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The Design Manual Method For Road Pollution: Assessment Of Its Limitations And Range of Application

by

D.R. Middleton

Met O (APR)
(Atmospheric Processes Research)
Meteorological Office
London Road
Bracknell
Berks, RG12 2SZ

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The Design Manual Method For Road Pollution: Assessment Of Its Limitations And Range Of Application

D R Middleton
Atmospheric Processes Research
Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ

Abstract

Local air quality management (LAQM) as envisaged under the Environment Act 1995 indicates a need for simple and easy to use methods for the review of air quality. It is advisable to use, as far as their limitations will allow, existing and familiar procedures.The Transport and Road Research Laboratory (TRRL) model for air pollution is the basis of the method used by highway engineers. This method is described in Volume 11 of the Design Manual for Roads and Bridges (DMRB). The TRRL Model PREDCO and the DMRB model are based on work conducted in 1972, when scientists from TRRL measured the concentrations of lead near to the M4 motorway. The decay of 24 hour average lead concentrations with distance from the motorway was described by an exponential decay. This decay was matched to the decay expected using an analytical formula for the pollution from a continuous infinite crosswind line source. In this formula the wind was adjusted to a direction of 45°, although this appears to have used slightly inappropriate axes. The dispersion parameters were thereby derived from the measurements as functions of distance from the road. This work analyses the derivation of the TRRL model and the DMRB model and reveals significant limitations in their range of application when seeking to model the pollution at increasing distances from a road. For the purposes of LAQM, if large numbers of roads are to be modelled, we can anticipate that dispersion distances will be much greater than the range covered by the TRRL and DMRB dispersion parameters. For these applications, the TRRL model and DMRB model would appear to be unsuitable, at least whilst they rely on the dispersion parameters that are studied here and which were derived from the measurements taken during 1972 of lead near the M4. It is suggested in this study that at distances beyond 80 metres, other models with better dispersion parameters will be more appropriate for LAQM.

Introduction

This report is a re examination of the original work upon which TRRL based their method for estimating air pollution from roads. The Design Manual for Roads and Bridges contains a step by step guide to the calculation of likely changes in air pollutant concentrations near to a proposed road development. The Manual is quite specific in limiting assessment of the likely effects of a new road development to a region no more than 200 m distant from the planned road. The Manual contains graphs from which within this region the pollution contributions from the road can be assessed. The graphs extend only to maximum distance 200 m. The graphs are for a standard traffic flow of 1000 vehicles per hour and a standard traffic speed of 100 kilometres per hour. The Manual includes correction factors to allow for different traffic flows and speeds.

The Manual also has graphs and tabulated data from which trends in emission rates and likely future pollution impact can be estimated. The trends are derived using estimates of changes in the vehicle fleet, emissions controls on vehicles, and the proportion of vehicles likely to be fitted with catalytic converters. At present the emissions adjustments are given up to the year 2020 AD.

In the first tier review of air quality an important task is to identify where pollution levels are likely to be greatest. Calculations or modelling of pollution cannot take place until the emissions data have been assembled. Therefore in parallel with any monitoring studies that may be under consideration, the first task is to assemble traffic flow data. This requires discussions with the highway planners. Then the method in the Design Manual can be used to convert these traffic flow data into estimates of pollutant emissions from vehicles on the roads in the study area. Careful consideration of vehicle speeds and driving modes (e.g.acceleration, cruise or braking) will be required if meaningful emissions estimates are to be obtained. The emissions estimates in the Manual should be used for major roads. For minor roads where traffic flow data are much scarcer, the Technical Guidance on Emissions Inventories will summarise the procedures to be used. Emissions for minor roads in towns may be evaluated as area sources, whilst main roads can be treated as line sources; these 'line' sources may be straight, curves or roundabouts according to which dispersion model is being used.

The curves in the Design Manual for Roads and Bridges show the characteristic decrease in concentration with increase in distance from the road. They were derived from calculations using dispersion parameters that were developed at TRRL. In order to understand the limitations of these curves and to assess their relevance for LAQM, it is necessary to examine in detail the original research on which they were based. We begin with the measurements of lead particles taken near the M4 that are reported in TRRL report LR 626 by Bevan, Colwill and Hickman (1974). Then we turn to TRRL report LR 1052 by Hickman and Colwill (1982) who derive dispersion curves from the measurements of lead by the M4. In evaluating these curves and by attempting to reproduce the concentrations in the Design Manual curves we are then able to identify limitations in the Design Manual method and in the TRRL model.

