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COOPERATIVE
RESEARCH

TXLINE: A COMPUTER MODEL FOR ESTIMATING POLLUTANT CONCENTRATIONS DOWNWIND OF A ROADWAY

in cooperation with the
Department of Transportation
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16. Abstract

A state-of-the-art computer model called TXLINE (Texas Line Source Dispersion Model) was developed to predict pollution concentrations near roadways. The model has a strong theoretical foundation, based on non-Fickian, gradient transport diffusion theory. The model does not assume constant wind speed and eddy diffusivity as is usually the case with most roadway pollutant dispersion models. A theoretically based treatment of non-perpendicular winds is also included in TXLINE, and resulted in a major improvement over its predecessor, TRAPS-IIM.

By comparing the concentration predictions of the initial form of the TXLINE Model to experimental data, it was found that the model overpredicted concentrations when the wind speed was low. A low wind speed correction factor was included in the final version of the model to cure this problem. During the development of the model, a method of measuring atmospheric stability was also investigated, and could perhaps be included in a future version of the model.

The final TXLINE Model was compared to several other current dispersion models using several comprehensive data bases, and was shown to either surpass or equal the performance of the other models in nearly every case. These comparisons were very encouraging, since TXLINE incorporated far less empiricism than the other models and also required less computer time for a typical run.

TXLINE was written in FORTRAN and was released along with a detailed user's guide which includes several illustrative examples. Although the model cannot currently predict dispersion near complicated roadway geometries such as intersections, the possibility of extending TXLINE to handle such cases is being considered.

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Research Report 283-1
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A user-orientated computer model to predict pollutant dispersion in the near vicinity of roadways has been developed. The new model, called TXLINE, was validated using several comprehensive data bases. The model was written in FORTRAN and has been released along with a detailed user's guide.

DISCLAIMER

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SUMMARY

A state-of-the-art computer model called TXLINE (Texas Line Source Dispersion Model) was developed to predict pollution concentrations near roadways. The model has a strong theoretical foundation, based on non-Fickian, gradient transport diffusion theory. The model does not assume constant wind speed and eddy diffusivity as is usually the case with most roadway pollutant dispersion models. A theoretically based treatment of non-perpendicular winds is also included in TXLINE, and resulted in a major improvement over its predecessor, TRAPS-IIM.

By comparing the concentration predictions of the initial form of the TXLINE Model to experimental data, it was found that the model overpredicted concentrations when the wind speed was low. A low wind speed correction factor was included in the final version of the model to cure this problem. During the development of the model, a method of measuring atmospheric stability was also investigated, and could perhaps be included in a future version of the model.

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CHAPTER 1

INTRODUCTION

An environmental impact statement must be submitted to the Federal Highway Administration prior to the start of any major roadway construction project. Future carbon monoxide concentrations in the vicinity of the roadway must be estimated and included in an air quality report, which is an important part of the environmental impact statement. The air quality report is reviewed not only by the Federal Highway Administration, but also by the Environmental Protection Agency, and other state and local agencies. If the estimated air quality is judged to be in violation of the National Ambient Air Quality Standards, the proposed roadway construction project will most likely be rejected.

In the past decade, several air quality computer models have been developed to predict pollutant concentrations near roadways. The first models were highly inaccurate, primarily because of the lack of quality data. Only recently have data bases become available which include accurate meteorological, traffic, and concentration measurements. These data bases have been used not only to develop models, but also to evaluate and compare models. Nearly every air quality model comparison study has concluded that even the best currently available models are highly approximate. Since decisions on roadway construction projects can be significantly influenced by the predictions of these models, there is a strong need for the development of better models.

General Approach to Dispersion Modelling

The general approach to modelling pollutant dispersion near roadways has been to first model the total vehicular emissions and to then separately model the subsequent downwind dispersion. The first model yields an average quantity known as the 'emission factor', which is usually in units of grams of carbon monoxide per typical vehicle, per mile travelled. Inputs to the emissions models normally include average speed, ambient temperature, the distribution of vehicle types, and vehicle operating conditions. Although the current emissions models are often blamed for erroneous concentration predictions, several controlled studies where vehicular emissions were accurately known, have indicated that the modelling of the dispersion process is also a major source of error in pollutant concentration predictions.

Dispersion models normally predict pollutant concentration as a function of source strength, downwind coordinates, wind speed, wind angle, and other pertinent meteorological parameters. Several different mathematical representations have been used to model the dispersion process. Most models have been developed by first proposing a theoretical physical model and then adding several adjustments based on observed data. The resulting semi-empirical model often bears little resemblance to the original theoretical model, and performs poorly when compared to data not used in the model development.

Objectives

The research described in this report has been conducted under Project 2-8-80-283 for the Texas State Department of Highways and Public Transportation. The primary objective of this project was to develop a state-of-the-art dispersion model, which retained an initial theoretical basis, but includes some adjustments based on a detailed analysis of the available data bases. The model also needed to be compared to other current highway pollutant dispersion models using several qualitative and quantitative comparison techniques.

Another objective was to present the final model, called TXLINE (Texas Line Source Dispersion Model), in a user-orientated package.

Organization of Report

The report was organized so that it follows the chronological order of the actual research project as closely as possible. A complete review of past and current literature pertaining to the study is presented in Chapter 2. The development of the TXLINE Model is reported in Chapter 3. The fourth chapter is a detailed presentation of the results of an extensive model evaluation and comparison procedure. Conclusions and recommendations for future work are contained in Chapter 5.

A detailed User's Guide for TXLINE is included as Appendix A. The User's Guide contains a FORTRAN listing of TXLINE, a description of the program, and several illustrated example cases.

CHAPTER 2

LITERATURE REVIEW

The literature review is divided into the following four sections: (1) dispersion modelling; (2) methods of determining source strength; (3) methods of testing and comparing models; and (4) experimental data. Literature which applied directly to the model developed as a part of this project is discussed in Chapter 3.

A. DISPERSION MODELLING NEAR ROADWAYS

The problem of developing a mathematical dispersion model to estimate pollutant concentrations in the vicinity of a roadway has been approached in several different ways. The following four approaches are most commonly used: (1) the gradient transport approach; (2) the statistical approach; (3) the similarity approach; and (4) the empirical approach. Pasquill (1974) noted that the gradient transport approach is a mathematical development of a particular physical model of mixing. The second approach models the turbulent field near the roadway in terms of statistical properties of motion. In the similarity approach, postulations are made regarding the diffusion controlling physical parameters. These parameters are then related to the diffusion process using dimensional analysis. The final approach uses a data base to develop empirical correlations relating concentration to a set of measured variables such as wind speed, wind angle, etc.

Nearly all of the existing roadway dispersion models use some form of the gradient transport approach, combined with empirical adjustments based on experimental data. The differences between the existing models are primarily due to the wide variety of assumptions made in solving the general diffusion equation and the amount of empiricism incorporated in the model. This report focuses on models which use the gradient transport approach. The reader is referred to Pasquill (1974) and Sutton (1953) for a review of the other methods of modelling atmospheric diffusion.

Gradient Transport Approach

The differential equation which has been the basis for most mathematical treatments of atmospheric diffusion is the instantaneous convective diffusion equation:

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} + w\frac{\partial C}{\partial z} = \frac{\partial}{\partial x}\left(K_x\frac{\partial C}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y\frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z\frac{\partial C}{\partial z}\right) \quad (2\text{-}1)$$

where: C = concentration

t = time

x,y,z = directions in a Euclidean coordinate system, as shown in Figure 1

u,v,w = component of wind velocity in the x,y,z directions, respectively

$K_i (i=x,y,z)$ = eddy diffusivity in the x, y, and z directions, respectively.

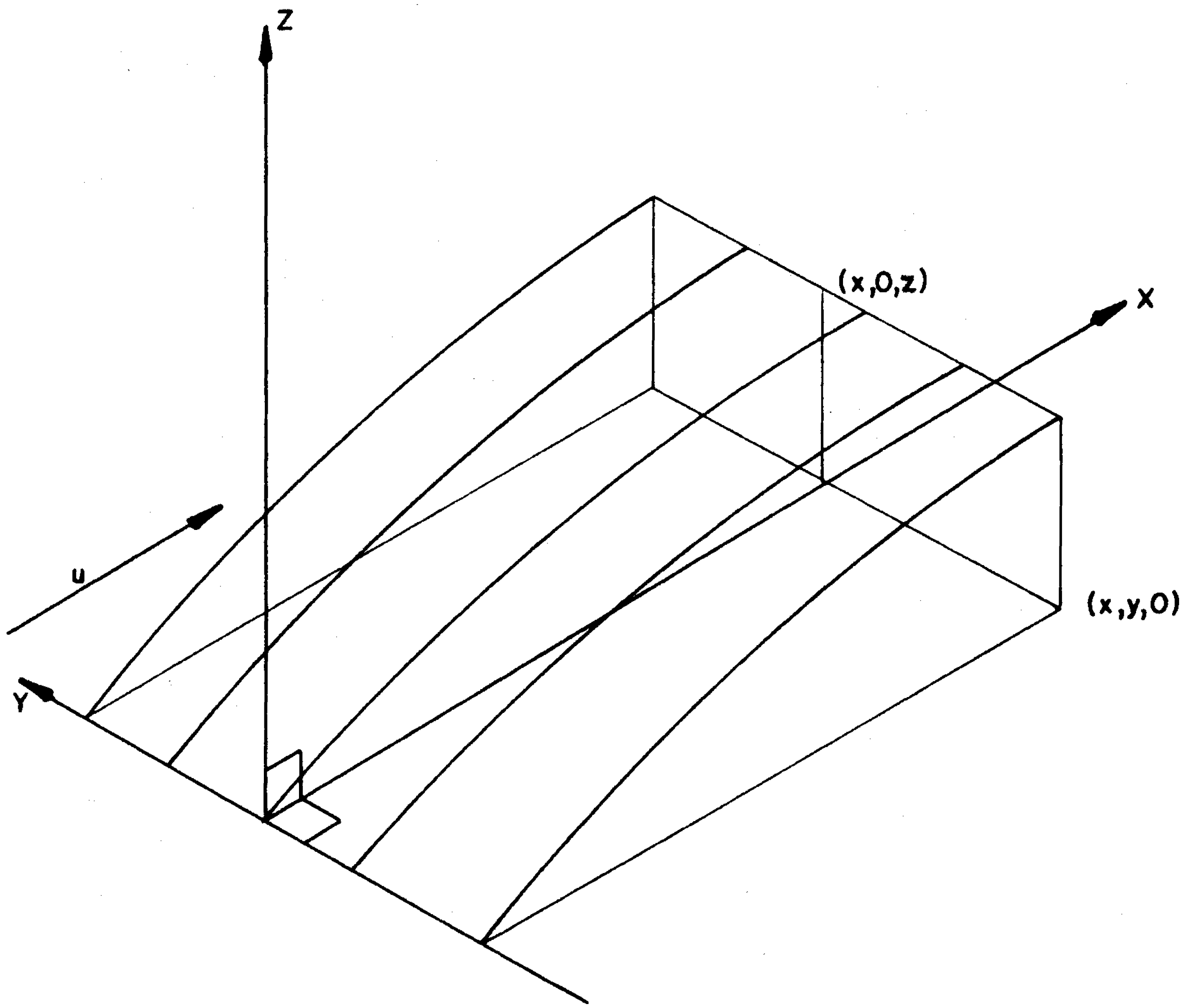


Fig. 1. Euclidean coordinate system used to model diffusion from a line source along the y-axis.

This equation is similar to the classical equation for the conduction of heat in a solid and is basically a statement of conservation of mass. Treybal (1968) presents the derivation of the above relationship from the equation of continuity.

Several general assumptions are common to most existing solutions of Equation (2-1). Using the assumptions of steady state, perpendicular wind (in the x-direction), no net flow in the z-direction (w=0), and that the eddy diffusivity term in the x-direction is negligible compared to the bulk flow term, the above equation can be reduced to the following:

$$u\frac{\partial C}{\partial x} = \frac{\partial}{\partial y}\left(K_y\frac{\partial C}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z\frac{\partial C}{\partial z}\right) \qquad (2\text{-}2)$$

The fluctuating nature of the wind is a result of the eddies. The K's are used as a measure of the net movement of the material down existing concentration gradients. In the above equation, the eddy diffusivities are considered to be functions of position and direction.

The most general solutions of Equation (2-2) found in the literature were presented by Smith (1957). These solutions assumed power law forms (in terms of z) for both the wind and eddy diffusivity profiles. Smith derived solutions for both a ground level infinite line source and a point source. Solutions were also presented for the case of an elevated source. These are the most rigorous solutions available at present. A detailed discussion of Smith's equations is presented in Chapter 3.

A less general solution of Equation (2-2) was derived by Roberts (unpublished, presented by Pasquill (1974)). The assumed forms of the wind and eddy diffusivity profiles were more restricted than in Smith's solution. Green (1980) used the solution to develop the TRAPS-IIM Model, which is discussed in a later section of this chapter.

Sutton (1953) presented solutions to both the ground level point source and the infinite line source problems. These solutions assumed that the eddy diffusivities were constant (Fickian diffusion). This implies that the rate of transfer across a particular boundary is a function of only the concentration gradient at the point being considered. In the case of Fickian diffusion, Equation (2-2) becomes:

$$u\frac{\partial c}{\partial x} = K_y \frac{\partial^2 c}{\partial y^2} + K_z \frac{\partial^2 c}{\partial z^2} \qquad (2-3)$$

Sutton's solutions to this equation are:

For the point source:

$$C = \frac{Q}{4\pi x (K_y K_z)^{1/2}} \exp\left[-\frac{\bar{u}}{4x}\left(\frac{y^2}{K_y} + \frac{z^2}{K_z}\right)\right] \qquad (2-4)$$

where: Q = point source strength (mass/t)
K_z = eddy diffusivity in z-direction (l^2/t)
K_y = eddy diffusivity in y-direction (l^2/t)
$\bar{u}$ = constant average wind speed (l/t).

and for the infinite line source:

$$C(x,z) = \frac{Q'}{(2\pi K_z x)^{1/2}} \exp\left(-\frac{\bar{u}z^2}{4K_z x}\right) \tag{2-5}$$

where: Q' = line source strength (mass/(l·t))

The above solutions are based on constant wind speed with height. Experimental studies have shown that wind speed is a function of height which can be closely approximated by a logarithmic or power law equation.

Pasquill (1961) pointed out that the eddy diffusivity theory is not thoroughly understood and that K values are therefore not readily attainable. Using data obtained by Calder (1949) and Barad (1958), Cramer (1959) tested the following Gaussian modification of Sutton's point source equation:

$$C = \frac{Q}{2\pi \sigma_y \sigma_z \bar{u}} \exp\left[-\frac{1}{2}\left(\frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right)\right] \tag{2-6}$$

where: σ_y and σ_z are standard deviations of the distance of pollutant molecules from the plume center in the y and z directions.

Gifford (1961) modified a set of dispersion curves originally presented by Pasquill (1961) to predict the standard deviations as a function of downwind distance and atmospheric stability. These curves, commonly referred to as the Pasquill-Gifford curves, have been used as the basis for several Gaussian dispersion models.

A similar Gaussian form of the infinite line source equation was also developed, but the equations still had not been extended to include the case of an elevated source. Sutton (1953) presented an argument for modification of the equations based on the assumption that the ground is impervious to the pollutant, which led to the variable source height form of the Fickian equations. The Gaussian forms of these equations are:

For the point source:

$$C = \frac{Q}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left(\exp\left[-\frac{1}{2}\left(\frac{z-h}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+h}{\sigma_z}\right)^2\right]\right) \quad (2\text{-}7)$$

where: h = source height.

and for the infinite line source:

$$C = \frac{Q'}{\sqrt{2\pi}\,\sigma_z\bar{u}}\left\{\exp\left(-\frac{1}{2}\left[\frac{z-h}{\sigma_z}\right]^2\right) + \exp\left(-\frac{1}{2}\left[\frac{z+h}{\sigma_z}\right]^2\right)\right\} \quad (2\text{-}8)$$

Most existing dispersion models use some form of Equations (2-7) and (2-8). Detailed reviews of the available user-oriented computer models are presented by Maldonado (1976) and Green (1980). Several recent models such as CALINE-3 (1979) are improved versions of earlier models (CALAIR (1972) and CALINE-2 (1975)). In this report only three of the most recent state-of-the-art models will be discussed; CALINE-3, HIWAY-2, and TRAPS-IIM. CALINE-3 and HIWAY-2 are the only highway pollutant dispersion models which are currently approved for use by the Environmental Protection Agency.

HIWAY-2

HIWAY-2 was developed by Peterson (1980) and is a revised version of the EPA's original model, HIWAY (1974). Each lane of traffic is modelled as a line source of finite length. By summing concentration predictions from separate finite line segments, the model is capable of modelling intersections. HIWAY-2 uses Gaussian dispersion equations similar to those originally presented by Turner (1970). Concentration predictions are determined by performing a numerical integration of the appropriate point source equation. The concentration is given by:

$$X = \frac{q}{u} \int_0^D f\,dx \qquad (2\text{-}9)$$

where: u = wind speed, m/s

D = line source length, m

q = line source emission rate, g/m/sec

f = point source dispersion function

X = pollutant concentration, g/m^3.

Based on the atmospheric conditions, the model integrates one of three point source dispersion functions. For stable conditions, the following function is used:

$$f = \frac{1}{2\pi \sigma_y \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \left(\exp\left[-\frac{1}{2}\left(\frac{z-h}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+h}{\sigma_z}\right)^2\right]\right) \qquad (2\text{-}10)$$

where: h = effective source height, m.

In unstable or neutral conditions, where σ_z is greater than 1.6 times the mixing height, L:

$$f = \frac{1}{\sqrt{2\pi}\,\sigma_y L} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \qquad (2\text{-}11)$$

In all other unstable or neutral conditions:

$$f = \frac{1}{2\pi\sigma_y\sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \left[\exp\left[-\frac{1}{2}\left(\frac{z-h}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+h}{\sigma_z}\right)^2\right] \right. \quad (2\text{-}12)$$

$$+ \sum_{N=1}^{\infty} \left(\exp\left[-\frac{1}{2}\left(\frac{z-h-2NL}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+h+2NL}{\sigma_z}\right)^2\right] \right.$$

$$\left. \left. + \exp\left[-\frac{1}{2}\left(\frac{z-h+2NL}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+h-2NL}{\sigma_z}\right)^2\right] \right) \right]$$

The value of the integral in Equation (2-9) is approximated by use of a Richardson extrapolation of the trapeziodal rule. Concentration estimates are made by dividing the line segment into the number of intervals equal to 3, 6, ... $3*(2)^9$. (Each interval is represented by a point source.) Calculations are repeated successively until the latest concentration estimate is within 2 percent of the previous estimate. If convergence is not reached by the time the number of intervals reaches 1536 (which is $3*(2)^9$), the final estimated integral value is stored. A new sequence of estimations for intervals equal to 4, 8, ... 2048 is then performed. Any new integral estimate having a relative error from the stored estimate of less than 2 percent is taken to signal convergence. If convergence is not obtained after 2048 intervals, the minimum of the current integral estimate and the stored estimate is used as the integrated result. This procedure is repeated for each lane of traffic. The resulting concentrations are then summed to represent the total concentration prediction.

HIWAY-2 is also capable of predicting concentrations downwind of a cut section of highway. The top of the cut is considered to be an area source and is represented by several equal strength line sources.

Several empirical correlations were employed in the HIWAY-2 Model. Rao and Keenan (1980) indicated that the wake effects due to moving vehicles on the roadway are superimposed upon the naturally occurring turbulence and play a dominant role in dispersing pollutants near the roadway. The dispersion curves for σ_y and σ_z were developed to include this effect using data collected by Cadle, et al. (1976) and Rao, et al. (1978), and replaced the Pasquill-Gifford curves used in the original HIWAY Model. The dispersion curves were also considered to be a function of stability class, downwind distance from the roadway, mean wind speed, and mean wind angle.

