INVESTIGATIONS DIVISION TECHNICAL NOTE NO 11

Estimation of Buoyant Gas Dispersion.

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This note describes a gas dispersion model which was developed to provide estimates of the mean dispersion of a buoyant gas in various weather conditions (during the first kilometre of travel downwind). Some speculative estimates of maximum short period plume centre-line concentrations, with associated probability levels, are also given.

(This work was done for the Nuclear Installations Inspectorate, September 1976).

Please note:

Permission to quote from this unpublished note should be obtained from the Head of Met O 9, Bracknell, Berks, UK.

Estimation of Buoyant Gas Dispersion

1. Problem

The problem is that of obtaining estimates of the likely dispersion of a buoyant gas released into the atmosphere, with the basic assumptions that the source or leakage is at ground level, that the effective radius, r_0 , of the source and volume rate of gas escape, Q, are both constant, and that the escaping gas is directed vertically upwards (with speed $W_0 = Q/\pi r_0^2$).

2. Proposed method of solution

The evolution of the gas plume after escape is treated in two stages:-

(i) Entrainment - donminated stage

To determine the path of the plume during this initial phase when the dilution is dominated by entrainment processes, I have used equations very similar to those suggested by Briggs (1969) (relevant to a buoyancy-dominated plume) as follows:-

$$z_p = 1.6 F^{1/3} x^{2/3} u^{-1} . E_m \tag{1a}$$

(for neutral/unstable atmosphere)

$$z_p = 2.4 \left(\frac{F}{us}\right)^{1/3} \left(\frac{x}{x_s^*}\right)^{2/3} . E_m \tag{1b}$$

(for stable conditions)

$$E_m = \left\{ 1 + \frac{2 F_m u}{F x} \right\}^{1/3} \tag{2}$$

$$F = g W_0 r_0^2 \Delta\rho / \rho_A \tag{3}$$

$$F_m = \frac{\rho_G}{\rho_A} W_0^2 r_0^2 \tag{4}$$

z_p - height of plume centre-line above release level

u - mean wind speed between release level and plume-level

x – distance downwind from release point

F – buoyancy flux parameter

F_m – Momentum flux parameter

E_m – Momentum enhancement factor

ρ_G – density of escaping gas

ρ_A – ambient atmospheric density

$\Delta\rho$ – density difference $\Delta\rho = \rho_A - \rho_G$

s – atmospheric stability parameter

$$s = \frac{g}{T_a}\left(\frac{\partial T_a}{\partial z} + \Gamma\right)$$

T_a – ambient atmospheric temperature

$\frac{\partial T_a}{\partial z}$ – atmospheric temperature lapse-rate

Γ – Dry adiabatic lapse-rate (DALR)

The momentum enhancement factor is normally excluded (usually very close to unity); however, if W_0 is large, z_p near to the source may be significantly inrecased, so E_m has been retained in this plume-rise model.

For neutral/unstable conditions Briggs defines a downwind distance, x^*, beyond which atmospheric turbulence becomes the dominant mixing process:-

$$x^* = 34 F^{2/5} \qquad (5a)$$

(for F in mks units)

In stable conditions the downwind distance at which the plume levels off, x_s^*, is:-

$$x_s^* = \pi u s^{-1/2} \qquad (5b)$$

as suggested by Briggs.

I have used x^* or x_s^* to determine the final plume-rise height and the point at which the entrainment dominated stage ends. (For the sake of computational convenience I have included the mixing by atmospheric turbulence, however insignificant, in this stage, as described in (ii) below).

The final plume rise height is:-

$$h = z_p(x = x^*) = 1.6 F^{1/3} (x^*)^{2/3} u^{-1} E_m \qquad (6a)$$

(neutral/unstable)

$$h = z_p(x = x_s^*) = 2.4 \left(\frac{F}{us}\right)^{1/3} . E_m \qquad (6b)$$

(stable)

For plume rise in stable conditions, both sets of equations, (1a) + (6a) and (1b) + (6b), were used to define alternative centre-line paths; at every downwind distance the two alternative heights were then compared and the smaller of the two was adopted as the true height at that downwind distance.

To obtain the variation of concentration with height within the plume, a few progressively less conservative approaches suggest themselves.

For a pure jet (or momentum plume) from a point source at $z = 0$ with zero buoyancy emerging vertically into a calm atmosphere, the variation of plume centre-line concentration, C' (proportion by volume), with height, z, above release level is proportional to z^{-1}, and r, the plume radius, is proportional to z ($r \approx z/5$). (Scorer 1958, 1959). In a smooth crosswind the rate of dilution with height is more rapid, being proportional to z^{-2}, and again the $r \propto z$ relationship is valid ($r \approx z/2.25$).

For a bent-over buoyant plume Scorer shows that C' is proportional to z^{-2}, the same as for a bent-over jet, and r is again proportional to z. For a bent-over plume of this type he quotes the relationship:-

$$r = z/p \approx z/2.25 \qquad (7)$$

From a wide range of observations of the rise of hot plumes, Briggs (1969,

1972) found $p \approx 2$ to 2.25; typical deviations from the average value of r/z were 10 to 15 per cent. Scorer shows that the addition of vertical momentum to a bent-over buoyant plume makes no difference to the dilution achieved at any given height; the constants which determine the rates of widening of the two types of bent-over plume are nearly the same, and the dilution is much more under the influence of the strength of the crosswind. For a buoyant plume in a calm atmosphere, $c' \propto z^{-5/3}$.

For the purposes of this study I have adopted four progressively less conservative methods of deriving plume centre-line concentrations as a function of height; these are based on:-

$$c'(z) = \left(\frac{z_0}{z + z_0} \right)^n \qquad (8)$$

where $$z_0 = p r_0$$

(For a finite radius source, a virtual point source is assumed to be at $z = -z_0$).

The four methods are achieved by varying p and n as follows:-

A $n = 1$ $p = 5$

B $n = 1$ $p = 2.25$

C $n = 2$ $p = 5$

D $n = 2$ $p = 2.25$

Method A is obviously the most conservative approach, since it applies strictly only to a non-buoyant jet emerging into a calm atmosphere. Method D provides the most realistic approach.

The gas concentration distribution about this derived centre-line value is assumed to be gaussian along the y and z axes. The method of obtaining the precise distribution is described in (ii) below, where inclusion of mixing due to atmospheric turbulence during the plume rise stage is described.

(ii) Atmospheric turbulence dominated stage

Beyond the downwind distance x^* or x_s^*, I have assumed that the plume levels off and that subsequent dilution of the plume is that effected by atmospheric turbulence alone.

The classical gaussian dispersion model is used to obtain concentrations, C (proportion by volume), in the xz plane, with the source assumed to be at x = y = 0, z = h, and the mean wind direction along the x - axis:-

$$c(x,0,z) = \frac{Q}{2\pi u \sigma_y \sigma_z}\left[\exp\left\{-\frac{1}{2}\left(\frac{z-h}{\sigma_z}\right)^2\right\} + \exp\left\{-\frac{1}{2}\left(\frac{z+h}{\sigma_z}\right)^2\right\}\right] \qquad (9)$$

where h is the plume rise as defined in equation (6a) or (6b). σ_y, σ_z are the horizontal and vertical dispersion coefficients or 'spreads' in the crosswind gaussian profiles (standard deviations of the concentration distributions), and are functions of downwind distance and stability. The values of σ_y and σ_z for various downwind distances and stabilities are based on those given by Turner (1969), after Pasquill (1961). McMullen (1975) gives best-fit quadratic equations of the form:-

$$\ln\sigma = a + b\ln x + c(\ln x)^2$$

for σ_y and σ_z, for each stability category; the values of a, b, c vary from category to category (see Appendix 1). This relationship gives adequately accurate σ values for x in the range 50 m to 100 km.

If r' is the effective standard deviation of plume concentration in both the y and z directions at $x = x^*$ (or x_s^*), assuming no atmospheric turbulence mixing up to that point, then, matching the centre-line concentrations given by equations (8) and (9) at $x = x^*$, we have:-

$$c'(h) \approx \frac{Q}{2\pi r'^2 u}$$

so

$$r' = \left\{\frac{Q}{2\pi u c'(h)}\right\}^{1/2} \qquad (10)$$

We now treat the problem as one of diffusion according to equation (9), from a virtual point source at height h and at an upwind distance, x_o, necessary to give a spread, or concentration standard deviation, of r' in the y and z directions at x = 0. i.e. we require that $\sigma_y(x_o) = \sigma_z(x_o) = r'$ Since the rates of increase of σ_y and σ_z with distance are different, the x_o values for σ_y and σ_z will also differ, so the above requirement becomes

$$\sigma_y(x_{oy}) = \sigma_z(x_{oz}) = r'$$

the virtual origin for the spread in the y direction being at $(-x_{oy}, o, h)$, and that for the spread in the z direction being at $(-x_{oz}, o, h)$. Equation (9) is then applied to obtain c(x, o, z), with σ_y and σ_z functions of $x + x_{oy}$ and $x + x_{oz}$ respectively. Figure 1 illustrates the virtual origin concept described here.

By taking r' as the standard deviation of plume concentration at x = o rather than at $x = x^*$, we are incorporating diffusion by atmospheric turbulence from x = o onwards, ie. diffusion by atmospheric turbulence is included during the plume-rise stage.

During the rise stage c', r' and therefore x_{oy} and x_{oz} are all known functions of z_p, so that the gaussian crosswind distributions of the plume concentration, with atmospheric turbulence included as a mixing process, can easily be derived using this virtual origin approach.

In equation (9), u is the windspeed at plume height; I have assumed no variation of windspeed with height in this diffusion model, so this u is the same as that in equations (1a), (1b) and (2).

Given the parameters Q (m^3s^{-1}), r_o (m), ρ_G/ρ_A, p and n, a computer program outputs values of c(x,o,z) for various heights up to 500m, downwind distances up to 1.5 km, windspeeds up to 20 ms^{-1} and 8 stability categories. Pasquill stability categories can be used, but temperature lapse rate categories can be substituted provided that the corresponding σ_y, σ_z functions are defined. In the current version of the computer program, Pasquill stability categories A, B, C and D comprise the first four stability classes. The remaining four are temperature lapse-rate categories S1, S2, S3, S4 (all stable). The aim is to assign to these four categories the 20, 10, 1 and 0.1 percentile values of stable lapse-rate for a particular layer, so that, for instance, the $\frac{\partial T_a}{\partial z}$ value for S2 category would be that which is exceeded on 10 per cent of all occasions. Once these percentile values have been allocated, corresponding values of S, the stability parameter, for use in the stable plume rise equations (1b) and (6b), can be calculated. Detailed climatological temperature lapse-rate data are available for Cardington, Bedfordshire (Hardy, 1974) in the form of frequency distributions of temperature differences across various layers. Figures for the layer from 1m to 150m, listed in table 1, are assumed to be sufficiently representative of the layers with which we are most concerned in this report. The terrain around Cardington is typical of most relatively flat rural sites in the UK and the frequencies of occurrence of given lapse-rates at the latter type of site should not be very different from those observed at Cardington. Note that the computed plume-rise in stable air is not particularly sensitive to small variations in the selected $\frac{\Delta T_a}{\Delta z}$ ($h \propto S^{-1/3}$), so that approximate values for $\Delta T_a/\Delta z$ for each category are sufficient.

Having selected the 20, 10, 1 and 0.1 percentile values of $\Delta T_a/\Delta z$ (and therefore of S) for the layer 1m to 150m, estimates of the corresponding values of σ_y and σ_z were selected as follows:-

Lapse-rate Category	$\Delta T_a/\Delta z$ (deg K m^{-1})	Probability of exceeding $\Delta T_a/\Delta z$	Estimate of most likely values of σ_y σ_z
S1	1.01×10^{-2}	0.20	as for Pasquill E stability
S2	2.01×10^{-2}	0.10	as for Pasquill F stability
S3	4.23×10^{-2}	0.01	as for Pasquill G stability
S4	8.39×10^{-2}	0.001	as for Pasquill G stability

This choice of σ_y and σ_z values is not inconsistent with the observed frequency of various Pasquill stability categories at Cardington; stabilities E, F, G occur 18 per cent of the time, F, G 10 per cent of the time, and G about 2 per cent of the time. The σ_y, σ_z functions for category G were obtained by simple extrapolation of Turner's graphical functions, which originally covered categories A to F (see Appendix 1). Definitions of the Pasquill stability categories are given in table 2. Note that category G cannot occur with windspeed more than 1 kn (0.5 ms^{-1}), categories A and F cannot occur with wind speed more than 5 kn (2.5 ms^{-1}), and categories B and E cannot occur with wind speed more than 9 kn (4.5 ms^{-1}).