Lead Measurements by the M4 Motorway

Measurements of lead particles taken near the M4 were reported in TRRL report LR 626 by Bevan, Colwill and Hickman (1974). The motorway runs East West between junctions 3 and 4 at the site near Harlington. The site is level and was only about one mile from the then London Airport Meteorological Office. Traffic counters were at first pneumatic, later electronic induction loops. Manual counts were used to estimate the proportion of petrol:diesel vehicles. There were approximately 70000 petrol engined vehicles passing the site per day.

In the early part of the study, particulate lead was collected on Millipore 0.8 μm pore size filters and the flow rate was corrected for the pressure drop across the filter. Later in the study, they used modified sequential smoke samplers. Whatman 4 paper was used as

a support to prevent tears. Whatman Glass Fibre GFA filter was laid on top to collect the lead. The double filter was wound on a spool and used in the sequential sampler. Flow rate was increased from 0.1 m^3 per hour to 1.3 m^3 per hour. This increased the sample collected, so shorter sampling periods down to 1 hour were achieved (at least near the road). The minimum sample size is set by the analytical procedure.

Materials collected on the filters were dissolved in 5% nitric acid with 0.2% of 30% (w/v) hydrogen peroxide added. These solutions were then analysed by Atomic Absorption Spectroscopy. In this technique the sample is volatilized and ionized in a very hot flame; any lead in the flame is then detected by shining a light of appropriate wavelength through the flame. It is a well proven and reliable method of analysing lead concentrations.

A sequential sampler placed in the central reservation of the M4 motorway collected sample for one hour, then halted the flow of sample air whilst it moved the paper on for the following period. At points located 30 m, 60 m, 90 m, 120 m from the edge of the road, samples were also taken, but these required periods of three hours to meet the needs of analysis. The main body of results, on which LR626, LR1052, and then the Design Manual all rely, were taken during the period 2 to 26 October 1972. The sampling and analyses were conducted with such care that the concentrations could be distinguished in wet and dry conditions: Figure 5 in LR626 reveals lower concentrations in wet conditions. The report does not distinguish whether the difference arises from the wet and spray conditions, changes in wind speed, or changes in driving speed. It is also a testament to the quality of the work that the results showed that lead concentrations closely followed the hourly traffic pattern. Traffic counts revealed that the traffic patterns were remarkably constant. This early work therefore establishes some basic premises for pollution modelling to meet the needs of LAQM, that traffic based pollutants are directly related to traffic flows, that their concentrations usually decrease quite quickly with distance from a road, and that it is reasonable to assume reproducible traffic patterns i.e. for LAQM, traffic need not be counted every day once the broad pattern is known.

At places 30 m up to 120 m perpendicular distances from the road, the sampling time was three hours. However when these samples were compared with those from the central reservation, no simple relationship was apparent. (We may speculate that this might be due to changes in meteorological conditions from one sample to the next.) Consequently the lead concentrations were averaged over 24 hour periods. The ratio of concentration at a perpendicular distance x from the road to that at the central reservation is a measure of the decrease in lead concentration with distance from the road. An exponential decay was fitted to these 24 hour average concentrations:

$$\frac{[Pb(x)]}{[Pb(c)]} = 0.964 \exp(-0.021x) \qquad (1)$$

where x m is perpendicular distance from the edge of the road, and the ratio is given in normalised form (the original report LR626 uses the ratio as a percentage). Here c denotes the position is at the centre reservation and the concentration value was taken at the same time as the more distant sample at x.

This equation is very important to the subsequent development. It is an empirical curve that summarises the decrease in 24 hour average particulate lead concentrations with distance from the edge of the motorway. It is the basis of the TRRL model and the subsequent Design Manual Curves (at least up to the 1994 version of DMRB Volume 11 as far as the present author can establish). It is used to provide dispersion parameters for the dispersion of gases such as carbon monoxide, total oxides of nitrogen, or total (non-methane) hydrocarbons, even though it is based on measurements of lead particles only as far as 120 m from the source for a limited study period of a few weeks. Before describing the derivation of these important dispersion parameters we first summarise some useful formulae.

Line Source Formulae

Turner (1969) in his classic workbook gives the formula for the concentration at a point (x, y, z); for a perpendicular wind, x is distance from the road. The formula assumes the source is emitting pollution continuously at a steady rate. It assumes the source is a straight line, infinitely long. The wind direction is assumed to be at right angles to the road axis. The formula is derived by integrating the point source formula in the cross wind direction y, i.e.along the road. The receptor is on the ground, and is located at the point (x,y,0;H): in this notation the fourth parameter H is the height of the road. Then

$$c(x,y,0;H) = \frac{2Q_L}{\sqrt{2\pi}u\sigma_z}\exp\left[-\frac{H^2}{2\sigma_z^2}\right] \qquad (2)$$

where Q_L is the line source emission rate (mass per unit length per unit time). The horizontal dispersion parameter σ_y does not appear because it vanishes when integrating in the y direction.