A wind speed correction factor was also included in the model. This factor was termed the 'aerodynamic drag factor'. This factor was developed using the General Motors data from Cadle, et al. (1976) and is given by the following function:

$$u = 1.85\, u_o^{0.164} \cos^2\theta \qquad (2\text{-}13)$$

where: u = the adjusted wind speed used in the model, m/sec

u_o = the ambient wind speed, m/sec

θ = the wind-road angle.

If the ambient wind speed is greater than the adjusted wind speed, no correction of the ambient wind speed is made. This allows correction only for low ambient wind speed situations.

CALINE-3

CALINE-3 is a third generation model developed by Benson (1979) for the California Department of Transportation. The roadway is modelled as a series of finite line sources. By summing concentration predictions from several line sources, CALINE-3 is capable of modelling complex highway configurations such as intersections.

Each finite line source is divided into a series of discrete elements. The elements are then modelled as 'equivalent line sources' positioned normal to the wind direction and centered at the element midpoint. Each element is further divided into five sub-elements represented by corresponding segments of the equivalent finite line source.

A more detailed explanation of the formulation of the finite line source equation would be inappropriate in this report. Instead, only the final form of the finite line source equation is given below:

$$C = \frac{1}{\sqrt{2\pi}u} \sum_{i=1}^{n} \left(\frac{1}{\sigma_{z_i}} \sum_{k=-CNT}^{CNT} \left[\exp\left(\frac{-(z-h+2kL)^2}{2\sigma_{z_i}^2} \right) + \exp\left(\frac{-(z+h+2kl)^2}{2\sigma_{z_i}^2} \right) \right] * \sum_{j=1}^{5} (WT_j * QE_i + PD_{ij}) \right) \quad (2\text{-}14)$$

where: C = receptor concentration prediction resulting from the 'link'

n = total number of elements

CNT = number of multiple reflections needed for convergence

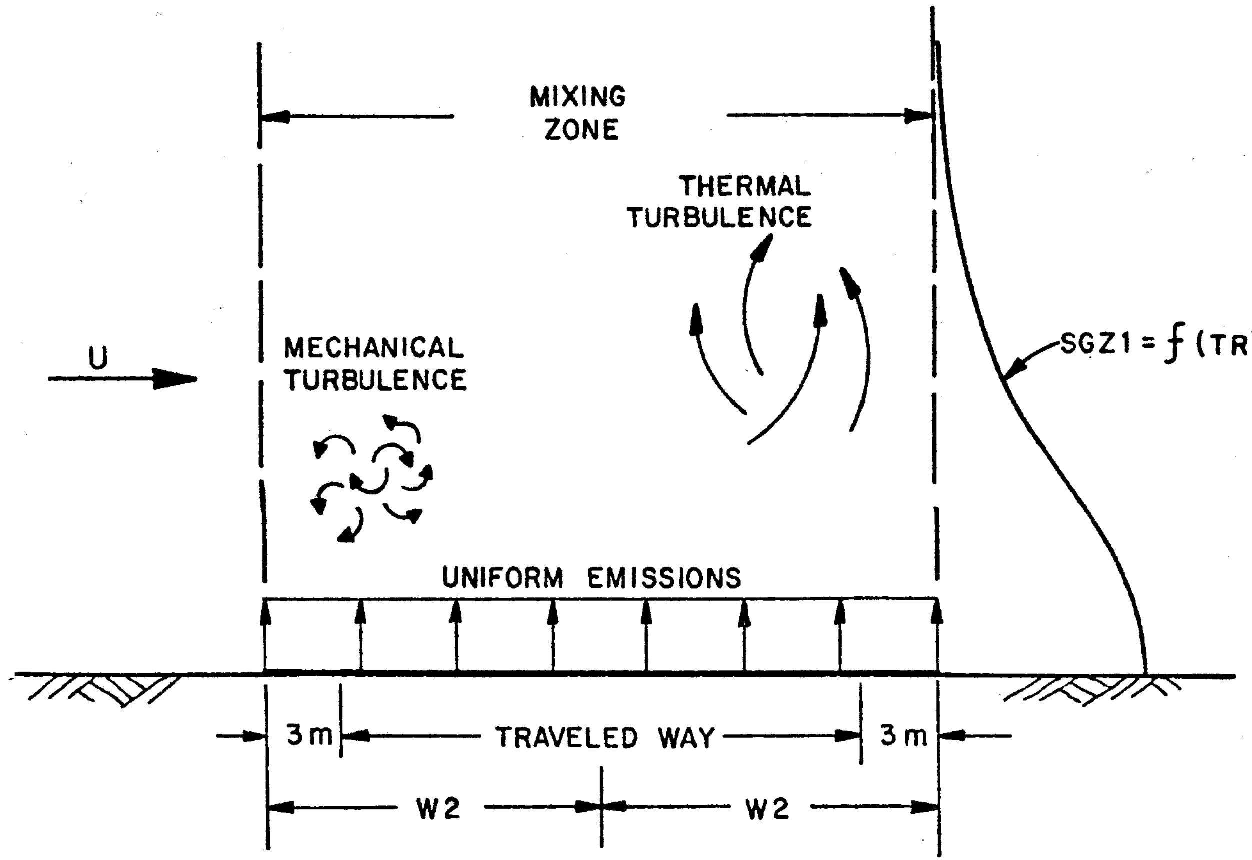
QE_i = Central sub-element lineal source strength for the ith element

WT_j = Source strength weighting factor for the jth sub-element

PD_{ij} = $\frac{1}{2}\int_{Y_j/\sigma_{Y_i}}^{(Y_{j+1})/\sigma_{Y_i}}$

Y_j = offset distance for the jth sub-element.

CALINE-3 treats the region directly over and including the roadway as a zone of uniform emissions and turbulence, defined as the mixing zone (see Figure 2). The initial dispersion parameter, σ_{z_1}, was fitted as a function of residence time in the mixing zone using the General Motors data. In CALINE-3, the mixing zone residence time was defined as:



SGZ1 = INITIAL VERTICAL DISPERSION PARAMETER
TR = MIXING ZONE RESIDENCE TIME

Fig. 2. CALINE-3 mixing zone concept (from Benson (1979)).

$$TR = \frac{W2}{\bar{u}} \tag{2-15}$$

where: TR = residence time
W2 = roadway width
$\bar{u}$ = mean horizontal wind speed.

The function used for σ_{z_1} was:

$$\sigma_{z_1} = 1.8 + 0.11TR \tag{2-16}$$

where: TR is in seconds and σ_{z_1} is in meters.

The value of the initial dispersion parameter is then arbitrarily adjusted for averaging times other than 30 minutes (the averaging time of the GM data base) using the following power law:

$$\sigma_{z_1,ATIM} = \sigma_{z_1}\left(\frac{ATIM}{30}\right)^{0.2} \tag{2-17}$$

where: ATIM = averaging time in minutes.

Vertical dispersion curves are formed by interpolating between the initial dispersion parameter, σ_{z_1}, from the mixing zone model, and the value of σ_z at 10 kilometers as defined by Pasquill (1974). The GM and SRI data bases were used to develop this relationship.

Horizontal dispersion curves used in CALINE-3 are identical to those used by Turner (1970) except for averaging time and surface roughness adjustments.

Shallow cut or fill sections (less than a 2:1 grade) are handled by CALINE-3 by assuming that air flow streamlines are undisturbed by the cut or fill. Using this approximation, ground level is always taken to be the z=0 plane, and no further modifications are necessary. For deeper depressed sections, the residence time within the mixing zone (TR) is increased by an empirically derived factor based on data taken by CALTRANS at a depressed site in Los Angeles. CALINE-3 is not capable of modelling street canyons.

TRAPS-IIM

TRAPS-IIM was developed by Green (1980) at Texas A&M University and was the final model in the TRAPS series. The TRAPS series of models is unique in that they do not employ the Gaussian dispersion parameters σ_y and σ_z. Instead Roberts' unpublished solution (as presented by Pasquill (1974)) of the more general non-Fickian equation is used:

$$C(x,z) = \frac{Qr}{u_1 \Gamma(s)} \left(\frac{u}{r^2 K_1 x}\right)^s \exp\left(\frac{-u_1 z^r}{r^2 K_1 x}\right) \qquad (2\text{-}18)$$

where: C = concentration at x,z due to an infinite line source (with perpendicular wind)
Q = line source strength (mass/(l·t))
K_1 = reference eddy diffusivity (l^2/t)
u_1 = reference wind speed (l/t)
r and s = defined below
Γ(s) = gamma function of s.

Equation (2-2) was solved by assuming the following power law profiles for the wind and eddy diffusivity:

$$K_z(z) = K_1\left(\frac{z}{z_1}\right)^n \tag{2-19}$$

where: K_1 = reference eddy diffusivity at $z=z_1$.

and

$$u_z(z) = u_1\left(\frac{z}{z_1}\right)^m \tag{2-20}$$

where: u_1 = reference wind speed at $z=z_1$.

Equation (2-18) is valid only for $r=m-n+2>0$ and where $s=(m+1)/r$. As a result of a sensitivity analysis completed during the development of the model, n was set to one, thereby forcing s and Γ(s) to one. This reduced Equation (2-18) to:

$$C(x,z) = \frac{Q}{rK_1x} \exp\left(\frac{-u_1 z^{1+m}}{r^2 K_1 x}\right) \tag{2-21}$$

In order to apply Equation (2-21), the following three parameters had to be estimated; u_1, K_1, and m. These parameters were estimated by fitting the power law to match the log-law wind velocity profile. The log-law wind profile (assuming neutral stability) is:

$$u = \frac{u_*}{k} \ln\left(\frac{z}{z_o}\right) \tag{2-22}$$

where: u = wind speed at height $z > z_o$
u_* = friction velocity
k = 0.4 = Von Karman's constant
z_o = surface roughness height.

By fitting the power law equation to the log-law equation, the following polynomials were found to predict the power law parameter, m, as a function of the surface roughness, z_o; when $z_o > 0.1$ meters:

$$m = 0.11 + 2.04z_o - 3.83z_o^2 + 3.43z_o^3 \tag{2-23}$$

and when $z_o \leq 0.1$ meters:

$$m = 0.12 + 4.09z_o - 59.5z_o^2 + 550.0z_o^3 - 1965.0z_o^4 \tag{2-24}$$

The reference height, z_1, was set equal to 1 meter. Given surface roughness, a reference wind speed, and a corresponding reference height, u_* can be calculated from Equation (2-22). Knowing u_*, u_1 (the reference wind speed at z=1 meter) can easily be calculated. K_1, the reference eddy diffusivity, was estimated by:

$$K_1 = 0.8u_* \qquad (2\text{-}25)$$

This function for K_1 was determined by fitting model predictions to the GM data.

The model was developed to predict the road edge concentration profile observed in the GM data base. A complicated equation is used by the model to predict the road edge concentration as a function of height, wind speed, wind angle, and stability class. The model determines a 'virtual' origin distance by 'moving' the location of the line source until the squared error between the GM road edge concentration profile and Equation (2-21) is minimized. Concentration predictions are then made using Equation (2-21), with the x-coordinates referred to the new 'virtual' origin.

The TRAPS-IIM Model cannot be used to model cut, fill or elevated source cases. Since the infinite line source equation was used, the model also cannot handle complicated geometries such as intersections. Use of the model is discussed in detail by Green (1980).

B. METHODS OF DETERMINING SOURCE STRENGTH

Every dispersion equation, regardless of its nature, requires a value for source strength. Source strength is a measure of the pollutant release rate. The most common units of source strength are: g/sec (for a point source), and g/m/sec (for a line source). Ideally, these rates could always be determined by measurements. This is the case when the source is stationary (e.g., a smokestack) or when the release rate is constant (e.g., Cadle's (1976) SF_6 tracer gas experiment), but for the case of pollutant dispersion from roadways, the source strength is difficult to estimate. This section presents the most common methods of estimating the source strength of vehicles travelling on a highway.

Inherent in every estimate of roadway source strength is the assumption that the vehicle emissions are distributed evenly along a line source. The emission factor is defined as the average release rate of the pollutant per vehicle per mile. Then:

$$Q = V * E \qquad (2\text{-}26)$$

where: Q = line source strength (mass/time/length)
V = traffic volume (vehicles/time)
E = average vehicle emission factor (mass/vehicle/length).

After measuring the traffic volume, the problem is reduced to estimating the emission factor, E. The problem of estimating the emission factor for straight roadways with vehicles travelling at relatively constant speeds is fairly complicated, and becomes even more complex when cars are accelerating, decelerating, or queueing, as is the case for an intersection. Three methods of estimating vehicle emissions are discussed in this section.

MOBILE-2

The most common method of estimating emission factors is by using MOBILE-2 (1981), an updated version of the EPA's original computer program, MOBILE-1 (1978). These programs estimate emission factors using methodologies first presented in the EPA publication, Compilation of Air Pollutant Emission Factors (AP-42) (1975). Emission factors were estimated using data collected from vehicle surveillance programs, vehicle prototype data, assembly line test data, and technical judgement.

The input information to the MOBILE-2 program includes various traffic variables, such as vehicle age distribution, percentage of vehicles in cold mode, percentage of travel by vehicle category (automobiles, light trucks, heavy trucks, etc.), average vehicle speed, ambient temperature, and geographic location (high or low altitude or California). The emission data are based on exhaust emission surveillance programs using test fleets of consumer-owned vehicles within various major cities. These fleets were selected by make, model, year, engine size, transmission type, and carburetor type in such proportion as to be representative of both the normal production of each model year and the contribution of that model year to total vehicle miles travelled.

The accuracy of the MOBILE-2 estimates are also limited by the reliability of the input information. For a specific roadway, some of this information is difficult if not impossible to obtain. This is especially true for the operation mode and age distribution. Despite its shortcomings, MOBILE-2 is considered to be one of the best methods of predicting emission factors when data is not available.

Modal Analysis Model

The Automotive Exhaust Emission Modal Analysis Model (1974) is a computer program which estimates the emissions measured during the Surveillance Driving Sequence. This is one of the few models which considers the effects of vehicle acceleration and deceleration. Five steady state modes were established at the following speeds: 0, 15, 30, 45 and 60 mph. Thirty-two other modes represent either periods of acceleration or deceleration from these speeds, and are characterized by an average acceleration, and an average speed. The acceleration/deceleration driving modes consist of all possible combinations of the five steady state speeds.

The Modal Analysis Model is a mathematical model which expanded the emissions from the 37 discrete modes into a continuous function of time, allowing vehicle emissions to be predicted for any specified driving sequence. The model can only be used to predict CO, HC and NO_x emission rates from light-duty vehicles and has not been updated since June 1977. (Dr. Clyde Lee of the University of Texas Center for Highway Research is currently working to extend the model to vehicles other than light-duty (Center for Highway Research Project No. 3-8-79-250)).

Mass-Balance Method

Given the vertical concentration and wind profiles at one downwind location (one tower), Bullin, et al. (1978) outlined a method of determining an average emission factor using a mass-balance technique.

The measured mass flux profile was numerically integrated in the z-direction. The assumption was made that both concentration and mass flux are a function only of height along any plane parallel to the highway. The total integrated mass flux was then equated to the line source strength (mass/time/(length of road)). Bullin, et al. (1980) showed that emission factors calculated using the mass-balance technique may average as much as three times the corresponding values predicted by MOBILE-1.

The mass-balance technique can not always be applied, because the roadway must already be in operation, and accurate physical data must be measured. The results of Bullin's work do however shed serious doubt on the validity of emission factors obtained from the MOBILE programs.

C. METHODS OF TESTING AND COMPARING MODELS

Which existing highway pollutant dispersion model is the 'best' model? This question has been considered by several researchers, but a definitive answer has never been reached. Since researchers rarely agree on which criteria should be used to evaluate dispersion models, the literature is filled with contradicting reports of model comparison studies. This section presents a general review of several methods which are currently used to test and compare dispersion models. (A more comprehensive literature review of this topic was included in a recent National Cooperative Highway Research Program report by Martinez, et al. (1981).)

Mass-Balance Test

Nearly every method which has been used to evaluate highway dispersion models involves comparison of model predictions to experimental data. One notable exception is a test which checks the model for internal mass conservation. This test applies the mass-balance theory which was presented in the previous section of this chapter. Any valid model should output the same amount of pollutant as was input to the model as the source strength. The mass-balance technique uses a numerical integration of the pollutant flux downwind of the source to check the source strength. The calculated value should agree with the input source strength value. Green, et al. (1982) applied the internal mass-balance check to several different models and found that some were not internally consistent.

Comparison to Data (General Discussion)

Since most methods of evaluating models involve comparing model predictions to experimental data, the assumption is often made that the measurements are exact. This assumption unfairly isolates the model as the only source of error. Martinez, et al. (1981) noted that there are actually three primary sources of error which affect the comparison of observed and predicted concentrations: (1) measurement errors, (2) errors in input to the model, and (3) modelling errors.

Only three reports could be found that considered the effects of observational error in the model evaluation process. Brier (1973) discussed the effect of normally distributed errors in the observations, and Maldonado and Bullin (1977) recognized the presence of observational errors by assigning a tolerance band to the observations. Martinez, et al. (1981) included statistical error margins in their report.

One of the major sources of error in determining experimental pollutant concentrations occurs when the concentrations are adjusted for background concentration. Usually one tower is placed upwind of the highway in order to measure background concentration. The average background value is then subtracted from each downwind concentration measurement. Assuming that the background value is constant, the 'adjusted' downwind concentrations are said to be the net concentration values resulting from the roadway source. Rodden, et al. (1982) noted that this assumption frequently results in a large number of negative 'observed' concentration values (23% negative in the El Paso data base (data collected by Bullin, et al. (1978)). Most other researchers either discount the negative points or arbitrarily set them equal to zero.

Background concentration values are not the only source of observational errors. Other sources include data averaging and instrument errors. Observational error is clearly a source of error which exists even in the best of data bases.

Several data bases are discussed in the next section. Once a data base has been chosen for use in a model evaluation, it is usually compared to the model predictions using the theory of statistics. The remaining portion of this section reviews some of the more common methods used to determine how well a model predicts the observed concentrations.

Graphical Techniques

The simplest, but perhaps most revealing methods of checking a model's ability to predict data are graphical techniques. The graph most commonly used has become known as the 'scatterplot'. A scatterplot is a simple plot of predicted versus observed concentration values. The scatterplot is usually drawn using a 1:1 scale, so that a 45° line through the origin represents 'ideal' prediction of the data. Several scatterplots are included in Chapter 4.

One drawback of the simple scatterplot is that it is impossible to discern which points correspond to certain input parameters. Messina, et al. (1982) dealt with this problem by using a different symbol to represent each downwind tower location. Messina also prepared separate plots for different arbitrarily determined wind speed and wind angle classifications. Other researchers, such as Rao and Keenan (1980) used histograms and bar graphs to help visualize model performance. Usually graphical techniques are supplemented by simple linear regression statistics.

Regression Statistics

A simple linear correlation (or least squares) analysis of predicted and observed values yields information which is often masked in simple graphical techniques such as the scatterplot. The slope and intercept of the regression line can serve as an indicator of a model's tendency to overpredict or underpredict. Supplementing the slope and intercept with the correlation coefficient adds a numerical measure of the overall degree of correspondence between predicted and observed values. Although early researchers used graphical techniques and simple regression statistics almost exclusively, the current trend is to also use at least some other method of statistical comparison.

Other Statistics

Several examples of other statistical methods of comparison were reviewed in the report by Martinez, et al. (1981). Examples of some of the simpler statistics include the difference between the 80th percentiles of the predicted and observed values, and the ratio of the average-predicted to the average-observed concentration. Other examples are the root mean squared error, average squared error, and the mean fractional error. Many other more complicated statistics have also been used, but further discussion would be beyond the scope of this report.