3. Additional comments on the method of solution

(i) Short-period concentrations

The method described can only give estimates of mean concentrations of gas at a point measured over a time period of the order of 3- to 10- minutes. In a paper entitled "Peak-to-average concentration ratios according to a fluctuating plume dispersion model", Gifford (1960) concluded that:-

(a) For source and receptor at the same level, peak-to-average ratios can be expected to be in the range from 1 to about 5, for 'average' and 'peak' sampling times in the ratio of 20 or more.

(b) For increasing difference in height between source and receptor, or increasing distance from the plume axis, peak values as great as 50 to 100 times the mean values may occur at the ground near a moderately tall stack. Such values are actually observed.

(c) With increasing distance downwind from an elevated source, the ground-level peak-to-average ratio will decrease towards unity, although values of this order occur only at considerable distances from the source, perhaps 20 to 50 stack-lengths or further.

The argument Gifford presents confirms the intuitive expectation that the short-period peak concentration at any point can never exceed the short-period peak concentration that could be achieved on the mean (3 to 10-minute) plume centre-line. So, for a given downwind distance, we can apparently assume that the maximum short-period concentration at any height would be about 5 times the mean (3 to 10-minute) plume centre-line concentration; the probability of obtaining this maximum concentration must decrease with increasing distance from the plume axis. In fact the probability of the maximum concentration occurring at any point is simply given by the ratio of the calculated mean concentration at that point to that at the mean plume centre-line, at the same downwind distance. If we are solely interesented in the maximum downwind distance at which a certain concentration occurs, then we need only consider the behaviour of, and concentration at, the plume axis, since this is where the maximum peak concentration will occur with the greatest probability.

On Gifford's simple model the ratio of instantaneous to time-mean concentration at (x,y,z) relative to a continuous point source is:-

$$\frac{c_i}{c_\tau} = \frac{(\sigma_y \sigma_z)_\tau}{(\sigma_y \sigma_z)_i} \exp\left[\frac{1}{2}\left(\frac{y^2}{(\sigma_y)_\tau^2} + \frac{z^2}{(\sigma_z)_\tau^2}\right)\right] \qquad (11)$$

where subscripts i and τ denote instantaneous values and values averaged over a sampling time τ. Both theory (Pasquill, 1974) and experience indicate that close in to a point source in ideal neutral flow the instantaneous spread is roughly half the time-mean spread as typically observed over tens of minutes. Consequently, putting y=z=0 in equation (11), we may expect to have values of c_i/c_τ near 4 downwind of (and at the same level as) an elevated or effectively elevated source. In practice, apart from departure from ideal flow conditions the short-period sampling of concentration is not instantaneous but typically occupies a finite sampling time of some 10 sec or more. The data quoted by Gifford for peak to average ratios at the same level as the source are therefore not obviously inconsistent with expectation.

Gifford makes no mention of the sort of level of probability associated with his centre-line peak-to-average ratios of 'up to 5'. If we assume, say, that the 'peak' sampling time is t seconds and the 'average' sampling time is τ seconds, then there are τ/t short-period values within the τ second sample; if we have a number of such τ second samples and select from each the largest short-period (t-second) value, then we can find the maximum t-sec value which is exceeded in 50 per cent of all τ-seconds samples - ie the median maximum value. Gifford's factor of 5 may be roughly equivalent to just such a median maxiumum. That is, in a series of 10-minute samples each comprising 60 10-sec average concentrations, a 10-sec value of 5 × (10-minute mean concentration) will occur within 50 per cent of the 10 minute samples.

If a log-normal or similar distribution can be assumed for the t-sec values, and given the validity of Gifford's fluctuating plume model, we should be able to infer probability levels associated with various multiples of the mean concentration.

A weakness of Giffords fluctuating plume model in attemping to assess likely peak-to-average ratios is that it assumes that the concentration within the instantaneous plume decreases monotonically with increasing downwind distance, and neglects the contribution to variability of concentration from patchiness, or lumpiness, within the plume section itself. Unfortunately not much is known about this aspect of short-period concentration variability. What we can say is that if we are concerned with amounts of gas (eg 100 kg methane) above the lower flammable limit (LFL) which are small compared with that part of the time-mean plume above LFL then the concentration variability due to patchiness in the instantaneous plume should be considered.

(ii) Error associated with the prediction equations

A recent paper by Guldberg (1975) comparing the performances of three plume-rise models, including a model suggested by Briggs which is very similar to the one used in this study, shows the typical scatter which occurs on a graph of predicted versus observed final plume rise. Whether or not the scatter is due mainly to errors in observation of plume-rise (photographic techniques were used in Guldberg's study), it is obviously advisable in the context of this study to quantify the degree of scatter in some way, perhaps simply by using some fraction of the predicted rise sufficient to cover the extreme variations which may be expected with a certain probability. Study of this aspect of the problem is continuing.

(iii) Vertical Wind shear

I have assumed that the wind speed at plume level is constant down to the surface, ie $u(z) = u(h) = \text{constant}$ $\left(\partial u / \partial z = 0 \right)$. If the complication of a non-zero gradient is introduced, with U decreasing linearly from plume level down to the surface, ie $u(z) = u(h) + k(z-h)$, $k > 0$ where k is a constant ($k = \partial u / \partial z$), then for a fixed value of wind speed, U(h), at plume-level, the plume would achieve a greater height (with reduced centre-line concentration) at a given downwind distance than it would in the $\partial u / \partial z = 0$ case (see figure 2). So the assumption of zero vertical wind shear is therefore a conservative one in this context.

The same general argument applies to the introduction of a (more realistic) logarithmic wind speed profile where $\partial u / \partial z \propto z^{-1}$. $\partial u / \partial z > 0$ is usual in most situations, particularly in stable weather conditions near the surface; $\partial u / \partial z < 0$ is very rare, normally only occurring in hilly terrain and in association with neutral or unstable stability categories.

(iv) Variation of concentration during plume rise

For the range of Q-values considered and the short downwind distances of interest (up to about 600 metres), the dilution of gas due to entrainment during the initial rise stage is generally much greater than the dilution due to mixing by atmospheric turbulence. For this reason it is important to ensure that the method used to determine the variation of concentration during plume rise is sound. Although the methods described, mainly due to Scorer, provide ways of determining the required variation of concentration, it is worth pointing out that Scorer provides very little experimental evidence of the actual behaviour of jets or buoyant plumes in crosswinds to support the theories presented in his book "Natural Aerodynamics". This is one of the reasons why I have tended to include conservative cases in applying the methods he suggests.

In summary then, it would be desirable to know something about how large, in relation to the computed mean centre-line concentration (c), the short period or instantaneous (~10-sec average) centre-line concentration (c_i) might be, and with what probability this peak value might occur. The information in the literature is not particularly helpful on this score, so that, at this stage, some 'speculative estimates' are necessary.

Firstly I will assume that each of the j instantaneous values within a τ-second sample (with mean concentration c) can be expressed as

$$(c_i)_j = (f_1)_j (f_2)_j c \qquad (12)$$

The factor f_1 is due to the fluctuations of the instantaneous plume and f_2 is due to the patchiness within the plume. I will further assume that $\ln(f_1)_j$ and $\ln(f_2)_j$ are normally distributed with standard deviations σ_1 and σ_2 respectively (there is some experimental evidence to support such an assumption). By assuming Gifford's factor of 5 to be a median maximum value, as described above, associated with $\tau/t \sim 20$ to 50, we can estimate σ_1 (standard deviation of $\ln(f_1)_j$) to be about 0.7, equivalent to a factor of $e^{0.7} \approx 2$. (The factor of 5 is equivalent to about $2.3\sigma_1$, or a probability of exceedance of about 1 per cent). In the absence of any reliable quantitative information about the uncertainty in centre-line concentration due to patchiness, I can really only assume a similar variability, ie a factor of 5 at the $2.3\sigma_2$ level, or $\sigma_2 \approx 0.7$.

I have already commented (see (ii) above) on the uncertainty associated with the use of the suggested methods for obtaining the mean concentration. The value of c in equation (12) is really the actual or true concentration, and I will assume that we can replace it with f_3c, where c is now the computed mean concentration and f_3 is an 'error factor' such that the true concentration $= f_3c$. It is convenient to assume that the probability distribution of $\ln f_3$ is gaussian, with standard deviation σ_3. Estimation of σ_3 is again very difficult; a conservative value would be, again, about 0.7 (factor of 2).

We now have the relationship :-

$$\frac{(c_i)_j}{c} = (f_1)_j (f_2)_j f_3$$

$$\text{So} \quad \ln\frac{(c_i)_j}{c} = \ln(f_1)_j + \ln(f_2)_j + \ln f_3$$

In the absence of any quantitative evidence to the contrary, I will assume negligible correlation between f_1, f_2 and f_3, so that the resultant standard deviation, σ, of $\ln \frac{(c_i)_j}{c}$ can be written

$$\sigma^2 = \sigma_1^2 + \sigma_2^2 + \sigma_3^2$$

My estimates of σ_1, σ_2 and σ_3 are all the same (0.7), giving

$$\sigma = (0.7^2 + 0.7^2 + 0.7^2)^{\frac{1}{2}} = 1.21$$

The multiplying factors, $f_1 f_2 f_3$, associated with various probability levels are therefore as follows:-

Probability level (per cent)	Multiple of σ	$f_1 f_2 f_3$ exceeded
10	1.28	4.7
1	2.33	16.8
0.1	3.09	42.1

Given the amount of guess-work involved, it is sufficient to conclude that, in order to obtain the peak instantaneous (~10 sec) centre-line concentration that might be exceeded on 10 per cent, 1 per cent and 0.1 per cent of occasions, we should multiply the computed mean centre-line concentration by factors of about 5, 20 and 50 respectively.

Results

The computer program was run using the following Q-values : 14, 80, 100, 300, 500 m^3s^{-1}. The source radius, r_o, was assumed to be 1.5m. ρ_G/ρ_A was taken as 0.56. As already mentioned, 2 values of n (n=1 and n=2) and 2 values of p (p=5.0 and p=2.25) were used, so that each Q-value yielded 4 sets of results.

Table 3 lists values of h given by equation (6a) (plume-rise in neutral/unstable conditions) and table 4 lists values of h given by equation (6b) (plume rise in stable conditions)for two of the temperature lapse-rate categories, S2 and S4. Values of E_m, the momentum enhancement factors are also given in tables 3 and 4; they are generally small - of the order of a few per cent or less. Table 5 lists values of x_s^*, the downwind distance of final plume rise in stable conditions (equation (5b)), for each lapse-rate category.

Tables 6 to 10 contain the derived mean centre-line concentrations at four downwind distances, 100m, 200m, 500m and 1000m, for the lapse-rate categories S1, S2, S3, S4 (all stable) and Pasquill categories A, B, C, D ; corresponding plume centre-line heights are also given. For each of the five flow-rates, four sets of results are presented, one for each of the four (progressively less conservative) methods used to determine the variation of centre-line concentration during plume rise.

For any given wind speed the worst conditions always occur in either stable conditions (for the light wind speed classes) or neutral conditions (for the moderate to strong wind speed classes).

Before commenting on the results listed in tables 6 to 10, it is worth drawing attention to table 11 which contains estimates of the percentage frequencies of the stability/wind speed classes used in tables 6 to 10, relevant to a relatively flat inland rural situation in the United Kingdom. These estimates are based on available climatological frequencies of Pasquill A, B, C, D, E, F and G stability categories for several sites in the United Kingdom. The frequencies given are for all wind directions grouped together; if a particular wind direction is of interest, the probability of occurrence of a stability/wind speed/wind direction sector (30 degrees) would be, as a first approximation, about an order of magnitude lower than the figure given; such an approximation assumes that the stability/wind speed classes are equi-probable for all wind directions.

