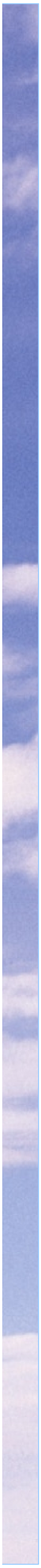
Air Quality Consultants

NO_2 Concentrations and Distance from Roads



Document Control

Client	Defra	**Principal Contact**	Janet Dixon

Job Number	J504

Report Prepared By:	Prof Duncan Laxen and Dr Ben Marner

Document Status and Review Schedule

Issue No.	Report No.	Date	Status	Reviewed by
1		12th June 2007	Draft Report	Stephen Moorcroft
2	**504/1/D1**	7th March 2008	Final Draft Report	Stephen Moorcroft
3	504/1/F1	18th July 2008	Final Report	Prof Duncan Laxen

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

Registered Office: 12 St Oswalds Road, Bristol, BS6 7HT
Companies House Registration No: 2814570

Contents

1 Executive Summary

1.1 Concentrations of nitrogen dioxide close to roads form the focus of attention of many air quality assessments, however little is known about the pattern of decline with distance and our ability to model this decline.

1.2 This report brings together results of measurements of concentrations of nitrogen dioxide made at different distances from busy roads to explore the consistency of the pattern of decline. It then examines the ability of commonly used models to reproduce the observed pattern of decline.

1.3 All of the measurement studies are shown to adhere closely to a single defined relationship: a linear reduction in the influence of the road with the natural logarithm of distance from the kerb. This is a much steeper rate of reduction than is implied by the DMRB screening model, Caline-4, or current Review and Assessment advice. The measurement-derived relationship does, however, agree relatively well with the results from ADMS-Roads (the chemistry module has not been tested).

1.4 A simple equation is provided that allows nitrogen dioxide measurements made at one distance from a road to be used to predict concentrations at a different distance from the same road.

2 Introduction

2.1 The focus of attention of much of the air quality assessment work carried out by local authorities under their air quality management duties, and that carried out by consultants when assessing air quality for new developments, is on the concentrations close to roads. Nitrogen dioxide is usually the key pollutant, as it frequently exceeds the UK annual mean objective of 40 $\mu g/m^3$. The distance from the road at which concentrations fall below the objective level is often a key concern. There is however little information on how concentrations decline with distance from the road. The Air Quality Expert Group (AQEG) reported that the few measurements then available indicated a rapid decline with distance over the first 20 m away from the kerb (AQEG, 2004). Experience of using the DMRB model (v1.03c) shows that this model does not reflect this rapid decline very well.

2.2 To provide an improved understanding of concentration patterns close to busy roads, results of several different studies that each measured transects of ambient nitrogen dioxide (NO_2) concentrations at different distances from roads have been compiled. The consistency in the pattern of decline of NO_2 concentrations with distance between these studies is examined. Following this, comparisons are made with the patterns of decline with distance derived using a number of routinely used dispersion models: the DMRB screening model; Caline-4 (within the AAQuIRE package) and ADMS-Roads. Finally, the observed patterns are compared with advice currently given to local authorities preparing their air quality Reviews and Assessments on how to adjust kerbside measurements to estimate concentrations at building facades.

3 Measured Data

Sources of Data

3.1 In the United Kingdom, a number of different studies have measured ambient NO_2 concentrations at several different distances from the same road. Some studies have used small transects involving only two monitoring sites (e.g. Green and Fuller, 2003), while others have used transects of up to eight sites (e.g. Hickman et al., 2002). This analysis has relied on reported results from the following five monitoring campaigns.

- Marylebone Road, Central London. Results taken from Green and Fuller (2003). Sampling using chemiluminescence monitors at 1.4 and 5.5 m from the kerb (at a height of 3m) for a 6-week period in winter.

- York Road, Central London. Results taken from Laxen and Noordally (1987). Sampling using diffusion tubes exposed weekly for 2 separate weeks at six different distances from the road.

- M25, near Staines. Results taken from Hickman *et al*. (2002). Sampling was carried out in transects near to both the clockwise and the anticlockwise carriageways using diffusion tubes exposed, typically, on a weekly basis. Monitoring for the anticlockwise carriageway extended from 29 October 1998 to 5 August 1999; while monitoring for the anticlockwise transect extended from 29 October 1998 to 30 September 1999. Hickman *et al.* (2002) combined these studies into a single dataset. They are treated separately here, since each will be influenced by different local factors.

- A14, Cambridgeshire. Results taken from the air quality assessment published by the Highways Agency (2007). Monitoring was carried out using monthly-exposed diffusion tubes at four different distances from the road for a period of 12 months (June 2004 to June 2005).

- M62, Rochdale. Results taken from Laxen and Marner (2003). Sampling was carried out using monthly-exposed diffusion tubes for a period of five months at eight different distances from the road.

3.2 Data were also provided for various roads in Coventry (Clamp, 2005) and alongside the A1 near to Wetherby (Lansley & Seakins, 2002). These studies have been excluded from this analysis since, in the case of the Coventry data, the sites were arranged along very long lengths of roadway and thus each site will have been influenced by other roads and site-specific factors. In the case of the

A1 study, the sampling was short term and not simultaneous at the different distances. For the six studies included, the uncertainty associated with each dataset will be different (for example a full year's worth of monthly-exposed diffusion tube data (e.g. A14) will provide more robust measurements than a single 2-weekly monitoring period (e.g. York Road)). For the purpose of this analysis, each dataset has been treated equally (i.e. no account has been taken of the different uncertainties).

Description of Measured Data

3.3 Table 1 sets out the measured concentrations, along with the distance from the kerb, for each of the studies included in this analysis. These results are also shown in Figure 1. Each study will be influenced by different site-specific factors: notably different traffic flows, background conditions, and meteorological factors. What is important to this analysis, however, is that each study appears to trace a similar pattern of reduction in concentration with distance from the kerb.

Table 1: Measured Data Used in this Analysis

Marylebone Rd		**York Rd**		**M25 Clockwise**		**M25 Anti-Clockwise**		**A14**		**M62**	
Green and Fuller, 2003		**Laxen and Noordally, 1987**		**Hickman *et al.*, 2002**		**Hickman et al., 2002**		**Highways Agency, 2006**		**Laxen and Marner, 2003**	
D	**C**	**D**	**C**	**D**	**C**	**D**	**C**	**D**	**C**	**D**	**C**
1.4	100	0.1	119	3.8	56	15.0	54	5	62	22.2	51
5.5	91	3.3	83	5.5	55	23.0	55	10	55	28.9	50
		8.8	80	7.6	51	29.6	47	50	38	29.1	50
		14.7	75	9.9	48	41.8	39	130	30	32.0	49
		19.5	71	21.3	42					60.0	47
		24.3	71	36.1	42					82.3	45
				69.8	32					99.5	42
				139.8	27					123	40

D = Distance from kerb in metres (note that the distances reported by Hickman *et al.* (2002) have been adjusted to account for the width of the motorway hard-shoulder).

C = Ambient NO_2 concentration (period mean) in µg/m^3.

