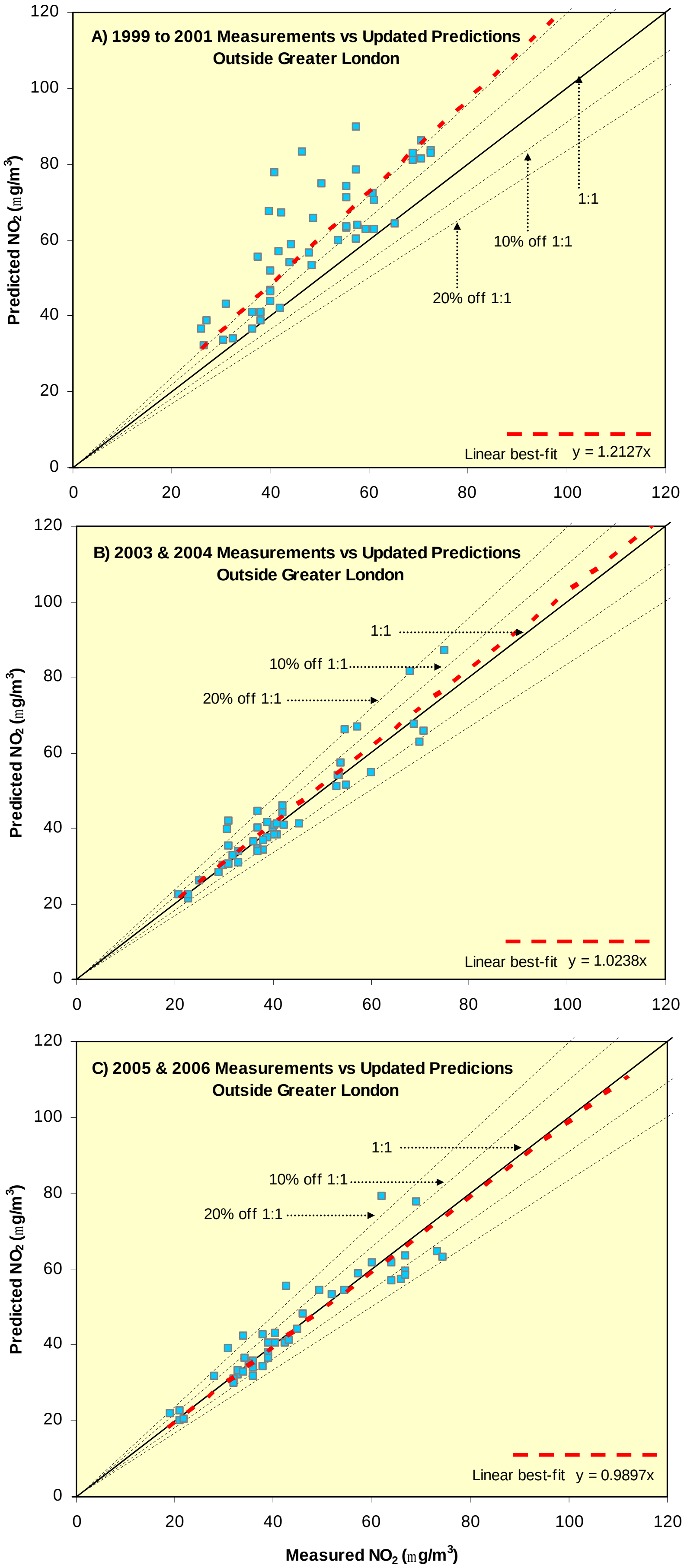

Figure 5 Predicted NO_2 Using the Updated Method for Outside Greater London vs Measured NO_2 in A) 1999-2001; B) 2003 & 2004; and C) 2005 & 2006

Sites within Greater London

7.4 Figure 6A plots the predicted NO_2 concentrations using Equation 3 against the concentrations measured within Greater London in 1999 and 2001[12]. As above, the updated method is clearly inappropriate for these data, leading to substantial over-predictions. Figure 6B shows the same plot for the 2003 and 2004 dataset[13]. There is still scatter around the 1:1 line, but the over-prediction is extremely small (and less than half of 1%). Figure 5C shows the same plot for the 2005 and 2006 dataset. Again, the data points are scattered around the 1:1 line, this time showing on average, a little over 1% under-prediction.

7.5 It is considered that the updated relationship for sites within Greater London is appropriate for application to the 2003 to 2006 datasets, but not to those prior to 2003 when the TG(03) relationship continues to perform better. The change between Figures 6B and 6C suggests a small continuing shift in NO_x/NO_2 ratios even within Greater London, consistent with the findings of AQEG. The change between Figure 6B and Figure 6C amounts to less than 2% on average, and so application of the updated relationship to future-year predictions is unlikely to introduce significant bias, at least over the short term (to 2010). It is, however, recommended that this situation is closely monitored and, if necessary, the within-London equation updated in the future.