Overall Judgement of Model Performance

The overall performance of a model is usually judged by examining the model's performance over a wide range of different comparison techniques. Recently, Martinez, et al. (1981) proposed a method which combines six unique statistical comparisons into a single figure of merit (FOM). The FOM was then used to compare several models on what was thought to be an equal basis. Although methods such as the one proposed by Martinez are quite appealing since they lead to a clear cut 'winner' in model comparison studies, some researchers dispute the use of complicated statistical comparisons. Chock (1982) argued that the most valid and direct approach to check a model's performance is a point-by-point comparison of predicted and observed values.

D. EXPERIMENTAL DATA

Several experimental atmospheric diffusion studies are reported in the literature. Most of the earliest studies involved observation of plumes emitted by smokestacks. One such study was performed by Etkes and Brooks (1918). Although these studies provided valuable information with regard to the various possible shapes of a dispersing plume, line source dispersion experiments are much more applicable to the modelling of dispersion from a roadway. Cramer (1959) carried out one of the first comprehensive line source dispersion experiments using sulfur dioxide as a tracer gas. Csanady, Hilst, and Bowne (1968) studied diffusion of a flourescent tracer gas which was released in a line from an airplane. Only recently have extensive experimental studies been conducted which were designed specifically to investigate the dispersion of pollutants from moving vehicles.

Accurate vehicular emission dispersion models cannot be developed and tested without access to reliable experimental data. The data must include accurate measurements of meteorological parameters and pollution levels at several different locations in the vicinity of the roadway. Within the past decade, several comprehensive and reliable data bases have become available. This section focuses on three such data bases which have been widely accepted for use in developing and testing dispersion models. The selection of these data bases is not meant to infer that they are the only reliable data bases available, but only that they were considered to be the most applicable to this study. A list of references for several other data bases is included at the end of this section.

General Motors Data

The General Motors (GM) dispersion experiment was performed at the GM proving grounds in Milford, Michigan and is discussed in detail by Cadle, et al. (1976). The EPA and other government agencies participated in the planning and execution of the experiment. The study measured dispersion of sulfur hexaflouride (a tracer gas), particulates, and sulfate. The sulfur hexaflouride experiment was of primary interest, since the SF_6 data was used to develop each of the dispersion models being considered in this report (CALINE-3, HIWAY-2, TRAPS-IIM, and TXLINE).

The test track was a 10 kilometer straightaway (5 km each direction) with banked turns at each end. A fleet of 352 cars was used to generate the roadway traffic. The drivers had been trained to drive in 32 packs of 11 cars each at a constant speed of 80 km/hr. Seven or eight pickup trucks equipped with cylinders of SF_6, released the tracer gas at a constant, measured release rate. These trucks were distributed evenly among the vehicle fleet.

Several towers were located near the test track as shown in Figure 3. The towers were instrumented at heights of 1, 4, and 10 metres with meteorological and sample collection equipment. The location of these instruments on a typical tower is illustrated in Figure 4.

Gas samples for the SF_6 analysis were collected using modified Development Science syringe samplers. The syringes were controlled by electric motors which pulled back the 'syringe' plungers at a constant rate. The system was designed so that a full syringe (30 cc) was collected over a thirty-minute sampling period. Samples were analyzed at the end of each day with a modified dual-column Perkin-Elmer 900 gas chromatograph. This chromatograph could detect SF_6 concentrations as low as 10 parts per trillion.

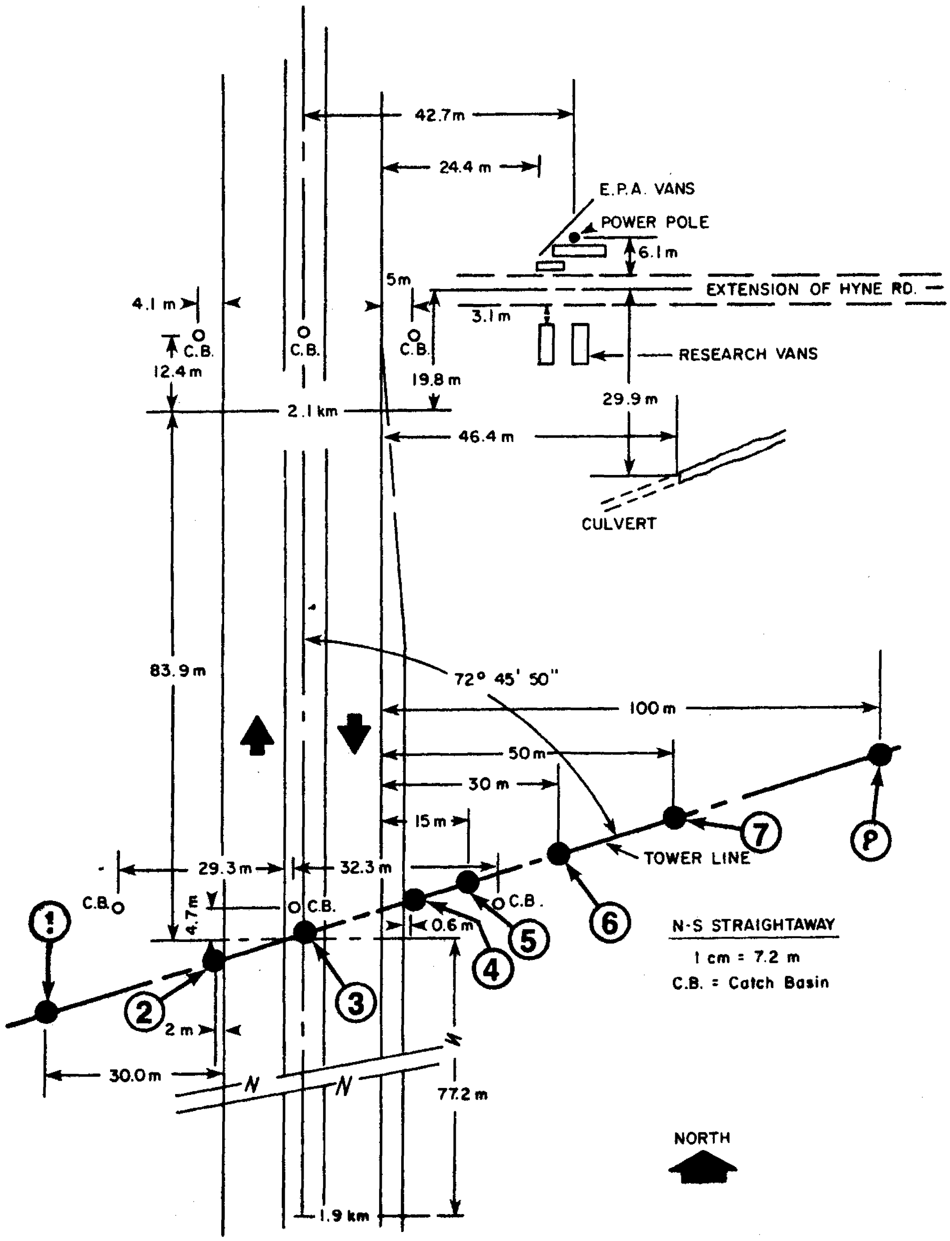


Fig. 3. Survey of the sampling area for the General Motors dispersion experiment (from Cadle, et al. (1976)).

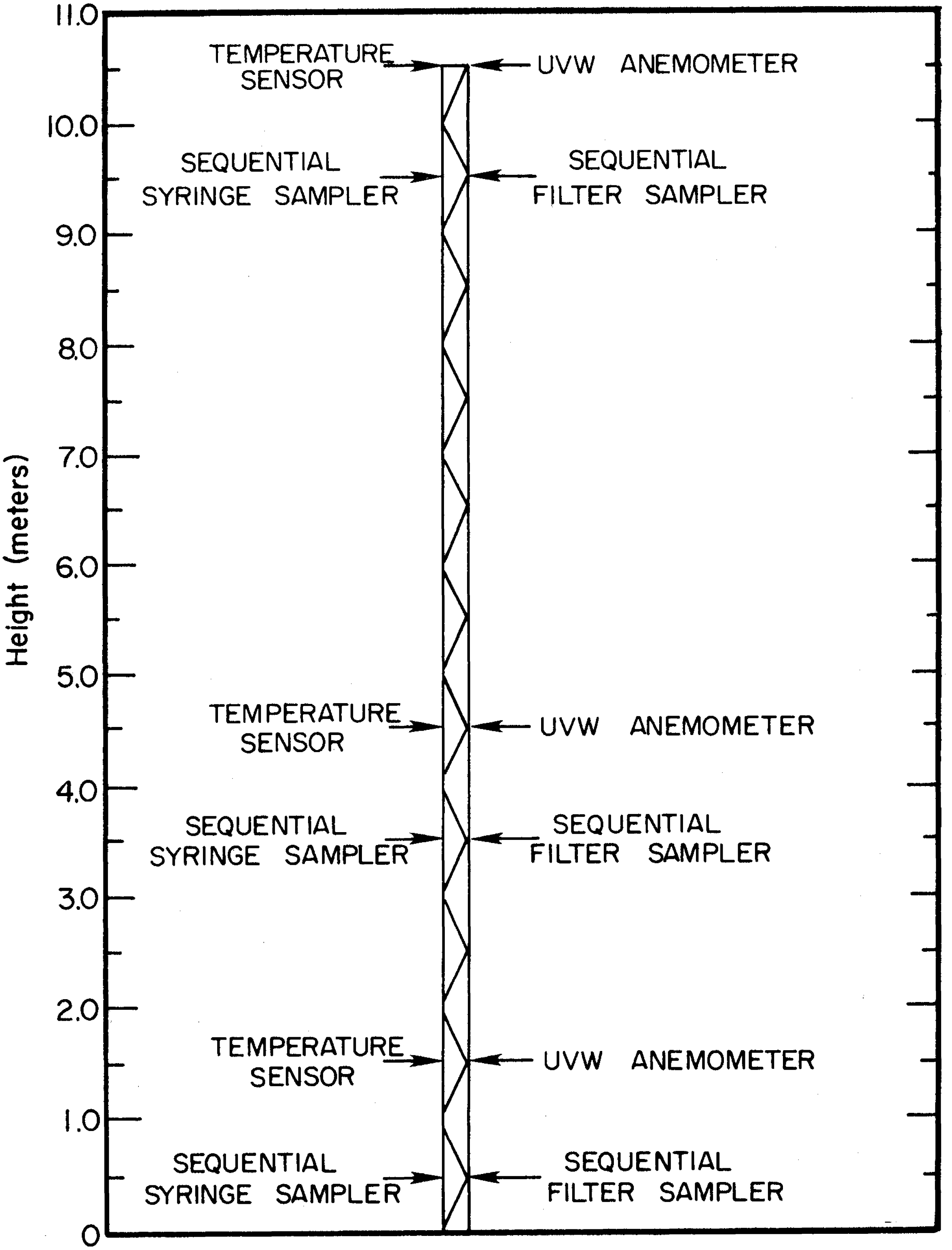


Fig. 4. Instrument elevations for the General Motors dispersion experiment (from Cadle, et al. (1976)).

Wind speed and direction were measured using Gill Model 27004 UVW anemometers equipped with propeller extensions. Measurements were recorded once per second using a Monitor Labs Model 9100 data logging system. Temperature data was recorded every 5 seconds on a Vidar 5403 D-DAS system. Wind speed, wind direction, and temperature were reported as half-hour averaged values in Cadle's (1976) final report.

Texas Data

One of the most extensive experimental studies of carbon monoxide dispersion from highways was conducted by Bullin, et al. (1978) at six different sites in Texas. Data were collected at four at-grade sites (Houston, Dallas, San Antonio, and El Paso), a cut-section in Houston, and an elevated section in Dallas.

The general instrumentation layout is shown in Figure 5. Vehicle count, average vehicle speed, and heavy duty vehicle mix were all determined using Stephenson Mark 5 doppler-shift radar units which were mounted above each lane of traffic. Carbon monoxide data was continuously measured using Ecolyzers. The Ecolyzers were mounted two per tower at heights of 5 and 33 feet, except for two which were mounted at 47 and 102 feet. One of the towers was positioned on the predominantly upwind side of the road, while the others were located at various distances downwind of the road.

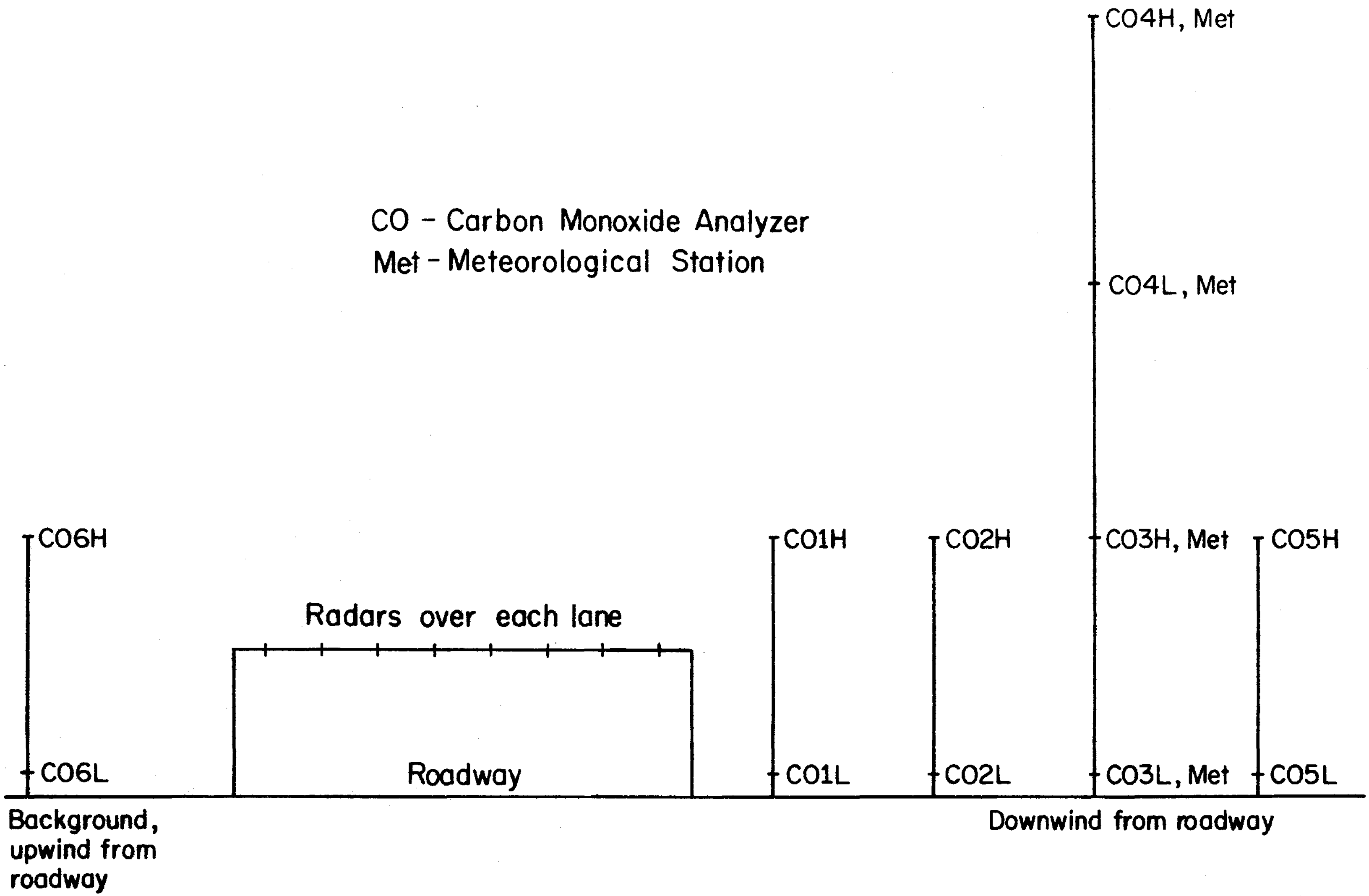


Fig. 5. General instrumentation layout for the Texas A&M data collection program.

Meteorological data was measured at four different levels on one of the downwind towers as shown in Figure 5. Horizontal wind speed and direction were measured with six-cup anemometers and wind vanes manufactured by Texas Electronics. Gill propeller anemometers were used to measure vertical wind speeds. Temperature, humidity, and solar radiation were also measured.

All of the measurements in the Texas experiments were logged on a Data General Nova 1200 minicomputer via a Radian analog to digital converter. Instruments were read at intervals ranging from 2 seconds (the vertical anemometers) to 60 seconds (temperature readings). Average values of any period length may be calculated from the raw data.

The Ecolyzers were calibrated every two to four hours and yielded data that was accurate within 0.5 ppm. Traffic data was accurate to 2% for count and to 3 mph (+10% of speed) for vehicle speed. Wind speed data was considered to be accurate from 1 to 5%. One unique and important feature of the Texas data is that the standard deviations of the measurements are included in the data base. Martinez, et al. (1981) noted that the Texas data is the only data base which includes enough information to permit study of the effects of instrument error on the measurements.

The first site was an at-grade section of Interstate 610 at Link Road in Houston. The instrument locations for this site are shown in Figure 6. The roadway consisted of

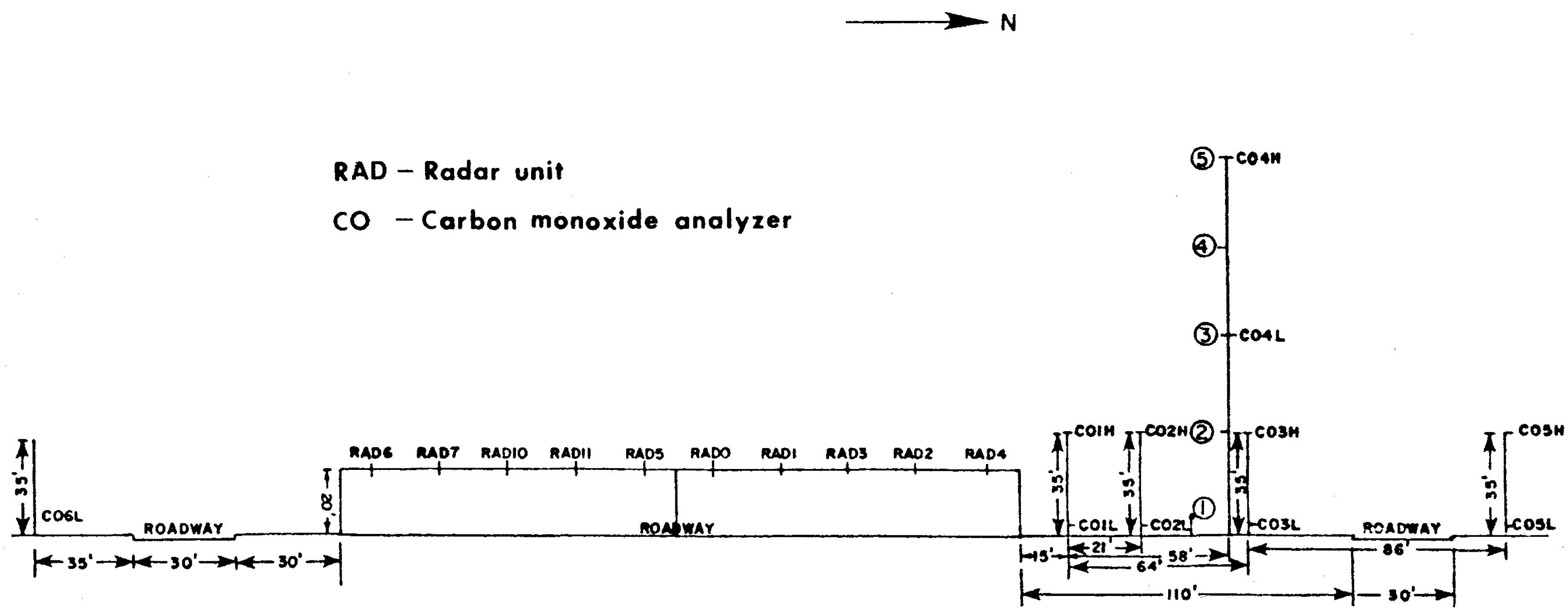


Fig. 6. Instrument locations for the Houston at-grade site.

five lanes of traffic in each direction with lightly travelled access roads on each side of the main roadway. The surrounding land was a residential area containing single and bi-level homes.