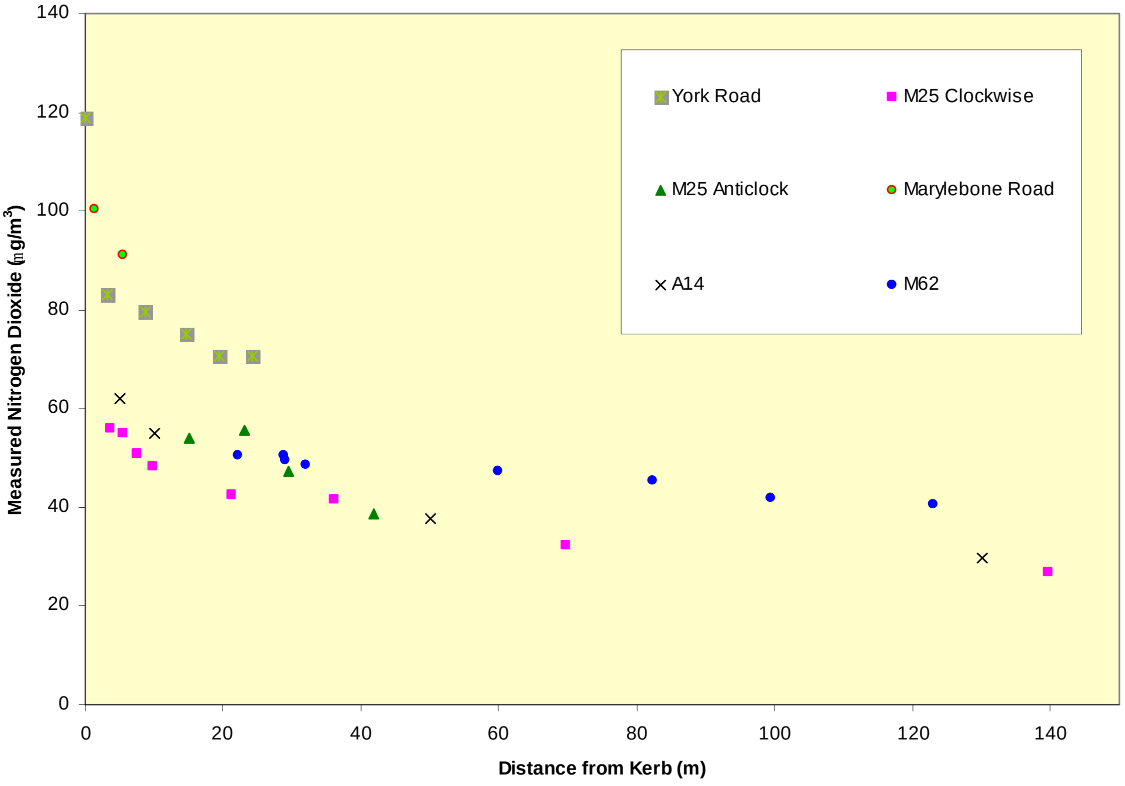


Figure 1 - Measured Data Used in this Analysis

Study-Specific Patterns

3.4 Several authors have recognised that the rate at which NO_2 concentrations decline with distance from roads can be described using logarithmic relationships (e.g. AQEG, 2004; Hickman *et al.;* 2003; Pleijel *et al*., 2004; Gilbert *et al*., 2005). Zou *et al*. (2006) fitted a shifted power law to measured gradients in Shanghai. All of the data shown in Figure 1 appear to adhere very strongly to a linear relationship with the natural logarithm of distance from the kerb, as shown by the fitted relationships in Figures 2A and 2B (these Figures are identical, except that Figure 2A is shown with a linear distance scale on the horizontal axis, while Figure 2B uses a logarithmic scale). The reason for this approach is that each scale brings out different features of the data. Table 2 sets out each logarithmic relationship and its coefficient of determination (R^2) value. Most of the R^2 values are greater than 0.9, and half of them greater than 0.98; indicating a very good agreement between the measurements and each study-specific relationship.

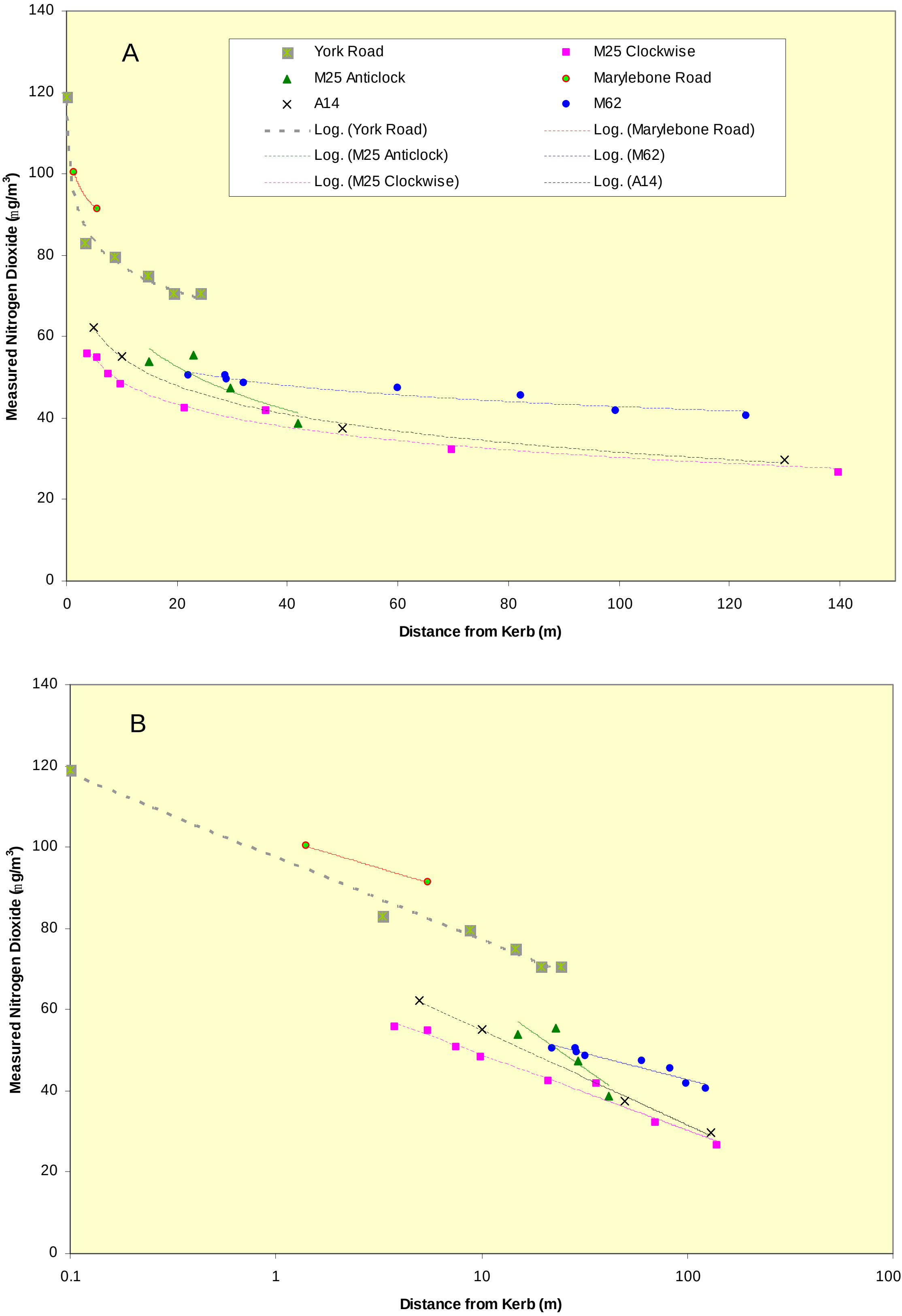


Figure 2 - Log-linear Relationships Fitted to Measured NO$_2$ Concentrations at Increasing Distances from Roads: A - on a linear distance scale and B - on a natural-logarithmic distance scale

Table 2: Logarithmic Relationships Fitted to Each Dataset in Figures 2A and 2B

Study	Study-Specific best-fit relationship [a]	Coefficient of determination (R^2) [b]
Marylebone Road	y = -6.5711Ln(x) + 102.45	na [c]
York Road	y = -8.8353Ln(x) + 97.517	0.987
M25 Clockwise	y = -8.0726Ln(x) + 67.536	0.9811
M25 Anticlockwise	y = -15.361Ln(x) + 98.657	0.7624
A14	y = -10.117Ln(x) + 78.229	0.9974
M62	y = -5.664Ln(x) + 68.888	0.9089

[a] Where y is the total measured NO_2 concentration (µg/m^3) and x is the distance from the kerb (m).
[b] R^2 is written in capitals since it describes a non-linear relationship. An R^2 close to 1 shows that the relationship comes very close to all of the points. An R^2 close to 0 shows that the best-fit curve fits the data no better than a horizontal line going through the mean of all y values.
[c] only two measurements were reported for this study.

3.5 Differences between the lines plotted in Figures 2A and 2B are inevitable since each dataset relates to a different setting. Furthermore, since all of the studies included here have focused either on a large motorway-like roads or on main roads in Central London, it is possible that a greater variation in patterns would occur if the analysis had included a larger range of sites. All other things being equal (e.g. ignoring the influence of site-specific meteorology), one would expect the angle of slope in Figure 2B to be steepest for studies with large traffic flows and low background concentrations (e.g. a rural motorway) and shallowest for studies with lower traffic flows and higher background concentrations (e.g. a small urban road). This is simply because the difference between the kerbside concentration and the background concentration is greatest in the former example and thus concentrations have further to fall to reach background levels. This trend is followed to some extent, with the steepest slope shown for the M25 and the A14, but other issues, such as local meteorology, are clearly having an influence on the lines plotted in Figures 2A and 2B.