The frequencies of various stability/wind speed/wind direction classes obviously vary with the nature of the surrounding terrain. At a coastal site for instance, the frequency of S3 and S4 categories with onshore winds may be almost negligible; with winds off the land however, the frequency of these most stable categories can be expected to be similar to those experienced at a comparable inland site. The strongest winds tend to occur mainly with winds from particular direction sectors (e.g. southwest, west and northeast). The favoured directions depend partly on the nature of the terrain; if, for instance, the site is in a valley, when strong winds are blowing roughly parallel to the valley there may be a 'funnelling' effect, enhancing the wind strength along the valley; when the wind blows roughly perpendicular to the valley there may be a sheltering effect resulting in a reduction in wind strength in the valley.

If the nature of the terrain at the site of interest is not too dissimilar from the Cardington-type terrain, the figures in table 11 provide reasonable working estimates. Even at a coastal site the figures should provide a useful guide if the wind direction which produces the potentially hazardous condition (i.e. source-to-receptor direction) is one with a substantially overland fetch, provided that the land is relatively flat. If potentially hazardous wind direction is on-shore, or if the upwind terrain is particularly rough, significant adjustment of the figures will almost cerainly prove necessary.

Of all the figures listed in tables 6 to 10 the most important are summarised in tables 12(a) to 12(d); these give, for a particular downwind distance and flow-rate, the maximum mean centre-line concentration together with the stability/wind speed combination which produces that concentration. For example S4/1 signifies that lapse rate category S4 combined with a wind speed of 1 ms^{-1} produced the 'worst-case'.

The best way to comment on the results is, I think, to draw attention briefly to some of the more interesting results, method by method, with particular reference to tables 12(a) to 12(d). Note that these tables (and tables 6 to 10) contain mean concentrations.

Method A (table 12(a))

All the 'worst cases' occur in stable conditions, mostly with S4/0.5 or 1 ms^{-1}. At x = 200 m and 500 m the largest mean concentrations occur at Q = 80 and 100 m^3s^{-1}, decreasing for higher flow rates. At the shortest downwind distance the maximum occurs with the lowest flow rate.

Note that the probability levels associated with the 'worst cases' are different for different stability/wind speed combinations (see table 11); the concentrations listed in tables 12(a) - 12(d) are not all equiprobable.

Method B (table 12(b))

As with method A, stable conditions produce the 'worst cases'; concentrations are generally about half those computed using method A. At x = 500 m and 1000 m the largest mean concentrations occur for Q $\approx$ 100 m^3s^{-1}; at shorter downwind distances the maxima occur with the lowest flow rate.

Method C (table 12(c))

At downwind distances beyond 200 m, stable/light wind conditions produce all the 'worst cases'. For large values of Q and downwind distances of 200 m and less, the neutral/strong wind combination gives the maximum mean concentrations.

Method D (table 12(d))

The tendency towards D-category/strong winds producing the worst conditions is more pronounced here. Only for low flow rates at the higher downwind distances do stable conditions produce 'worst cases'. As with method C, at x = 200 m and beyond, the largest concentrations occur with the lowest flow rate.

Note that (table 11) the D/20 class can be expected to occur with about the same frequency as S1/4, about 10 times the frequency of S4/0.5 and about 40 times the frequency of S4/1.

I have already pointed out that method D (n = 2, p = 2.25) is probably the most realistic approach to adopt in most non-calm weather conditions (I have not looked at gas dispersion in dead-calm conditions mainly because of the lack of available information about atmospheric diffusion in such conditions). We have seen however that, for a buoyant plume rising in a calm atmosphere, p is nearer to 5, equivalent to a plume cone half-angle of about 10-degrees, and $n = 5/3$. It may therefore be advisable, for the near-calm wind classes ($0.5\ ms^{-1}$ and perhaps also $1\ ms^{-1}$), to regard the results for method C as being the best estimates of mean dispersion.

Conclusions

On the evidence of the results for methods C and D, a mean (3 to 10-minute) concentration exceeding 1.7 per cent will rarely extend much beyond 100 m downwind, whatever the flow rate, and at 500 m downwind a mean concentration of 0.8 per cent would appear to be even more rare. Tentative estimates of the likely error involved in applying the suggested methods to obtain mean concentrations indicate that a mean concentration at least double that computed may occur with a probability of about 15 per cent, relative to the probability of occurrence of the computed concentration. (On the assumption that the errors are log-normally distributed with standard deviation $\approx$ 0.7).

Very tentative estimates of the peak short-period ($\sim$ 10 sec average) concentrations which can be expected to be exceeded on 10, 1 and 0.1 per cent of occasions with a given computed mean concentration can be obtained by multiplying the computed mean concentration by factors of 5, 20 and 50. Note that the total probability of experiencing a concentration level of, say, 5 times the computed mean downwind concentration in a particular weather condition, say $S1/4\ ms^{-1}$, is given by the product of three conditional probabilities - the probability of occurrence of the weather condition $S1/4\ ms^{-1}$ (about 1 per cent), the probability of obtaining a concentration 5 times the mean concentration (about 10 per cent) and the probability of the wind blowing (within 15 degrees or so) from source to receptor (typically 5 to 20 per cent depending on the terrain characteristics of the site). In this particular example the total probability would be 5 to 20 x 10^{-5} (0.005 - 0.02 per cent).

Gas dispersion in dead-calm wind conditions has not been dealt with, mainly because of the lack of available information about atmospheric diffusion in such conditions. Dead-calm conditions probably occur about 0.5 to 2 per cent of the time at a typical relatively flat inland site in the U.K.

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Figure 1. Concept of a Virtual Origin (in the xz plane)

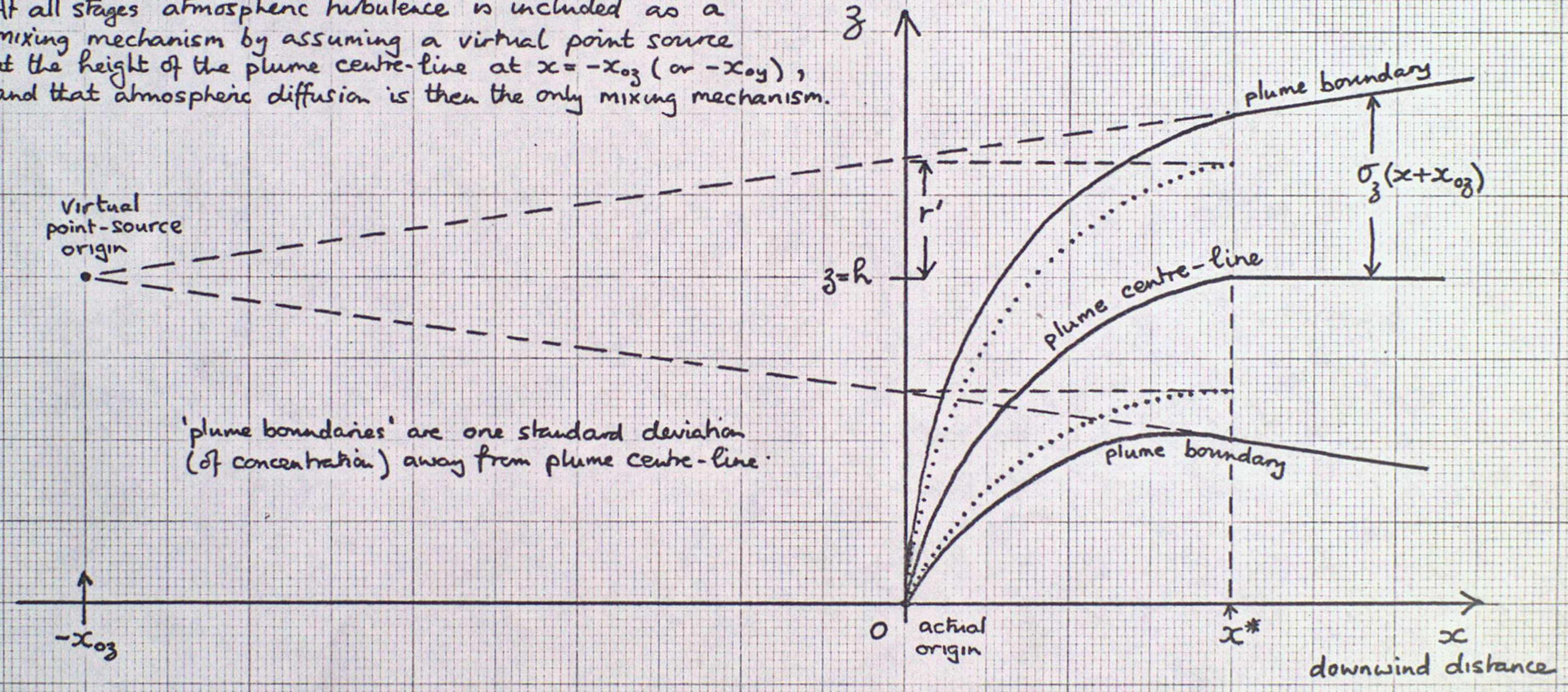
·········· plume boundaries assuming no mixing due to atmospheric turbulence

——— plume boundaries with mixing due to atmospheric turbulence from $x = 0$ onwards.

r' is the standard deviation of concentration assuming no mixing due to atmospheric turbulence.

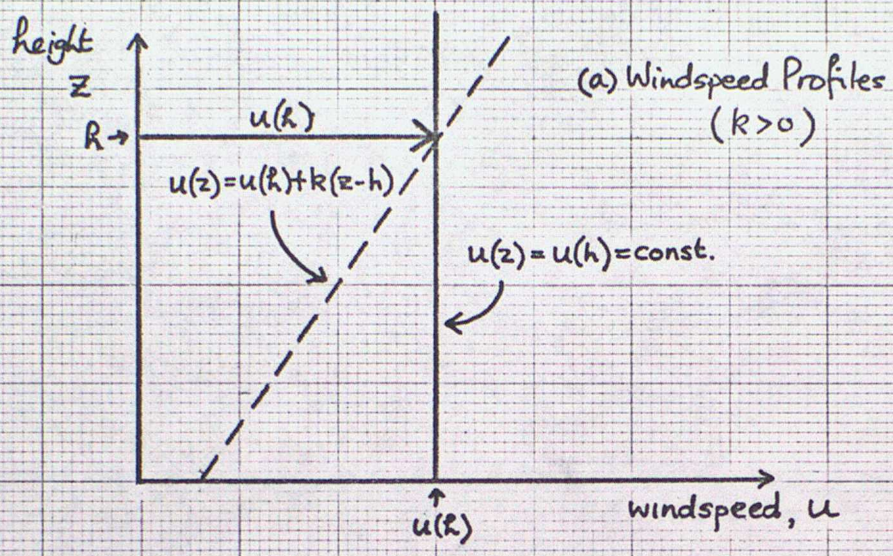
During plume rise (up to $x = x^*$) height of plume centre-line $\propto x^{2/3}$

At all stages atmospheric turbulence is included as a mixing mechanism by assuming a virtual point source at the height of the plume centre-line at $x = -x_{oz}$ (or $-x_{oy}$), and that atmospheric diffusion is then the only mixing mechanism.



'plume boundaries' are one standard deviation (of concentration) away from plume centre-line.