The second site was an at-grade section of Interstate 30 at Motley Drive in Mesquite (just outside of the Dallas city limits). The instrument locations for this site are shown in Figure 7. The roadway consisted of a main roadway with two lanes of traffic in each direction separated by a wide median, and a two-lane access road on each side of the main roadway. The surrounding terrain was flat, open, and covered with grass.

Site three was at an at-grade section of Interstate 410 at Military Highway in San Antonio. The instrument locations for this site are shown in Figure 8. The roadway consisted of three lanes in each direction. The surrounding area was residential, but the instruments were situated in a large, grassy field.

The fourth site was an at-grade section of Interstate 10 at Luna Street in El Paso. The instrument locations for this site are shown in Figure 9. There were six lanes of traffic in each direction on the main roadway with lightly travelled access roads on each side. The surrounding area was residential.

The data recorded at the cut and elevated sites was not used in this study. Most of the receptors at the Houston cut site were located within the cut and could be modelled

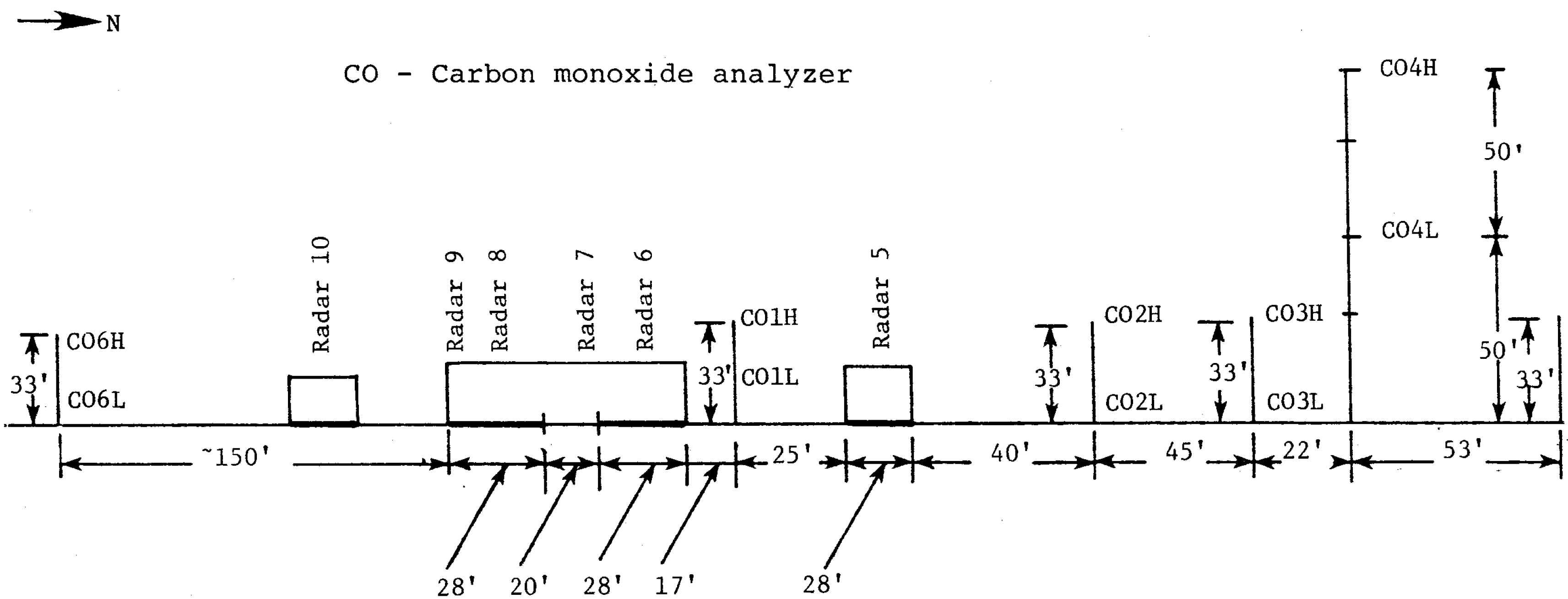


Fig. 7. Instrument locations for the Dallas at-grade site.

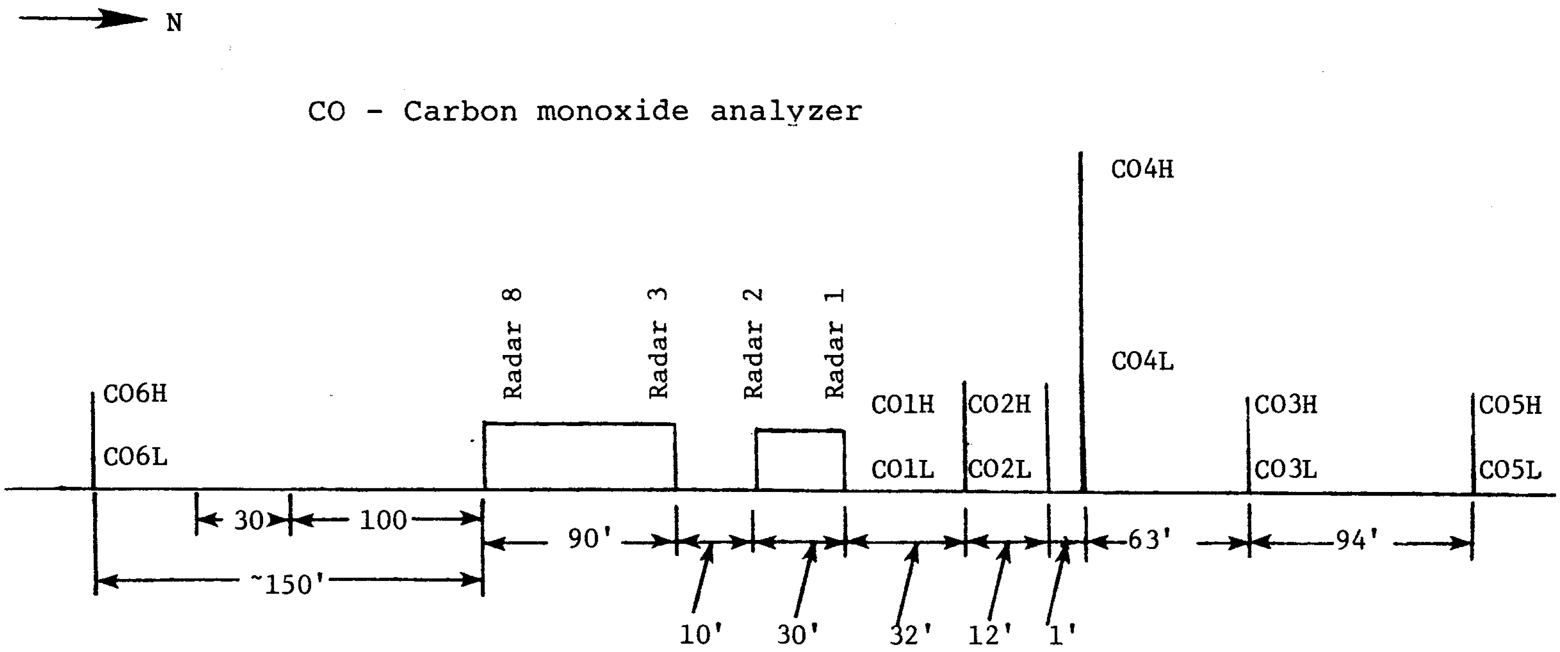


Fig. 8. Instrument locations for the San Antonio site.

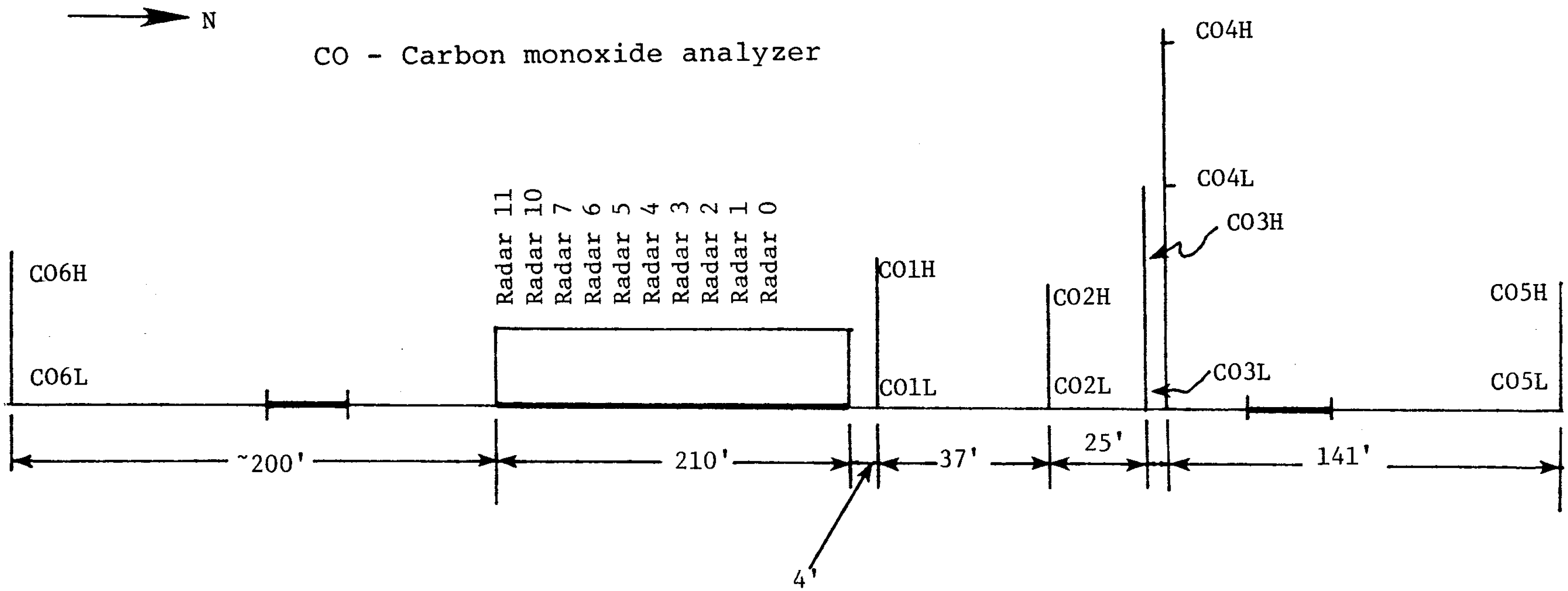


Fig. 9. Instrument locations for the El Paso site.

by only one of the dispersion models considered in this report (CALINE-3). The Dallas elevated roadway was located on top of an earth-filled concrete mass which obstructed wind flow under the roadway and could not be modelled by any current dispersion model. These data bases should be of extreme interest in the future when more sophisticated models are available.

SRI Data

The results of an extensive experimental project performed by the Stanford Research Institute were recently published by Dabberdt, et al. (1981). Diffusion experiments were conducted at grade-level, elevated, and depressed sections of roadway. A unique feature of the SRI study was that two different tracer gases were released (one in each direction of traffic). Several wind tunnel experiments were also conducted, but these will not be discussed in this report.

The at-grade experiment was conducted in the San Francisco Bay Area on a stretch of U.S. Highway 101, in Santa Clara, California. The road is a major intrastate freeway with three lanes of traffic in each direction. The surrounding area was primarily a subdivision of single level homes.

During all of the data collection periods, two vans were driven continuously in the traffic stream. The vehicles always drove in the center lane at the general traffic speed. SF_6 was released in the west direction and $F_{13}B_1$ in the east direction. Both gases were released at a measured uniform rate, between points approximately 400 metres to either side of the sampling line.

The location and orientation of the instrumentation used at the at-grade site is given in Figure 10. Traffic was measured using traffic sensors (cables) placed across the roadway. Comprehensive traffic information including speed and axle number for each vehicle was recorded. R.M. Young Co. UVW anemometers and propeller vanes were used to record wind data. A computer was used to log meteorological data every 2.5 seconds. As in the Texas study, temperature and insolation were also recorded.

Concentration measurements were not continuous. Environmental Measurements, Inc. sequential multiple bag samplers were used to obtain hourly air samples. The sample bags were made of clear Tedlar and held approximately 5 litres of gas. The samples were analyzed for SF_6 and $F_{13}B_1$ using a modified Perkin-Elmer gas chromatograph. Carbon monoxide, methane, and hydrocarbon concentrations were determined using a Beckman Model B6800 Air Quality Chromatograph.

The elevated diffusion experiment was conducted at a viaduct section of I-280 in San Jose, California. This section consisted of two 7 metre high viaducts, each about

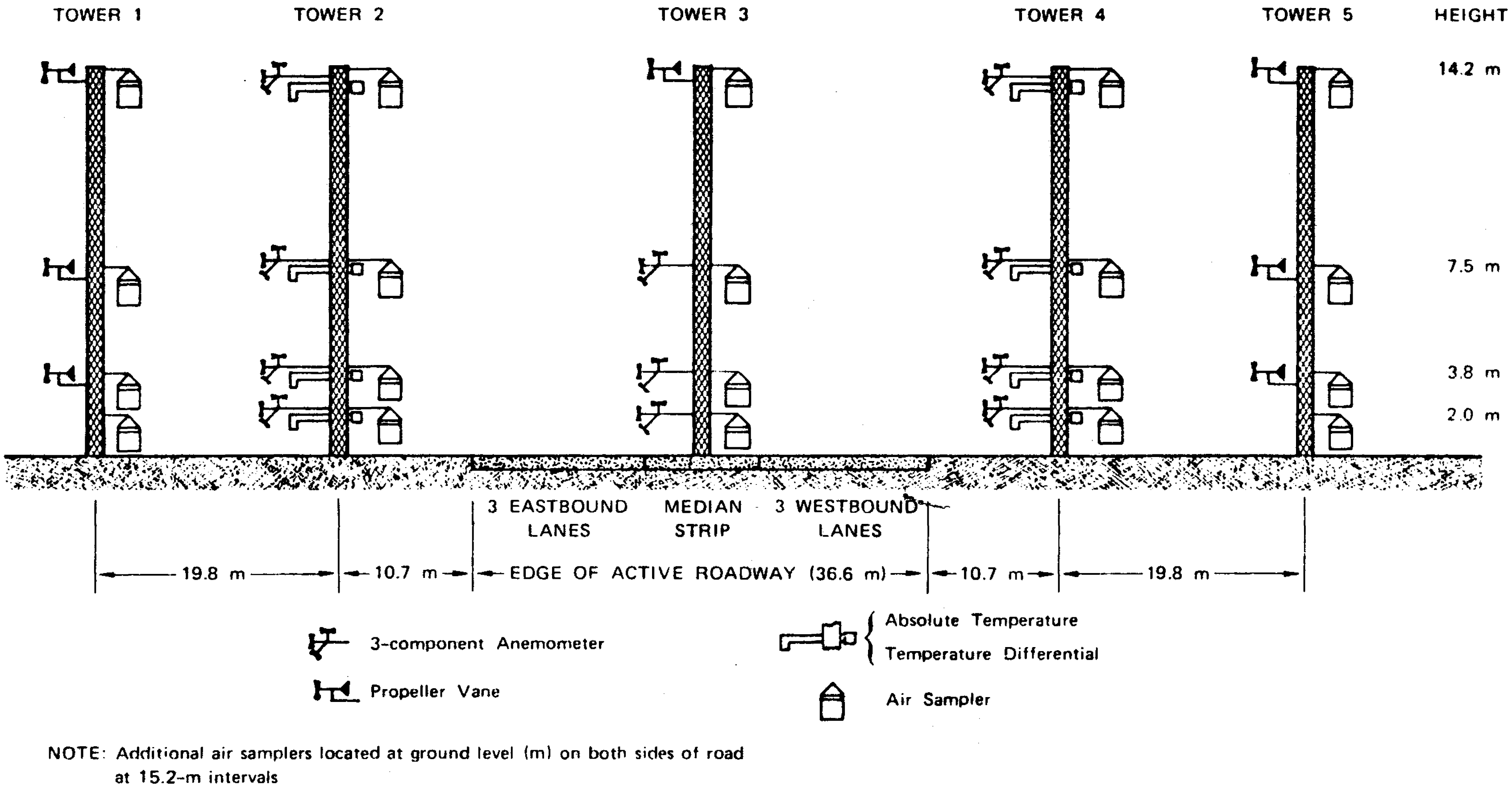


Fig. 10. Instrument locations for the SRI at-grade site (from Dabberdt (1981)).

24 metres wide. The viaducts were separated by 15 metre gap. The top of the viaducts were just above the roof level of several two-story houses which were located on each side of the roadway. The elevated roadway experiment was conducted in the same manner as was the at-grade experiment. Instrument locations are shown in Figure 11.

The cut section experiments were not included in the present work. Receptors were located inside of a deep-cut section and could not be modelled by any of the existing dispersion models.

Other Data Bases

Several other data bases have been collected for use in roadway pollutant dispersion modelling. Since these data bases were not used directly in the study, they will be mentioned only briefly.

A comprehensive review of data sets collected in several different states was presented by Green (1980). These data sets were: North Carolina, by Noll (1973); Tennessee, by Noll, et al. (1975); Virginia, by Carpenter and Clemena (1975a); Illinois, by Habegger, et al. (1974); California, by Ranzieri, Bemis, and Shirley (1975); and Washington, by Badgely, et al. (1976). Another important study which Green failed to mention was conducted in New York State by Rao, et al. (1978). Bullin, et al. (1982) recently completed a tracer gas mass balance study in Texas.

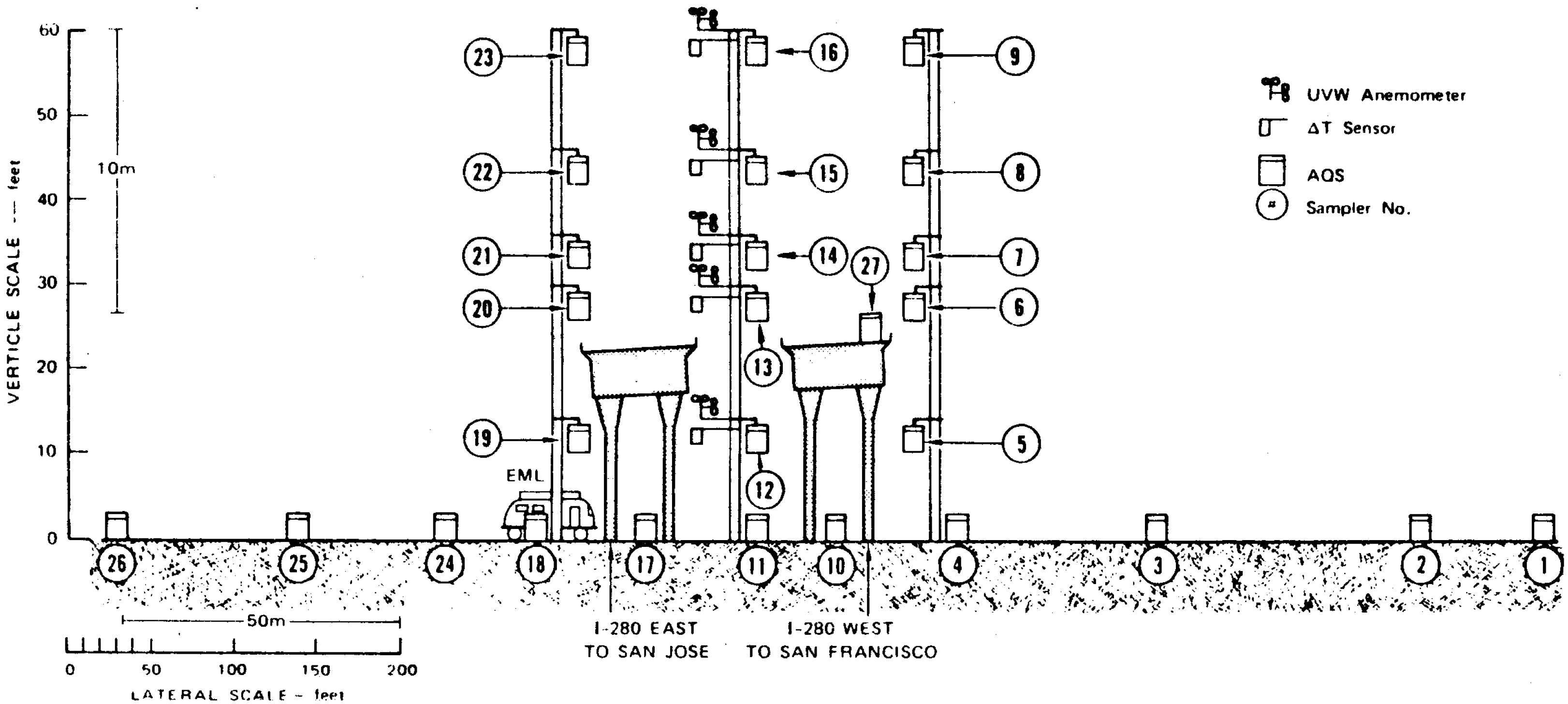


Fig. 11. Instrument locations for the SRI elevated roadway site (from Dabberdt (1981)).