Overall Trends in the Measurements

Data Manipulation

3.6 In order to directly compare the results from different studies, Hickman *et al.* (2003) and AQEG (2004) have presented measured concentrations as a percentage of the concentration measured at 20m from the edge of the road. This “normalisation” allows the relative reduction in concentrations to be plotted without specific reference to the actual measurements. It has the advantage that it can allow different datasets to be compared directly. The main disadvantages are that:

a) in order to compare two studies, both must measure at the same distances from their road; and

b) normalising to the concentration at 20m will adjust, in part, for the effect of the background conditions and, in part, for the effect of the road setting and traffic flows. This makes the analysis sensitive to the arbitrary choice of normalising distance and also limits the degree to which two different types of site can be compared[1].

3.7 A derivation of this approach is described below which has allowed four of the six studies to be compared directly. These are the M25 Clockwise; the M25 Anticlockwise; the A14 and the M62. The approach requires measurements to be made at large distances from the road and thus the Marylebone Road and York Road studies have been excluded. These two studies are, however, used to test the observed patterns (see "*Testing the Fitted Relationship*", below).

3.8 In order to overcome issue a) the relationships presented in Table 2 have been used to interpolate (it is important to note that these relationships have not been extrapolated) between the measured data. A distance of 23m has been chosen for the normalisation. This distance was chosen since it is the closest distance to the road that applies to all four studies[2]. Concentrations at 23m from the kerb of each road have thus been estimated following Equation 1 - with the specific relationships for each road given in Table 2. Figures 2A and 2B show that interpolating study-specific concentrations at 23m is unlikely to introduce significant error, since each line fits the measurements around this distance very well.

Equation 1: concentration 23m from the M62 = $-5.664 \times \ln 23 + 68.888$ [a]

[a] The concentration 23m from each other road (except York Road and Marylebone Road) is given by substituting the relevant relationship given in Table 2.

3.9 In order to overcome issue b), this current analysis has divided each measurement into two components: the background, and the road-increment. It is assumed that the background, which is not driven by the road emissions, will remain constant across each transect. The difference between the background level and the total measured concentration is the road-increment (Equation 2).

Equation 2: road-increment = total measured concentration - background level

---

[1] For example, the concentration 20m from road A might be mainly driven by the road emissions, while the concentration 20m from road B might be mainly driven by the background levels. If the concentrations were normalised to a different distance, the way in which the two slopes compare with each other would change.

[2] The point closest to the road was chosen since it represents the point where the influence of the road will be greatest.

3.10 It is not considered appropriate to use annual mean background levels to compare with any of the short-term measured datasets[3]. However, it is usually acknowledged that beyond 50m from the road, concentrations approach background levels. Thus, at 100m or more from the road, the difference between the total concentration and the background concentration should be as close to zero as will make virtually no difference. Figure 2A supports this conclusion, showing that while measured concentrations do tend to decline between 50m and 140m from the kerb, these reductions are extremely small[4]. Thus, the background concentration for the M62 survey is assumed to be the concentration measured 123m from the kerb; the background concentration for the A14 survey is taken as that measured 130m from the kerb; the concentration measured 140m from the clockwise edge of the M25 is taken to represent both M25 datasets (since they were collected in the same area, and at largely the same time and since the anticlockwise M25 dataset only extends 42m from the motorway).

3.11 Each measured road-increment has been normalised to the study-specific road-increment 23m from the kerb (Equation 3). In other words, each measured road-increment is presented as a fraction of the road-increment 23m from the same road, as derived from equation 1 with the background subtracted. This value is described as the normalised road-increment, and takes account of both problems (a) and (b).

Equation 3: Normalised road-increment = measured road-increment / road-increment 23m from the kerb

Description of a Fitted Relationship

3.12 Figures 3A and 3B show the normalised road-increment at different distances from each road. As previously, the two figures are identical, except that Figure 3B uses a logarithmic distance scale. Both plots also show a log-linear relationship fitted to the four aggregated datasets. It must be stressed that this fitted relationship is largely driven by the way in which the data have been treated - so much so that its shape could almost have been predicted without the benefit of the measurements (i.e. it will intersect 1 at 23m; it will intersect zero at a distance defined by the locations of the monitors; and is likely to fit a log-linear relationship). Despite these caveats, it is clear that the measured observations fit the trend line extremely well. This close fit is **not** dictated by the way in which the data have been treated. The fit shows that when the effect of background levels and source strength (and to an extent, other factors such as meteorology) have been taken

---

[3] Data from the national background maps published at www.airquality.co.uk have thus not been used, even for the A14 study which was carried out over a full year.

[4] The same the same reductions appear greater in Figure 2B than in Figure 2A since distance is shown on a logarithmic scale, but it should be recognised that at this end of the logarithmic scale, the distance increments are very large and the lines clearly cannot be extrapolated down to zero.

into account, the rate at which NO_2 concentrations decline in each of these studies is very similar and clearly follows a log-linear pattern.

3.13 This suggests that within the range of these measurements, and at these specific types of sites (i.e. motorways or busy dual-carriageways in open settings), it might be possible to use measurements made at one distance from the road to predict the concentration at any other distance from the road. Equation 4 shows the empirically-derived function that might be used.

Equation 4: $C_z = ((C_y - C_b) / (-0.5476 \times Ln(D_y) + 2.7171)) \times (-0.5476 * Ln(D_z) + 2.7171) + C_b$

Where:
C_y is the total measured concentration (µg/m^3) at distance $D_{y;}$
D_y is the distance from the kerb at which concentrations were measured;
C_z is the total predicted concentration (µg/m^3) at distance D_z
D_z is the distance from the kerb (m) at which concentrations are to be predicted;
C_b is the background concentration (µg/m^3); and
Ln(D) is the natural log of the number D