Turner (1969) also gives a formula for when the wind is not perpendicular to the road axis, but makes an angle ϕ with it. Then we have

$$c(x,y,0;H) = \frac{2Q_L}{\sin\phi\sqrt{2\pi}u\sigma_z}\exp\left[-\frac{H^2}{2\sigma_z^2}\right] \qquad (3)$$

This formula of Turner for an oblique wind is essentially the same as Calder's formula that we now discuss. Note that Turner's axes imply that x is taken in the downwind direction so for an oblique wind, x is here no longer the perpendicular distance from the road.

Calder (1973) examines the same problem of pollution from a line source, but prefers to use the more natural angle θ which is between the wind and the **normal** to the road. Then in Turner's notation, we have $\theta = \pi / 2 - \phi$ and so Calder's formula is written in cosines rather than sines. Calder defines his formula very precisely by stating explicitly the distance at which σ_y is evaluated. It is the distance along the wind, $x / \cos\theta$, where now we can use the convention that x here is **perpendicular** distance from the road.

$$c(\frac{x}{\cos\theta}, y, 0; H) = \frac{2Q_L}{\cos\theta\sqrt{2\pi}u\sigma_z(\frac{x}{\cos\theta})}\exp\left[-\frac{H^2}{2\sigma_z^2(\frac{x}{\cos\theta})}\right] \qquad (4)$$

Calder explores the implications of neglecting to check whether the distance at which σ_x is evaluated is along the wind, or is perpendicular distance to the road. For wind directions up to 30° with the road axis, errors in using the perpendicular distance (erroneous) rather than the down wind distance (correct) can be neglected. For angles of 45° and beyond the errors get larger.

In report LR1052, Hickman and Colwill (1982) state Turner's formula for the case of an oblique wind; with receptor and road on the ground, z = 0 and H = 0, the exponential term in equation (3) becomes unity and:

$$c(x, y, 0; 0) = \frac{2Q_L}{\sin\phi\sqrt{2\pi}u\sigma_z} \qquad (5)$$

For simultaneous measurements of concentratations c_x and c_0 at two distances x and x_0 respectively, both taken here as **perpendicular** distances from the road, they obtained the ratio:

$$\frac{c_x}{c_0} = \frac{\sigma_z(x_0)}{\sigma_z(x)} \qquad (6)$$

However if we use Calder's explicit form equation (4), this ratio should be in a form expressed using the **down wind** distances $x / \cos\theta$, $x_0 / \cos\theta$, which gives:

$$\frac{c_x}{c_0} = \frac{\sigma_z(\frac{x_0}{\cos\theta})}{\sigma_z(\frac{x}{\cos\theta})} \qquad (7)$$

Hickman and Colwill (1982) are therefore using the inappropriate axes identified by Calder (1973). However his work suggests the error arising in this ratio will be **small.**

Vertical Dispersion Parameter from Measured Decay of Lead

From the M4 data taken at Harlington by Bevan, Colwill and Hogbin (1974) in LR626, the 24 hour averages of lead particulate concentrations c had an exponential decay:

$$\frac{c_x}{c_c} = 0.964\exp(-0.021x) \qquad (8)$$

which is equation (1) but in a notation similar to equations (6, 7). Here subscript x represents experimentally determined perpendicular distance from the road of each sampler position and subscript c denotes the centre reservation.

Curve fitting was then used by Hickman and Colwill (1982) in LR1052 to find a function that described the growth in vertical dispersion parameter **with distance along the wind** such that when substituted in the line source formula equation (5) for an oblique wind at 45°, it would enable the line source formula to match the measured exponential decay in 24 hour average lead concentrations with perpendicular distance from the road. In other words, the aim was to find a function for $\sigma_z(x)$ so that equation (5) could describe the measured decay of the exponential equation (1) . Since $\sigma_z(x)$ has to be defined using the downwind distance, a quantity D was defined to allow for the angle ϕ =45° and that the edge of the road was 10 m from the centre reservation (where x = 0). Define

$$D = \frac{x + 10.0}{\sin\phi} \qquad (9)$$

The equation for $\sigma_z(x)$, (which when substituted in (5) follows (8)), derived by curve-fit is thus:

$$\sigma_z(x) = \sigma_z(x_0)\{1.0 + \exp[0.39\ln^3 D - 4.76\ln^2 D + 20.95\ln D - 32.67]\} \qquad (10)$$

where the quantity D takes account of the centre to edge distance and an oblique wind at 45°. It is only possible to calculate $\sigma_z(x)$ at x m perpendicular distance from the edge of the road once the central value $\sigma_z(x_0)$ has been found.