CHAPTER 3

MODEL DEVELOPMENT

The history and development of the roadway pollutant despersion model, TXLINE, is presented in this chapter. The TXLINE Model was developed as a part of Project 2-8-80-283. Literature relevant to the model development process is discussed within the pertinent section of the development.

As the model was being developed, several ideas and theories were tested which were not incorporated in the final version of the model. Many of these ideas are presented in this chapter because they played an important role in the model development process.

The chapter is divided into several sections, each intended to highlight a particular stage of the dispersion model development process. Although some overlap could not be avoided, the sections were primarily written in the chronological order in which they were investigated. Detailed discussion of the actual input and output of the computer program is explained in a user's guide which is included as an Appendix.

A. DISPERSION EQUATIONS

The dispersion equations used in the TXLINE Model were all derived by F.B. Smith (1957), from the most general form of the diffusion equation:

$$u(z)\frac{\partial C}{\partial x} = \frac{\partial}{\partial z}\left(K_z\frac{\partial C}{\partial z}\right) + \frac{\partial}{\partial y}\left(K_y\frac{\partial C}{\partial y}\right) \qquad (3\text{-}1)$$

where: C = concentration
u = wind speed
x = direction of wind
and K = eddy diffusivity, (l^2/time).

The term containing the x-component of the eddy diffusivity was assumed negligible when compared to the bulk flow term, $u(z)\frac{\partial C}{\partial x}$.

Assumed Wind Speed Profile

In order to solve Equation (3-1), functional forms were needed for the wind speed and eddy diffusivity profiles. With the exception of the TRAPS-IIM Model, all previous models had assumed a flat wind speed profile. The logarithmic profile, given in Equation (2-22), has been generally accepted as the most realistic profile, but substitution of the logarithmic profile into Equation (3-1) yields a very complex differential equation which has not yet been solved analytically. Following Calder (1949), Smith (1957) assumed the power law wind profile which was presented in Equation (2-20).

Assumed Eddy Diffusivity Profile

The form of the eddy diffusivity profile in the z-direction follows directly from the assumption of a power law wind profile. According to the Reynolds analogy, K_z, which is the coefficient of vertical mass transfer, is proportional to the coefficient of vertical momentum transfer or:

$$\rho K_z \frac{\partial u}{\partial z} = \text{constant} = \tau_o \qquad (3-2)$$

where: ρ = fluid density
and τ_o = shearing stress = ρu_*^2.

This equation implies that the shearing stress is constant with height. Ertel (1933) showed that this assumption is reasonable in the lower 30 metres of the atmosphere. If u satisfies Equation (2-20) and assuming Equation (3-2) to be valid, then K_z must also obey the simple power law expression:

$$K_z = K_1 \left(\frac{z}{z_1}\right)^{1-m} \qquad (3-3)$$

where: m = the power law wind speed parameter (see Equation (2-20)).

According to Sutton (1953), there is a high enough degree of isotropy in the lower atmosphere to justify the assumption that $K_y = K_z$. Therefore the K_y was also assumed to be defined by Equation (3-3).

All of the dispersion equations used by the TXLINE Model are solutions to Equation (3-1) and each assumes the appropriate power law profile for u, K_x, and K_y. The method used to fit the parameters u_1 and K_1 is presented in a later section. A brief discussion and presentation of each dispersion equation used in the TXLINE Model follows.

Infinite Line Source Equation

The infinite line source equation for a perpendicular wind and source elevated at height, h, above ground level was used in TXLINE. The simplified, differential equation can be obtained by substituting Equations (2-20) and (3-3) into Equation (3-1). The result is:

$$u_1 (z)^m \frac{\partial C}{\partial x} = K_1 \frac{\partial}{\partial z} \left[z^{1-m} \left(\frac{\partial C}{\partial z} \right) \right] \qquad (3\text{-}4)$$

The appropriate boundary conditions are:

(i) In the plane of the source, $x = 0$; $C = 0$, except for at the source where C is infinite.

(ii) The ground is impervious to the pollutant: at $z = 0$, $K_z \frac{\partial C}{\partial z} = 0$.

(iii) The concentration dies away at great heights; $C \rightarrow 0$ as $z \rightarrow \infty$.

(iv) The flux across any plane x = constant is independent of the value of x, or:

$$\int_0^\infty C\, u\, dz = Q = \text{source strength}$$

(This condition is not independent of the others.)

Smith (1957) showed the solution to be:

$$C = \frac{Q}{(1+2m)} \frac{(h(z-h) + h^2)^{m/2}}{K_1 z} \exp\left[\frac{u_1 z^{1+2m} + u_1 h^{1+2m}}{K_1 (2m+1)^2 x}\right] \tag{3-5}$$

$$\cdot\ I_{-m/(1+2m)}\left[\frac{2u_1 ((z-h)h + h^2)^{(1+2m)/2}}{K_1 (2m+1)^2 x}\right]$$

where: Q = source strength, g/m/sec

and $I_{-m/1+2m}$ is a modified Bessel function of the first kind with order equal to $-m/1+2m$.

For the special case of a ground level source (h=0), this equation reduces to:

$$C = \frac{Q\left(x\left(\frac{K_1}{u_1}\right)\right)^{-(1+m)/(1+2m)}}{u_1 (1+2m)^{1/(1+2m)} (-m/(1+2m))!} \cdot \exp\left[\frac{-u_1 z^{1+2m}}{K_1 (1+2m)^2 x}\right] \tag{3-6}$$

where: $(-m/1+2m)!$ is a factorial of a non-integer. The model calculates this quantity using a gamma function. ($\Gamma(1-m/1+2m) = (-m/1+2m)!$)

Elevated Point Source Equation

Due to the complex nature of the equations, the solution of the elevated point source problem for general values of the power law parameter, m, has not yet been found analytically, but Smith (1957) was able to solve the problem for the case of m = 1/2. This solution provided Smith with a valuable hint regarding the form of the general ground level point source equation. The solution to Equation (3-1) for an elevated point source and $m = 1/2$ is:

$$C = \frac{Q}{4\sqrt{\pi}} \frac{((z-h)h + h^2)^{\frac{1}{4}}}{(K_1 x)^{3/2}} \exp\left[\frac{-y^2 + h^2 + z^2}{4K_1(x/u_1)}\right] \bullet I_{-\frac{1}{4}} \frac{(z-h)h + h^2}{2K_1(x/u_1)} \tag{3-7}$$

where: Q = point source strength, (g/sec).

<u>General Level Point Source Equation</u> (for general values of m)

The ground level point source equation was solved by "guessing" the form of the solution. Smith expressed the concentration, C, in terms of the following two functions:

$$C_0 = \int_{-\infty}^{\infty} C \, dy \tag{3-8}$$

$$\text{and } C_2 = \int_{-\infty}^{\infty} y^2 C \, dy \tag{3-9}$$

The advantages of finding the solution for C in terms of these two functions are that they are two-dimensional, the boundary conditions are known, and each represents an important feature of the complete solution. C_0 is the infinite line source equation. The second function is the second moment of the transverse concentration profile, and thus C_2/C_0 can be considered as a measure of the 'spread' in the y-direction.

Smith noted that the solution for m = 1/2 had a Gaussian distribution in the crosswind (y) direction. Assuming that this was also the case for the general solution, he "guessed" the form of the general solution to be the following:

$$C = X(x,z)e^{-y^2/f(x,z)} \tag{3-10}$$

where: $f = 2C_2/C_0$

$X = C_0\sqrt{(C_0/2\pi C_2)}$.

The Gaussian distribution in the crosswind direction should not be confused with the form of the commonly used Gaussian dispersion equations which are used in most other air pollution models. The equations used in the other models assume a Gaussian distribution in both the y and z directions. Smith's equations show that although the crosswind concentration distribution has a Gaussian form, the z distribution is definitely not Gaussian.

The solution to the infinite line source equation, C_0, has already been presented as Equation (3-6). The "spread" function, C_2, as given by Smith is:

$$C_2 = \frac{2QK_1^{(b-a)}}{u_1^{(b-a+1)}} (1+2m)^{(3b-4)/2} \left[\frac{(b-1)!(b+a-2)!}{(a-1)!(2b-1)!}\right] x^{(b-a)} \tag{3-11}$$

$$\bullet\ e^{-\eta} \left[\frac{(b-1)!}{(a-1)!}\ {}_1F_1(b;a;\eta) - \eta^b V(b;a;\eta)\right]$$

where: $$\eta = \frac{u_1 z^{1+2m}}{(1+2m)^2 K_1 x}$$

$$a = (1+m)/(1+2m)$$

and $$b = 2/(1+2m).$$

The solution contains two rapidly converging series; ${}_1F_1$, which is Kummer's function:

$$ {}_1F_1(b;a;\eta) = 1 + \frac{b\eta}{a} + \frac{(b)_2\eta^2}{(a)_2 2!} \cdots \frac{(b)_n\eta^n}{(a)_n n!} \quad (3\text{-}12)$$

where:

$$(a)_n = a(a+1)(a+2)\ .\ .\ .\ (a+n-1),$$
$$(a)_0 = 1$$
$$(b)_n = b(b+1)(b+2)\ .\ .\ .\ (b+n-1),$$
$$(b)_0 = 1.$$

and an allied function, V:

$$V(b;a;\eta) = \sum_{r=0}^{\infty} \frac{(2b+r-1)!}{(b+r)!(b+a+r-1)!}\eta^r \quad (3\text{-}13)$$

The factorials needed are calculated in the model using the gamma function.

The final solution to the ground level point source equation was found by substituting Equations (3-6) and (3-11) into Equation (3-10).

B. A THEORETICAL CONSIDERATION OF ATMOSPHERIC STABILITY

Before values for the constants which appear in the dispersion equations were determined, the effect of atmospheric stability was considered. In Gaussian models, the effect of stability is included in the estimation of the Gaussian dispersion parameters σ_y and σ_z. Green (1980) presented a detailed review of the literature on this topic. In this study, the eddy diffusivity profile, K(z), was assumed to be a function of stability. Calder (1949) has shown that the eddy diffusivity profile is defined mathematically once the wind profile has been determined. (A complete discussion of this topic is presented in the next section.) Thus, the effect of stability on the wind profile needed to be examined.

The simple form of the log-law wind profile is valid only for neutral stability conditions. Bussinger (1973) proposed the following modified forms of the log-law to account for adverse stability conditions:

$$u = \frac{u^*}{k} \left(\ln(z/z_o) - 4.7\ z/L\right) \quad \text{for } z/L > 0 \qquad (3\text{-}14)$$

and

$$u = \frac{u^*}{k} \left(\ln(z/z_o) - \Psi\ z/L\right) \quad \text{for } z/L < 0 \qquad (3\text{-}15)$$

where: $\Psi(z/L)$ = a complicated function of the well-known stability parameter, z/L.

The quantity L, a function of surface heat and momentum fluxes, was first proposed by Monin and Obukhov (1953) and has since become known as the Monin-Obukhov length.

$$L = \frac{u_*^3 C_p \rho T}{MgH} \qquad (3\text{-}16)$$

where: u_* = friction velocity
C_p = specific heat of air at constant pressure
ρ = density of air
T = temperature
M = dimensionless constant
H = vertical heat flux.

According to Pasquill (1974), L is positive for stable conditions, negative for unstable conditions, and approaches infinity (z/L approaches zero) under neutral conditions.

Monin and Obukhov (1953) generalized the log-law to the log-linear form:

$$\frac{\partial u}{\partial z} = \frac{u_*}{kz} \phi \qquad (3\text{-}17)$$

where: ϕ = an empirically determined stability parameter.

They suggested that ϕ is a function of the well-known dimensionless stability parameter z/L, and proposed the following form of the function:

$$\phi = 1 + a_1(z/L) + a_2(z/L)^2 + \ldots a_i(z/L)^i \qquad (3\text{-}18)$$

where: $a_i(i=1,2,\ldots)$ = empirical constants.

Several other forms of the stability parameter ϕ have also been proposed. Dyer (1967) developed the following empirical relationship:

$$\phi = (1 - 15(z/L))^{-0.55} \qquad (3\text{-}19)$$

Businger, et al. (1967) expressed ϕ as a function of the Richardson number:

$$\phi = (1 - \alpha Ri)^{-0.25} \qquad (3\text{-}20)$$

where: α = an empirically determined constant

$$Ri = \frac{g}{T} \frac{dT/dz}{(du/dz)^2}$$

where: g = acceleration due to gravity
T = absolute temperature.

The Richardson number has a distinct disadvantage in that it is not applicable in unstable conditions caused by negative wind shear. z/L is the preferred measurement of stability, but has not been used extensively. Determination of L requires accurate measurements of surface heat and momentum fluxes, which are difficult and expensive to obtain.

Recently, Misra (1979) published a method of determining z/L using common meteorological instrumentation. Misra outlined a method of relating z/L to the auto-correlation function of the vertical wind velocity. The wave length at which the normalized spectrum of the vertical velocity shows a maximum, λ_m, is given by:

$$\frac{z}{\lambda_m} = \frac{z}{T_E u} \tag{3-21}$$

where: z = the height of the measurement

u = the mean horizontal wind speed

and $T_E = \int^{\infty} R_W(\xi)\, d\xi$

$R_W(\xi)$ is the Eulerian auto-correlation function of the vertical velocity. Misra noted that Kaimal, et al. (1972) have shown that z/λ_m is a unique function of z/L in the range of $-2 < z/L < 2$. Kaimal assumed in his derivation that the wind profile is described by Equations (3-14) and (3-15). z/L was shown to be defined by:

For $z/L < -1$; $\frac{z}{\lambda_m} = 0.18$ (3-22a)

For $-1 < z/L \leq 0$; $\frac{z}{\lambda_m} = 0.55 - 0.38|z/L|$ (3-22b)

For $0 < z/L < 2$; $\frac{z}{\lambda_m} = 2.5(1 + 4.7z/L)/(\ln z/z_o + 4.7)$ (3-22c)

Given sufficient vertical anemometer data, T_E, can be determined, which can be used to predict z/L, using Equation (3-21) and the appropriate form of Equation (3-22). Knowing z/L, other parameters such as u_* are also easily determined.

In a separate paper, Misra (1978) discussed the auto-correlation function in detail. He suggested that a one second averaging time and a 30-minute period (1800 measurements) be used for the auto-correlation. Misra also suggested that $R(\xi)$ be integrated only up until the first zero of the function.

Several values of z/L were calculated by the method presented in this section using randomly selected portions of the Texas A&M data base. Since vertical anemometer data was only recorded every 5 seconds, a one-hour time period was used (720 observations). Even though there were far fewer observations than the number suggested by Misra, results were encouraging. The shape of the auto-correlation curves agreed closely with the plots reported by Misra (1978). In most cases, the calculated value of z/L was near zero. This indicated that most of the data was taken in conditions of near neutral stability. An example auto-correlation curve for the El Paso site is given in Fig. 12. The area under the curve, T_E, was found to be 23.9 seconds. This value resulted in a predicted value of z/L = 0.17 using Equs. (3-21) and (3-22c), assuming z_o = 0.50m (Equ. (3-22c) is not very sensitive to z.).

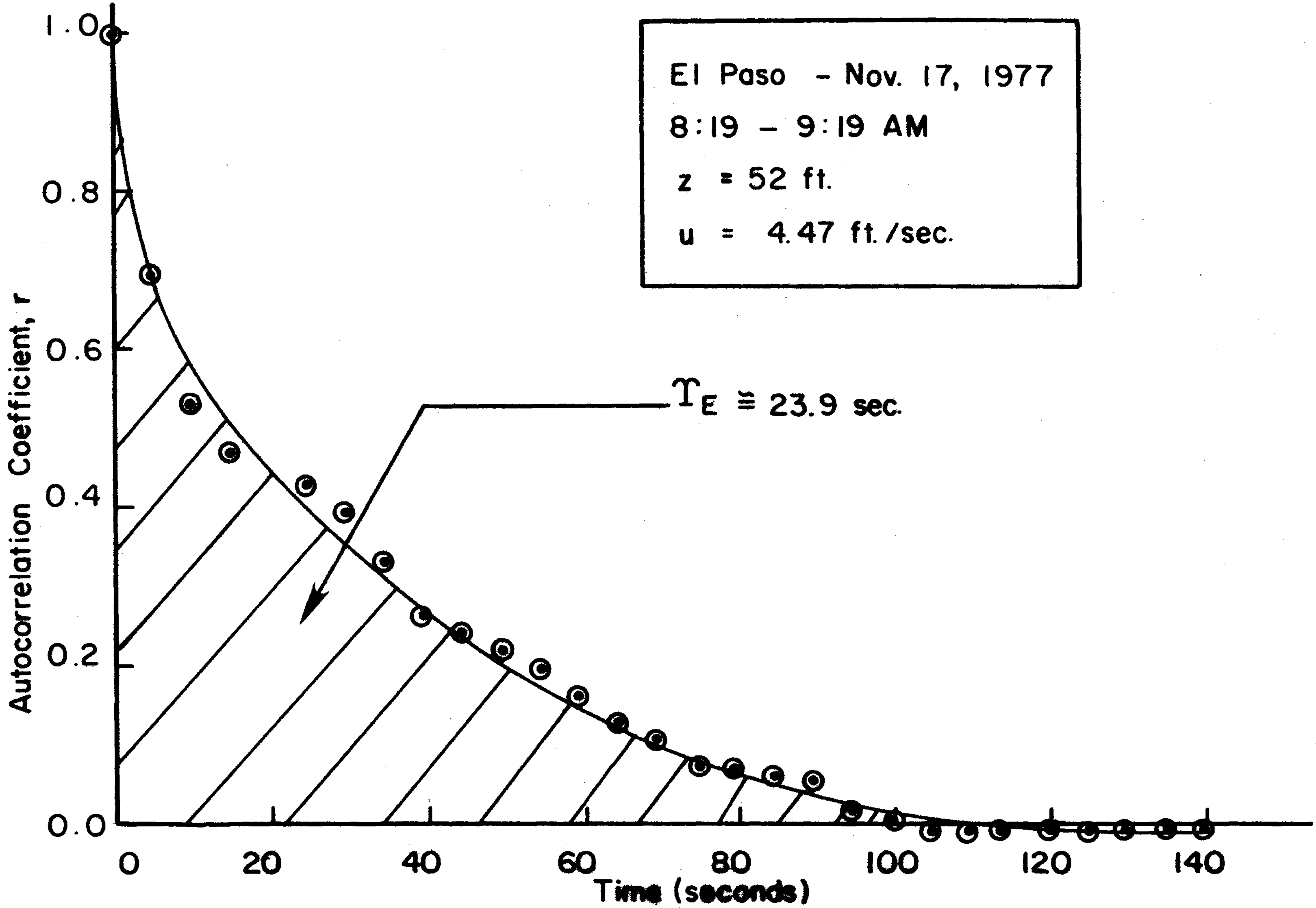


Fig. 12. Autocorrelation of vertical wind speed to determine the stability parameter, Z/L, for a typical case from the Texas data base.