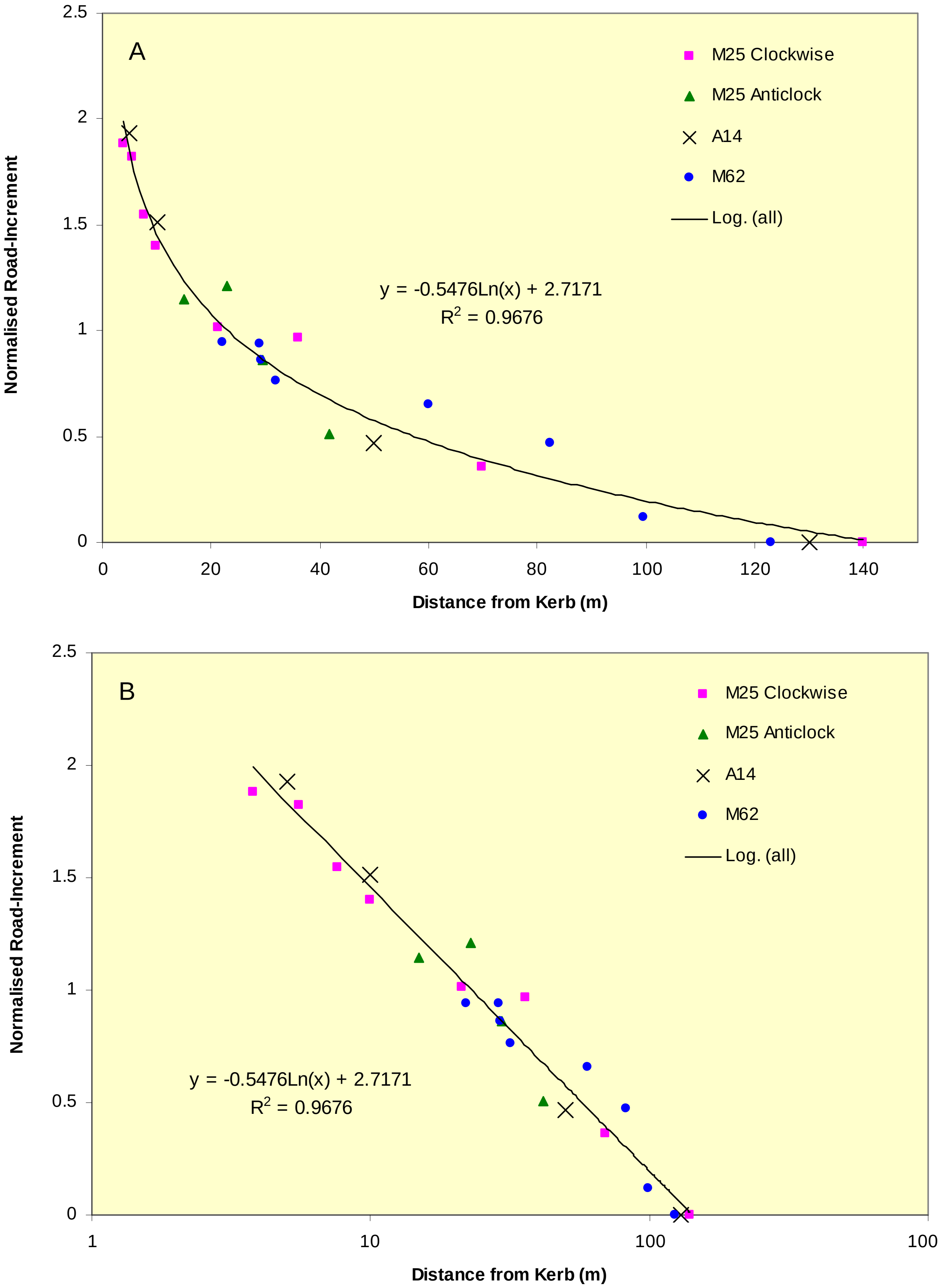


Figure 3 - Normalised Road-Increment at Increasing Distance from Four Roads: A - on a linear distance scale and B - on a logarithmic distance scale

Testing the Fitted Relationship

3.14 The relationship shown in Figures 3A and 3B, and described in Equation 4, fits the observations at the four open motorway-like sites very well over the range 4m to 140m from the kerb. Both the York Road and Marylebone Road studies describe busy urban canyon-like roads. Furthermore, both studies contained measurements less than 4m from the kerb. It is thus interesting to test the performance of Equation 4 in predicting concentrations in these locations (i.e. using one measured datum, along with Equation 4, to predict each other measured datum). It should be stressed that these are independent datasets - in that they were not used to derive Equation 4.

3.15 This testing is complicated by the need to define the background concentrations during each of the London monitoring periods. In each case, predictions of annual mean background concentrations are available, but these will not accurately reflect either of the short-term monitoring periods. For Marylebone Road, the background concentration is taken as the approximate study-period average of measured concentrations at five nearby urban background locations (57 µg/m^3)[5]. Concurrent data for the 1985 York Road study are not available. For the purpose of this current exercise, the logarithmic relationship for York Road shown in Figures 2A and 2B and given in Table 2 has been extrapolated to predict the concentration 150m from the kerb (52 µg/m^3). While this is clearly not a robust way in which to define local background levels, it allows the data to be compared with those from the other studies and is unlikely to introduce significant error given the number of different sites included for this study[6].

3.16 Figure 4 shows the measured concentrations for both York Road and Marylebone Road alongside predictions made using each measured datum and Equation 4 (Figure 4 is shown only on a linear scale since a logarithmic scale does not assist interpretation of these data). Since York Road contained five different monitoring sites, there are five different predictions for each distance. Marylebone Road only contained two monitoring sites and so only one prediction is given for each distance (i.e. one prediction has been made from each measurement). Figure 5 shows the same data in a different way, plotting measurements along the horizontal axis and predictions along the vertical axis. In Figure 5 a perfect fit would be shown by data-points lying directly on the 1:1 line. The York Road predictions fit the measurements very well. It is particularly interesting to note that the relationship given in Equation 4 fits the York Road measurements even up to 10cm from the kerb, suggesting not only that Equation 4 can describe urban as well as open settings, but also that it can be extrapolated down to just 10cm from the kerb.

---

[5] The sites used were Kensington and Chelsea 1, West London AURN, City of London 1 - Senator House; Westminster AURN; and Islington 1. All data downloaded from the London Air Quality Network website. The average of these sites for the period 1 Jan 2003 to 1 Mar 2003 was 57 µg/m^3. Even though this does not match the precise dates of the Marylebone Road study, the value is considered fit for purpose.

[6] How well two measurements will fit the predictions of Equation 4 is fairly sensitive to the choice of background, but this sensitivity reduces with the addition of extra sites.

3.17 The fit between measurements and predictions at Marylebone Road is also reasonable. However, with only two data points the test cannot be as robust.

Conclusions Regarding Measured Data

3.18 All of the measured data presented appear to follow a very similar pattern in terms of the relative rate at which road-incremental NO$_2$ concentrations reduce with increasing distance from the road. The logarithmic relationship set out in Equation 4 appears to perform well in open and enclosed settings and across a variety of different roads. It also appears to perform well at distances between 10cm and 140m from the kerb. Figure 6 shows the normalised road-increment concentrations for all six monitoring studies, alongside the relationship identified above. Figure 7 shows all of the total measured concentrations alongside the line derived by applying Equation 4 to a single datum from each dataset (in all cases, the maximum measured value - i.e. closest to the kerb - was chosen for this comparison. Both of these plots highlight the very close agreement of this approach with the results of all six measurement studies.

3.19 These results demonstrate that Equation 4 can be applied in a wide range of settings.

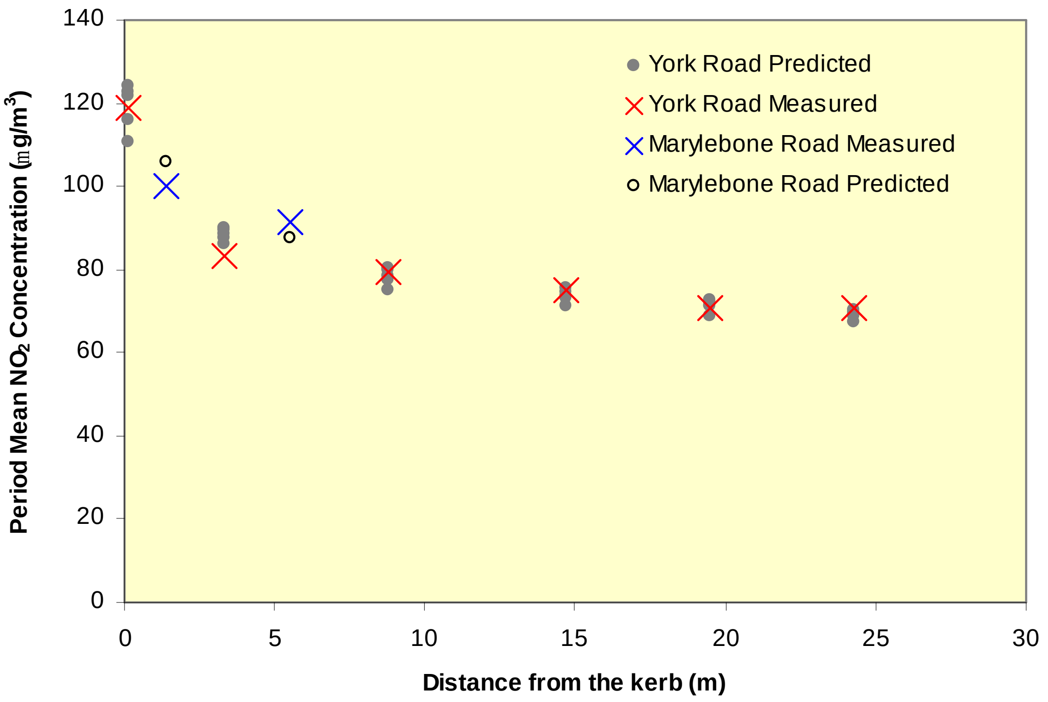


Figure 4 - Measured and Predicted Period-Mean NO$_2$ Concentrations at Different Distances from Two Roads