Figure 2 Comparison of plume-rise with and without vertical windspeed gradient (assuming same windspeed, $u(h)$, at computed final rise)



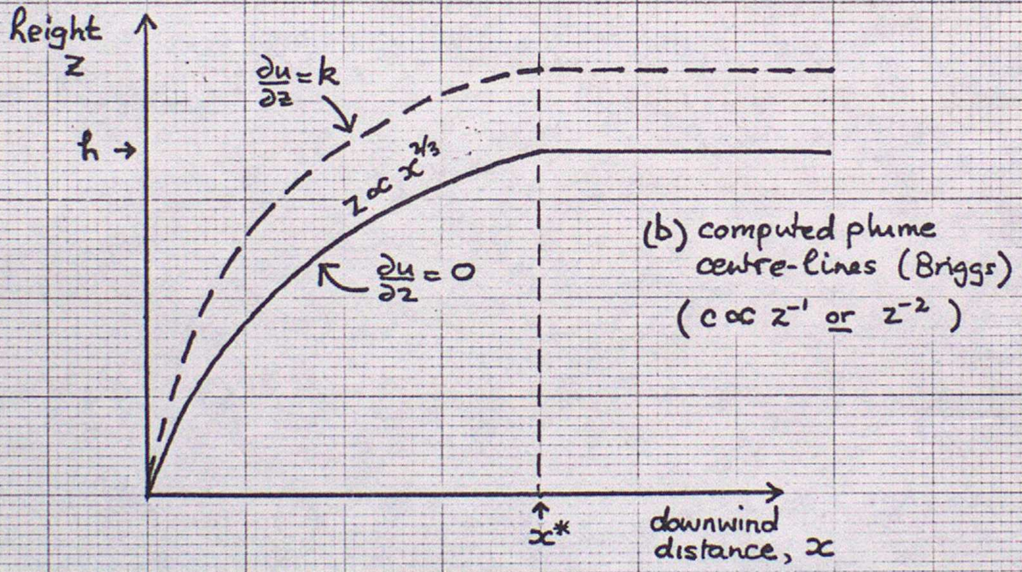


Table 1

Temperature Differences across the layer 1m - 150 m at Cardington from Hardy (1974)

Vaules of Ta (150m) - Ta (1m) exceeded on x per cent of occasions

x (per cent)	ΔT_a (deg C)	$\Delta T_a/\Delta z$ (deg K m^{-1})	S (sec^{-2})	$S^{-\frac{1}{3}}$ ($sec^{2/3}$)
20	1.5	1.01×10^{-2}	7.03×10^{-4}	14.2
10	3.0	2.01×10^{-2}	1.06×10^{-3}	9.8
1	6.3	4.23×10^{-2}	1.83×10^{-3}	8.2
0.1	12.5	8.39×10^{-2}	3.29×10^{-3}	6.7

TABLE 2

MODIFIED PASQUILL STABILITY CATEGORIES

Wind Speed (kt)	DAYTIME (excluding 1 hour after sunrise and 1 hour before sunset) Incoming Solar Radiation ($mW\ cm^{-2}$)				Within 1 hour before sunset or after sunrise	NIGHT-TIME Cloud Amount (oktas)		
	Strong(≥60)	Mod(30-60)	Slt.(<30)	Overcast		0-3	4-7	8
<4	A	A-B	B	C	D	F or G see note 2 below	F	D
4-5	A-B	B	C	C	D	F	E	D
6-9	B	B-C	C	C	D	E	D	D
10-12	C	C-D	D	D	D	D	D	D
>12	C	D	D	D	D	D	D	D

Notes

1. Night was originally defined to include periods of one hour before sunset and after sunrise. These two hours are always categorised here as D.

2. Pasquill said that in light winds on clear nights the vertical speed may be less than for category F but excluded such cases because the surface plume is unlikely to have any definable travel. However, they are important from the point of view of the build up of pollution and category G (night-time, 0 or 1 okta of cloud, wind speed 0 or 1 kt) has been added.

Table 3

Rise of a buoyant plume with added momentum (Neutral/Unstable)

(ρ_G/ρ_A = 0.56, r_o = 1.5 m)   Briggs - equation (6a)

Q ($m^3 s^{-1}$)	F ($m^4 s^3$)	W_o ($m s^{-1}$)	x^* (m)	h(metres) u=0.5	u=1	u=2	u=3	u=10 $m s^{-1}$
14	19.2	1.98	111	198 (1.001)	99 (1.002)	50 (1.003)	20 (1.007)	10 (1.015)
80	110.0	11.32	223	565 (1.002)	283 (1.004)	142 (1.009)	57 (1.021)	30 (1.042)
100	137.5	14.15	244	647 (1.003)	323 (1.005)	162 (1.010)	66 (1.024)	34 (1.048)
300	412.4	42.44	378	1251 (1.005)	628 (1.010)	317 (1.019)	130 (1.046)	68 (1.089)
500	687.3	70.74	464	1704 (1.007)	857 (1.013)	434 (1.026)	179 (1.062)	95 (1.117)

(Values of E_m are shown in parenthesis below each value of h)

Table 4

Rise of a buoyant plume with added momentum (Stable)

$\rho_G/\rho_A = 0.56$, $r_o = 1.5$ m)   Briggs - equation (6b)

(a) Temperature lapse-rate cateogry S2   ($S=1.06 \times 10^{-3}$ sec^{-2})

Q (m^3s^{-1})	W_o (ms^{-1})	E_m	h(metres) u=0.5	u=1	u=2	u=5ms^{-1}
14	1.98	1.002	80	63	50	37
80	11.32	1.010	143	114	90	67
100	14.15	1.012	155	123	98	72
300	42.44	1.036	229	182	144	106
500	70.74	1.059	277	220	175	129

(b) Temperature lapse-rate category S4   ($S=3.29 \times 10^{-3}$ sec^{-2})

Q (m^3s^{-1})	W_o (ms^{-1})	E_m	h(metres) u=0.5	u=1	u=2	u=5ms^{-1}
14	1.98	1.003	55	43	34	25
80	11.32	1.017	99	79	62	46
100	14.15	1.022	107	85	68	50
300	42.44	1.063	161	128	101	75
500	70.74	1.101	197	157	124	92

Values for wind speeds to the right of the pecked lines are hypothetical since the indicated lapse rate is unlikely to occur above a limiting wind speed.

Table 5

Downwind distance of final plume rise (Stable)

$x_s^* = \pi u s^{-1/2}$ (equation (5b))

Lapse-rate category	S (sec^{-2})	x_s^* (metres) u=0.5	u=1	u=2	u=5ms^{-1}
S1	7.03×10^{-4}	59	118	237	592
S2	1.06×10^{-3}	48	97	193	483
S3	1.83×10^{-3}	37	73	147	367
S4	3.29×10^{-3}	27	55	110	273

Vaules for wind speeds to the right of the pecked lines are hypothetical only, since the indicated lapse rate is unlikely to occur above a limiting wind speed.

TABLE 6 (a) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 14\ m^3\ s^{-1}$ method A $n = 1$ $p = 5$

lapse/stab category	U ($m\ s^{-1}$)	Centre-line concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	3.4	2.0	0.77	0.32
		(91)	(91)	(91)	(91)
	1	3.0	1.5	0.46	0.18
		(65)	(72)	(72)	(72)
	2	2.5	0.97	0.27	0.09
		(32)	(50)	(50)	(50)
	4	1.7	0.60	0.15	0.05
		(16)	(25)	(25)	(25)
S2	0.5	4.9	3.2	1.4	0.65
		(80)	(80)	(80)	(80)
	1	4.4	2.5	0.92	0.38
		(63)	(63)	(63)	(63)
	2	4.2	1.7	0.54	0.21
		(32)	(50)	(50)	(50)
S3	0.5	6.6	4.7	2.3	1.1
		(66)	(66)	(66)	(66)
	1	6.2	3.9	1.6	0.68
		(53)	(53)	(53)	(53)
S4	0.5	7.5	5.2	2.5	1.2
		(55)	(55)	(55)	(55)
	1	6.9	4.2	1.6	0.70
		(43)	(43)	(43)	(43)
D	6	0.76	0.25	0.07	0.03
		(16)	(17)	(17)	(17)
	10	0.51	0.17	0.06	0.02
		(9)	(10)	(10)	(10)
	20	0.35	0.14	0.03	0.01
		(5)	(5)	(5)	(5)

height of plume centre-line in metres is given below each percentage figure.

Table 6(a)

$Q = 14\ m^3 s^{-1}$ Method A

Stability category	U (ms^{-1})	Centre line concentration (per cent) at: x=100	200	500	1000m
A	0.5	0.53	0.18	0.03	0.008
	1	0.37	0.12	0.02	0.005
B	0.5	0.75	0.31	0.07	0.02
	1	0.61	0.21	0.04	0.02
	2	0.41	0.12	0.02	0.01
	4	0.24	0.07	0.02	0.006
C	0.5	1.2	0.57	0.17	0.06
	1	1.1	0.42	0.10	0.03
	2	0.78	0.27	0.06	0.02
	4	0.49	0.15	0.04	0.02
	6	0.35	0.12	0.04	0.01
	10	0.23	0.10	0.02	0.007
D	0.5	1.8 (185)	1.0 (198)	0.39 (198)	0.16 (198)
	1	1.9 (93)	0.87 (99)	0.26 (99)	0.09 (99)
	2	1.5 (46)	0.59 (50)	0.15 (50)	0.05 (50)
	4	1.0 (23)	0.35 (25)	0.08 (25)	0.04 (25)

TABLE 6 (b) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 14\ m^3\ s^{-1}$ method B $n = 1$ $p = 2.25$

lapse/stab category	U (ms^{-1})	Centre-line concentration (per cent) at;- x=100	200	500	1000m
S1	0.5	2.1	1.4	0.62	0.28
	1	2.0	1.1	0.40	0.16
	2	2.0	0.80	0.24	0.09
	4	1.5	0.54	0.14	0.05
S2	0.5	2.8	2.1	1.1	0.55
	1	2.7	1.8	0.76	0.34
	2	3.0	1.4	0.48	0.19
S3	0.5	3.6	2.8	1.7	0.92
	1	3.7	2.6	1.2	0.59
S4	0.5	4.2	3.2	1.8	0.98
	1	4.3	2.9	1.3	0.62
D	6	0.70	0.24	0.07	0.03
	10	0.48	0.17	0.06	0.02
	20	0.34	0.14	0.03	0.01

plume centre-line heights are the same as for method A

Table 6(b)

$Q = 14\ m^3 s^{-1}$ Method B

Stability category	U (ms^{-1})	Centre-line concentration (per cent) at: x=100	200	500	1000m
A	0.5	0.36	0.13	0.02	0.007
	1	0.36	0.11	0.02	0.004
B	0.5	0.51	0.24	0.07	0.02
	1	0.47	0.18	0.04	0.02
	2	0.35	0.11	0.02	0.01
	4	0.22	0.07	0.02	0.006
C	0.5	0.75	0.41	0.14	0.05
	1	0.80	0.35	0.09	0.03
	2	0.65	0.24	0.05	0.02
	4	0.44	0.14	0.04	0.02
	6	0.33	0.12	0.03	0.01
	10	0.23	0.10	0.02	0.007
D	0.5	1.0	0.67	0.30	0.14
	1	1.3	0.66	0.22	0.09
	2	1.2	0.51	0.14	0.05
	4	0.90	0.32	0.08	0.04

TABLE 6 (c) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 14\ m^3 s^{-1}$ method C   n = 2   p = 5

lapse/stab category	U (ms^{-1})	Centre-line concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	0.47	0.04	0.26	0.16
	1	0.71	0.45	0.23	0.12
	2	1.2	0.49	0.19	0.08
	4	1.3	0.46	0.13	0.05
S2	0.5	0.64	0.56	0.41	0.28
	1	0.85	0.68	0.40	0.23
	2	1.7	0.71	0.33	0.16
S3	0.5	0.92	0.82	0.63	0.44
	1	1.2	1.0	0.65	0.39
S4	0.5	1.3	1.1	0.80	0.54
	1	1.7	1.3	0.79	0.44
D	6	0.63	0.22	0.07	0.03
	10	0.47	0.17	0.06	0.02
	20	0.34	0.14	0.03	0.01

plume centre-line heights are the same as for method A.