Since this curve fit is the basis of so much subsequent work, the present author has checked the calculations to confirm that the curve fit does reproduce the exponential function (8). Let

$$F = \frac{c_x}{c_0} - 1.0 \qquad (11)$$

In Table 1, the bottom two rows have very similar values for ln(F). They show that equation (5) with $\sigma_z(x)$ is a good fit to equation (8), the normalised form of equation (1). The line source formula with the TRRL function for $\sigma_z(x)$ is good at describing the measurements of lead as summarised by the empirical exponential formula.

Vertical Dispersion Parameter at the Road where x=0

We have now established that the experimentally observed decrease in concentration with perpendicular distance from the road has been very well described by the function obtained by Hickman and Colwill (1982) for $\sigma_z(x)$. The method is to first calculate D, then find $\sigma_z(x)$ using equation (10), and substitute $\sigma_z(x)$ into equation (5). To obtain the magnitude of the concentration in this way it is however necessary to specify the initial or centre reservation value for $\sigma_z(x_0)$. Their approach is now described.

We first remark that in the preceding analysis the curve fit was using (c_o / c_x)-1, and this means common factors like Q_L, 2, π, u, sin ϕ, have cancelled. The above curve fit will represent the measured relative decay of concentration away from the road, even if quantities such as Q_L, u, or sin ϕ, were inaccurately known. Uncertainties in these quantities become important however when estimating the centre reservation value $\sigma_z(x_0)$.

Hickman and Colwill (1982) proposed a factor K to allow for the effects of background pollution. (It is not exactly clear from page 38 of their report LR1052 just what K represents). The M4 data covered most of October 1972, so they assumed a representative wind direction was $\phi = 45°$. They also modified the wind speed (see later) to take account of traffic disturbances to the flow, so used their quantity u^* rather than the windspeed u. (We have made the asterisk a superscript, to avoid confusion with the friction velocity u_* which is a different quantity widely adopted in boundary layer meteorology). Equation (5) was written as

$$c(x,y,0;0) = \frac{K2Q_L}{\sin\phi\sqrt{2\pi}u^*\sigma_z} \qquad (12)$$

and with K = 2.2, $\phi = 45°$, $\sin\phi = 0.7071$, (as in their work):

$$\sigma_z(x_0) = 2.4824\frac{Q_L}{cu^*} \cong 2.5\frac{Q_L}{cu^*} \qquad (13)$$

Using the measured lead concentrations at each receptor, the measured wind speed, Q_L calculated from the traffic counts and proportion of petrol vehicles, they found four similar values for $\sigma_z(x_0)$ with average value 1.85 m. Hickman and Colwill (1982) arrived at the complete formula for (10) where $\sigma_z(x_0)$ is now found:

$$\sigma_z(x) = 1.85\{1.0 + \exp[0.39\ln^3 D - 4.76\ln^2 D + 20.95\ln D - 32.67]\} \qquad (14)$$

Calder (1973) chose a value of 1.5 m for the initial vertical dispersion parameter due to vehicle wakes, and this is close to their estimate of 1.85 m. Middleton et al. (1979) also used an initial wake effect, by an imaginary initial dispersion distance of 27 m. (In unpublished work now in progress, the author has replaced this by a fixed initial vertical dispersion parameter of 2 m and uses this in all stability classes in the revised SPAGLINK model; cf Middleton, 1996)

Horizontal Dispersion Parameter

For a continuous and infinite crosswind line source, the horizontal dispersion parameter $\sigma_y(x)$ is not required as it vanishes in integrating crosswind. In order to model more complex roads, such as roundabouts, it is necessary to describe the cross wind dispersion explicitly. Therefore in order to develop the TRRL model which uses point sources stepped along roads, Hickman and Colwill (1982) assumed that

$$\sigma_y(x) = k\sigma_z(x) \qquad (15)$$

They suggested a value of 2 for k (NB not the same as K seen earlier) for the Pasquill Gifford curves up to a few hundred metres and sampling times of about 3 minutes for $\sigma_y(x)$, whereas $\sigma_z(x)$ is largely independent of sampling time up to about 1 hour. In order to develop a model suitable for 1 hour averages, they applied the formula

$$\frac{\sigma_y(x,t_1)}{\sigma_y(x,t_2)} = \left(\frac{t_1}{t_2}\right)^a \qquad (16)$$

where k = 2, t_1 = 60 minutes, t_2 = 3 minutes and exponent a = 0.25, which gave them their 1 hour averaged $\sigma_y(x)$ as

$$\sigma_y(x,1hour) = A\sigma_z(x;24hour) \qquad (17)$$

where A is a constant. These values give A = 4.2, but page 40 in their report LR1052 has a range of values for A in the range 10 to 15. Finally they chose A = 12.5.