12 Using the background mapping that was available at that time.
13 Using the latest (2006) background maps.

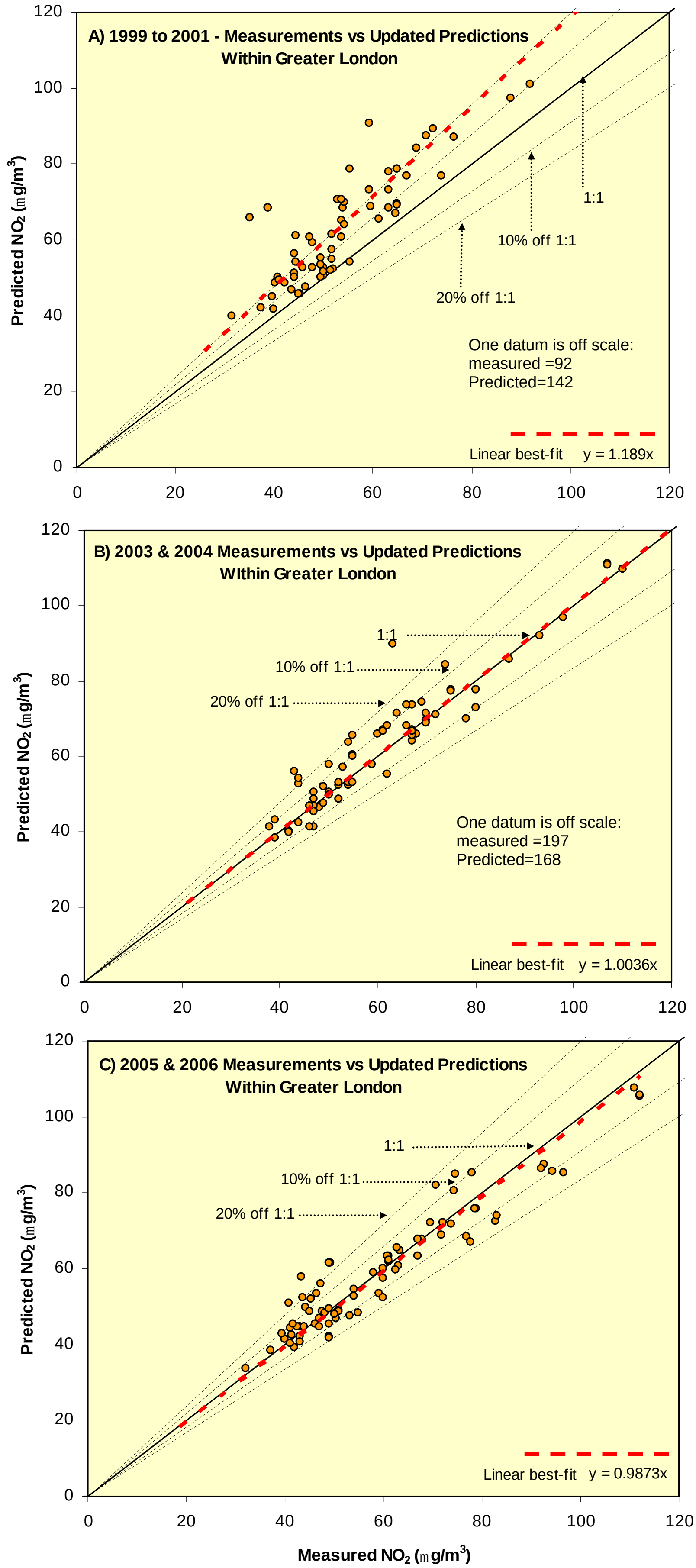

Figure 6 Predicted NO_2 Using the Updated Method for Within Greater London vs Measured NO_2 in A) 1999-2001; B) 2003 & 2004; and C) 2005 & 2006

Testing Across the Range of Possible Situations

7.6 Appendix 3 shows how the updated approach performs at sites near to motorways and fast-traffic dual-carriageways. It shows that these sites appear to behave slightly differently from the majority of other sites, but the degree of difference is small (much smaller than the within / outside Greater London effect). Using the approaches set out in Equations 2 and 3 for motorway and fast-traffic dual-carriageways in 2005 and 2006 gives, on average, a 3% over-prediction, which is considered acceptable and does not warrant a site-type-specific approach.

7.7 Figure 7 shows the range of road-NO_2 concentrations that the TG(03) approach and the updated relationships give for different values of road-NO_x and total-NO_x (with road-NO_x shown as a percentage of total-NO_x by the different lines). An example of interpreting Figure 7A (the TG(03) method) is that a total-NO_x concentration of 152 $\mu g/m^3$, 50% of which is road-NO_x, would be associated with a road-NO_2 concentration of 14 $\mu g/m^3$. In Figure 7B (updated non-London method), the same NO_x concentrations would equate with a road-NO_2 concentration of 20 $\mu g/m^3$; while in Figure 7C (updated within-London), the same NOx concentration would equate to 23 $\mu g/m^3$ of road-NO_2. In each case, the road-NO_2 concentration would then be added to the background-NO_2 concentration to give total-NO_2. As well as showing the increased response of the updated approach in relation to the TG(03) method, these plots are useful since they demonstrate that the updated model continues to behave appropriately across the full range of conditions that might be encountered within the UK.