Table 6(c)

$Q = 14\ m^3s^{-1}$ Method C

Stability category	U (ms^{-1})	Centre-line concentration (per cent) at: x=100	200	500	1000m
A	0.5	0.07	0.04	0.02	0.004
	1	0.14	0.05	0.02	0.003
B	0.5	0.10	0.06	0.03	0.01
	1	0.20	0.10	0.03	0.01
	2	0.25	0.09	0.03	0.01
	4	0.20	0.07	0.02	0.006
C	0.5	0.12	0.08	0.05	0.03
	1	0.28	0.16	0.06	0.02
	2	0.41	0.18	0.05	0.02
	4	0.38	0.13	0.04	0.02
	6	0.21	0.11	0.03	0.01
	10	0.22	0.10	0.02	0.007
D	0.5	0.13	0.10	0.08	0.05
	1	0.37	0.24	0.12	0.06
	2	0.67	0.34	0.11	0.04
	4	0.80	0.29	0.08	0.04

TABLE 6(d) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 14\ m^3\ s^{-1}$ method D $n = 2$ $p = 2.25$

lapse/stab category	U (ms^{-1})	Centre-line concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	0.12	0.11	0.09	0.07
	1	0.21	0.15	0.10	0.07
	2	0.52	0.21	0.11	0.06
	4	0.81	0.31	0.11	0.05
S2	0.5	0.16	0.15	0.13	0.10
	1	0.23	0.21	0.16	0.11
	2	0.63	0.27	0.17	0.10
S3	0.5	0.23	0.22	0.19	0.16
	1	0.33	0.30	0.24	0.18
S4	0.5	0.33	0.31	0.26	0.21
	1	0.46	0.42	0.32	0.23
D	6	0.46	0.19	0.07	0.03
	10	0.39	0.16	0.06	0.02
	20	0.34	0.14	0.03	0.01

plume centre-line heights are the same as for method A

Table 6(d)

$Q = 14\ m^3s^{-1}$ Method D

Stability category	U (ms^{-1})	Centre-line concentration (per cent) at: x=100	200	500	1000m
A	0.5	0.02	0.02	0.008	0.003
	1	0.05	0.03	0.01	0.003
B	0.5	0.03	0.02	0.01	0.01
	1	0.07	0.04	0.02	0.01
	2	0.13	0.06	0.03	0.01
	4	0.15	0.07	0.02	0.006
C	0.5	0.03	0.02	0.02	0.01
	1	0.09	0.06	0.03	0.02
	2	0.19	0.10	0.04	0.02
	4	0.25	0.10	0.04	0.01
	6	0.24	0.10	0.03	0.01
	10	0.21	0.09	0.02	0.007
D	0.5	0.03	0.03	0.02	0.02
	1	0.10	0.08	0.05	0.03
	2	0.27	0.17	0.08	0.04
	4	0.44	0.20	0.07	0.03

TABLE 7(a) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 80\ m^3\ s^{-1}$ method A n = 1 p = 5

lapse/stab category	U (ms^{-1})	Centre-line concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	3.4 (147)	2.8 (164)	1.7 (164)	1.0 (164)
	1	4.0 (117)	2.7 (130)	1.4 (130)	0.69 (130)
	2	5.0 (59)	2.4 (92)	0.97 (103)	0.42 (103)
	4	5.0 (30)	2.1 (47)	0.62 (71)	0.24 (71)
S2	0.5	4.2 (144)	3.7 (144)	2.6 (144)	1.7 (144)
	1	4.7 (114)	3.8 (114)	2.3 (114)	1.3 (114)
	2	6.6 (59)	3.5 (91)	1.7 (91)	0.84 (91)
S3	0.5	5.2 (120)	4.7 (120)	3.6 (120)	2.5 (120)
	1	6.0 (95)	5.0 (95)	3.3 (95)	2.0 (95)
S4	0.5	6.2 (99)	5.5 (99)	4.1 (99)	2.8 (99)
	1	7.0 (79)	5.8 (79)	3.7 (79)	2.2 (79)
D	6	2.7 (29)	1.0 (45)	0.27 (48)	0.09 (48)
	10	2.1 (18)	0.72 (27)	0.17 (29)	0.07 (29)
	20	1.3 (10)	0.41 (14)	0.13 (15)	0.05 (15)

height of plume centre-line in metres is given below each percentage figure.

Table 7(a)

$Q = 80\ m^3 s^{-1}$ Method A

Stability category	U (ms^{-1})	Centre-line concentration (per cent) at:- x=100	200	500	1000m
A	0.5	0.79	0.29	0.07	0.02
	1	0.92	0.30	0.05	0.02
B	0.5	1.1	0.53	0.21	0.08
	1	1.3	0.54	0.16	0.05
	2	1.3	0.44	0.11	0.03
	4	0.94	0.30	0.06	0.03
C	0.5	1.4	0.75	0.37	0.18
	1	1.9	0.88	0.33	0.13
	2	2.1	0.82	0.24	0.08
	4	1.7	0.60	0.15	0.05
	6	1.4	0.47	0.11	0.05
	10	1.0	0.32	0.09	0.04
D	0.5	1.7 (332)	0.99 (526)	0.63 (565)	0.39 (565)
	1	2.6 (167)	1.4 (263)	0.67 (283)	0.33 (283)
	2	3.2 (84)	1.5 (132)	0.55 (142)	0.22 (142)
	4	3.1 (43)	1.2 (67)	0.36 (72)	0.13 (72)

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TABLE 7(b) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 80\ m^3\ s^{-1}$ method B $n = 1$ $p = 2.25$

lapse/stab category	U (ms^{-1})	centre-line concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	1.7	1.5	1.1	0.71
	1	2.1	1.6	0.95	0.54
	2	3.1	1.6	0.74	0.36
	4	3.5	1.6	0.53	0.22
S2	0.5	2.1	1.9	1.5	1.1
	1	2.4	2.1	1.4	0.92
	2	3.8	2.1	1.2	0.67
S3	0.5	2.5	2.4	2.0	1.5
	1	3.0	2.7	2.0	1.4
S4	0.5	3.0	2.8	2.3	1.7
	1	3.6	3.1	2.3	1.5
D	6	2.1	0.84	0.24	0.09
	10	1.7	0.64	0.16	0.07
	20	1.2	0.39	0.13	0.05

plume centre-line heights are the same as for method A.

Table 7(b)

$Q = 80\ m^3s^{-1}$ Method B

Stability category	U (ms^{-1})	Centre-line concentration (per cent) at: x=100	200	500	1000m
A	0.5	0.45	0.18	0.05	0.02
	1	0.58	0.20	0.04	0.02
B	0.5	0.63	0.32	0.15	0.07
	1	0.84	0.37	0.13	0.05
	2	0.90	0.34	0.09	0.03
	4	0.77	0.26	0.06	0.03
C	0.5	0.75	0.41	0.24	0.13
	1	1.1	0.56	0.25	0.11
	2	1.4	0.59	0.20	0.07
	4	1.3	0.50	0.13	0.05
	6	1.2	0.41	0.10	0.05
	10	0.90	0.30	0.09	0.03
D	0.5	0.86	0.51	0.36	0.25
	1	1.4	0.78	0.45	0.25
	2	2.0	0.99	0.43	0.19
	4	2.2	0.96	0.32	0.12

LK

ABLE 7(c) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 80\ m^3\ s^{-1}$ method C $n = 2$ $p = 5$

lapse/stab category	U (ms^{-1})	centre-line concentration (per cent) at:- x = 100	200	500	1000m
S1	0.5	0.19	0.18	0.16	0.14
	1	0.34	0.26	0.21	0.16
	2	0.99	0.41	0.25	0.17
	4	2.0	0.83	0.29	0.15
S2	0.5	0.24	0.23	0.21	0.18
	1	0.36	0.34	0.30	0.25
	2	1.1	0.48	0.38	0.28
S3	0.5	0.34	0.33	0.30	0.27
	1	0.51	0.50	0.44	0.37
S4	0.5	0.49	0.48	0.44	0.40
	1	0.72	0.70	0.60	0.50
D	6	1.4	0.53	0.19	0.08
	10	1.4	0.52	0.15	0.07
	20	1.1	0.37	0.13	0.05

plume centre-line heights are the same as for method A.

Table 7(c)

$Q = 80\ m^3 s^{-1}$ Method B

Stability category	U (ms^{-1})	Centre-line concentration (per cent) at: x=100	200	500	1000m
A	0.5	0.04	0.02	0.01	0.005
	1	0.10	0.04	0.02	0.007
B	0.5	0.05	0.02	0.01	0.01
	1	0.14	0.05	0.03	0.02
	2	0.32	0.12	0.05	0.03
	4	0.48	0.16	0.05	0.02
C	0.5	0.05	0.02	0.02	0.01
	1	0.16	0.06	0.04	0.03
	2	0.42	0.16	0.08	0.04
	4	0.75	0.27	0.09	0.05
	6	0.83	0.29	0.08	0.04
	10	0.77	0.25	0.08	0.03
D	0.5	0.05	0.02	0.02	0.02
	1	0.17	0.07	0.05	0.04
	2	0.51	0.21	0.13	0.08
	4	1.1	0.44	0.20	0.09

LK

TABLE 7(d) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 80\ m^3\ s^{-1}$ method D $n = 2$ $p = 2.25$

lapse/stab category	U (ms^{-1})	centre-line concentration (per cent) at:- x = 100	200	500	1000m
S1	0.5	0.06	0.06	0.06	0.06
	1	0.10	0.08	0.07	0.06
	2	0.28	0.11	0.08	0.07
	4	0.75	0.31	0.12	0.08
S2	0.5	0.08	0.08	0.08	0.07
	1	0.11	0.10	0.10	0.09
	2	0.29	0.12	0.11	0.10
S3	0.5	0.12	0.12	0.11	0.11
	1	0.15	0.15	0.14	0.13
S4	0.5	0.17	0.17	0.16	0.15
	1	0.22	0.21	0.20	0.18
D	6	0.59	0.24	0.11	0.06
	10	0.84	0.31	0.12	0.07
	20	0.85	0.31	0.12	0.05

plume centre-line heights are the same as for method A.

Table 7(d)

$Q = 80\ m^3s^{-1}$ Method D

Stability category	U (ms^{-1})	Centre-line concentration (per cent) at: x=100	200	500	1000m
A	0.5	0.01	0.005	0.003	0.002
	1	0.04	0.02	0.008	0.003
B	0.5	0.01	0.006	0.005	0.005
	1	0.05	0.02	0.01	0.01
	2	0.12	0.04	0.03	0.02
	4	0.23	0.09	0.04	0.02
C	0.5	0.02	0.006	0.005	0.005
	1	0.05	0.02	0.01	0.01
	2	0.13	0.05	0.04	0.03
	4	0.30	0.11	0.06	0.04
	6	0.42	0.16	0.07	0.04
	10	0.50	0.18	0.07	0.03
D	0.5	0.02	0.006	0.006	0.005
	1	0.05	0.02	0.02	0.02
	2	0.14	0.06	0.04	0.03
	4	0.38	0.15	0.09	0.06

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TABLE 8(a) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 100\ m^3\ s^{-1}$ method A $n = 1$ $p = 5$

lapse/stab category	U (ms^{-1})	centre-line concentration (per cent) at:- x = 100	200	500	1000m
S1	0.5	3.3	2.8	1.8	1.1
		(177)	(177)	(177)	(177)
	1	3.9	2.8	1.5	0.79
		(126)	(141)	(141)	(141)
	2	5.2	2.6	1.1	0.50
		(64)	(100)	(112)	(112)
	4	5.4	2.4	0.73	0.29
		(33)	(51)	(81)	(81)
S2	0.5	4.0	3.6	2.7	1.8
		(155)	(155)	(155)	(155)
	1	4.6	3.8	2.4	1.4
		(123)	(123)	(123)	(123)
	2	6.6	3.6	1.9	0.97
		(64)	(98)	(98)	(98)
S3	0.5	5.0	4.5	3.6	2.6
		(130)	(130)	(130)	(130)
	1	5.7	4.9	3.4	2.2
		(103)	(103)	(103)	(103)
S4	0.5	5.8	5.3	4.1	2.9
		(107)	(107)	(107)	(107)
	1	6.7	5.7	3.8	2.4
		(85)	(85)	(85)	(85)
D	6	3.0	1.2	0.32	0.11
		(32)	(49)	(55)	(55)
	10	2.4	0.85	0.21	0.08
		(20)	(30)	(34)	(34)
	20	1.5	0.50	0.15	0.06
		(11)	(16)	(18)	(18)

height of plume centre-line in metres is given below each percentage figure.