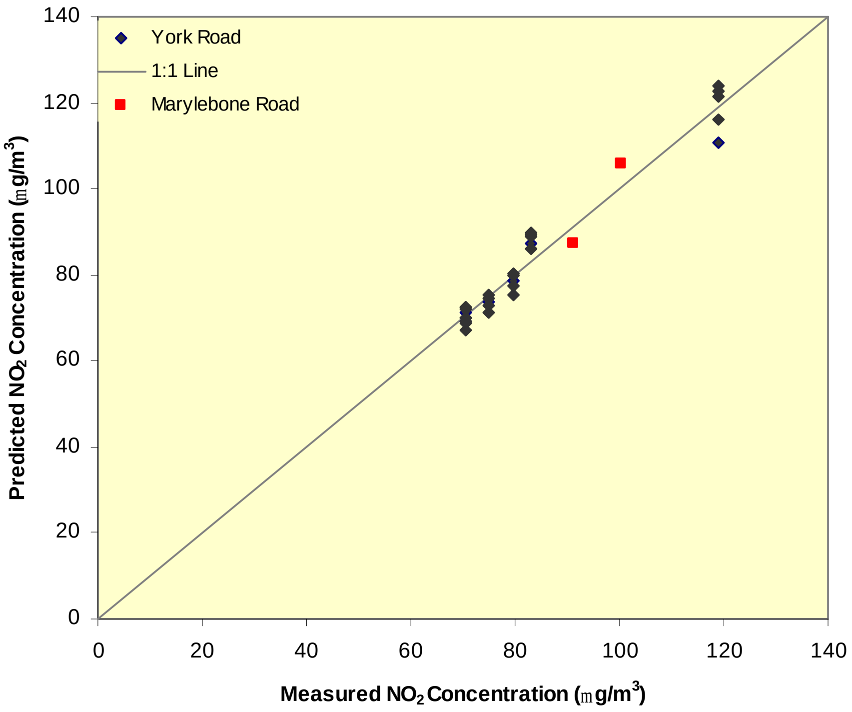


Figure 5 - Measured vs Predicted Period-Mean NO_2 Concentrations near to Two Roads

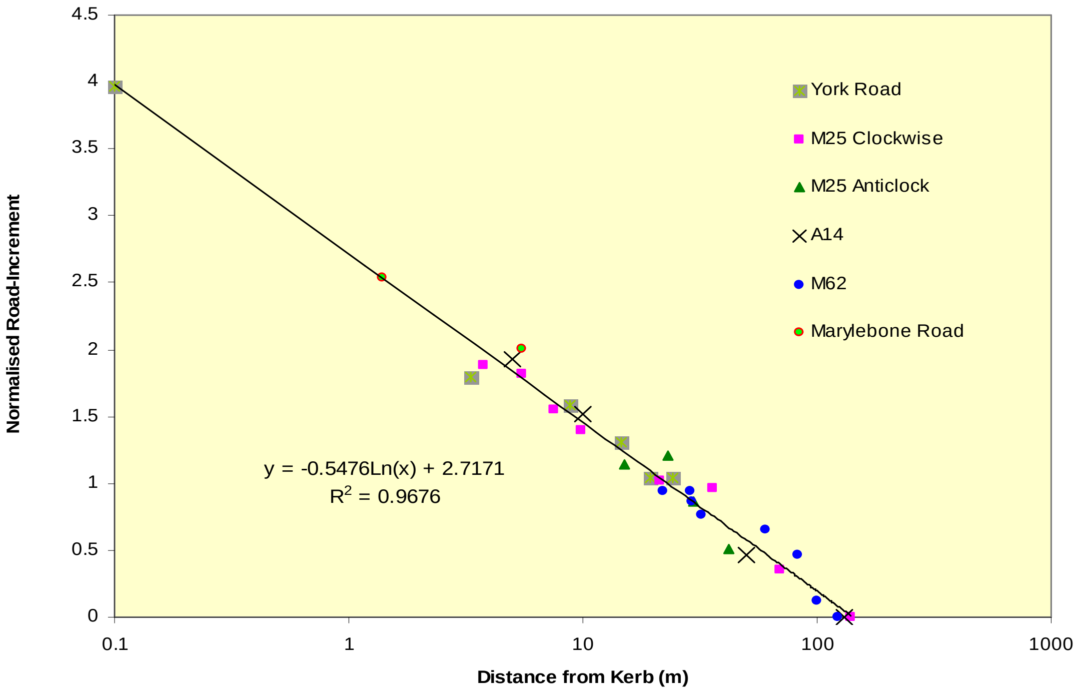


Figure 6 - Normalised Road-Increment at Increasing Distance from Six Roads on a logarithmic distance scale.

.

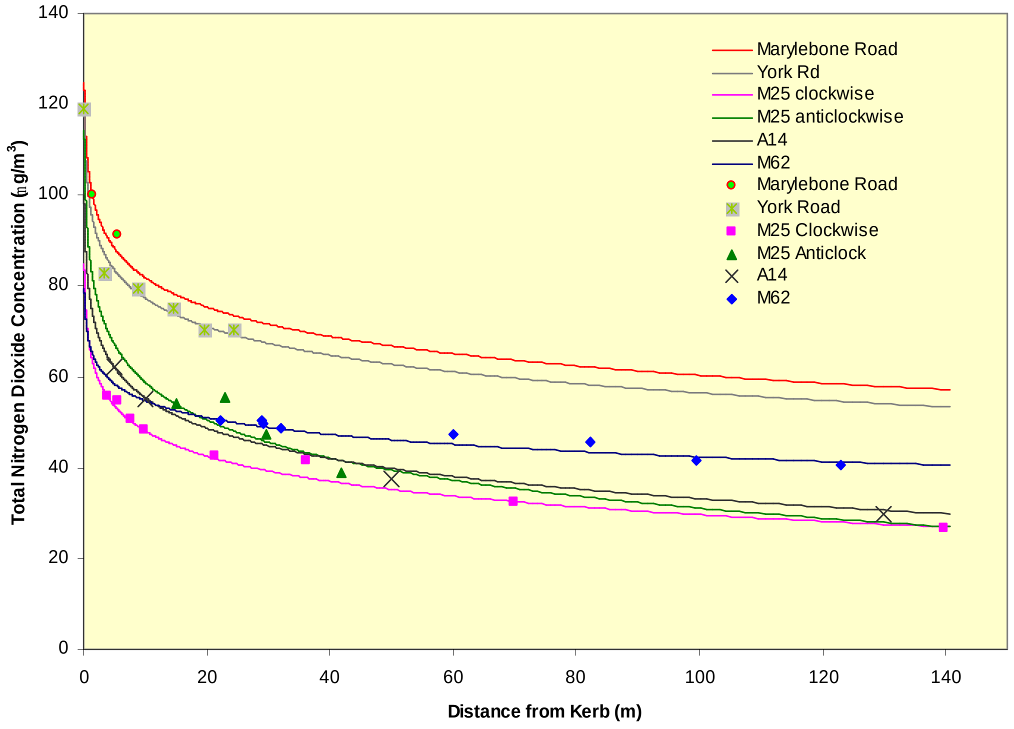


Figure 7 - Measured Data Used in this Analysis, Alongside the Range of Concentrations Predicted by Applying Equation 4 to the Maximum (i.e. closest to the road) Measurement from Each Study.

4 Modelled Data

4.1 Several modelling methods are commonly used to predict concentrations of NO_2 near to roads in the UK. The most common are probably the Design Manual for Roads and Bridges (DMRB) screening model, and the more sophisticated dispersion models ADMS-Roads, and Caline-CAL3QHC within the Breeze Roads package and Caline-4 within the AAQuIRE package.

4.2 In the case of the DMRB screening model, which only requires limited site-specific input data, the rate at which predicted concentrations reduce with increasing distance from the road (assuming only one road is entered into the model) is defined entirely by the relative magnitude of the source emission and the background concentration. As explained in paragraph 2.5, where the background makes up a large proportion of the total kerbside concentration (e.g. beside a minor road within a city), the decline with distance will be slight (i.e. concentrations do not have to fall far before they reach background levels). Where the background concentrations make up only a small proportion of the kerbside concentration (e.g. beside a rural motorway), the decline with distance will be more pronounced (i.e. concentrations have further to fall before they reach background levels). In the case of the dispersion models, results will also take account of site-specific factors such as meteorology.