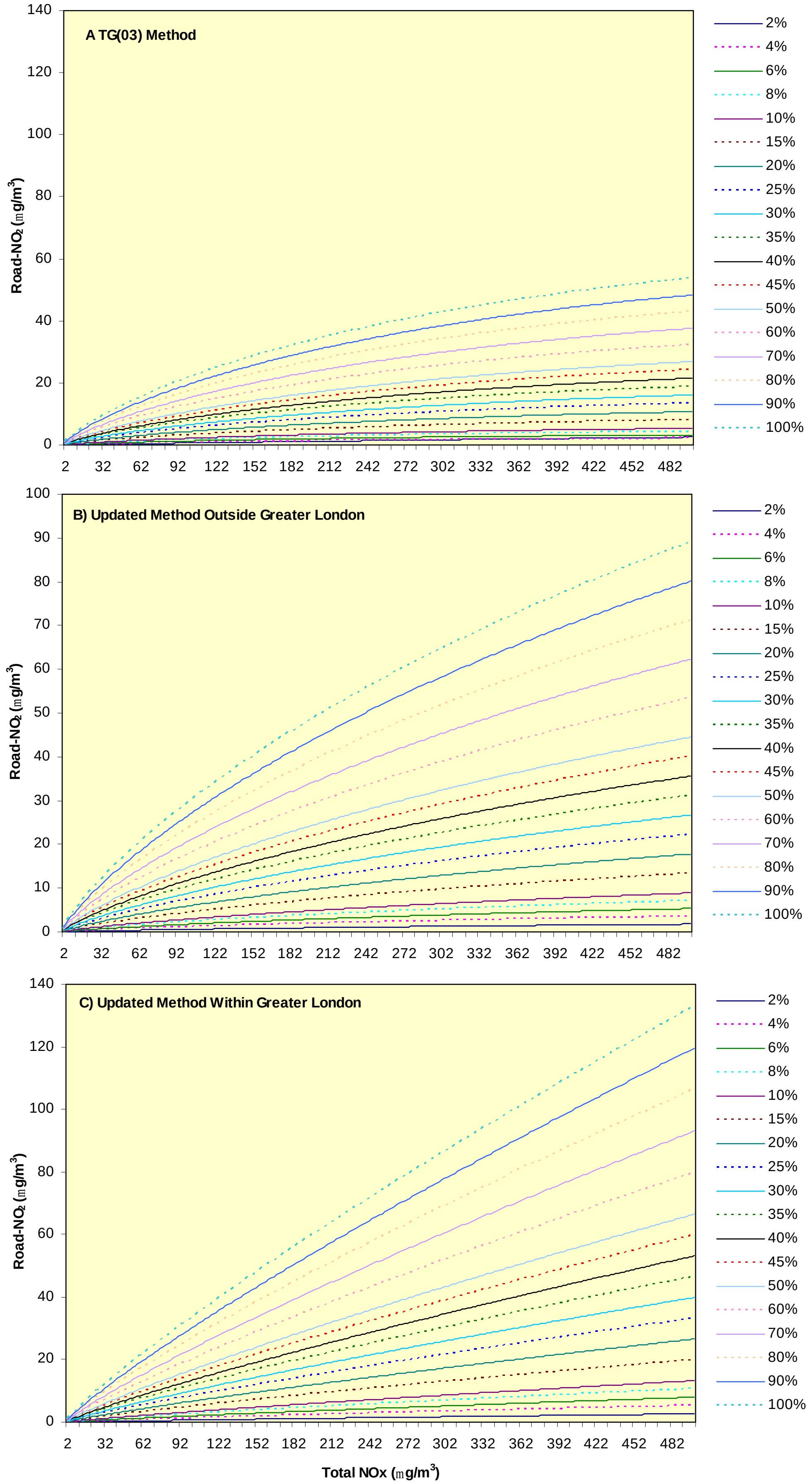

Figure 7 Predicted Road-NO_2 as a Function of Road-NO_x and Total-NO_x using A) the TG(03) Method, B) the Updated Method for Outside Greater London; and C) the Updated Method for Within Greater London. Each line represents a different proportion of Road-NOx within the Total.

8 Alternative Methodologies

8.1 This analysis has shown that the updated approach to deriving NO_2 from NO_x works well in current UK conditions. However, the proportion of primary NO_2 in NO_x emissions appears to be increasing and this is likely to lead to further changes in NO_2/NOx rations. Since this updated approach is empirically-derived, it is unable to predict future conditions and it might not represent future conditions as well as it does existing ones.

8.2 Alternative methods for calculating NO_2 from NO_x exist, and these are reviewed in the Laxen and Wilson report, and Annex 3 of the 2006 AQEG report. Jenkin (2004) demonstrated a way of considering NO_2/NO_x ratios in relation to "oxidant" concentrations (equal to the sum of O_3 and NO_2). This "oxidant-partitioning approach" enables predictions that take account of changes in both O_3 levels and primary NO_2 emissions. The main disadvantage of this latter approach is that it requires near-road and background concentrations to be treated separately, while the TG(03) method allows a smooth transition from roadside to background levels. If the oxidant-partitioning approach can be developed so that it incorporates projected oxidant concentrations and a smooth transition between roadside and background levels then it might, in future, provide a more suitable alternative than this current updated approach.

8.3 It is recommended that the updated method set out in this report should be used in preference to the TG(03) method. However, if an alternative method is deemed more appropriate for a particular assessment then there is no reason why it should not be used - so long as its suitability can be demonstrated. Work is likely to continue in the future to update and refine the NO_2 from NOx calculation, and it may be possible to provide an improved approach taking account of expected future changes in NO_2/NO_x concentration ratios.