Table 8(a)

$Q = 100\ m^3s^{-1}$ Method A

Stability category	U (ms^{-1})	Centre-line concentration (per cent) at: x=100	200	500	1000m
A	0.5	0.81	0.31	0.07	0.02
	1	0.97	0.32	0.06	0.02
B	0.5	1.1	0.55	0.23	0.09
	1	1.4	0.59	0.18	0.06
	2	1.4	0.51	0.13	0.04
	4	1.1	0.35	0.08	0.03
C	0.5	1.4	0.75	0.39	0.20
	1	2.0	0.94	0.37	0.15
	2	2.2	0.91	0.27	0.10
	4	1.9	0.70	0.17	0.06
	6	1.6	0.55	0.13	0.05
	10	1.2	0.38	0.10	0.04
D	0.5	1.7 (358)	0.97 (566)	0.62 (646)	0.41 (646)
	1	2.6 (180)	1.4 (284)	0.71 (324)	0.37 (324)
	2	3.4 (91)	1.6 (143)	0.62 (163)	0.26 (163)
	4	3.4 (47)	1.4 (72)	0.43 (82)	0.16 (82)

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TABLE 8 (b) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 100\ m^3s^{-1}$ method B n = 1 p = 2.25

lapse/stab category	U (ms^{-1})	centre-line concentration (per cent) at:- x = 100	200	500	1000m
S1	0.5	1.6	1.5	1.1	0.75
	1	2.1	1.6	1.0	0.59
	2	3.1	1.6	0.81	0.41
	4	3.7	1.7	0.59	0.26
S2	0.5	2.0	1.8	1.5	1.1
	1	2.3	2.0	1.5	0.99
	2	3.7	2.1	1.3	0.76
S3	0.5	2.4	2.2	1.9	1.5
	1	2.9	2.6	2.0	1.4
S4	0.5	2.8	2.7	2.2	1.8
	1	3.4	3.0	2.3	1.6
D	6	2.3	0.95	0.29	0.11
	10	2.0	0.75	0.20	0.08
	20	1.4	0.46	0.14	0.06

plume centre-line heights are the same as for method A.

Table 8(b)

$Q = 100\ m^3 s^{-1}$ Method B

Stability category	U (ms^{-1})	Centre-line concentration (per cent) at: x=100	200	500	1000m
A	0.5	0.45	0.19	0.05	0.02
	1	0.60	0.22	0.05	0.02
B	0.5	0.62	0.32	0.15	0.07
	1	0.86	0.39	0.14	0.06
	2	0.97	0.38	0.11	0.04
	4	0.87	0.30	0.07	0.03
C	0.5	0.73	0.41	0.24	0.14
	1	1.1	0.57	0.26	0.12
	2	1.4	0.64	0.22	0.09
	4	1.5	0.57	0.15	0.05
	6	1.4	0.52	0.13	0.05
	10	1.0	0.35	0.10	0.04
D	0.5	0.82	0.49	0.35	0.25
	1	1.4	0.78	0.46	0.27
	2	2.0	1.0	0.47	0.22
	4	2.4	1.1	0.37	0.15

Table 8 (c) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 100\ m^3 s^{-1}$ method C n = 2 p = 5

lapse/stab category	U (ms^{-1})	Centre-line concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	0.17	0.16	0.14	0.13
	1	0.30	0.23	0.20	0.16
	2	0.90	0.38	0.24	0.17
	4	2.0	0.83	0.28	0.16
S2	0.5	0.22	0.21	0.19	0.17
	1	0.32	0.30	0.27	0.23
	2	0.98	0.43	0.36	0.27
S3	0.5	0.31	0.30	0.28	0.25
	1	0.45	0.43	0.40	0.34
S4	0.5	0.44	0.42	0.39	0.35
	1	0.63	0.60	0.54	0.46
D	6	1.4	0.55	0.20	0.09
	10	1.6	0.58	0.17	0.08
	20	1.3	0.43	0.14	0.06

plume centre-line heights are the same as for method A

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Table 8(c)

$Q = 100\ m^3s^{-1}$ Method C

Stability category	U (ms^{-1})	Centre line concentration (per cent) at:- x=100	200	500	1000m
A	0.5	0.04	0.01	0.008	0.005
	1	0.10	0.04	0.02	0.007
B	0.5	0.04	0.02	0.01	0.01
	1	0.13	0.05	0.03	0.02
	2	0.31	0.11	0.05	0.03
	4	0.50	0.17	0.05	0.03
C	0.5	0.04	0.02	0.01	0.01
	1	0.14	0.06	0.04	0.03
	2	0.39	0.15	0.08	0.04
	4	0.75	0.28	0.10	0.05
	6	0.89	0.31	0.09	0.05
	10	0.87	0.29	0.09	0.04
D	0.5	0.04	0.02	0.01	0.01
	1	0.15	0.06	0.04	0.04
	2	0.47	0.19	0.12	0.08
	4	1.0	0.43	0.20	0.10

Table 8 (d) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 100\ m^3 s^{-1}$ method D n = 2 p = 2.25

lapse/stab category	U (ms^{-1})	Centre-line concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	0.06	0.06	0.05	0.05
	1	0.10	0.08	0.07	0.06
	2	0.26	0.11	0.08	0.06
	4	0.68	0.29	0.10	0.08
S2	0.5	0.08	0.07	0.07	0.07
	1	0.10	0.10	0.09	0.08
	2	0.27	0.12	0.10	0.09
S3	0.5	0.11	0.11	0.10	0.10
	1	0.14	0.14	0.13	0.12
S4	0.5	0.16	0.15	0.15	0.14
	1	0.21	0.20	0.19	0.17
D	6	0.56	0.23	0.11	0.06
	10	0.83	0.33	0.13	0.07
	20	0.94	0.34	0.13	0.06

plume centre-line heights are the same as for method A

Table 8(d)

$Q=100m^3s^{-1}$ Method D

Stability category	U (ms^{-1})	Centre line concentration (per cent) at:- x=100	200	500	1000m
A	0.5	0.01	0.005	0.002	0.001
	1	0.04	0.01	0.007	0.003
B	0.5	0.01	0.006	0.004	0.004
	1	0.04	0.02	0.01	0.01
	2	0.11	0.04	0.03	0.02
	4	0.23	0.09	0.04	0.02
C	0.5	0.01	0.006	0.004	0.004
	1	0.05	0.02	0.01	0.01
	2	0.12	0.05	0.03	0.03
	4	0.28	0.11	0.06	0.04
	6	0.42	0.16	0.07	0.04
	10	0.53	0.20	0.08	0.03
D	0.5	0.01	0.006	0.004	0.004
	1	0.05	0.02	0.01	0.01
	2	0.12	0.05	0.04	0.03
	4	0.35	0.14	0.08	0.06

Table 9(a) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 300\ m^3s^{-1}$ method A   n = 1   p = 5

lapse/stab category	U (ms^{-1})	Centre-line concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	2.6 (260)	2.4 (260)	1.9 (260)	1.5 (260)
	1	3.3 (186)	2.7 (207)	1.9 (207)	1.3 (207)
	2	5.2 (96)	3.0 (147)	1.7 (164)	0.97 (164)
	4	6.8 (51)	3.6 (76)	1.3 (130)	0.66 (130)
S2	0.5	3.0 (229)	2.8 (229)	2.5 (229)	2.0 (229)
	1	3.6 (182)	3.3 (182)	2.6 (182)	1.9 (182)
	2	5.9 (96)	3.6 (144)	2.5 (144)	1.7 (144)
S3	0.5	3.6 (193)	3.5 (193)	3.1 (193)	2.6 (193)
	1	4.4 (153)	4.1 (153)	3.4 (153)	2.7 (153)
S4	0.5	4.3 (161)	4.1 (161)	3.6 (161)	3.0 (161)
	1	5.1 (128)	4.8 (128)	3.9 (128)	3.0 (128)
D	6	4.6 (51)	2.1 (75)	0.69 (109)	0.28 (109)
	10	4.3 (33)	1.8 (47)	0.51 (68)	0.19 (68)
	20	3.2 (19)	1.2 (26)	0.30 (36)	0.11 (36)

height of plume centre-line in metres is given below each percentage figure.

Table 9(a)

$Q=300 m^3 s^{-1}$ Method A

Stability category	U_1 (ms^{-1})	Centre line concentration (per cent) at:- $x=100$	200	500	1000 m.
A	0.5	0.78	0.35	0.09	0.03
	1	1.1	0.44	0.09	0.03
B	0.5	1.0	0.57	0.26	0.15
	1	1.6	0.77	0.28	0.13
	2	1.9	0.84	0.25	0.09
	4	1.9	0.72	0.17	0.06
C	0.5	1.2	0.69	0.36	0.25
	1	1.9	1.0	0.47	0.25
	2	2.7	1.3	0.47	0.21
	4	3.0	1.3	0.37	0.14
	6	2.9	1.1	0.30	0.10
	10	2.4	0.89	0.21	0.08
D	0.5	1.3 (522)	0.79 (822)	0.47 (1251)	0.38 (1251)
	1	2.3 (266)	1.3 (415)	0.71 (629)	0.49 (629)
	2	3.5 (137)	1.9 (211)	0.87 (317)	0.48 (317)
	4	4.1 (72)	2.2 (109)	0.86 (161)	0.42 (161)

Table 9(b) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 300\ m^3 s^{-1}$ method B $n = 2$ $p = 2.25$

lapse/stab category	U (ms^{-1})	Centre-line concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	1.2	1.22	1.0	0.82
	1	1.6	1.3	1.1	0.80
	2	2.7	1.6	1.1	0.68
	4	4.0	2.2	0.92	0.51
S2	0.5	1.4	1.4	1.2	1.1
	1	1.7	1.6	1.4	1.1
	2	3.0	1.9	1.5	1.1
S3	0.5	1.7	1.6	1.5	1.4
	1	2.1	2.0	1.8	1.5
S4	0.5	2.0	1.9	1.8	1.6
	1	2.5	2.4	2.1	1.7
D	6	3.0	1.5	9.54	0.24
	10	3.1	1.4	0.44	0.17
	20	2.6	1.0	0.28	0.11

plume centre-line heights are the same as for method A

Table 9(b)

$Q=300\ m^3s^{-1}$ Method B

Stability category	U_1 (ms^{-1})	Centre line concentration (per cent) at:- x=100	200	500	1000m
A	0.5	0.40	0.19	0.06	0.03
	1	0.62	0.26	0.06	0.03
B	0.5	0.52	0.30	0.15	0.09
	1	0.85	0.45	0.19	0.09
	2	1.2	0.55	0.18	0.08
	4	1.3	0.54	0.15	0.05
C	0.5	0.57	0.34	0.19	0.15
	1	0.99	0.56	0.28	0.17
	2	1.5	0.79	0.32	0.16
	4	1.9	0.90	0.29	0.12
	6	2.0	0.86	0.25	0.09
	10	1.9	0.73	0.19	0.08
D	0.5	0.61	0.38	0.23	0.20
	1	1.1	0.67	0.38	0.29
	2	1.9	1.1	0.53	0.34
	4	2.7	1.4	0.58	0.30

Table 9(c) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 300\ m^3 s^{-1}$ method C $n = 2$ $p = 5$

lapse/stab category	u (ms^{-1})	Centre-line concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	0.12	0.12	0.11	0.10
	1	0.17	0.14	0.13	0.12
	2	0.50	0.22	0.16	0.14
	4	1.4	0.62	0.21	0.16
S2	0.5	0.15	0.15	0.14	0.14
	1	0.18	0.18	0.17	0.16
	2	0.51	0.24	0.22	0.19
S3	0.5	0.21	0.21	0.20	0.20
	1	0.26	0.25	0.24	0.23
S4	0.5	0.30	0.30	0.29	0.28
	1	0.36	0.35	0.34	0.32
D	6	1.1	0.51	0.20	0.12
	10	1.7	0.75	0.26	0.13
	20	2.0	0.81	0.23	0.11

plume centre-line heights are the same as for method A

Table 9(c)

$Q=300\ m^3s^{-1}$ Method C

Stability category	U_1 (ms^{-1})	Centre line concentration (per cent) at:- x=100	200	500	1000m
A	0.5	0.03	0.01	0.003	0.002
	1	0.08	0.03	0.01	0.005
B	0.5	0.03	0.01	0.005	0.005
	1	0.08	0.04	0.01	0.01
	2	0.22	0.09	0.03	0.03
	4	0.47	0.19	0.06	0.04
C	0.5	0.03	0.01	0.005	0.005
	1	0.08	0.03	0.01	0.01
	2	0.24	0.10	0.04	0.03
	4	0.59	0.25	0.09	0.05
	6	0.87	0.36	0.12	0.06
	10	1.1	0.45	0.13	0.07
D	0.5	0.03	0.01	0.005	0.005
	1	0.09	0.04	0.01	0.01
	2	0.25	0.11	0.05	0.04
	4	0.71	0.32	0.13	0.10

TABLE 9 (d) COMPUTED DOWNWIND CENTRELINE CONCENTRATIONS

$Q = 300\ m^3\ s^{-1}$ method D n = 2 p = 2.25

lapse/stab category	U_1 (ms^{-1})	Centreline concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	0.03	0.03	0.03	0.03
	1	0.06	0.05	0.04	0.04
	2	0.18	0.08	0.06	0.06
	4	0.47	0.21	0.07	0.06
S2	0.5	0.04	0.04	0.04	0.04
	1	0.06	0.06	0.06	0.05
	2	0.18	0.08	0.08	0.07
S3	0.5	0.06	0.06	0.05	0.05
	1	0.08	0.08	0.08	0.08
S4	0.5	0.08	0.08	0.08	0.08
	1	0.12	0.12	0.11	0.11
D	6	0.37	0.17	0.07	0.06
	10	0.63	0.29	0.12	0.08
	20	1.1	0.46	0.16	0.09

plume centre-line heights are the same as for method A.