4.3 Three models, DMRB, ADMS-Roads and Caline-4 have been run to predict **annual mean** NOx concentrations at a range of distances from different types of roads. The roads evaluated had nominal flows of 5,000 vehicles per day; 25,000 vehicles per day; and 120,000 vehicles per day. Each of these roads has been assessed in relation to three different background settings: a) background NOx = 4 $\mu g/m^3$, background NO_2 = 3 $\mu g/m^3$; b) background NOx = 52 $\mu g/m^3$, background NO_2 = 31 $\mu g/m^3$; and c) background NOx = 90 $\mu g/m^3$, background NO_2 = 48 $\mu g/m^3$. Most significant roads in the UK fall within these ranges. Road widths have not been varied. The roads were set to run due east-west with one transect of receptors running due north and another running due south. For the purposes of this current study, these broad-brush and nominal model input data are considered appropriate, since the sole intention is to define the range of relative concentration reduction rates. For the dispersion models, a nominal meteorological dataset has been used. Canyons have not been included and ADMS-Roads has been run without chemistry. NO_x concentrations have been used to predict NO_2 concentrations following the relationship advised (outside of Greater London) by Laxen *et al.* (2007).

4.4 Following the approach used to treat the monitoring results in Section 2, the road-increment concentration (i.e. total-NO_2 minus background-NO_2) has been normalised by the road-increment at 23m. Figures 8A and 8B set out the results for the various DMRB-modelled scenarios. The solid line depicts the relationship from equation 4, which represents the measurement data. Figures 8A and 8B suggest that the DMRB model agrees well with the measurements at distances greater than 10m from the kerb, but that it tends to under-predict very significantly nearer to the road.

4.5 Figures 9A and 9B present the normalised road-increment for the various Caline-4-modelled scenarios. The solid line depicts the relationship from equation 4, which represents the measurement data. In comparison with the measurements, the Caline-4 results over-predict significantly at large distances from the road and under-predict close to the road. It should, however, be noted that the point at which the measured road-increment reaches zero was not defined directly from the measurements. Thus, while Caline-4 may indeed over-predict the influence of roads at large distances, there is a lack of direct evidence with which to support this conclusion.

4.6 Figures 10A and 10B present the normalised road-increment for the various ADMS-modelled scenarios. The solid line depicts the relationship from equation 4, which represents the measurement data. Between 20m and 100m, the model results fit well with the measurement-derived trend line. The range of different model scenarios gives a large spread of results at smaller distances. At the kerbside, this spread appears to fit very well with the observations. Between the kerb and 20m, the normalised road-increment as predicted by ADMS-Roads traces a distinct and detailed pattern, tending to over-predict in relation to the measurement-derived trend-line. This pattern probably relates to the simulation of an initial turbulent dispersion immediately adjacent to the road. ADMS-Roads thus predicts a steeper slope than the measurement-derived trend line between 20m and 5m from the kerb, and a shallower than observed slope between 5m and the kerb.

Conclusions for the Modelled Data

4.7 Of the three models, ADMS-Roads appears to describe the rate at which NO_2 concentrations reduce with increasing distance from the road better than either the DMRB screening model or Caline-4. The DMRB, in particular, appears to significantly under-predict the rate at which measured concentrations reduce close to the road. The Caline-4 model comes slightly closer to predicting the measured rate of concentration reduction near to roads, although still under-predicting the decline with distance. However it seems to under-predict the rate at which concentrations reduce at distances greater than 20m. The predictions made using ADMS-Roads provide a better representation, although this model shows a smaller initial decline out to 5m then a larger decline from 5 to 20m than the trend derived from the measurements.

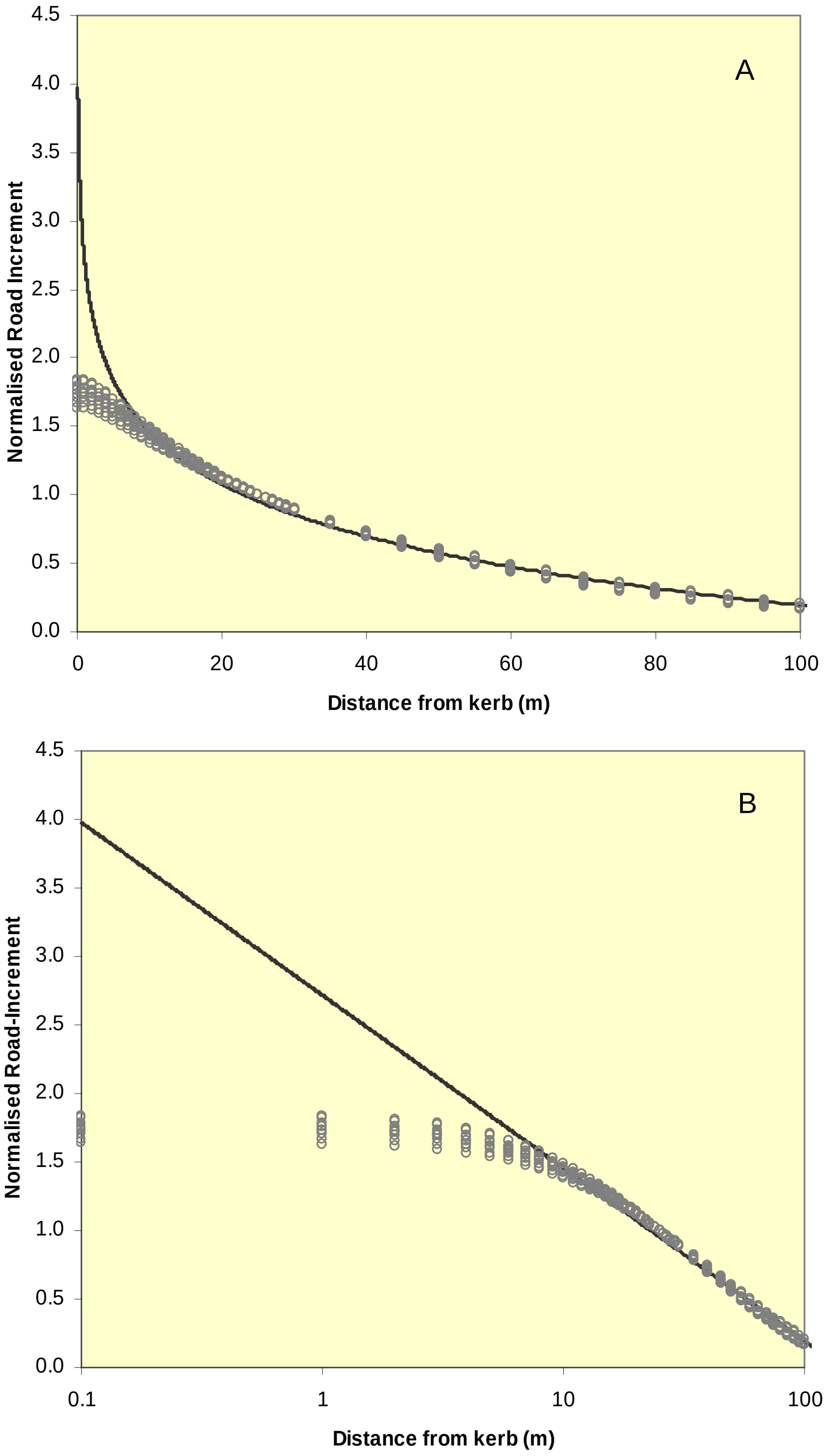


Figure 8 - DMRB-modelled Normalised Road-Increment at Increasing Distance from Hypothetical Roads: A - on a linear distance scale and B - on a logarithmic distance scale