We can observe that there is still a contradiction lying within this approach, in that their function for $\sigma_z(x)$ is derived from 24 hour averages of the concentrations of the lead particulate. It seems unlikely that this value of A is correct. In that case the TRRL model for stepping point sources may be affected (by how much is unclear), whilst the Design Manual method for straight cross wind roads is probably less affected by any problems in the size of A and $\sigma_y(x)$ (due to cross wind integration).

Comparison with Line Source Formula

The program SPAGLINK was modified in order to include the Colwill and Hickman (1982) function for $\sigma_z(x)$ and to apply it with equation (5). The infinite cross wind line source formula equation (2) was also coded. The program still had its original coding for numerical integration of point sources along lines, curves or circles. The emissions factor for carbon monoxide was taken from the 1994 edition of DMRB, Table 9, for vehicle speed 100 km / hour., as 3.62 g / km. Traffic flow was 1000 vehicles/hour, as in the Design Manual. Wind speed was set to exactly 2.0 metres/second, within the program (to avoid conversion from knots), also as in the Manual. For the line source formula and numerical integral stability was set to neutral (MST2=7) and the dispersion parameters used as in the original model of Middleton et al. (1979). The initial value of $\sigma_z(x_0)$ was 1.85 m to match Hickman and Colwill (1982).

When the three methods were compared, the numerical integral and the infinite line source formula (wind perpendicular to road axis) agreed to within 1%, but were quite different from the Hickman and Colwill (1982) method.

The coding of the Hickman and Colwill formula was then progressively modified until the **same concentrations** were obtained **near to the road** from all three methods. The subsequent decays of concentration away from the road could then be compared. The changes that were made were:

1. To set $\sigma_z(x_0)$ = 1.85 in the integral and crosswind line formula (as noted above)
2. To ensure all three models used wind speed 2.0 m/s (as noted above). This meant removing the wind speed adjustment u^* (which is discussed below).
3. To change the 'background' factor K from 2.2 back to 1.0.
4. To set up the Colwill and Hickman method for a perpendicular wind, $\phi = 90°$ rather than 45°.
5. To use the same emission factor 3.62 g/km and traffic flow 1000 v/h in each method.
6. To convert CO from $\mu g\ m^{-3}$ to ppb, multiply by 0.859, QUARG (1993).

The results at selected distances from the road were as in Table 2.

Table 2 columns 2, 3 gives the values of $\sigma_z(x)$ and $\sigma_z(x)$ from the Hickman and Colwill (1982) method as in report LR1052. Columns 5, 6 give the values of $\sigma_z(x)$ and $\sigma_z(x)$ after Geomet (see Middleton et al., 1979) from the neutral stability class in the numerical model SPAGLINK. The models were set up to commence with $\sigma_z(x_0)$ = 1.85 m at the road, but the LR1052 values rapidly increase so that after 100 m from the road they are becoming increasingly large. At 200 m and beyond $\sigma_z(x)$ is too big, and at x = 800 m is quite impossibly large. There is in the present author's mind a simple explanation for the rapid growth in the vertical dispersion parameter beyond 100 m. The original data were from samples of particulates, and deposition is likely to accelerate the decrease in concentration with distance from the road. Therefore the fitted curve for $\sigma_z(x)$ has to effectively model the disappearance of the material by deposition, so it deviates to large numbers. The Figure 2 in the report LR1052 by Colwill and Hickman (1982) (cf Figure 1) shows that $\sigma_z(x)$ begins to grow above the Pasquill Gifford Class C-D curves from about 80 m downwind. It appears that the TRRL model and the Design Manual method should not be regarded as applicable to gaseous pollutants at any position that is more than 80 m from a road. An alternative explanation might be the effect of buoyancy due to the heat carried by the exhaust gas, but this may be a weaker effect than deposition.

Table 2 column 4 therefore has concentrations from the LR1052 method which at 100 m distance are similar (52 versus 68 ppb CO) to the model results columns 7,8 using the Geomet curves (see Middleton et al., 1979, for details of the model; note special amendments as above), but at 200 m the LR1052 results have dropped to almost one third of the expected results (11.6 instead of 40.1 ppb CO).

To summarise, the three models were tuned to give the same concentration at the road; the infinite cross wind formula and numerical model remained in step to 1%, whilst from 80 m from the road the method of Colwill and Hickman (1982) moved increasingly rapidly to unrealistically large dispersion and unrealistically small concentrations. Their method was fitted to measured particulate lead, so may describe this pollutant adequately, but beyond 80 m from a road it is likely to seriouly underestimate the concentrations of gaseous pollutants.