9 Summary and Conclusions

9.1 AQEG (2006) has reported that the ratio of NO_2/NO_x concentrations at many roadside sites, particularly those in London, is changing. This is thought to be largely associated with an increasing proportion of primary NO_2 emissions. Laxen and Wilson (2002) set out an approach to calculate NO_2 concentrations from NO_x concentrations, which has been incorporated both into LAQM TG(03) and into the DMRB screening model. The TG(03) approach was based on measurements of NO_2/NO_x ratios made prior to 2002. This report has assessed the performance of the TG(03) method against more recent measurements made at automatic monitoring stations across the UK during the period 2003 to 2006.

9.2 While the TG(03) method performs well in relation to earlier (pre-2002) measurements, it tends to under-predict NO_2 concentrations when compared with more recent measurements. The degree of under-prediction has been shown to be, on average, approximately 20%, with greater errors at higher concentrations.

9.3 Following the TG(03) method, but incorporating the most recent (2005 and 2006) measurements, an updated approach to calculating NO_2 from NO_x at roadside sites has been derived. The updated method, which is set out in Box 1, acknowledges the differences in observed trends within and outside of Greater London and fits two different relationships. The revised method has been shown to perform well not only against the 2005 and 2006 dataset, but also against measurements made during 2003 and 2004. It appears to work reasonably well for all types of roads, including fast-traffic dual-carriageways and motorways. Whilst NO_2/NO_x concentration ratios are expected to continue to "drift" upward, the revised approach is considered to be broadly applicable over the next few years, although it will become increasingly uncertain after 2010. The inverse of the approach in Box 1 can be used to calculate NO_x concentrations from measured NO_2 concentrations.

9.4 Box 1 provides an appropriate method for calculating NO_2 from NO_x. However, it is strongly recommended that modelling studies using this approach verify against both NO_x and NO_2 measured concentrations (following one of the approaches set out in TG(03)). Where versions 1.03 and earlier of the DMRB screening model are used, it is recommended that the approach set out in Box 2 is followed. It is also recommended that the performance of this updated method is revisited once data from future years become available.

Box 1: An updated approach to deriving NO_2 from NO_x for road traffic sources

The updated empirical method to convert annual mean NO_x to NO_2 at roadside locations involves the following steps:

1. Obtain the annual mean background-NO_2 and background-NO_x concentrations for the area. These can be derived from the national 1x1 km background maps or from local monitoring at background sites.
2. Calculate the annual mean contribution due to the road, road-NO_x, at the location of interest. This could be from any suitable verified model.
3. Convert the road-NO_x to road-NO_2 using one of the three equations set out below depending on location and year of interest.
4. Add the road-NO_2 to the background-NO_2 to get the total-NO_2.

Equations to convert road-NO_x to road-NO_2:

Prior to 2003;

All locations:

$$\text{road-}NO_2 = ((-0.068 \times \text{Ln(total-NOx)})+0.53) \times \text{road-}NO_x$$

2003 onward;

Outside Greater London:

$$\text{road-}NO_2 = ((-0.0719 \times \text{Ln(total-NOx)})+0.6248) \times \text{road-}NO_x$$

Within Greater London:

$$\text{road-}NO_2 = ((-0.0413 \times \text{Ln(total-NOx)})+0.5225) \times \text{road-}NO_x$$

where total-NO_x = background-NO_x + road-NO_x, and Ln is log to the base e

Box 2: Instructions for applying versions 1.02; and 1.03 of the DMRB Screening Model taking account of recent changes in NO_2/NO_x ratios

1. Run the screening model as usual, but record the predicted NO_x concentration and **not** the predicted NO_2 concentration.
2. Calculate Road-NO_x by subtracting the background-NO_x (that was used to run the screening model) from the predicted NO_x concentration.
3. Calculate Road-NO_2 using the appropriate equation from Box 1.
4. Add the road-NO_2 to the background-NO_2 (that was used to run the screening model) to get the total-NO_2 concentration.

References

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Laxen and Wilson (2002) A New Approach to Deriving NO_2 from NO_x for Air Quality Assessments of Roads.

Stedman J R, Goodwin J W L, King K, Murrells T P and Bush T J (2001) An empirical model for predicting urban roadside nitrogen dioxide concentrations in the UK, Atmos. Env. 35, 1451-1463.