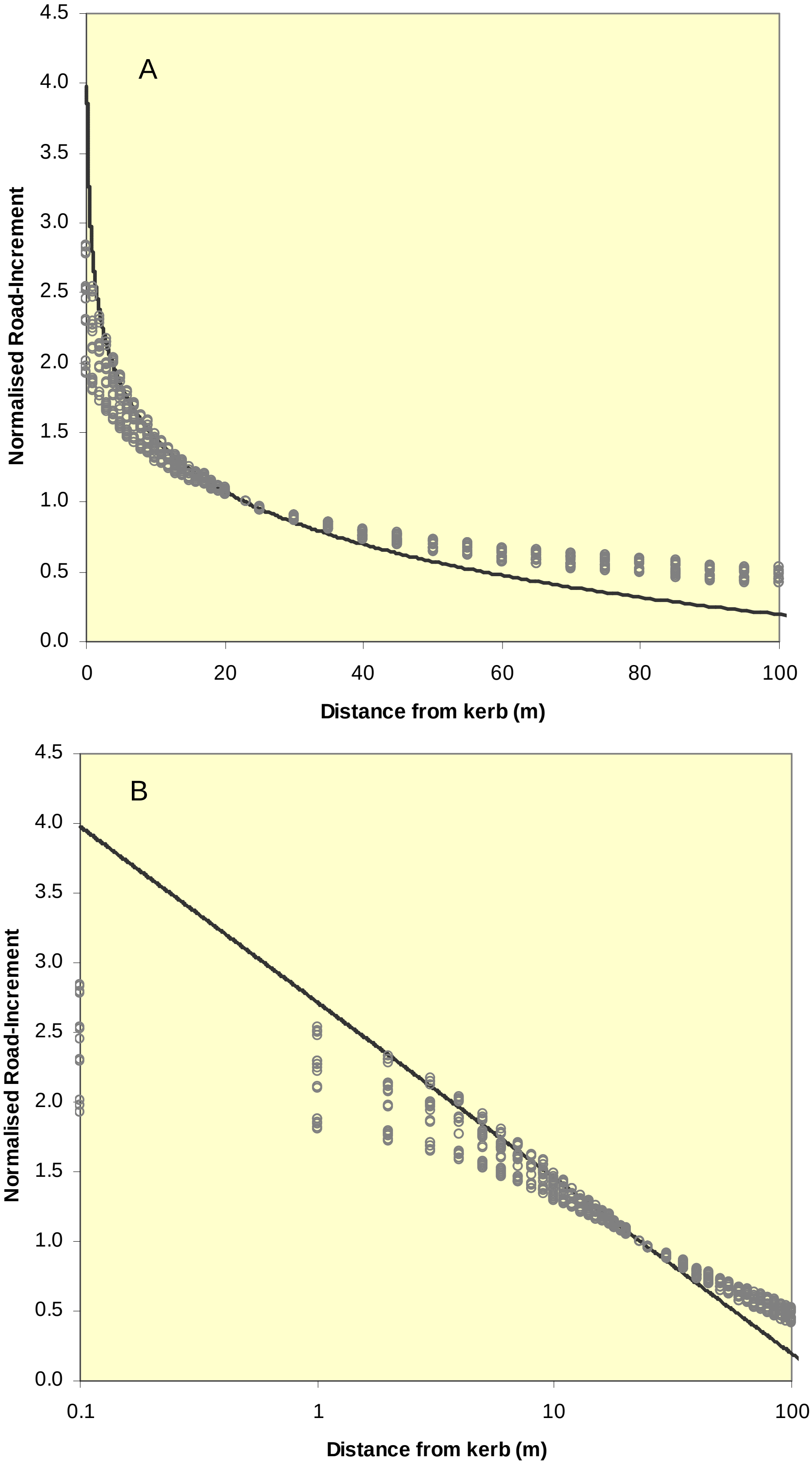


Figure 9 - Caline-modelled Normalised Road-Increment at Increasing Distance from Hypothetical Roads: A - on a linear distance scale and B - on a logarithmic distance scale

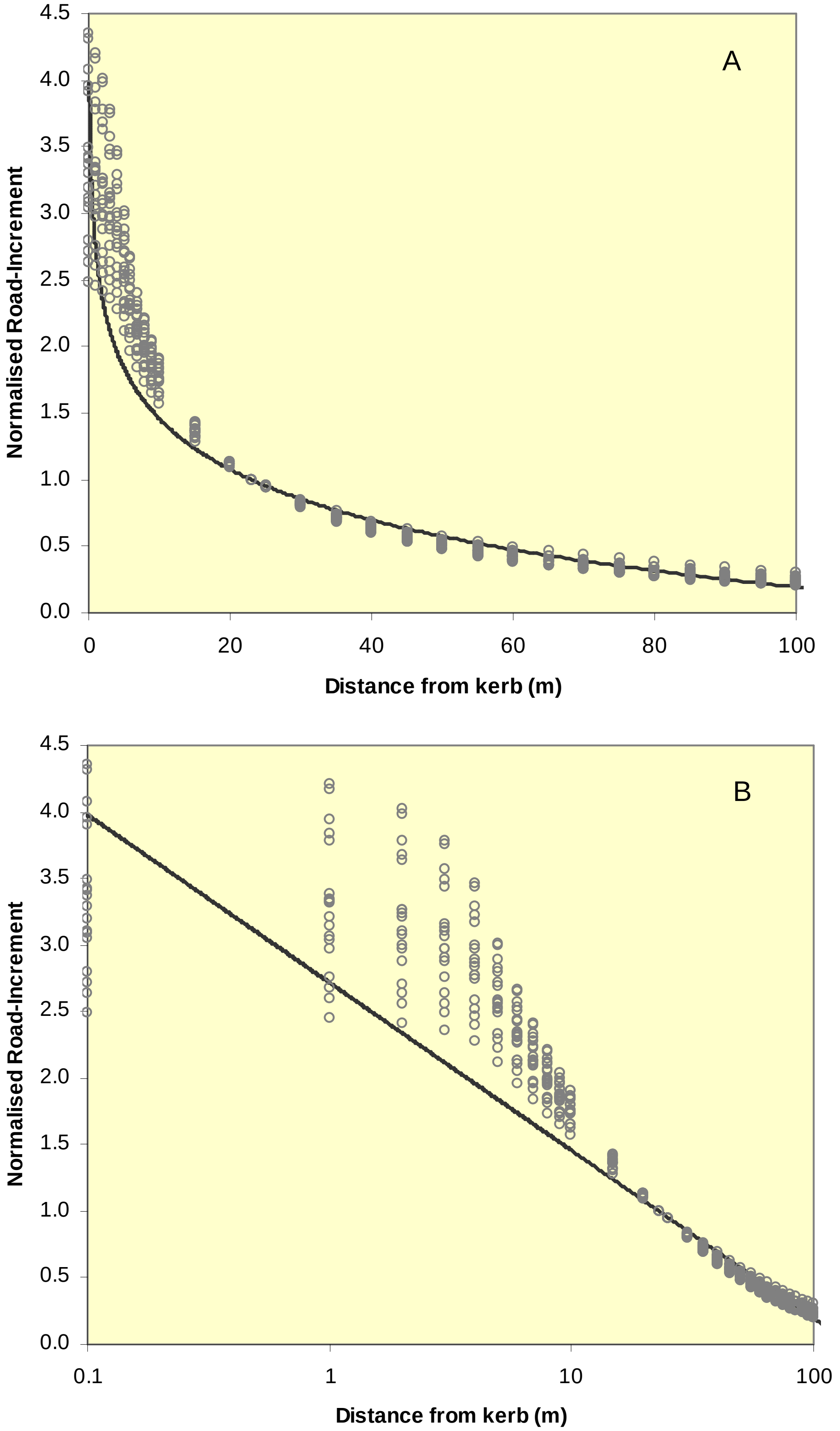


Figure 10 - ADMS-modelled Normalised Road-Increment at Increasing Distance from Hypothetical Roads: A - on a linear distance scale and B - on a logarithmic distance scale

5 Review and Assessment Advice

5.1 A Frequently Asked Question (FAQ) on the Review and Assessment Helpdesk Website[7] asks:

"*Measurements of* NO_2 *have been made over the last few years at the kerbside using diffusion tubes. Is there any way the results can be used to assess concentrations at the facade of nearby residential properties, to allow comparison with the annual mean objective*?"

The answer given is as follows:

"Yes. Concentrations will be slightly lower at the building facade. The limited information that is available would suggest that the following adjustments can be applied to the kerbside results to estimate roadside values:

Distance from kerb Multiply Kerbside Result by

2-5 m 0.95
5-10 m 0.90
10-20 m 0.75

These adjustments are still conservative in nature, but are appropriate for an Updating and Screening Assessment and may be useful in a Detailed Assessment".

5.2 This approach is thus to adjust the whole measured concentration and not just the road-increment. Thus, if the background makes up more than 75% of the total measured kerbside concentration (which would only occur alongside relatively minor roads), the adjustment could potentially take the total concentration below the background level. Because the plots presented previously only show the road-increment of concentration, while the FAQ approach adjusts the whole concentration, it is not straightforward to compare them directly on the same scales. The simplest way to compare the two approaches is to present the lines given in Figure 7, above, (i.e. the predicted decline with distance according to Equation 4 in each of the measurement studies) as a fraction of the predicted kerbside concentration. For the purpose of this comparison, the kerbside concentration is assumed to be 0.1m from the kerb.