Limitations of the Design Manual Curves

The curves for concentration decrease with distance from a road apply to 24 hour averaged particulate lead concentrations, wind speed 2 m/s and wind at an angle 45° with the road. If the special factors K and sin ϕ are set to 1.0, and the wind speed correction u^* returned to the usual wind speed u, then agreement with other models in the concentrations at the road can be obtained.

If these factors are set to K = 2.2 and sin ϕ = 0.7071 respectively as in Colwill and Hickman (1982) then the Design Manual curves **near the road will apparently overpredict** by perhaps a factor of 3 times. In terms of estimating the environmental impact of a new road, such as a new bypass, overprediction at the road might be regarded as a conservative (or fail-safe) design tool.

However as the distance from the road is increased, a more serious limitation in terms of air quality management becomes apparent. **At larger distances**, where the vertical dispersion parameter rapidly increases to unrealistic values, any overprediction will soon become a **serious underprediction for gaseous pollutants**. It appears that the Design Manual method should not be used beyond 80 m from a road. This means for example that when assessing a network of several roads the pollutant concentrations are unlikely to be properly combined. According to DMRB, the most distant roads (if beyond 80m) will contribute unduly small concentrations. The road network as a whole would then not be modelled in a representative manner.

Limitations of the TRRL Model

The TRRL model if it still uses the same dispersion parameters as in LR1052 will also be subject to the same deficiencies. Also, the latter model requires $\sigma_y(x)$ and Table 2 shows that these values are too large, presumably because the value of A was too big. There is also the inconsistency in averaging times between the original lead measurements over 24 hours and the 1 hour period chosen for $\sigma_y(x)$ and $\sigma_z(x)$ in the model.

The Question of Wind Speed Correction

Traffic causes a disturbance to the wind field. If a cup anemometer is located near the road, it will be accelerated by gusts of air displaced outwards by passing vehicles. It will also be speeded up by gusts in the opposite direction. Traffic will appear to increase the wind speed. If a three dimensional fast response anemometer is placed by a road, we can expect to see increased levels of turbulence, but the effect of traffic is likely to appear different from that exhibited by the cup anemometer.

Colwill and Hickman (1982) replaced the wind speed u by a corrected wind speed u^* (which is not the friction velocity u_* as already noted). They defined

$$u^* = \frac{u}{0.59 + 0.11u} \qquad (18)$$

Here $u^* > u$ for $u < 3.8$ m/s, and $u^* < u$ for $u > 3.8$ m/s. At large u, the limit on u^* is 9.09 m/s. At 1 m/s, the wind is increased by about 43%, whilst at 5 m/s it is reduced by about 12%.

The present author suggests that just because the cup anemometer speeds up near the road does not mean that the model should increase the prevailing wind that is advecting the pollutants. It may be better to ensure that the initial dispersion parameter $\sigma_z(x_0)$ is set to an appropriate value for vehicle wakes, and not to adjust the mean wind speed for the turbulence. Therefore u^* should not replace u in the formula.

Dispersion Parameter Curves beyond 80 m for LAQM

The present analysis has concluded that whilst the dispersion parameter curve derived by Hickman and Colwill (1982) may represent lead particles near the motorway, it is very unwise to use it for gases at positions beyond 80 m from a road. The present author believes that an initial vertical plume spread of about 1.85 m can represent the wake effect, but at increasing distances from the road this initial effect should be less important. It is better beyond 80 m to use the more usual dispersion curves, such as those of Pasquill, Gifford; or Briggs rural / urban; or the curves of Geomet that we used here, or the more modern curves of the Indic and ADMS models. For the purposes of

Local Air Quality Management, whilst the Design Manual method may be very useful as a first tier screening method to highlight high concentrations along heavily trafficked roads, it should not be used further away than 80 m. Reviews and assessments of local air quality as well as planning decisions may address road networks as a whole. Modelling that involves contributions from several roads will need to cover larger distances, and the Design Manual method needs to be supplemented by or brought into line with dispersion models which use accepted dispersion parameter curves. This is likely to exclude the TRRL model PREDCO whilst it uses the Hickman and Colwill (1982) form for $\sigma_y(x)$ and $\sigma_z(x)$. To summarise, serious underprediction at positions beyond 80 m is to be expected from the Design Manual method DMRB and from the TRRL model PREDCO.