Appendix 1 Data Used in this Analysis

Site Name	Years	Official Classification	Study-Specific Classification	Motorway or Fast Dual Carriageway
AURN Sites				
Aberdeen	**2004,2005,2006**	Urban Background	Background / Urban Background	
Aston Hill	**2005**	Rural	Background / Urban Background	
Barnsley Gawber	**2003,2004**	Urban Background	Background / Urban Background	
Bath Roadside	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
Belfast Centre	**2003,2004,2006**	Urban Centre	Roadside / Kerbside	
Birmingham Centre	**2006**	Urban Centre	Background / Urban Background	
Birmingham Tyburn	**2005**	Urban Background	Background / Urban Background	
Blackpool Marton	**2006**	Urban Background	Background / Urban Background	
Bolton	**2003,2004**	Urban Background	Background / Urban Background	
Bournemouth	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
Bradford Centre	**2003,2004,2006**	Urban Centre	Roadside / Kerbside	
Brentford Roadside	**2005**	Roadside	Roadside / Kerbside	
Brighton Preston Park	**2005,2006**	Urban Background	Background / Urban Background	
Brighton Roadside	**2004,2005,2006**	Roadside	Roadside / Kerbside	
Bristol Old Market	**2004,2005,2006**	Roadside	Roadside / Kerbside	
Bury Roadside	**2004,2005**	Roadside	Roadside / Kerbside	Yes
Bush Estate	**2004**	Rural	Background / Urban Background	
Cambridge Roadside	**2004,2005**	Roadside	Roadside / Kerbside	
Camden Kerbside	**2006**	Kerbside	Roadside / Kerbside	
Canterbury	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
Cardiff Centre	**2004,2006**	Urban Centre	Background / Urban Background	
Coventry Memorial Park	**2004,2005,2006**	Urban Background	Background / Urban Background	
Cwmbran	**2004,2005,2006**	Urban Background	Background / Urban Background	
Derry	**2003,2004,2005**	Urban Background	Background / Urban Background	
Dumfries	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
Edinburgh St Leonards	**2004,2005,2006**	Urban Background	Background / Urban Background	
Eskdalemuir	**2005,2006**	Rural	Background / Urban Background	
Exeter Roadside	**2003,2004,2006**	Roadside	Roadside / Kerbside	
Glasgow Centre	**2005,2006**	Urban Centre	Background / Urban Background	
Glasgow City Chambers	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
Glasgow Kerbside	**2003,2004,2005,2006**	Kerbside	Roadside / Kerbside	
Glazebury	**2005,2006**	Rural	Background / Urban Background	
Haringey Roadside	**20042005**	Roadside	Roadside / Kerbside	
Harwell	**2004,2005,2006**	Rural	Background / Urban Background	
Hove Roadside	**2003,2004,2005**	Roadside	Roadside / Kerbside	
Hull Freetown	**2003**	Urban Centre	Background / Urban Background	
Inverness	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
Ladybower	**2003,2005**	Rural	Background / Urban Background	
Leamington Spa	**2004,2006**	Urban Background	Background / Urban Background	
Leeds Centre	**2004,2005,2006**	Urban Centre	Background / Urban Background	

Leicester Centre	**2003,2005,2006**	Urban Centre	Background / Urban Background	
Leominster	**2006**	Suburban	Background / Urban Background	
Liverpool Speke	**2004,2005,2006**	Urban Background	Background / Urban Background	
London A3 Roadside	**2004,2005,2006**	Roadside	Roadside / Kerbside	Yes
London Bexley	**2004,2005,2006**	Suburban	Background / Urban Background	
London Bloomsbury	**2004,2005,2006**	Urban Centre	Background / Urban Background	
London Brent	**2003,2004,2006**	Urban Background	Background / Urban Background	
London Bromley	**2003,2004,2005**	Roadside	Roadside / Kerbside	
London Cromwell Road 2	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
London Eltham	**2003,2004,2006**	Suburban	Background / Urban Background	
London Hackney	**2003,2004,2005**	Urban Centre	Roadside / Kerbside	
London Hillingdon	**2004,2005,2006**	Suburban	Roadside / Kerbside	Yes
London Lewisham	**2003,2004,2005,2006**	Urban Centre	Roadside / Kerbside	
London Marylebone Road	**2003,2004,2005,2006**	Kerbside	Roadside / Kerbside	
London N. Kensington	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
London Southwark	**2005**	Urban Centre	Background / Urban Background	
London Teddington	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
London Wandsworth	**2003,2004,2005,2006**	Urban Centre	Roadside / Kerbside	
London Westminster	**2006**	Urban Background	Roadside / Kerbside	
Lullington Heath	**2004**	Rural	Background / Urban Background	
Manchester Piccadilly	**2003,2004,2006**	Urban Centre	Background / Urban Background	
Manchester South	**2003**	Suburban	Background / Urban Background	
Manchester Town Hall	**2003,2004,2005**	Urban Background	Background / Urban Background	
Market Harborough	**2004,2005,2006**	Rural	Background / Urban Background	
Narberth	**2005,2006**	Remote	Background / Urban Background	
Newcastle Centre	**2003,2005,2006**	Urban Centre	Background / Urban Background	
Northampton	**2003,2006**	Urban Background	Background / Urban Background	
Norwich Centre	**2003,2004,2006**	Urban Centre	Background / Urban Background	
Norwich Forum Roadside	**2006**	Roadside	Roadside / Kerbside	
Norwich Roadside	**2003,2004,2006**	Roadside	Roadside / Kerbside	
Nottingham Centre	**2004,2005,2006**	Urban Centre	Background / Urban Background	
Oxford Centre Roadside	**2003,2005,2006**	Roadside	Roadside / Kerbside	
Plymouth Centre	**2003,2005**	Urban Centre	Background / Urban Background	
Portsmouth	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
Preston	**2003,2004,2006**	Urban Background	Background / Urban Background	
Reading New Town	**20042005**	Urban Background	Background / Urban Background	
Redcar	**2003,2004**	Suburban	Background / Urban Background	
Rochester	**2003,2004,2005,2006**	Rural	Background / Urban Background	
Rotherham Centre	**2003,2004,2005**	Urban Centre	Background / Urban Background	
Sandwell West Bromwich	**2004,2005,2006**	Urban Background	Background / Urban Background	
Sheffield Centre	**2003,2004**	Urban Centre	Roadside / Kerbside	
Southampton Centre	**2003,2004,2006**	Urban Centre	Roadside / Kerbside	
Southend-on-Sea	**2004,2005,2006**	Urban Background	Background / Urban Background	
Southwark Roadside	**2003,2005**	Roadside	Roadside / Kerbside	
St Osyth	**2003,2004,2005,2006**	Rural	Background / Urban Background	
Stockport Shaw Heath	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
Stockton-on-Tees Yarm	**2004,2005,2006**	Roadside	Roadside / Kerbside	
Stoke-on-Trent Centre	**2003,2004,2005,2006**	Urban Centre	Roadside / Kerbside	
Sunderland Silksworth	**2005,2006**	Urban Background	Background / Urban Background	
Swansea	**2003,2004,2005**	Urban Centre	Background / Urban Background	