5.3 Figure 11 compares the range of results given by Equation 4 with the factors given in the FAQ. The FAQ clearly under-predicts the rate at which concentrations reduce with distance; particularly

---

[7] www.uwe.ac.uk/review

in the first few metres. This will make the FAQ predictions conservative so long as the direction of the calculation is not reversed (i.e. so long as measurements made at large distance from the kerb are not used to predict kerbside concentrations).

5.4 Another approach often suggested by the Review and Assessment Helpdesk is to use the DMRB screening model to predict concentrations: first at the distance from the kerb at which concentrations were measured, and then at the distance at which concentrations are to be predicted. The measurement can then be adjusted following the relationship between the two model results. As has been shown in Figure 8, the DMRB model is not the ideal tool for this purpose.

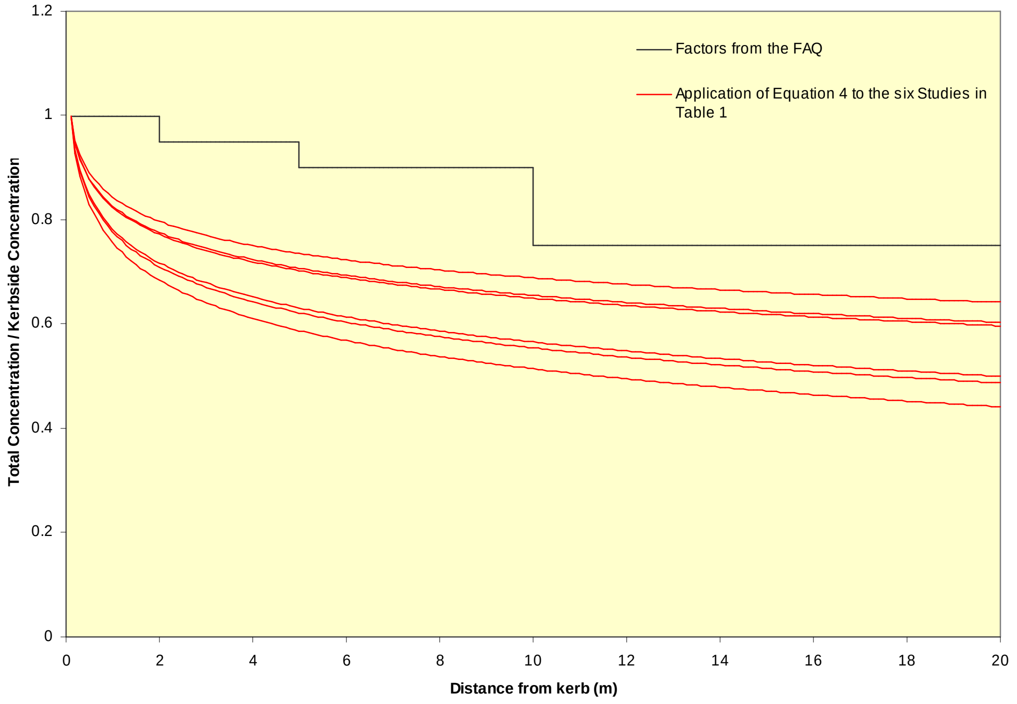


Figure 11 - Adjustment Factors Presented in the FAQ on the Review and Assessment Helpdesk Website, and Some Comparative Predictions made using the Measurement-Derived Relationship set out in Equation 4

6 Conclusions

6.1 The results from six different studies that have measured NO_2 concentrations at different distances from UK roads have been analysed. The studies relate to both open motorway-like settings and busy urban canyons. Once the most significant local factors are taken into account, the results from all six studies tend to follow a very similar pattern. The decline of NO_2 concentrations is essentially linear on a log-linear scale between 10cm from the kerb and 140m from the kerb.

6.2 Predictions made using the DMRB screening model, the Caline-4 model (within the AAQuIRE package), and ADMS-Roads have been compared with the measured relationship (see equation 4). The DMRB model predicts a significantly reduced rate of decline on moving away from a road. Similarly, Caline-4 appears to significantly under-predict the measured reduction with distance from the kerb. Of the three models, ADMS-Roads (run to predict NOx, which was subsequently used to derive NO_2 using the empirically derived relationship published by Defra (2007)) provided the most reasonable match to the measurement-derived patterns, although there were still departures within 20 m of the kerb.

6.3 For Review and Assessment purposes, local authorities occasionally use measurements made at one distance from a road to predict concentrations at a different distance from the same road. To do this, they are currently advised to use factors published on the Review and Assessment Helpdesk website, or alternatively, to derive a factor using the DMRB screening model. This analysis suggests that both of these approaches will tend to under-predict the rate at which concentrations reduce with distance from the road. Thus, if kerbside measurements are used to predict concentrations further from the road, they will be over-estimated. If, however, measurements made away from the road are used to predict kerbside values, they will be under-estimated. The approach set out in Box 1 is likely to provide a more accurate estimate of concentrations at different distances from a road.

6.4 The measurements on which this analysis is based are limited and it would be worthwhile to test these conclusions against additional monitoring data.

Box 1: An Empirical Approach to Predicting NO_2 Concentrations at Different Distances from Roads

This method allows measurements made at one distance from a road to be used to predict concentrations at a different distance from the same road. It is appropriate for distances between 0.1m and 140m of the kerb.

Step 1: Identify the local background concentration in µg/m^3 (either from local monitoring or from the national maps published at www.airquality.co.uk). Note that the background concentration must be less than the measured concentration.

Step 2: apply the following calculation

$$C_z = ((C_y - C_b) / (-0.5476 \times \mathrm{Ln}(D_y) + 2.7171)) \times (-0.5476 * \mathrm{Ln}(D_z) + 2.7171) + C_b$$

Where:

C_z is the total predicted concentration (µg/m^3) at distance D_z;
C_y is the total measured concentration (µg/m^3) at distance D_y;
C_b is the background concentration (µg/m^3);
D_y is the distance from the kerb at which concentrations were measured;
D_z is the distance from the kerb (m) at which concentrations are to be predicted; and
Ln(D) is the natural log of the number D

Results derived in this way will have a greater uncertainty than the measured data. Further assistance with this procedure and interpretation of the results can be obtained from the Review and Assessment helpdesk (www.uwe.ac.uk/aqm/review).

7 References

AQEG (2004) Particulate Matter in the United Kingdom, Air Quality Expert Group, Defra, London.

Clamp, G E (2005) Nitrogen Dioxide Distribution in Urban Roadside Locations, MSc Dissertation, University of Derby.

Green, D & Fuller, G (2003). Marylebone Road Concentration Gradient Study – Preliminary NO2 Report. Environmental Research Group, King's College London.

Lansley, D & Seakins, P (2002) Chemistry and Dispersion of Pollutants from a Rural Motorway: Measurements and Modelling, in Air Pollution Modelling and Simulation, Ed. B Sportisse, Published by Springer, 2002

Laxen, D P H and Marner, B (2003), un-published results.

Laxen, D P H, Marner, B and Donovan, S (2007) Deriving NO2 from NOx for Air Quality Assessments of Roads – Updated to 2006, available at www.uwe.ac.uk/aqm/review/

Laxen, D P H and Noordally, E (1987) Nitrogen Dioxide Distribution in Street Canyons, Atmos. Environ., 21, (9), 1899-1903.

Hickman, A J, McCrae, I S, Cloke, J & Davies, G J (2002). Measurements of Roadside Air Pollution Dispersion. TRL Rept. PR/SE/445/02, TRL Ltd., Crowthorne.

Highways Agency (2006) A14 Ellington to Fen Ditton, Environmental Assessment Report Addendum.

Gilbert, N.L., Woodhouse, S., Stieb, D.M. and Brook, J.R. (2003) Ambient nitrogen dioxide and distance from a major highway, Sci Total Env, 312, (1-3), 43-46.

Pleijel, H., Karlsson, G. and Gerdin, E. (2004) On the logarithmic relationship between NO_2 concentration and the distance from a highroad. Sci. Total Env., 332, (1-3), 261-264

Zou, X, Shen, Z, Yuan, T, Yin, S, Cai, J, Chen, L & Wang, W (2006) Shifted power-law relationship between NO_2 concentration and the distance from a highway: A new dispersion model based on the wind profile model, Atmos. Environ., 40, (40) 8068-8073.