Conclusions

The aim was to investigate the suitability of the Design Manual for Local Air Quality Management, especially for the reviews of air quality that are envisaged by the Environment Act 1995. This work has been carried out in order to establish the original basis of the air pollution assessment method from the Design Manual for Roads and Bridges. All the conclusions and points in this work are made assuming that TRRL report LR1052 by Hickman and Colwill (1982) is the basis for the Design Manual method DMRB and for the TRRL model PREDCO. This study shows that the original experiments were carefully carried out and that the curve fitting procedures gave a good representation of the original measurements. The Design Manual method is therefore able to model lead pollution from petrol vehicles on roads, at least within the recommended distance of 200 m.

The present study reveals significant deficiencies when seeking to extend the method to gaseous pollutants. The Design Manual method should not be used for gaseous pollutants beyond 80 m from a road (for reasons listed below). The Design Manual method can be used to compare one road with another to identify likely polluted localities, but is unlikely to predict gaseous pollutant concentrations that will be matched by measurements. Whilst the decay of pollution near a road may be described, there is a need to calibrate any modelling with more up to date measurements of gaseous pollutants.

Technical comments are summarised below:

1. The Design Manual method for air pollution from roads is based upon the decay with distance of 24 hour average lead particulate concentrations.
2. The TRRL model appears to have the same basis. The averaging times in $\sigma_y(x)$ and $\sigma_z(x)$ appear to be 1 hour, whilst the measurements were averaged to 24 hours, so there is some inconsistency here. The factor A used to obtain $\sigma_y(x)$ seems too large.
3. The dispersion parameters seem to rapidly approach unrealistically large values, presumably reflecting the use of particulate concentrations which are subject to losses by deposition. More widely accepted curves for the dispersion parameters should be used, whilst retaining the notion of an initial wake effect.
4. The wind speed correction for traffic effects should be removed, as should the 'background factor' K. Also, background contribution should be regarded as additive (though NO_2 is a special case: see below).
5. Beyond 80 m, dispersion modelling of gaseous pollutants from roads should use more widely used dispersion parameter curves to avoid serious underpredictions.

6. The Design Manual method and the TRRL model should not be used for large networks of roads whilst they rely on the measurements of particulate lead for their description of dispersion. They should only be used in Local Air Quality Management during the first tier review seeking to identify pollution 'hot spots' in the immediate vicinity of individual roads.
7. For completeness, if estimates of NO_2 are required, a procedure is needed to allow for the nonlinear effects of chemistry such as are discussed in Derwent and Middleton (1996) and Middleton (1996). The background NO_x has to be added to the NO_x for an individual road under study before the NO_2 can be estimated.

Recommendations

1. The Department of Transport should be approached to clarify the basis of the dispersion parameter curves that are currently used in the Design Manual for Roads and Bridges (DMRB). The Met Office should have a responsiblity for ensuring that the dispersion curves in DMRB use the latest understanding of boundary layer meteorology, and should assist in any revisions of the dispersion parts of the Design Manual.
2. Research should be carried out by the Met Office to measure both the turbulence and dispersion of a pollutant (or tracer) as a function of distance from road, traffic speed, wind direction, wind speed, and atmospheric stability. It should apply expertise from Met Research Unit Cardington to field measurements of the boundary layer, and from Atmospheric Processes Research to modelling the turbulent dispersion in terms of modern theory.
3. D Tp and DoE should be approached for funding in view of the importance of properly reviewing and assessing air quality.

Acknowledgement

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Table 1. Checking the TRRL function for $\sigma_z(x)$ against the measured curve for lead concentrations. F_5 used equation (5) with $\sigma_z(x)$, while F_8 used the exponential equation (8). Results are given at each distance from 0 to 120 m.

x, m	0	10	30	60	90	120
$(c_0/c_x)-1$	0	0.2797	0.9477	2.6571	5.8666	11.893
$D=(x+10)/0.7071$	14.14	28.28	56.57	98.99	141.42	183.85
$\ln(F_5)$	-	-1.2616	-0.01367	0.9299	1.7070	2.4410
$\ln(F_8)$	-	-1.2740	-0.05372	0.9772	1.7693	2.4759

Table 2. Comparison of calculations of CO concentration (ppb) from the three methods after they were modified for agreement by the road (see text for details).

x, m	LR1052 $\sigma_y(x)$, m	LR1052 $\sigma_z(x)$, m	LR1052 Formula CO, ppb	Geomet $\sigma_y(x)$, m	Geomet $\sigma_z(x)$, m	Numeric Integral CO, ppb	Analytic LineEqn CO, ppb
0	23.1	1.85	186.3	1.85	1.85	55.7 *	186.3
10	23.3	1.86	184.9	2.12	1.98	174.0	174.1
20	25.8	2.07	166.7	2.68	2.23	154.3	154.3
50	41.9	3.35	102.9	4.82	3.25	106.1	106.1
100	82.9	6.63	51.97	8.52	5.08	67.78	67.80
200	371.7	29.74	11.59	15.66	8.60	40.06	40.08
300	1789.3	143.15	2.407	22.50	11.89	28.99	28.99
500	34079.6	2726.4	0.1264	35.62	18.01	19.13	19.13
800	******	131007.	0.00263	54.41	26.49	13.01	13.01

Note: * The numerical model is known to have a numerical difficulty when the receptor lies exactly on the line source; a low value here is expected.