Thurrock	**2003,2006**	Urban Background	Background / Urban Background	
Tower Hamlets Roadside	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
Walsall Alumwell	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
Walsall Willenhall	**2003,2004**	Suburban	Background / Urban Background	
West London	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
Wicken Fen	**2005,2006**	Rural	Background / Urban Background	
Wigan Centre	**2005,2006**	Urban Background	Background / Urban Background	
Wirral Tranmere	**2003,2004,2006**	Urban Background	Background / Urban Background	
Wolverhampton Centre	**2003,2005,2006**	Urban Centre	Background / Urban Background	
Wrexham	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
Yarner Wood	**2004**	Rural	Background / Urban Background	
Highways Agency Sites				
A40, Cheltenham	**2003,2004,2005**	kerbside	Roadside / Kerbside	
M4, Pinglewood	**2003,2005**	motorway	Roadside / Kerbside	Yes
M25, Staines	**2003,2005**	motorway	Roadside / Kerbside	Yes
M60 Kirkhams	**2003,2005**	motorway	Roadside / Kerbside	Yes
LAQN Sites				
Barking & Dagenham1 BG1	**2003,2004,2005,2006**	Suburban	Background / Urban Background	
Barnet2 BN2	**2004,2005,2006**	Urban Background	Background / Urban Background	
Bexley2 BX2	**2003,2004,2005,2006**	Suburban	Background / Urban Background	
Bexley7 BX7	**2006**	Roadside	Roadside / Kerbside	
Bexley8 BX8	**2005,2006**	Roadside	Roadside / Kerbside	
Brent4 BT4	**2004**	Roadside	Roadside / Kerbside	
Brentwood1 BW1	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
Bromley7 BY7	**2003,2004,2005**	Roadside	Roadside / Kerbside	
Camden3 CD3	**2003,2004**	Roadside	Roadside / Kerbside	
Castle Point1 CP1	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
City of London1 CT1	**2006**	Urban Background	Background / Urban Background	
Croydon2 CR2	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
Croydon4 CR4	**2004,2006**	Roadside	Roadside / Kerbside	
Croydon5 CR5	**2003,2004,2005,2006**	Kerbside	Roadside / Kerbside	
Croydon6 CR6	**2003,2005,2006**	Suburban	Background / Urban Background	
Crystal Palace1 CY1	**2003**	Roadside	Roadside / Kerbside	
Ealing1 EA1	**2004,2005,2006**	Urban Background	Background / Urban Background	
Ealing2 EA2	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
Ealing7 EA7	**2005**	Urban Background	Background / Urban Background	
Enfield1 EN1	**2003,2005**	Suburban	Background / Urban Background	
Enfield2 EN2	**2003,2004,2005**	Roadside	Roadside / Kerbside	
Enfield3 EN3	**2003,2004,2006**	Urban Background	Background / Urban Background	
Enfield4 EN4	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
Greenwich10 GN0	**2005,2006**	Roadside	Roadside / Kerbside	
Greenwich12 GN2	**2005**	Urban Background	Background / Urban Background	
Greenwich 13 GN3	**2006**	Roadside	Roadside / Kerbside	
Greenwich4 GR4	**2003,2004**	Urban Background	Background / Urban Background	
Greenwich5 GR5	**2003,2004,2005**	Roadside	Roadside / Kerbside	
Greenwich7 GR7	**2003,2005,2006**	Roadside	Roadside / Kerbside	
Greenwich8 GR8	**2005,2006**	Roadside	Roadside / Kerbside	
Greenwich9 GR9	**2005**	Roadside	Roadside / Kerbside	
Greenwich Bexley6 GB6	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
Hsmith & Fulham1 HF1	**2005,2006**	Roadside	Roadside / Kerbside	