Although it was hoped that the z/L theory presented in this section could be incorporated in the model, there was not enough data available to develop any reasonable correlations. However, two important conclusions were drawn from this study: 1) z/L can be determined quite easily using only a vertical anemometer, and 2) using the most accurate estimation of stability (z/L), initial calculations indicate that a large portion of the Texas data was taken during near neutral stability conditions.

Although most existing dispersion models do consider the atmospheric stability to have a significant effect on dispersion near a roadway, there is also strong evidence in the literature that it does not. Rao, et al. (1979), and Eskridge and Hunt (1979) clearly demonstrated that the dispersion near the roadway is completely dictated by locally generated turbulence and is not significantly influenced by atmospheric stability. Stability in the vicinity of the roadway still is not well-defined, but appears to usually be near neutral based on this preliminary investigation of z/L using the Texas data base. The current version of the TXLINE Model therefore assumes neutral stability in all cases. Hopefully, the stability theory presented in this section can be applied to a future version of the model, in order to account for significant deviations from neutral stability.

C. ESTIMATION OF THE METEOROLOGICAL PARAMETERS

The methods used to estimate the meteorological parameters required to define the power law wind speed and eddy diffusivity profiles are presented in this section. The power law wind speed profile parameters were chosen so that the power law approximated the preferred log-law profile as closely as possible.

Calder (1949) discussed the various forms of the log-law and power law profiles in great detail. According to Calder, the common log-law profile (Equation (2-22)) should be modified in the following manner:

$$u = \frac{u_*}{k} \ln\left(\frac{z-d}{z_o}\right) \qquad (3\text{-}23)$$

where d is a 'zero-point displacement' distance, which is a datum level above which active turbulent exchange first begins and the logarithmic law is valid. Since little support for this form of the log-law could be found in the literature, d was assumed to be equal to zero in the TXLINE Model. With this assumption, Equation (3-23) reduces to the common form of the log-law (Equation (2-22)).

The power law approximation can be stated in a slightly different form than that of Equation (2-20):

$$u = u_* \, q(z/z_o)^m \qquad (3\text{-}24)$$

where q is a dimensionless constant. This equation is consistent with Equation (2-20), as can easily be verified by algebraic rearrangement of the equations.

The two parameters q and m, which appear in Equation (3-24), were fit in order to approximate the log-law over the range of $z_o < z < 30$ metres. (z_o is the lower limit of the log-law. Thirty metres is the upper limit given by Ertel (1933) for the region of constant shearing stress.)

The following function was developed to minimize the squared error between the power law and the log-law in the range of z_o to 30 metres:

$$F = \int_{z_o}^{30} (u_* q(z/z_o)^m - \frac{u_*}{k} \ln(z/z_o))^2 \, dz \qquad (3\text{-}25)$$

The corresponding values of q and m which minimize the function, F, were calculated using Newton's method for values of z_o ranging from 0 to 5m at 2.5cm increments.

The results of this procedure showed that both q and m are functions of z_o only. This was expected, since k is a constant, and u_* is raised to the same power in each profile. The following polynomials were determined using SAS (1976) and were used to correlate the 'best fit' values of q and m as a function of surface roughness:

For $0 < z_o \leq 0.30$ metres; (3-26)

$$m = 0.143 + 1.901*z_o - 15.62*z_o^2 + 83.24*z_o^3 - 224.4*z_o^4 + 236.0*z_o^5$$

and (3-27)

$$q = 5.818 - 46.12*z_o + 416.4*z_o^2 - 2162.3*z_o^3 + 5671.*z_o^4 - 5830.*z_o^5$$

For $0.30 < z_o < 5.0$ metres; (3-28)

$$m = 0.229 + 0.306*z_o - 0.122*z_o^2 + 0.040*z_o^3 - 0.0066*z_o^4 + 0.0004*z_o^5$$

and (3-29)

$$q = 3.827 - 4.385*z_o + 4.50*z_o^2 - 2.88*z_o^3 + 1.102*z_o^4 - 0.245*z_o^5 + 0.029*z_o^6 - 0.0014*z_o^7$$

Once these general expressions for q and m were determined, the reference wind speed, u_1, could be calculated for any case. Given surface roughness, z_o, and a reference wind speed at a known height, the friction velocity, u_*, is easily determined using Equation (2-22). Substitution of u_* into Equation (3-24), with z = 1 metre, yields the corresponding value for u_1.

The reference eddy diffusivity, K_1, can be determined once u_* is known. From the definition of the friction velocity, the constant shearing stress, τ_o, can be determined. Substitution of τ_o, and the wind speed profile given by Equation (3-24), into Equation (3-2), verifies that the form of eddy diffusivity profile which was presented in Equation (3-3) is correct. Solving the resultant equation for K_1, yields:

$$K_1 = \frac{u_1 z_o^{2m}}{mq^2} \qquad (3-30)$$

where: K_1 = the eddy diffusivity at z=1.

A difficulty arises in estimating the power law parameters for the elevated case, since the elevated point source solution was solved only for the case of m = ½.

Two possible methods of estimating u_1 and K_1 for the elevated roadway were considered:

(1) Fixing m = ½ in the minimization function (Equation (3-25)) and determining different polynomials to predict q for the elevated cases.

(2) Using the actual 'best fit' values of q and m to predict K_1 and u_1 (as described in this section), neglecting the fact that the elevated point source solution is valid only for m = ½.

These two methods were tested by allowing the source elevation to approach zero in the elevated point source solution and then solving for the concentration predictions for a wide range of input variables. Ideally, the concentration predictions should approach the predictions of the ground level point source solution. The second method was a much better approximation than the first one, and was therefore used in the final model.

D. <u>TREATMENT OF THE OBLIQUE WIND ANGLE CASE</u>

As discussed earlier, the existing dispersion models treat oblique winds in a variety of ways. The ideal method of treating oblique winds would be to solve the differential equations analytically for general wind angles, but due to the complex nature of the equations, no analytical solutions were found in the literature.

The GM data base was chosen to test several other proposed methods of treatment for the oblique wind angle case. This data base encompasses a large range of wind angles and has been used extensively to develop several state-of-the-art roadway pollutant dispersion models.

Each method of treatment which was tested is outlined in this section. More detailed descriptions of the various methods were presented by Rodden (1983). The final method of treatment which is discussed was incorporated in the TXLINE Model.

Attempts to Modify the Infinite Line Source Equation

Although all existing infinite line source equations were originally derived for perpendicular winds only, Green (1980) demonstrated that it is possible to estimate diffusion in an oblique wind by distorting a perpendicular wind equation in order to fit empirical data.

The following methods of modifying the infinite line source equation used in TXLINE (Equation (3-6)), were investigated in detail;

(1) neglecting wind angle entirely

(2) adjusting the wind speed as a function of wind angle

(3) adjusting the eddy diffusivity as a function of wind angle

(4) adjusting the power law exponent as a function of wind angle

(5) using a 'virtual' line source location

(6) raising the source height.

Rodden (1983) reported varying degrees of success with these methods. However, none of the methods could satisfactorily represent the relationships between wind angle and concentration which were observed in the GM data base. Rodden concluded that a more theoretical treatment of wind angle was preferable to any of these methods.

Theoretical Approach to the Problem

Since the solution to the point source dispersion equation was already known (Equation (3-10)), the infinite line source problem for general wind angles was reduced to an integration of the point source equation. The infinite line source was considered to be represented by an infinite number of very closely placed point sources located along a line. Each point source coordinate system was orientated with the x-axis parallel to the wind as can be seen in Figure 13. Before the point source equations could be integrated, a coordinate transformation was necessary. Since each point source coordinate system has a different origin, the x and y coordinates of a given receptor depend on the location of the point source, as shown in Figure 13.

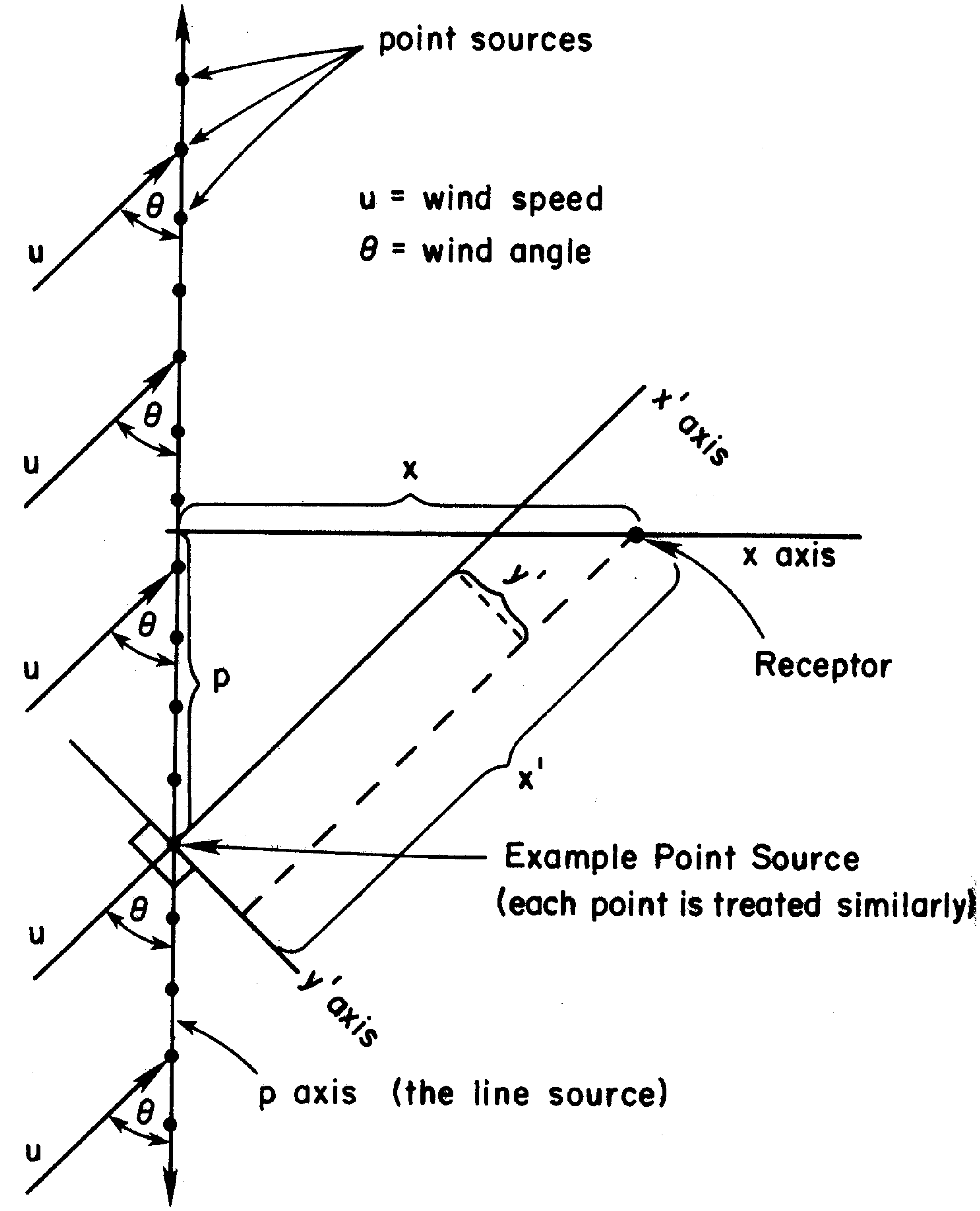


Fig. 13. TXLINE point source representation of a line source for general wind angles.

The point source coordinate transformations are given below, and are easily verified using the following simple geometric relationships:

$$x' = x \sin\Theta - p \cos\Theta \qquad (3\text{-}31)$$

and

$$y' = x \cos\Theta + p \sin\Theta \qquad (3\text{-}32)$$

where: Θ = wind angle with line source (0°=parallel, 90°=perpendicular)

x' = x-coordinate of the receptor with respect to the point source coordinate system

y' = y-coordinate of the receptor with respect to the point source coordinate system

x = x-coordinate of the receptor with respect to the line source (the line source is the p axis)

p = p-coordinate of the point source (not the p-coordinate of the receptor).

The concentration profile downwind of a ground level infinite line source for any general wind angle was defined mathematically by: (1) Replacing the variables x and y in the ground level point source equation with the transformed variables x' and y' defined in Equations (3-31) and (3-32), and (2) integrating from $-\infty$ to ∞ with respect to the p direction (along the line source). The equation for the profile is:

$$C = \int_{-\infty}^{\infty} C_o \sqrt{\frac{C_o}{2\,C_2}} \exp \frac{-(C_o)(x \cos\Theta + p \sin\Theta)^2}{2C_2}\, dp \qquad (3\text{-}33)$$

where: C_o is defined by Equation (3-6), with x replaced by x'
C_2 is defined by Equation (3-11), with x replaced by x'.

By changing the limits of the integration in Equation (3-33) to finite values, the finite line source equation was obtained for general wind angles.

Solving the Theoretical Problem

Several attempts were made to integrate Equation (3-33) analytically, but due to the complex functional form of the equation, a solution could not be derived. Integration by parts showed promise of resulting in an infinite series solution, but a final solution was not obtained in this study. As a result, the equation was integrated numerically. Point sources were equally spaced along the line source. Each point source represented a small segment of the line source as shown in Figure 14. The point source strength was determined by:

$$Q_{pt} = Q_{line} * S \qquad (3\text{-}34)$$

where: Q_{pt} = point source strength (g/sec)
Q_{line} = line source strength (g/(m sec))
S = segment length (equal to the distance between point sources) (m).

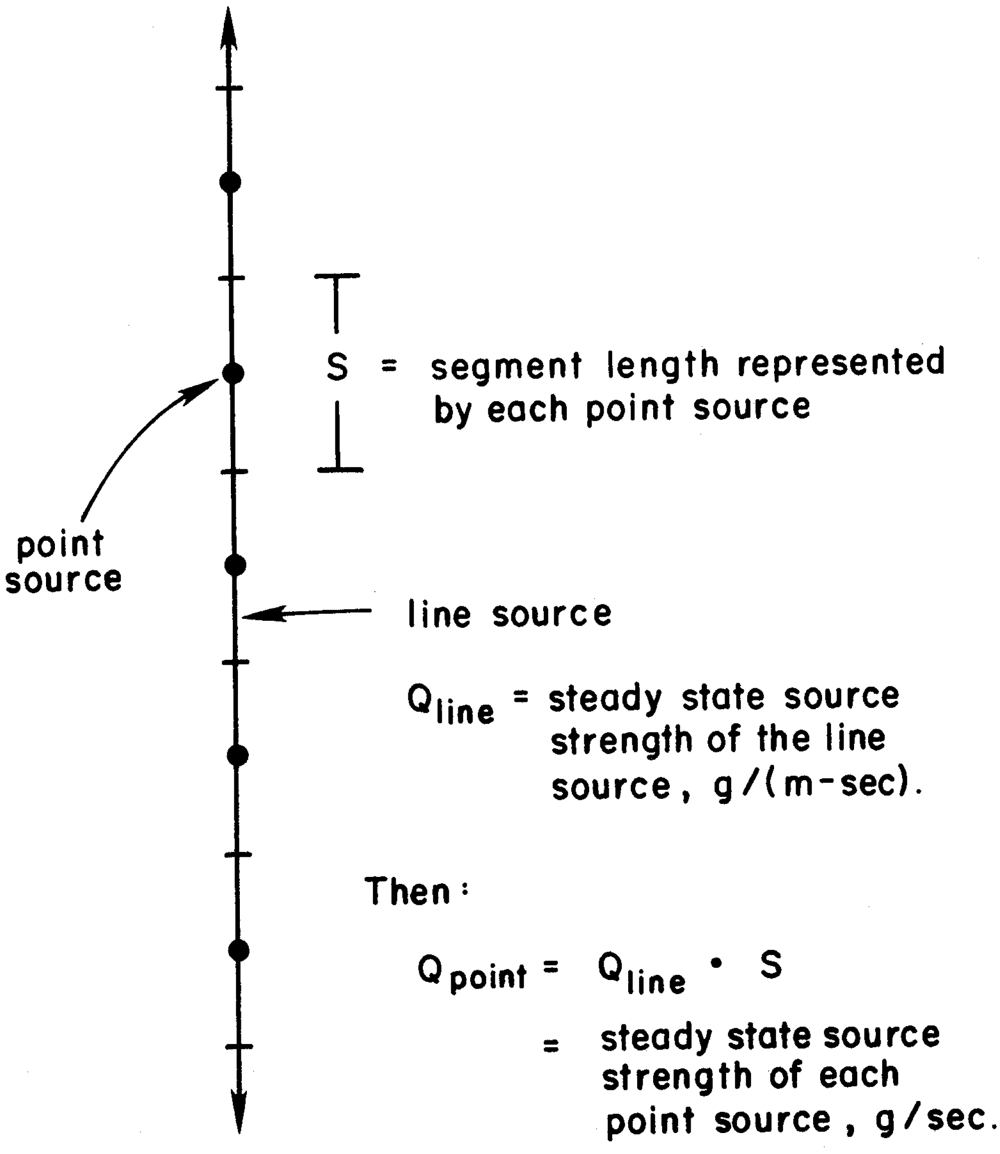


Fig. 14. Determination of point source strength for TXLINE.

Initially, point sources were placed very close together (0.10m) to insure an adequate approximation of the integral. The numerical integration was started at p = 0 (the receptor line). Point source contributions were added in the positive p direction (p = 0.10, 0.20, 0.30, ...) and then in the negative p direction (p = -0.10, -0.20, -0.30, ...). The integration was continued in each direction until the effect on the total predicted concentration value was negligible.

The new model was checked for consistency by letting $\theta = 89°$, and comparing concentration predictions to the predictions given by Equation (3-6) for the case of a perpendicular wind and an infinite line source. Predictions were compared over a wide range of input variables x, z, and u. The new model predicted concentrations which were nearly identical to those predicted by Equation (3-6) in every case. The numerical integration was therefore proven to agree with the analytical solution for the special case of a perpendicular wind. This comparison is discussed in detail in the RESULTS chapter.

The model now included the effect of wind angle in the concentration prediction, and was ready to be tested against the GM data base. The results of the comparison of predictions from this version of the model were very encouraging. As input wind angle decreased, road edge concentration predictions increased, and downwind predictions decreased. This pattern agreed with the GM data, and had not been predicted by any of the earlier versions of the model. For windspeeds above 2.5 metres/sec the magnitude of the concentration predictions agreed very closely with the GM data, regardless of wind angle, but at lower wind speeds, the model tended to overpredict. Although the model predicted more wind speed dependence than observed in the GM data, the wind angle dependence agreed closely with the data.

Preliminary comparisons indicated that although the present model still required some improvements, the model was already approaching the accuracy of the established models. This observation was extremely encouraging, since the established models used in the comparison employed several empirical parameters, which were fit using the GM data.

The primary problems of the current model were overprediction for low wind speed cases and excessive use of computer time. However, before considering these two problems, the model was extended to cover the cases of elevated, cut, and fill sections of highway.

General Wind Angle Solution for Elevated Roadways

The equation for an elevated point source was also numerically integrated to obtain the solution for an elevated line source, as shown below:

$$C = \int_{-\infty}^{\infty} C_{ep}\, dp \qquad (3\text{-}35)$$

where: C = concentration downwind of the line source

C_{ep} = elevated point source solution as given in Equation (3-7), but with x replaced by x', where x' is defined by Equation (3-31)

p = distance along the line source.

This solution was included in the model to predict concentrations downwind of a bridge. Bridges which severely obstruct wind flow underneath the roadway should not be modelled with TXLINE.

Since Equation (3-7) was only solved for one value of the power law exponent ($m = \frac{1}{2}$), the elevated line source solution is not completely consistent with the ground level line source solution. This problem is discussed in detail in the RESULTS chapter.