Figure 1. A copy of the variation in vertical standard deviation with distance taken from the Figure 2 of TRRL report LR1052 by A J Hickman and D M Colwill (1982). Note the deviation of their curve (broken line) away from Pasquill Gifford curves for neutrally buoyant gaseous pollutants. The departure is most likely the result of particle deposition.

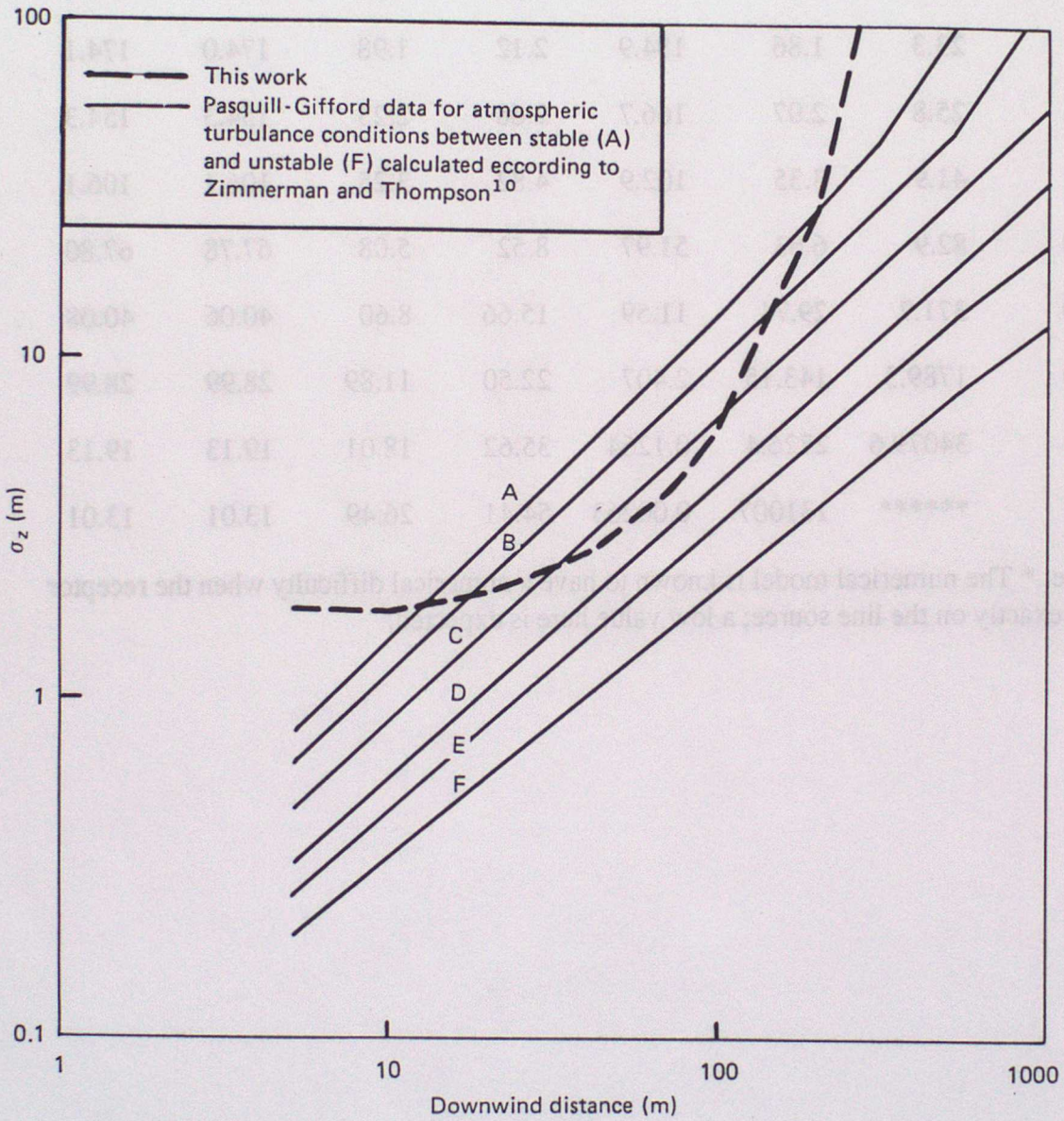

Fig. 2 Vertical standard deviation