Hsmith & Fulham2 HF2	**2004,2005,2006**	Urban Background	Background / Urban Background	
Hackney4 HK4	**2003,2004,2005**	Urban Background	Background / Urban Background	
Hackney6 HK6	**2004,2005,2006**	Roadside	Roadside / Kerbside	
Haringey1 HG1	**20042005**	Roadside	Roadside / Kerbside	
Haringey2 HG2	**2004,2005,2006**	Suburban	Background / Urban Background	
Harrow1 HR1	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
Harrow2 HR2	**20042005**	Roadside	Roadside / Kerbside	
Havering1 HV1	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
Havering3 HV3	**2004,2005,2006**	Roadside	Roadside / Kerbside	
Heathrow Airport LH2	**2003,2004,2005**	Urban Background	Background / Urban Background	
Hillingdon1 HI1	**2003,2006**	Roadside	Roadside / Kerbside	
Hillingdon2 HI2	**2006**	Roadside	Roadside / Kerbside	
Hounslow2 HS2	**2003**	Suburban	Background / Urban Background	
Hounslow4 HS4	**2004,2005,2006**	Roadside	Roadside / Kerbside	
Hounslow5 HS5	**20042005**	Roadside	Roadside / Kerbside	
Islington1 IS1	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
Islington2 IS2	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
Kens and Chelsea1 KC1	**2003,2004,2005**	Urban Background	Background / Urban Background	
Kens and Chelsea2 KC2	**2003,2004,2005**	Roadside	Roadside / Kerbside	
Kens and Chelsea3 KC3	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
Kens and Chelsea4 KC4	**2003,2005,2006**	Roadside	Roadside / Kerbside	
Lambeth1 LB1	**2003,2004,2006**	Roadside	Roadside / Kerbside	
Lambeth3 LB3	**2003,2004,2006**	Urban Background	Background / Urban Background	
Lambeth4 LB4	**2004**	Kerbside	Roadside / Kerbside	
Lambeth 5 LB5	**2006**	Roadside	Roadside / Kerbside	
Lewisham1 LW1	**2003,2004,2005**	Urban Background	Background / Urban Background	
Lewisham2 LW2	**2003,2004**	Roadside	Roadside / Kerbside	
Maidenhead Roadside MW1	**2006**	Roadside	Roadside / Kerbside	
Marylebone Rd MY1	**2003,2004,2005**	Kerbside	Roadside / Kerbside	
Mole Valley2 MV2	**2003,2004,2005**	Suburban	Background / Urban Background	
Mole Valley3 MV3	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
Redbridge1 RB1	**2003,2004,2005**	Urban Background	Background / Urban Background	
Redbridge3 RB3	**20042005**	Kerbside	Roadside / Kerbside	
Redbridge5 RB5	**2004,2005,2006**	Roadside	Roadside / Kerbside	
Reigate and Banstead1 RG1	**2003,2004,2005,2006**	Suburban	Background / Urban Background	
Reigate and Banstead2 RG2	**2005,2006**	Suburban	Background / Urban Background	
Reigate and Banstead 3 RG3	**2006**	Roadside	Roadside / Kerbside	
Richmond1 RI1	**2003,2004,2005,2006**	Urban Background	Background / Urban Background	
Richmond2 RI2	**2003,2004,2005,2006**	Suburban	Background / Urban Background	
Southwark1 SK1	**2005**	Urban Background	Background / Urban Background	
Southwark2 SK2	**2003,2005**	Roadside	Roadside / Kerbside	
Sutton3 ST3	**2005**	Suburban	Background / Urban Background	
Sutton4 ST4	**2003,2004,2005,2006**	Kerbside	Roadside / Kerbside	
Thurrock2 TK2	**2004,2005,2006**	Roadside	Roadside / Kerbside	
Thurrock3 TK3	**2004,2005,2006**	Roadside	Roadside / Kerbside	
Tower Hamlets1 TH1	**2003,2004,2005**	Urban Background	Background / Urban Background	
Tower Hamlets2 TH2	**2003,2004,2005**	Roadside	Roadside / Kerbside	
Tower Hamlets3 TH3	**2003,2006**	Urban Background	Background / Urban Background	
Waltham Forest1 WL1	**20042005**	Urban Background	Background / Urban Background	

Waltham Forest3 WL3	**2006**	Roadside	Roadside / Kerbside	
Wandsworth2 WA2	**2003,2004,2005**	Urban Background	Background / Urban Background	
Wandsworth4 WA4	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	
Windsor MW2	**2006**	Roadside	Roadside / Kerbside	
Local Authority Sites				
South Cambs Barr Hill	**2003,2005,2006**	Roadside	Roadside / Kerbside	Yes
South Cambs Impington	**2003, 2005**	Roadside	Roadside / Kerbside	Yes
Rushmore Medway Drive	**2004,2005,2006**	Roadside	Roadside / Kerbside	Yes
Gravesham A2 Roadside	**2003,2004,2005,2006**	Roadside	Roadside / Kerbside	Yes

Appendix 2 Case Study

A Dispersion Model

A dispersion model has been run to calculate NO_x concentrations at a roadside property (all concentrations are given as annual means).

The dispersion model predicts a **Road-NO_x** concentration of **60 µg/m^3**; and/or a **Total-NO_x** concentration of **94 µg/m^3** (some models give road-NOx while others give total-NOx).

The **background-NO_x** concentration is **34 mg/m^3**

The **background-NO_2** concentration is **23 µg/m^3**

If NO_2 is calculated using the **TG(03) equation**, Road-NO_2 is predicted to be 13 µg/m^3, and so **total NO_2 is 36 µg/m^3** - the objective is achieved by a margin of 10%.