General Wind Angle Solution for Cut and Fill Roadways

Moderate cut sections (a 2:1 grade or less) were handled in the same way as in CALINE-3. The assumption was made that air flow streamlines are not disturbed as they pass over a gradual cut. Gloyne (1964) discussed the reasoning for this assumption in detail. This assumption allowed the datum level (z=0) to be left at ground level, and did not require any modification of the dispersion equations.

Moderate fill sections (2:1 grade or less) were treated in the same way as the cut section. The current TXLINE model is not able to model steep cut sections or fill sections of roadway.

E. LOW WIND SPEED ADJUSTMENT FACTOR

The problem of overpredicting concentrations for low wind speed cases was minimized by applying an empirical wind speed correction factor. Several reports of the use of a similar correction are given in the literature. Carpenter and Clemeña (1975b) argued that a wind speed correction factor needed to be applied to the traditional Gaussian dispersion equation for low wind speed cases. Rao and Keenan (1980) suggested that a wind angle dependent wind speed correction factor would improve the original HIWAY Model. Rao's suggestion was incorporated in the recent HIWAY-2 Model. Chock (1978) also included a wind speed correction factor in the semi-empirical model that he developed based on the General Motors data.

The GM data was used to develop a correction factor for the TXLINE Model. The corrected wind speed which resulted in the lowest average squared error between observed and predicted values was found for each of the 58 General Motors cases used in this study. These 'corrected' wind speeds were compared to the actual measured wind speeds at the 4.4m level. As expected, little correction was necessary for cases with wind speeds above 2.5 metres per second. As the actual wind speed decreased, a larger correction was required. The amount of correction also increased slightly as the wind angle decreased.

Wind speed correction factors were estimated for wind speeds of 0.5, 1.0, ..., 4.0 m/sec at angles of 0, 5, 10, ..., and 90 degrees by carefully studying tables of the corrected wind speed values and the corresponding measured wind speeds and wind angles. Before the model could be improved, a simple function to predict these correction factors as a function of wind speed and wind angle was required.

The wind speed correction function needed to exhibit the following characteristics: 1) simple functional form, 2) consistency with the actual input wind speeds; that is, for any given wind angle, a decrease in input wind speed had to also result in a decrease in the final corrected wind speed, 3) negligible effect as wind speed increased, regardless of wind angle, and 4) result in an improved overall statistical comparison of the model to the GM data base.

During the development of the function, the correction factor was observed to be fairly independent of wind angle for wind angles below 10 degrees and also for angles above 45 degrees. For angles between 10 and 45 degrees, the factor was linearly related to wind angle at a constant wind speed. These patterns were most easily modelled by fitting two simple functions, both of which were a function of wind speed only. One function was developed to apply for any wind angle less than 10 degrees. The second function was developed for wind angles greater than 45 degrees. Using a linear regression routine, the following functions which satisfied all of the required criteria, were finally chosen:

$$F_{10} = 0.3431 + 2.8337/u - 0.2297/u^2 \qquad (3\text{-}36)$$

$$F_{45} = 0.8918 + 0.4946/u + 0.3037/u^2 \qquad (3\text{-}37)$$

where: F_{10} = wind speed correction factor for $0 \leq 10°$
F_{45} = wind speed correction factor for $0 \geq 45°$
u = input wind speed, (m/sec).

For angles between 10 and 45 degrees, a linear interpolation between Equations (3-36) and (3-37) was used to estimate the correction factor.

The corrected wind speed was estimated by:

$$u_c = uF \qquad (3\text{-}38)$$

where: u_c = corrected wind speed
u = input wind speed
F = the wind speed correction factor.

Figure 15 is a plot of actual input wind speed vs. corrected wind speed for various wind angles as predicted by Equation (3-38). The correction factor decreases as input wind speed increases, until the input wind speed is equal to 4 m/sec. For input wind speeds greater than 4 m/sec, a wind speed correction factor is not applied. The wind speed

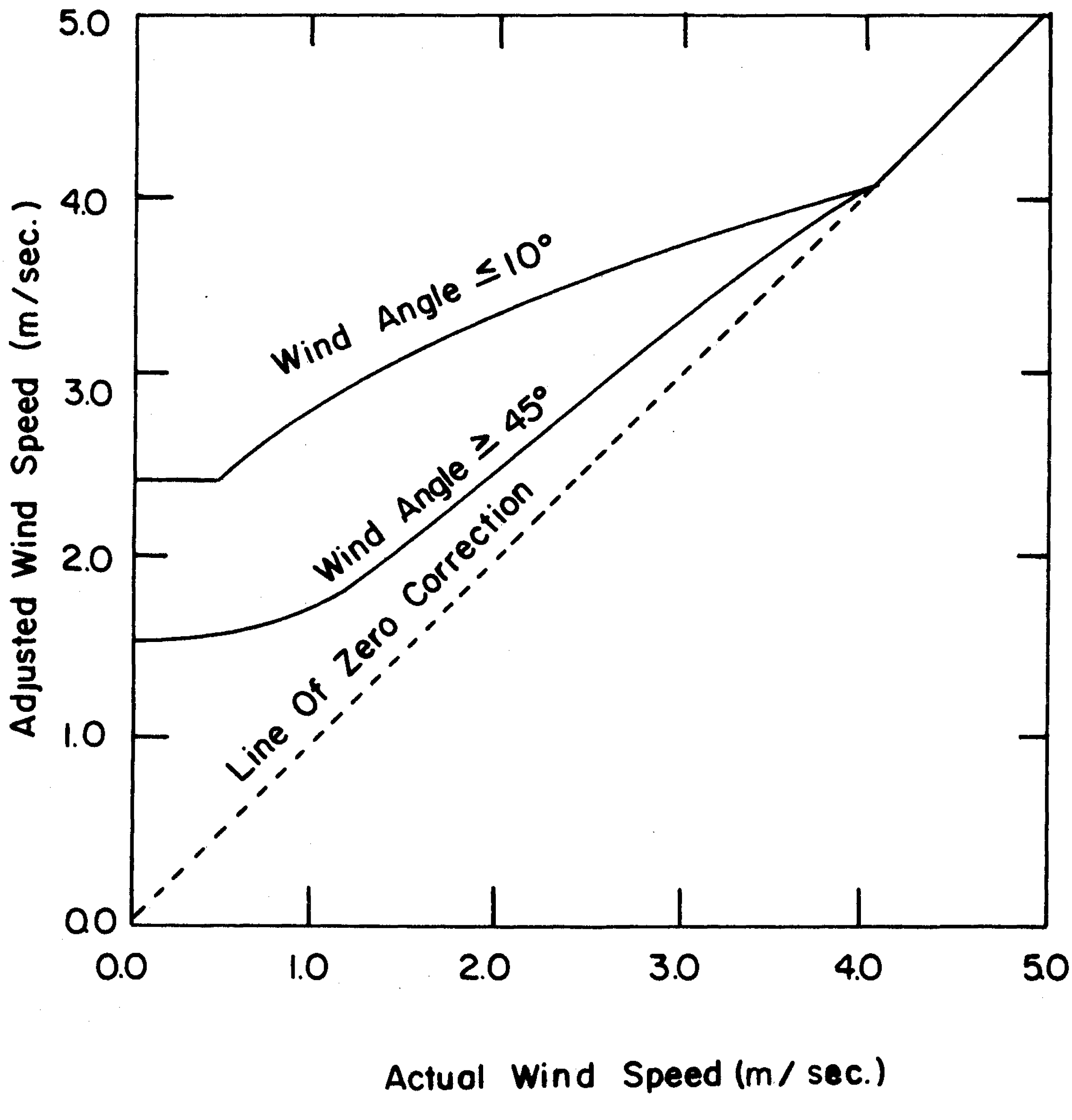


Fig. 15. TXLINE adjusted wind speed vs. actual wind speed.

correction factor was included as a recommended option in TXLINE.

F. IMPROVEMENTS TO REDUCE COMPUTER TIME

At this stage in the model development, the computer time required for a typical model run was excessive. Evaluation of the model revealed that this problem was caused by the conservative method used to perform the point source integration.

The point source integration was always started at $p = 0$ (the receptor line) and continued in both directions with points placed 0.10 metres apart. A detailed analysis of the model indicated that the integration should instead be started at the point on the line which contributes the maximum concentration to a given receptor. The analysis also revealed that a much larger point source spacing could be used without altering the final concentration predictions. Rodden (1983) developed functions to predict the ideal starting point and the maximum point source spacing for the integration. Modification of the model to include these functions reduced computer time requirements dramatically without affecting the model's performance. A detailed discussion of these modifications is presented by Rodden (1983).

G. A USER-ORIENTED MODEL

The model was modified so that it could be easily understood and applied. Documentation and error messages added to the model. A FORTRAN listing of the program, comprehensive instructions regarding its structure, application, and limitations, and several example cases are included in the Appendix ('TXLINE User's Guide'). The reader is referred to this appendix for a detailed discussion of the user-orientated aspects of the model.

Summary of Input Parameters

The primary input parameters are: wind speed, height of wind speed measurement, wind angle, source strength, source height, surface roughness, and receptor coordinates. Molecular weight and temperature are required in some cases, but are only used as conversion factors. These parameters can all be easily measured or estimated using methods given in the user's guide.

Organization and Flow Scheme of the Program

The code was written as a series of documented subprograms. The function and organization of the subprograms is outlined in the Appendix.

Division of the program into subprograms allows for convenient modifications to any specific part of the program.

CHAPTER 4

RESULTS

The completed TXLINE Model is examined in detail in this chapter. The model was tested for internal mass balance, accuracy of the wind profile fit, sensitivity to input parameters, continuity, and internal consistency. Finally, TXLINE was compared to several current dispersion models using the data bases which were discussed in Chapter 2.

A. MASS BALANCE CHECK

The mass balance method of checking a model for internal consistency was discussed in Chapter 2. The TXLINE Model was checked using this method. Input parameters for the mass balance test are included on Figure 16. The vertical mass flux profile was determined by multiplying the predicted wind speed profile by the predicted concentration profile at 25 metres downwind of the roadway.

A plot of height versus mass flux is shown in Figure 16. A graphical integration of the area under the curve resulted in a calculated mass flux of 15.02 g/km/sec. This value agreed very closely with the input source strength of 15.00 g/km/sec, thus proving that the TXLINE Model was internally consistent for this case. Arguments presented later in this chapter show that this example can be extended to prove that the model is in mass balance for any general wind speed.

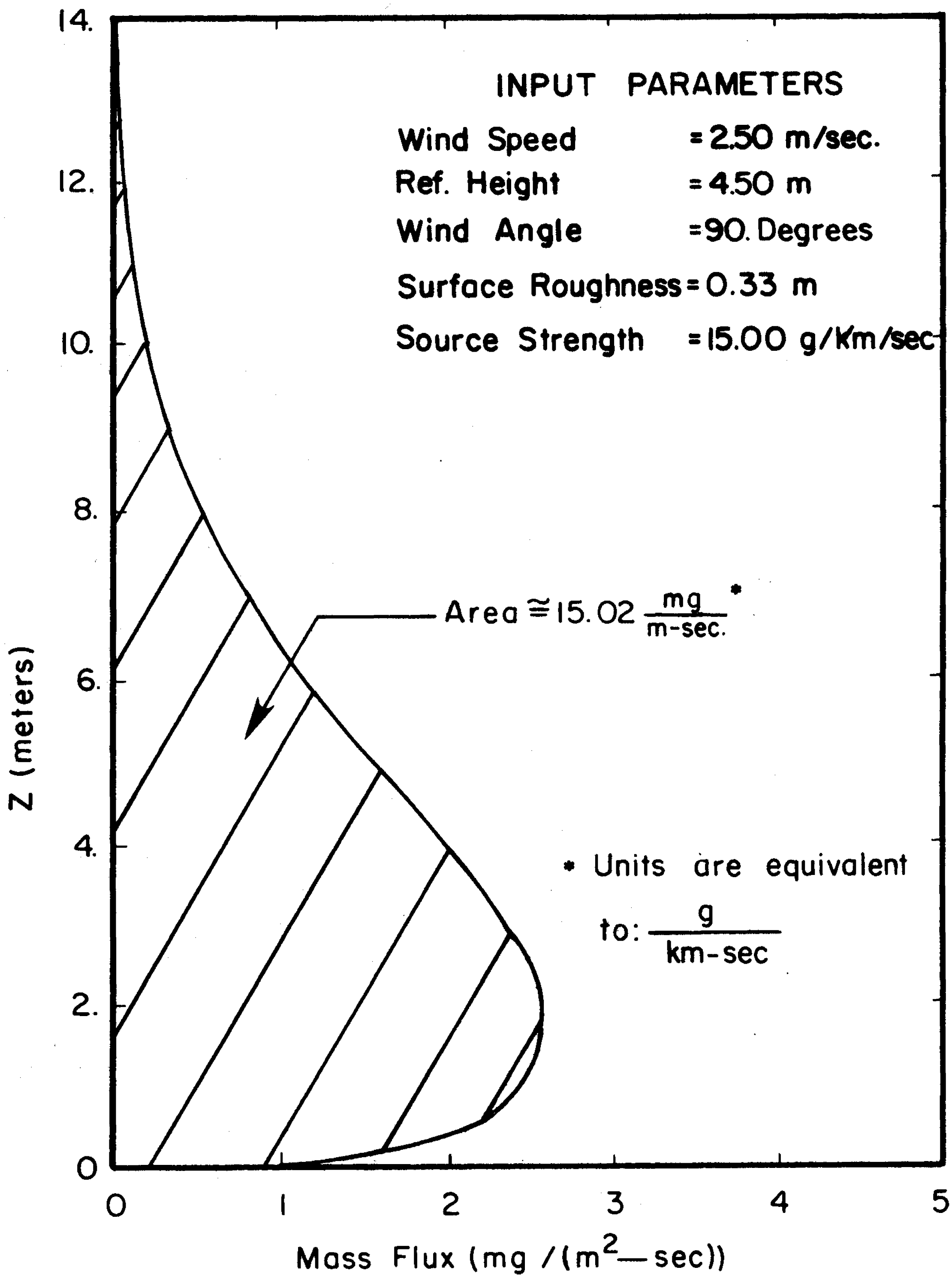


Fig. 16. Mass balance check of the TXLINE model.

B. VALIDATION OF THE ASSUMED WIND PROFILE

The method of fitting the parameters of the power law wind profile to match the log-law profile was presented in detail in Chapter 3. The accuracy of this fit was tested by plotting both the TXLINE power law wind speed profile and the log-law profile, versus height, z. TRAPS-IIM also assumed a power law fit of the log-law wind profile, and therefore was included in the comparison.

Comparison plots were prepared for a wide range of surface roughness values. A plot for a typical surface roughness value of 0.20m is presented in Figure 17. This plot was prepared for a reference wind speed of 2.5 m/sec at a reference height of 5.0m. Since the log-law profile was determined by the reference wind speed, the log-law profile passed through the reference point.

For the example comparison, TXLINE closely matched the log-law profile over the entire height range of 0 to 30m. Similar comparisons for several different surface roughness values showed that the TXLINE power law wind profile closely matched the log-law profile for surface roughness values between zero and three metres.

For the example case, the TRAPS-IIM Model represented the log-law fairly well near ground level, but overpredicted considerably as height increased. Comparisons for other surface roughness values showed that as surface roughness increased, the fit became increasingly worse. The TRAPS-IIM

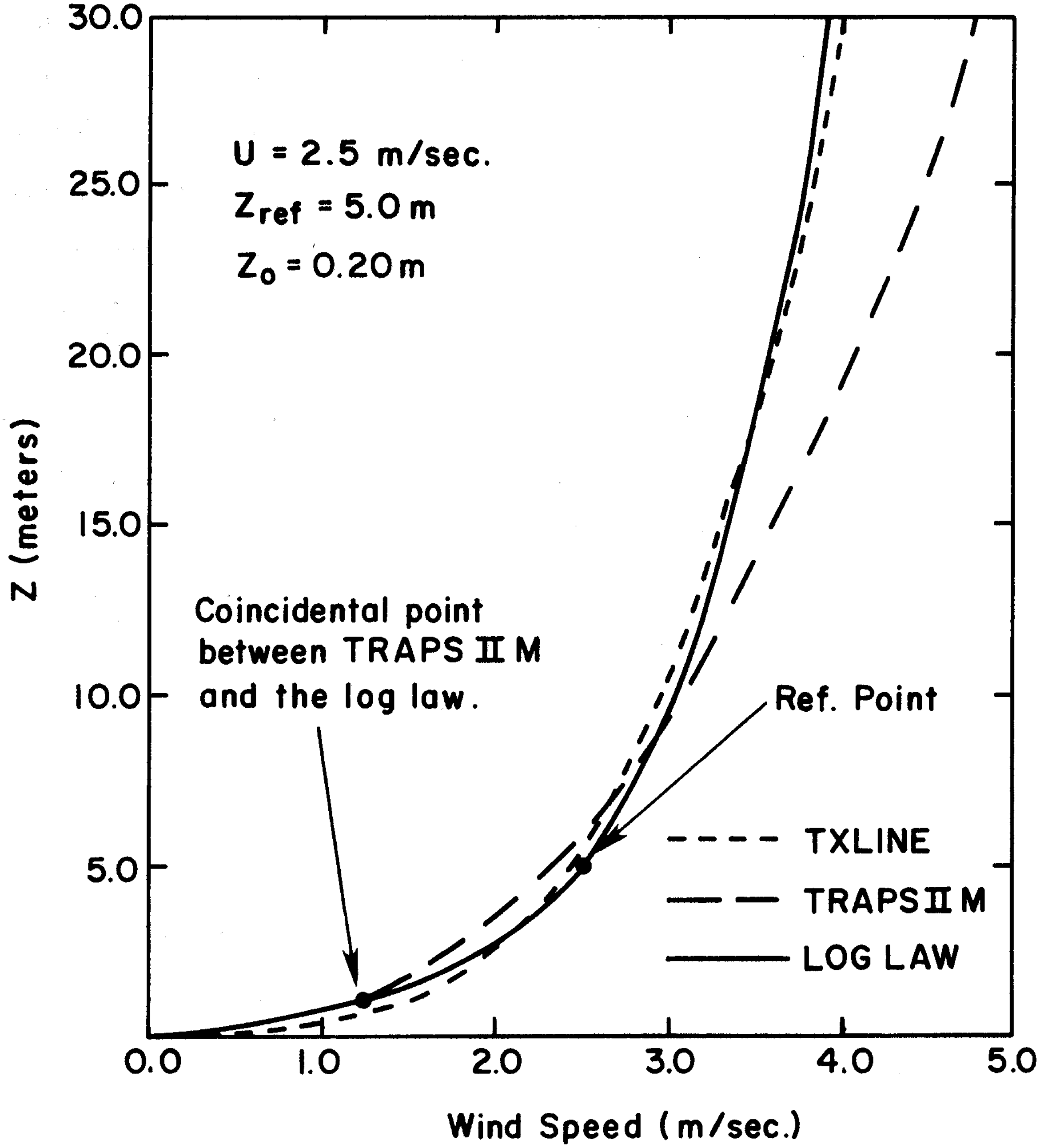


Fig. 17. Comparison of wind speed profiles.

method of fitting the power law parameters was inapplicable for surface roughness values above 0.80m. An analysis of the method showed that during the development of TRAPS-IIM, the power law had erroneously been forced to coincide with the log-law at z = 1m. This assumption severely limited the accuracy of the fit.

The TXLINE power law wind profile was clearly a marked improvement over the TRAPS-IIM profile, and demonstrated that the power law profile can be used to accurately approximate the log-law profile.

C. SENSITIVITY ANALYSIS AND CONTINUITY CHECK OF THE TXLINE MODEL

The TXLINE Model was tested to examine the sensitivity of output concentration profiles to changes in several input parameters. The general approach of the sensitivity analysis was to vary each input parameter individually, holding the others constant. Additional tests to examine the continuity of the model predictions were also conducted.