Table 9(d)

$Q=300\ m^3s^{-1}$ Method D

Stability category	U_1 (ms^{-1})	Centre line conentration (per cent) at:- x=100	200	500	1000m
A	0.5	0.007	0.003	0.001	0.001
	1	0.02	0.01	0.003	0.002
B	0.5	0.008	0.003	0.001	0.001
	1	0.03	0.01	0.005	0.004
	2	0.08	0.03	0.01	0.01
	4	0.21	0.09	0.03	0.02
C	0.5	0.008	0.003	0.001	0.001
	1	0.03	0.01	0.005	0.005
	2	0.09	0.04	0.02	0.01
	4	0.22	0.10	0.04	0.03
	6	0.35	0.15	0.06	0.04
	10	0.53	0.23	0.09	0.05
D	0.5	0.008	0.003	0.001	0.001
	1	0.03	0.01	0.005	0.005
	2	0.09	0.04	0.02	0.02
	4	0.24	0.10	0.05	0.04

TABLE 10(a) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 500\ m^3\ s^{-1}$ method A $n = 1$, $p = 5$

lapse/stab category	U_1 (ms^{-1})	Centre-line concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	2.2 (314)	2.1 (314)	1.8 (314)	1.5 (314)
	1	2.9 (225)	2.4 (250)	1.9 (250)	1.4 (250)
	2	4.8 (118)	2.9 (178)	1.9 (198)	1.2 (198)
	4	6.8 (64)	3.8 (94)	1.6 (157)	0.91 (157)
S2	0.5	2.5 (278)	2.4 (278)	2.2 (278)	1.9 (278)
	1	3.1 (220)	2.9 (220)	2.5 (220)	2.0 (220)
	2	5.2 (118)	3.3 (175)	2.6 (175)	1.9 (175)
S3	0.5	3.0 (235)	2.9 (235)	2.7 (235)	2.4 (235)
	1	3.7 (186)	3.5 (186)	3.1 (186)	2.6 (186)
S4	0.5	3.6 (197)	3.5 (197)	3.2 (197)	2.8 (197)
	1	4.3 (157)	4.1 (157)	3.6 (157)	3.0 (157)
D	6	4.9 (65)	2.5 (93)	0.91 (151)	0.41 (151)
	10	5.0 (43)	2.3 (60)	0.62 (95)	0.34 (95)
	20	4.2 (25)	1.7 (34)	0.51 (51)	0.22 (51)

height of plume centre-line in metres is given below each percentage figure.

Table 10(a)

$Q=500\ m^3s^{-1}$ Method A

Stability category	U_1 (ms^{-1})	Centre line concentration (per cent) at:- x=100	200	500	1000m
A	0.5	0.73	0.34	0.10	0.03
	1	1.1	0.47	0.11	0.04
B	0.5	0.95	0.54	0.24	0.16
	1	1.5	0.80	0.31	0.16
	2	2.0	0.97	0.30	0.12
	4	2.2	0.93	0.24	0.08
C	0.5	1.0	0.63	0.31	0.24
	1	1.8	1.0	0.45	0.28
	2	2.6	1.4	0.53	0.26
	4	3.3	1.5	0.48	0.20
	6	3.3	1.5	0.41	0.15
	10	3.0	1.2	0.31	0.10
D	0.5	1.1 (626)	0.70 (980)	0.38 (1703)	0.33 (1703)
	1	2.0 (322)	1.2 (497)	0.62 (857)	0.48 (857)
	2	3.2 (169)	1.9 (255)	0.87 (434)	0.56 (434)
	4	4.5 (91)	2.4 (134)	0.95 (222)	0.49 (222)

TABLE 10 (b) COMPUTED DOWNWIND CONTRE-LINE CONCENTRATIONS

$Q = 500\ m^3\ s^{-1}$ method B $n = 1$, $p = 2.25$

lapse/stab category	U_1 (ms^{-1})	Centre-line concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	1.0	0.99	0.90	0.78
	1	1.4	1.2	1.0	0.82
	2	2.4	1.5	1.1	0.77
	4	3.7	2.2	1.0	0.64
S2	0.5	1.2	1.1	1.0	0.87
	1	1.5	1.4	1.3	1.1
	2	2.6	1.7	1.4	1.1
S3	0.5	1.4	1.3	1.2	1.1
	1	1.7	1.7	1.5	1.4
S4	0.5	1.6	1.6	1.4	1.3
	1	2.1	2.0	1.8	1.6
D	6	2.9	1.6	0.64	0.33
	10	3.3	1.7	0.57	0.25
	20	3.1	1.4	0.40	0.16

plume centre-line heights are the same as for method A.

Table 10(b)

$Q=500m^3s^{-1}$ Method B

Stability category	U_1 (ms^{-1})	centre line concentration (per cent) at:- x=100	200	500	1000m
A	0.5	0.37	0.18	0.05	0.02
	1	0.59	0.27	0.07	0.03
B	0.5	0.46	0.27	0.13	0.09
	1	0.78	0.44	0.18	0.11
	2	1.2	0.59	0.21	0.10
	4	1.4	0.65	0.19	0.07
C	0.5	0.49	0.30	0.16	0.13
	1	0.88	0.52	0.25	0.18
	2	1.4	0.79	0.33	0.19
	4	1.9	1.0	0.35	0.16
	6	2.1	1.0	0.32	0.13
	10	2.2	0.94	0.26	0.09
D	0.5	0.52	0.32	0.18	0.16
	1	0.96	0.60	0.32	0.27
	2	1.6	1.0	0.49	0.35
	4	2.5	1.4	0.63	0.36

TABLE 10 (c) COMPUTED DOWNWIND CENTRE-LINE CONCENTRATIONS

$Q = 500\ m^3\ s^{-1}$ method C n = 2, p = 5

lapse/stab category	U_1 (ms^{-1})	Centre-line concentration (per cent) at :- x=100	200	500	1000m
S1	0.5	0.09	0.09	0.08	0.08
	1	0.15	0.12	0.11	0.10
	2	0.38	0.17	0.13	0.12
	4	1.0	0.47	0.17	0.14
S2	0.5	0.12	0.11	0.11	0.11
	1	0.16	0.15	0.15	0.14
	2	0.39	0.18	0.17	0.15
S3	0.5	0.17	0.16	0.16	0.15
	1	0.23	0.22	0.21	0.20
S4	0.5	0.24	0.23	0.22	0.21
	1	0.31	0.20	0.29	0.28
D	6	0.85	0.42	0.15	0.11
	10	1.4	0.68	0.24	0.14
	20	2.0	0.91	0.28	0.13

plume centre-line heights are the same as for method A.

Table 10(c)

$Q=500\ m^3s^{-1}$ Method C

Stability category	U_1 (ms^{-1})	centre line concentration (per cent) at:- x=100	200	500	1000m
A	0.5	0.02	0.008	0.002	0.001
	1	0.06	0.02	0.006	0.004
B	0.5	0.02	0.01	0.003	0.003
	1	0.07	0.03	0.01	0.01
	2	0.18	0.08	0.03	0.02
	4	0.39	0.17	0.05	0.04
C	0.5	0.02	0.01	0.003	0.003
	1	0.07	0.03	0.01	0.01
	2	0.18	0.08	0.03	0.02
	4	0.45	0.21	0.07	0.05
	6	0.59	0.27	0.09	0.06
	10	1.1	0.46	0.14	0.07
D	0.5	0.02	0.01	0.003	0.003
	1	0.07	0.03	0.01	0.01
	2	0.19	0.08	0.03	0.03
	4	0.51	0.24	0.09	0.07

Table 10(d)

$Q = 500\ m^3s^{-1}$ Method D

Stability category	U_1 (ms^{-1})	centre line concentration (per cent) at:- x=100	200	500	1000m
A	0.5	0.005	0.002	0.001	0.001
	1	0.02	0.007	0.002	0.001
B	0.5	0.005	0.002	0.001	0.001
	1	0.02	0.008	0.003	0.003
	2	0.06	0.03	0.01	0.008
	4	0.17	0.07	0.03	0.02
C	0.5	0.006	0.002	0.001	0.001
	1	0.02	0.008	0.003	0.003
	2	0.06	0.03	0.01	0.01
	4	0.18	0.08	0.03	0.02
	6	0.29	0.14	0.05	0.04
	10	0.46	0.22	0.08	0.05
D	0.5	0.006	0.002	0.001	0.001
	1	0.02	0.008	0.003	0.003
	2	0.07	0.03	0.01	0.01
	4	0.18	0.09	0.03	0.03

TABLE 10(d) COMPUTED DOWNWIND CONTRE-LINE CONCENTRATIONS

$Q = 500\ m^3\ s^{-1}$ method D $n = 2,$ $p = 2.25$

lapse/stab category	U_1 (ms^{-1})	Centre-line concentration (per cent) at:- x=100	200	500	1000m
S1	0.5	0.02	0.02	0.02	0.02
	1	0.04	0.03	0.03	0.03
	2	0.14	0.06	0.05	0.04
	4	0.37	0.18	0.06	0.06
S2	0.5	0.03	0.03	0.03	0.03
	1	0.05	0.04	0.04	0.04
	2	0.14	0.06	0.06	0.06
S3	0.5	0.04	0.04	0.04	0.04
	1	0.06	0.06	0.06	0.06
S4	0.5	0.05	0.05	0.05	0.05
	1	0.09	0.08	0.08	0.08
D	6	0.31	0.15	0.04	0.03
	10	0.50	0.25	0.09	0.07
	20	0.87	0.43	0.15	0.10

plume centre-line heights are the same as for method A.

TABLE 11 ESTIMATED APPROXIMATE PERCENTAGE FREQUENCIES OF STABILITY/WIND SPEED CLASSES

(All wind directions together)

Lapse/stability category	U (ms^{-1})	Wind speed class limits	Estimated Percentage frequency
S1	0.5	0-0.7	6
	1	0.7-1.5	8
	2	1.5-3	5
	4	3-5	1
S2	0.5	0-0.7	4
	1	0.7-1.5	4
	2	1.5-3	2
S3	0.5	0-0.7	0.6
	1	0.7-1.5	0.4
S4	0.5	0-0.7	0.08
	1	0.7-1.5	0.02
D	6	5-7.5	25
	10	7.5-15	15
	20	>15	1

(estimates are relevant to a relatively flat inland rural site in United Kingdom).

Table 11 (continued)

Stability category	U_1 (ms^{-1})	wind speed class limits	estimated percentage frequency
A	0.5	0 - 0.7	0.5
	1	0.7 - 1.5	0.5
B	0.5	0 - 0.7	0.5
	1	0.7 - 1.5	1.0
	2	1.5 - 3	1.5
	4	3 - 5	1.5
C	0.5	0 - 0.7	0.4
	1	0.7 - 1.5	0.5
	2	1.5 - 3	4
	4	3 - 5	6
	6	5 - 7.5	1.5
	10	7.5 - 15	0.1
D	0.5	0 - 0.7	2
	1	0.7 - 1.5	2
	2	1.5 - 3	5
	4	3 - 5	12

TABLE 12(a) DOWNWIND CENTRE-LINE CONCENTRATIONS - WORST CASES

Method A $n = 1$, $p = 5$

Q (m^3s^{-1})	Maximum centre-line concentration (per cent) at:- x = 100	200	500	1000 m
14	7.5 (S4/0.5)	5.2 (S4/0.5)	2.5 (S4/0.5)	1.2 (S4/0.5)
80	7.0 (S4/1)	5.8 (S4/1)	4.1 (S4/0.5)	2.8 (S4/0.5)
100	6.7 (S1/4)	5.7 (S4/1)	4.1 (S4/0.5)	2.9 (S4/0.5)
300	6.8 (S1/4)	4.8 (S4/1)	3.9 (S4/1)	3.0 (S4/0.5)
500	6.8 (S1/4)	4.1 (S4/1)	3.6 (S4/1)	3.0 (S4/1)

The stability/wind speed (ms^{-1}) combination producing the maximum (worst case) concentration is given in parenthesis below each percentage figure.