If NO_2 is calculated using the **updated (outside London) equation**, Road-NO_2 is predicted to be 18 µg/m^3, and so **total-NO_2 is 41 µg/m^3** - the objective is exceeded.

If NO_2 is calculated using the **updated (within London) equation**, Road-NO_2 is predicted to be 20 µg/m^3, and so **total-NO_2 is 43 µg/m^3** - the objective is exceeded by almost 10%.

As noted in the main text, if the model results are verified against locally-measured nitrogen dioxide levels, this artefact is removed.

The DMRB Screening Model

Since the DMRB screening model follows the same principals as those given above (i.e. the model predicts Road-NO_x and uses background-NO_x and background-NO_2 to calculate Road-NO_2 and then Total-NO_2) it will be subject to precisely the same sensitivities. This means that an annual mean nitrogen concentration of 36 µg/m^3 predicted using the 2003 DMRB model would, under the new assumptions, be 41 µg/m^3 outside of London and 43 µg/m^3 within London.

Appendix 3 Motorways and Fast-Traffic Dual-Carriageways

It has been suggested that NO_2/NO_x ratios near to motorway and motorway-like sites might differ from those near to other roads. Figure A3.1 isolates those data from Figures 5 and 6 which relate to motorways and fast dual carriageways (as listed in Appendix 1[14]). Applying the updated relationships to these sites will tend, on average, to over-predict NO_2 concentrations. The average degree of over-prediction is, however, just 4% in 2003 and 2004, and 1% in 2005 and 2006. Given the relatively small degree of over-prediction and given that it will give conservative predictions, it is concluded that the equations set out in Box 1 can be applied to all types of roadside sites.

[14] In addition to the sites listed in Appendix 1, data from Salford Council measured beside the M60, which were received too late to be incorporated in the derived approach, are shown in Figure A3.1.

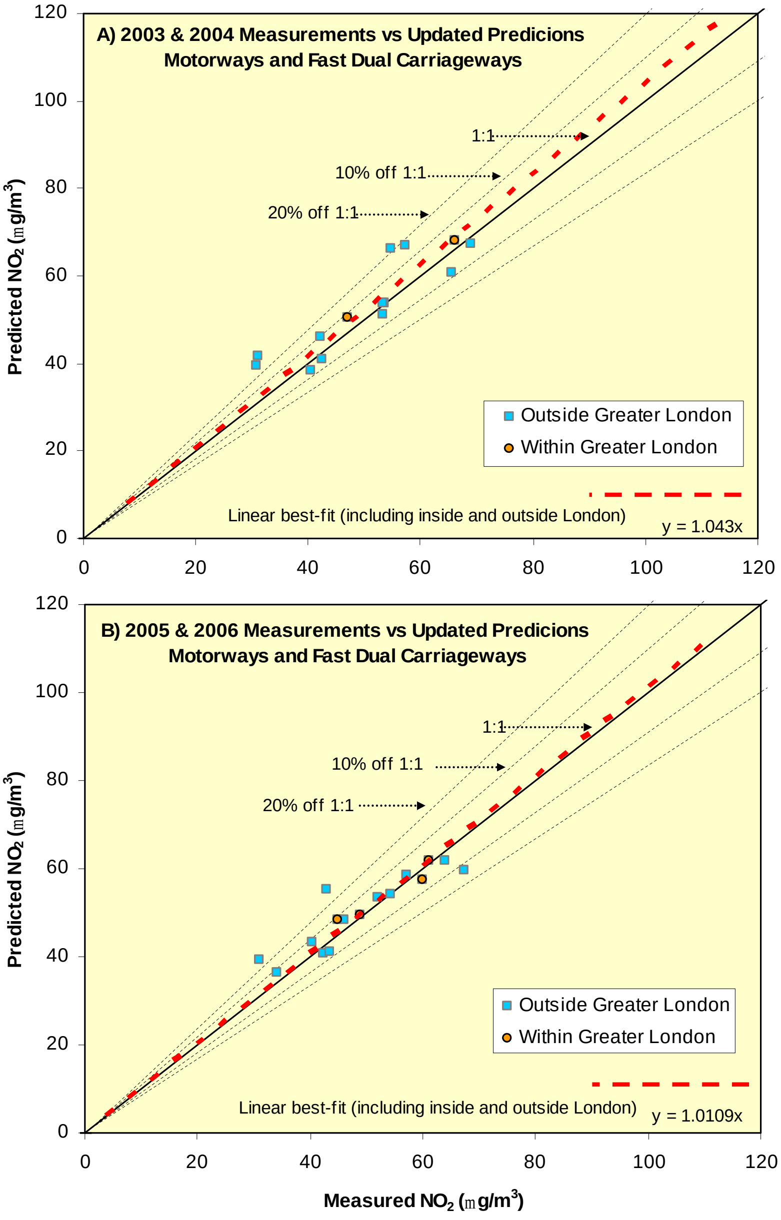

Figure A3.1 Predicted NO_2 Using the Updated Approach versus Measured NO_2 Near to Motorways and Fast Dual Carriageways in A) 2003 & 2004; and B) 2005 & 2006