TABLE 12(b) DOWNWIND CENTRE-LINE CONCENTRATIONS - WORST CASES

Method B $n = 1$, $p = 2.25$

Q (m^3s^{-1})	Maximum centre-line concentration (per cent) at:- x = 100	200	500	1000 m
14	4.3 (S4/1)	3.2 (S4/0.5)	1.8 (S4/0.5)	0.98 (S4/0.5)
80	3.8 (S2/2)	3.1 (S4/1)	2.3 (S4/0.5)	1.7 (S4/0.5)
100	3.7 (S2/2)	3.0 (S4/1)	2.3 (S4/1)	1.8 (S4/0.5)
300	4.0 (S1/4)	2.4 (S4/1)	2.1 (S4/1)	1.7 (S4/1)
500	3.7 (S1/4)	2.2 (S1/4)	1.8 (S4/1)	1.6 (S4/1)

The stability/wind speed (ms^{-1}) combination producing the maximum (worst case) concentration is given in parenthesis below each percentage figure.

TABLE 12(c) DOWNWIND CENTRE-LINE CONCENTRATIONS - WORST CASES

Method C $n = 2$, $p = 5$

Q (m^3s^{-1})	Maximum centre-line concentration (per cent) at:- x = 100	200	500	1000 m
14	1.7 (S4/1)	1.3 (S4/1)	0.80 (S4/0.5)	0.54 (S4/0.5)
80	2.0 (S1/4)	0.83 (S1/4)	0.60 (S4/1)	0.50 (S4/1)
100	2.0 (S1/4)	0.83 (S1/4)	0.54 (S1/4)	0.46 (S1/4)
300	2.0 (D/20)	0.81 (D/20)	0.34 (S4/1)	0.32 (S4/1)
500	2.0 (D/20)	0.91 (D/20)	0.29 (S4/1)	0.28 (S4/1)

The stability/wind speed (ms^{-1}) combination producing the maximum (worst case) concentration is given in parenthesis below each percentage figure.

TABLE 12(d) DOWNWIND CENTRE-LINE CONCETRATIONS - WORST CASES

Method D $n = 2.$[illegible] $p = 2.25$

Q (m^3s^{-1})	Maximum center-line concentration (per cent) at:- x = 100	200	500	1000 m
14	0.81 (S1/4)	0.42 (S4/1)	0.32 (S4/1)	0.23 (S4/1)
80	0.85 (D/12)	0.31 (D/12)	0.20 (S4/1)	0.18 (S4/1)
100	0.94 (D/15)	0.34 (D/15)	0.19 (S4/1)	0.17 (S4/1)
300	1.1 (D/20)	0.46 (D/20)	0.16 (D/20)	0.11 (S4/1)
500	0.87 (D/20)	0.43 (D/20)	0.15 (D/20)	0.10 (D/20)

The stability/wind speed (ms^{-1}) combination producing the maximum (worst case) concentration is given in parenthesis below each percentage figure.

Appendix 1

Variation of σ_y and σ_z with stability and distance

McMullen (1975) uses :-

$$\sigma_y = \exp\left[a_y + b_y(\ln x) + c_y(\ln x)^2 \right]$$

$$\sigma_z = \exp\left[a_z + b_z(\ln x) + c_z(\ln x)^2 \right]$$

x is downwind distance in kilometres

σ_y, σ_z are dispersion distances in metres

Pasquill Stability	a_y	b_y	c_y	a_z	b_z	c_z
A	5.357	0.8828	-0.0076	6.035	2.1097	0.2770
B	5.058	0.9024	-0.0096	4.694	1.0629	0.0136
C	4.651	0.9181	-0.0076	4.110	0.9201	-0.0020
D	4.230	0.9222	-0.0087	3.414	0.7371	-0.0316
E	3.922	0.9222	-0.0064	3.057	0.6794	-0.0450
F	3.533	0.9181	-0.0070	2.621	0.6564	-0.0540
(G)	(3.200	0.9200	-0.0070	2.300	0.6300	-0.0540)

The values for Pasquill stability category G are extrapolated.

Figures A1 and A2 are Turner's (1969) figures for σ_y, σ_z for stabilities A to F;

I have added the lines for stability G.

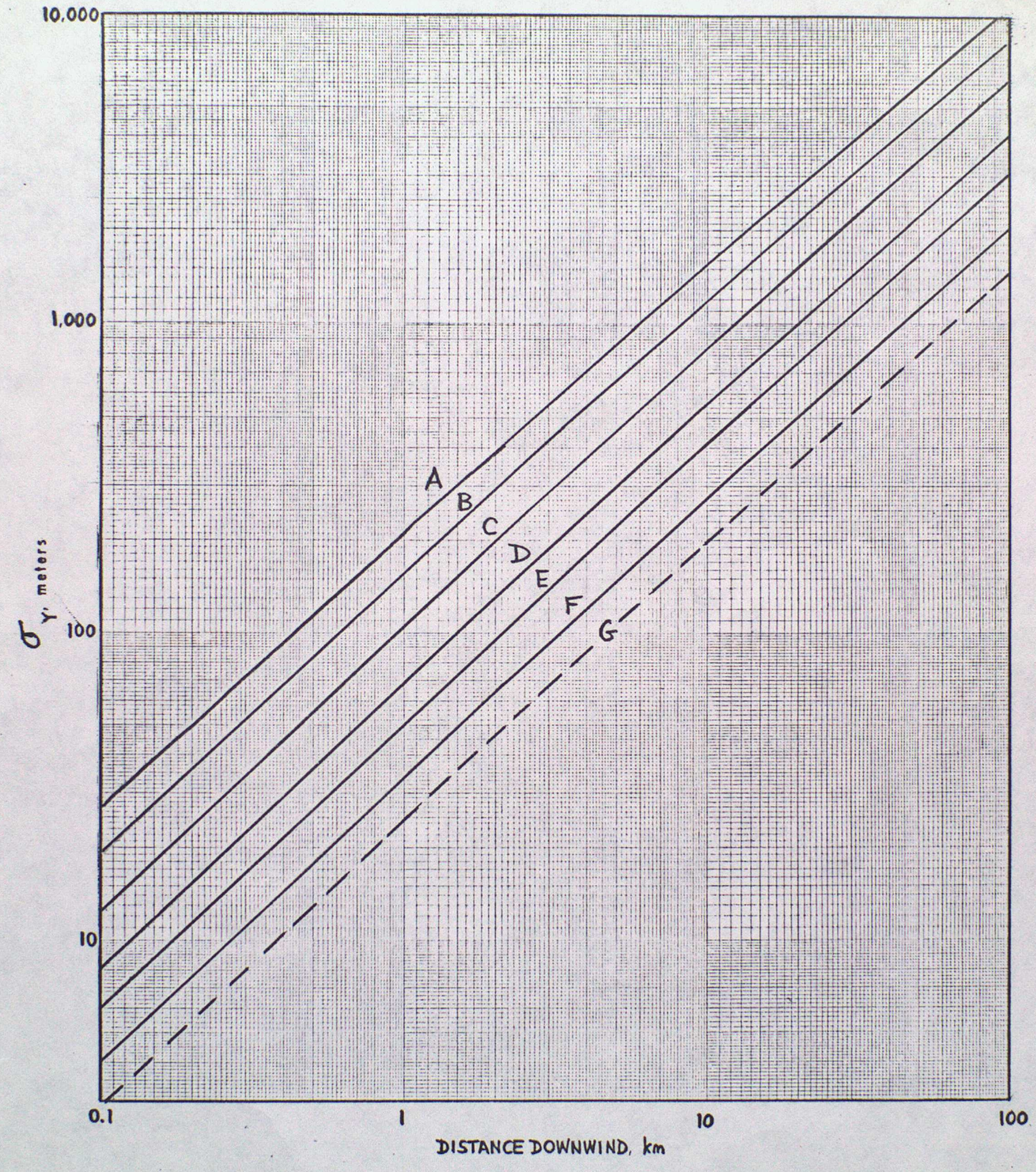

Figure A-1. Horizontal dispersion coefficient as a function of downwind distance from the source.

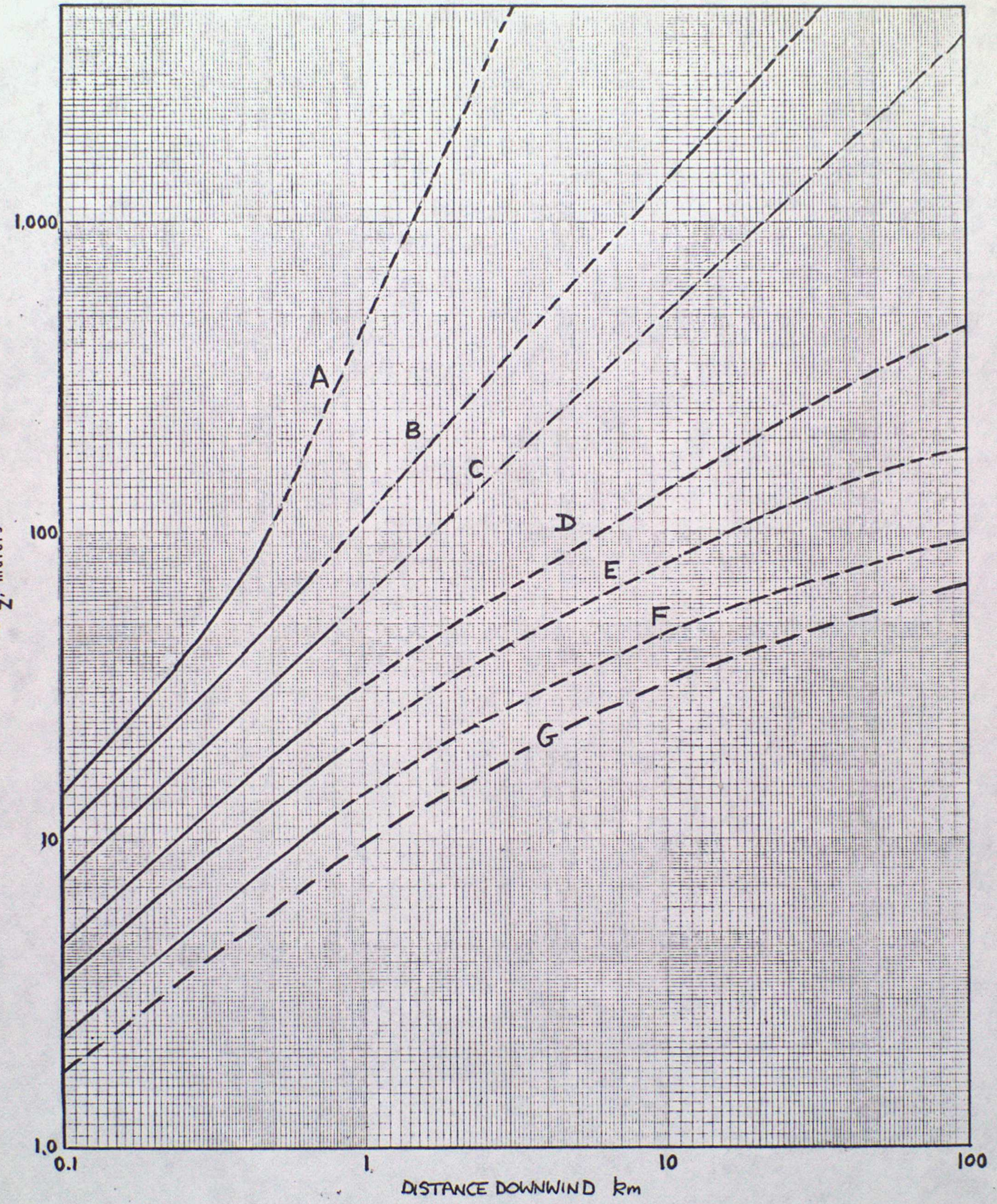

Figure A-2 Vertical dispersion coefficient as a function of downwind distance from the source.

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