Sensitivity Analysis Methodology

A hypothetical base set of input parameters was chosen for the sensitivity analysis. The input parameters and resulting concentration array for this base case are presented in Figure 18 which is a copy of the output from TXLINE. The parameter being tested was varied over a wide range of values so that its effect on the predicted concentration values could be examined in detail.

```
*****************************************************************************
* TXLINE - TEXAS LINE SOURCE AIR POLLUTION DISPERSION SIMULATOR (NOV., 1982 ) *
*****************************************************************************

  I.  RUN DESCRIPTION
      --- -----------

        SENSITIVITY ANALYSIS


 II.  METEOROLOGICAL PARAMETERS
      -------------- ----------

        WIND SPEED  =  2.50 M/SEC       *     REFERENCE HEIGHT  =  4.50 M
        WIND ANGLE  = 45.   DEGREES     *     SURFACE ROUGHNESS =  0.33 M
        TEMPERATURE = 25.00 C           *     POLLUTANT MOWT    = 28.00 G/MOLE

        NOTE: WIND SPEED CORRECTION FACTOR WAS APPLIED AS REQUESTED.


III.  LINE SOURCE INFORMATION
      ---- ------ -----------

        LINE * X COORDINATE * HEIGHT *  E FACTOR  *    VPH    * SOURCE STRENGTH
          #  *      (M)     *  (M)   * (G/VEH/MI) * (VEH/HR)  *   (G/KM/SEC)
        -----*--------------*--------*------------*-----------*-----------------
          1  *      0.0     *  0.0   *     NA     *     NA    *     15.0000


 IV.  CONCENTRATION ARRAY
      ------------- -----

        HEIGHT (M) *    DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE
                   *     5.00     10.00     25.00     50.00     75.00    100.00
        -----------*------------------------------------------------------------
                   *           C O N C E N T R A T I O N   ( P P M )
           20.00   *     0.00      0.00      0.00      0.02      0.06      0.08
           15.00   *     0.00      0.00      0.01      0.09      0.13      0.15
           10.00   *     0.00      0.00      0.15      0.26      0.27      0.26
            5.00   *     0.14      0.48      0.68      0.56      0.46      0.39
            3.00   *     1.06      1.33      1.03      0.69      0.53      0.43
            1.50   *     3.07      2.28      1.28      0.77      0.56      0.45
                   *
                   *           AMBIENT CONCENTRATION =  0.0

*****************************************************************************
* TXLINE  *  END OF RUN  *  NUMBER OF WARNINGS =  0  *  END OF RUN  *  TXLINE *
*****************************************************************************
```

Fig. 18. Base computer run for the TXLINE sensitivity analysis.

A sensitivity analysis was performed for each of the following input parameters; wind speed (with correction factor applied), wind speed (without correction factor), wind angle, surface roughness, and source height. Results of these analyses are presented in Tables 1 - 6. The model sensitivity can be observed over the entire downwind concentration field. The parameter being varied is noted on each table. All other input parameters are the same as for the base case (Figure 18).

Wind Speed Sensitivity Analysis

As mentioned in Chapter 3, the TXLINE Model included a low wind speed correction factor as a recommended option. Therefore, the wind speed sensitivity analysis served two purposes; (1) to test the model with the wind speed correction applied as recommended; and (2) to test the model without applying the wind speed correction factor.

The results of the wind speed sensitivity analysis with the correction factor applied are presented in Table 1. Concentration predictions decrease as wind speed increases, regardless of downwind distance from the roadway. The model is not very sensitive to changes in wind speed for wind speeds below 1 m/sec. This trend is a result of the low wind speed correction factor which increases wind speeds which are lower than 4 m/sec. For wind speeds above 4 m/sec, the factor is not applicable.

TABLE 1. Sensitivity of TXLINE (with wind speed adjustment factor) Concentration Predictions to Changes in Wind Speed

HEIGHT (M)	DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE 5.00	10.00	25.00	50.00	75.00	100.00
	CONCENTRATION (PPM)					
	WIND SPEED = 0.50 M/SEC					
20.00	0.00	0.00	0.00	0.04	0.10	0.15
15.00	0.00	0.00	0.01	0.16	0.25	0.28
10.00	0.00	0.01	0.27	0.48	0.50	0.48
5.00	0.27	0.88	1.25	1.03	0.84	0.71
3.00	1.95	2.44	1.89	1.27	0.97	0.79
1.50	5.64	4.19	2.35	1.41	1.04	0.83
	WIND SPEED = 1.00 M/SEC					
20.00	0.00	0.00	0.00	0.04	0.09	0.13
15.00	0.00	0.00	0.01	0.15	0.23	0.26
10.00	0.00	0.01	0.25	0.44	0.46	0.44
5.00	0.24	0.81	1.14	0.94	0.77	0.65
3.00	1.79	2.23	1.73	1.16	0.89	0.72
1.50	5.17	3.84	2.15	1.30	0.95	0.76
	WIND SPEED = 2.00 M/SEC					
20.00	0.00	0.00	0.00	0.03	0.07	0.09
15.00	0.00	0.00	0.01	0.11	0.16	0.18
10.00	0.00	0.01	0.17	0.30	0.32	0.31
5.00	0.17	0.56	0.79	0.66	0.54	0.45
3.00	1.24	1.55	1.20	0.81	0.62	0.50
1.50	3.60	2.67	1.49	0.90	0.66	0.53
	WIND SPEED = 4.00 M/SEC					
20.00	0.00	0.00	0.00	0.02	0.04	0.06
15.00	0.00	0.00	0.01	0.06	0.10	0.11
10.00	0.00	0.00	0.11	0.18	0.19	0.19
5.00	0.10	0.34	0.48	0.40	0.33	0.27
3.00	0.75	0.94	0.73	0.49	0.37	0.30
1.50	2.18	1.62	0.91	0.55	0.40	0.32

TABLE 2. Sensitivity of TXLINE (without wind speed adjustment factor) Concentration Predictions to Changes in Wind Speed

HEIGHT (M)	DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE 5.00	10.00	25.00	50.00	75.00	100.00
	CONCENTRATION (PPM)					
	WIND SPEED = 0.50 M/SEC					
20.00	0.00	0.00	0.00	0.13	0.32	0.45
15.00	0.00	0.00	0.04	0.51	0.76	0.87
10.00	0.00	0.03	0.84	1.48	1.56	1.49
5.00	0.82	2.73	3.86	3.19	2.60	2.20
3.00	6.04	7.55	5.85	3.93	2.99	2.44
1.50	17.47	12.99	7.27	4.38	3.21	2.57
	WIND SPEED = 1.00 M/SEC					
20.00	0.00	0.00	0.00	0.07	0.16	0.23
15.00	0.00	0.00	0.02	0.26	0.38	0.44
10.00	0.00	0.01	0.42	0.74	0.78	0.75
5.00	0.41	1.36	1.93	1.60	1.30	1.10
3.00	3.02	3.78	2.93	1.97	1.50	1.22
1.50	8.74	6.49	3.63	2.19	1.61	1.29
	WIND SPEED = 2.00 M/SEC					
20.00	0.00	0.00	0.00	0.03	0.08	0.11
15.00	0.00	0.00	0.01	0.13	0.19	0.22
10.00	0.00	0.01	0.21	0.37	0.39	0.37
5.00	0.21	0.68	0.96	0.80	0.65	0.55
3.00	1.51	1.89	1.46	0.98	0.75	0.61
1.50	4.37	3.25	1.82	1.10	0.80	0.64
	WIND SPEED = 8.00 M/SEC					
20.00	0.00	0.00	0.00	0.01	0.02	0.03
15.00	0.00	0.00	0.00	0.03	0.05	0.05
10.00	0.00	0.00	0.05	0.09	0.10	0.09
5.00	0.05	0.17	0.24	0.20	0.16	0.14
3.00	0.38	0.47	0.37	0.25	0.19	0.15
1.50	1.09	0.81	0.45	0.27	0.20	0.16
	WIND SPEED = 16.00 M/SEC					
20.00	0.00	0.00	0.00	0.00	0.01	0.01
15.00	0.00	0.00	0.00	0.02	0.02	0.03
10.00	0.00	0.00	0.03	0.05	0.05	0.05
5.00	0.03	0.09	0.12	0.10	0.08	0.07
3.00	0.19	0.24	0.18	0.12	0.09	0.08
1.50	0.55	0.41	0.23	0.14	0.10	0.08

TABLE 3. Sensitivity of TXLINE Concentration Predictions to Changes in Wind Angle (1°-30°)

HEIGHT (M)	DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE 5.00	10.00	25.00	50.00	75.00	100.00
	CONCENTRATION (PPM)					
	WIND ANGLE = 1. DEGREE					
20.00	1.32	1.32	1.11	0.78	0.50	0.32
15.00	1.77	1.70	1.27	0.83	0.53	0.33
10.00	2.54	2.24	1.43	0.87	0.54	0.34
5.00	3.99	2.91	1.55	0.90	0.56	0.35
3.00	4.80	3.14	1.59	0.90	0.56	0.35
1.50	5.35	3.25	1.60	0.91	0.56	0.35
	WIND ANGLE = 5. DEGREES					
20.00	0.36	0.47	0.62	0.58	0.49	0.42
15.00	0.64	0.80	0.87	0.69	0.55	0.46
10.00	1.29	1.42	1.16	0.80	0.61	0.50
5.00	2.98	2.44	1.45	0.89	0.65	0.52
3.00	4.16	2.88	1.54	0.91	0.67	0.53
1.50	5.07	3.15	1.58	0.92	0.67	0.54
	WIND ANGLE = 10. DEGREES					
20.00	0.05	0.11	0.26	0.34	0.33	0.31
15.00	0.15	0.27	0.47	0.48	0.42	0.36
10.00	0.50	0.73	0.80	0.62	0.50	0.41
5.00	1.89	1.80	1.19	0.76	0.57	0.46
3.00	3.20	2.38	1.33	0.80	0.59	0.47
1.50	4.38	2.77	1.41	0.82	0.60	0.48
	WIND ANGLE = 20. DEGREES					
20.00	0.00	0.00	0.05	0.14	0.18	0.19
15.00	0.01	0.03	0.17	0.27	0.28	0.26
10.00	0.08	0.20	0.45	0.45	0.39	0.34
5.00	0.87	1.14	0.95	0.66	0.50	0.41
3.00	2.18	1.92	1.18	0.73	0.54	0.43
1.50	3.81	2.53	1.31	0.77	0.56	0.44
	WIND ANGLE = 30. DEGREES					
20.00	0.00	0.00	0.01	0.07	0.11	0.13
15.00	0.00	0.00	0.06	0.16	0.20	0.20
10.00	0.01	0.07	0.27	0.35	0.33	0.30
5.00	0.43	0.77	0.80	0.60	0.47	0.39
3.00	1.57	1.59	1.08	0.69	0.52	0.42
1.50	3.36	2.35	1.26	0.75	0.55	0.44

TABLE 4. Sensitivity of TXLINE Concentration Predictions to Changes in Wind Angle (60°-90°)

HEIGHT (M)	DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE 5.00	10.00	25.00	50.00	75.00	100.00
	CONCENTRATION (PPM)					
	WIND ANGLE = 60. DEGREES					
20.00	0.00	0.00	0.00	0.00	0.03	0.05
15.00	0.00	0.00	0.00	0.05	0.09	0.12
10.00	0.00	0.00	0.09	0.19	0.22	0.22
5.00	0.03	0.31	0.55	0.50	0.42	0.36
3.00	0.72	1.07	0.92	0.64	0.49	0.40
1.50	2.65	2.08	1.20	0.73	0.54	0.43
	WIND ANGLE = 70. DEGREES					
20.00	0.00	0.00	0.00	0.00	0.02	0.04
15.00	0.00	0.00	0.00	0.04	0.08	0.10
10.00	0.00	0.00	0.07	0.17	0.20	0.21
5.00	0.00	0.25	0.51	0.47	0.40	0.34
3.00	0.60	0.98	0.88	0.62	0.48	0.39
1.50	2.48	2.00	1.17	0.72	0.53	0.42
	WIND ANGLE = 80. DEGREES					
20.00	0.00	0.00	0.00	0.00	0.02	0.04
15.00	0.00	0.00	0.00	0.04	0.07	0.09
10.00	0.00	0.00	0.06	0.16	0.19	0.20
5.00	0.00	0.22	0.48	0.46	0.39	0.34
3.00	0.53	0.92	0.85	0.61	0.47	0.39
1.50	2.39	1.95	1.15	0.71	0.52	0.42
	WIND ANGLE = 85. DEGREES					
20.00	0.00	0.00	0.00	0.00	0.02	0.04
15.00	0.00	0.00	0.00	0.03	0.07	0.09
10.00	0.00	0.00	0.05	0.15	0.19	0.19
5.00	0.00	0.21	0.47	0.45	0.39	0.34
3.00	0.52	0.91	0.85	0.61	0.47	0.39
1.50	2.36	1.94	1.15	0.71	0.52	0.42
	WIND ANGLE = 90. DEGREES					
20.00	0.00	0.00	0.00	0.01	0.02	0.04
15.00	0.00	0.00	0.00	0.03	0.07	0.09
10.00	0.00	0.00	0.05	0.15	0.19	0.19
5.00	0.03	0.21	0.47	0.45	0.39	0.33
3.00	0.51	0.90	0.85	0.61	0.47	0.39
1.50	2.35	1.93	1.15	0.70	0.52	0.42

TABLE 5. Sensitivity of TXLINE Concentration Predictions to Changes in Surface Roughness

HEIGHT (M)	DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE 5.00	10.00	25.00	50.00	75.00	100.00
	CONCENTRATION (PPM)					
	SURFACE ROUGHNESS = 0.01 M					
20.00	0.00	0.00	0.00	0.00	0.00	0.00
15.00	0.00	0.00	0.00	0.00	0.02	0.06
10.00	0.00	0.00	0.00	0.07	0.15	0.21
5.00	0.00	0.00	0.25	0.55	0.61	0.60
3.00	0.00	0.25	0.98	1.09	0.96	0.84
1.50	1.00	2.20	2.30	1.66	1.28	1.04
0.01	15.89	9.02	4.05	2.21	1.55	1.20
	SURFACE ROUGHNESS = 0.10 M					
20.00	0.00	0.00	0.00	0.00	0.02	0.05
15.00	0.00	0.00	0.00	0.03	0.09	0.12
10.00	0.00	0.00	0.03	0.18	0.25	0.27
5.00	0.00	0.15	0.56	0.63	0.57	0.50
3.00	0.35	0.95	1.18	0.92	0.73	0.60
1.50	2.69	2.71	1.80	1.13	0.84	0.67
0.01	8.77	4.90	2.27	1.27	0.91	0.71
	SURFACE ROUGHNESS = 0.33 M					
20.00	0.00	0.00	0.00	0.02	0.06	0.08
15.00	0.00	0.00	0.01	0.09	0.13	0.15
10.00	0.00	0.00	0.15	0.26	0.27	0.26
5.00	0.14	0.48	0.68	0.56	0.46	0.39
3.00	1.06	1.33	1.03	0.69	0.53	0.43
1.50	3.07	2.28	1.28	0.77	0.56	0.45
0.01	5.19	2.96	1.41	0.81	0.58	0.46
	SURFACE ROUGHNESS = 0.66 M					
20.00	0.00	0.00	0.00	0.05	0.08	0.09
15.00	0.00	0.00	0.05	0.13	0.15	0.16
10.00	0.00	0.06	0.23	0.27	0.25	0.23
5.00	0.44	0.68	0.63	0.46	0.36	0.29
3.00	1.40	1.27	0.81	0.52	0.39	0.31
1.50	2.60	1.73	0.92	0.55	0.40	0.32
0.01	3.39	1.97	0.97	0.56	0.41	0.33
	SURFACE ROUGHNESS = 1.00 M					
20.00	0.00	0.00	0.01	0.06	0.09	0.10
15.00	0.00	0.01	0.08	0.14	0.15	0.14
10.00	0.03	0.12	0.25	0.25	0.22	0.19
5.00	0.60	0.70	0.54	0.37	0.29	0.24
3.00	1.38	1.40	0.65	0.41	0.30	0.25
1.50	2.09	1.35	0.70	0.42	0.31	0.25
0.01	2.45	1.46	0.73	0.43	0.31	0.25

TABLE 6. Sensitivity of TXLINE Concentration Predictions to Changes in Source Height

HEIGHT (M)	DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE 5.00	10.00	25.00	50.00	75.00	100.00
	CONCENTRATION (PPM)					
	SOURCE HEIGHT = 1.00 M					
20.00	0.00	0.00	0.00	0.00	0.00	0.01
15.00	0.00	0.00	0.00	0.01	0.04	0.05
10.00	0.00	0.00	0.04	0.11	0.15	0.16
5.00	0.10	0.28	0.45	0.41	0.35	0.30
3.00	0.87	0.97	0.77	0.54	0.42	0.35
1.50	2.22	1.65	0.97	0.61	0.46	0.37
	SOURCE HEIGHT = 2.00 M					
20.00	0.00	0.00	0.00	0.00	0.01	0.01
15.00	0.00	0.00	0.00	0.02	0.04	0.06
10.00	0.00	0.00	0.05	0.12	0.15	0.16
5.00	0.24	0.38	0.46	0.40	0.34	0.30
3.00	1.11	0.96	0.73	0.52	0.41	0.34
1.50	1.69	1.36	0.88	0.58	0.44	0.36
	SOURCE HEIGHT = 4.00 M					
20.00	0.00	0.00	0.00	0.00	0.01	0.02
15.00	0.00	0.00	0.00	0.03	0.05	0.06
10.00	0.00	0.03	0.10	0.15	0.16	0.16
5.00	0.77	0.61	0.45	0.37	0.32	0.28
3.00	0.89	0.72	0.56	0.44	0.36	0.31
1.50	0.45	0.61	0.60	0.48	0.39	0.33
	SOURCE HEIGHT = 8.00 M					
20.00	0.00	0.00	0.00	0.01	0.03	0.04
15.00	0.00	0.01	0.05	0.08	0.09	0.09
10.00	0.27	0.32	0.26	0.20	0.17	0.16
5.00	0.16	0.25	0.26	0.24	0.22	0.20
3.00	0.02	0.07	0.18	0.22	0.22	0.21
1.50	0.00	0.02	0.13	0.21	0.22	0.22
	SOURCE HEIGHT = 12.00 M					
20.00	0.00	0.00	0.02	0.05	0.06	0.06
15.00	0.00	0.13	0.17	0.15	0.13	0.11
10.00	0.09	0.29	0.23	0.18	0.15	0.14
5.00	0.00	0.01	0.06	0.10	0.12	0.12
3.00	0.00	0.00	0.02	0.07	0.10	0.11
1.50	0.00	0.00	0.01	0.06	0.09	0.11

The results of the wind speed sensitivity analysis for the model without the correction factor are presented in Table 2. These results demonstrate a very interesting feature of the model. Concentration predictions are identically inversely proportional to the input wind speed (all other parameters held constant). This relationship is not an inherent feature of Smith's (1957) general dispersion equations, but is a result of the form of the equation which was assumed to estimate K_1, the reference eddy diffusivity. K_1 is predicted by Equation (3-30) and therefore is proportional to u_1. Substitution of this form of K_1 into the general dispersion equations results in the concentration being inversely proportional to wind speed. The fact that this relationship occurs supports the need for a low wind speed correction factor.

Since concentration is inversely proportional to wind speed, the mass balance check (Figure 16) can be extended to verify the internal consistency of the model for any general wind speed.

Wind Angle Sensitivity Analysis

The wind angle sensitivity analysis illustrated the treatment of oblique wind angle cases. The results from this analysis are presented in Tables 3 and 4. For angles above 70 degrees, the sensitivity of concentration predictions to wind angle was negligible. Consequently, the

TXLINE Model was modified to apply the infinite line source equation (for 90° winds) whenever the wind angle is greater than 70 degrees. This modification further reduced computer time requirements by eliminating the need for a numerical integration for these cases.

Analysis of the lower wind angle cases showed that concentration profiles near the line source gradually flattened and increased in magnitude as the wind angle decreased. This gradual continuous increase verified the consistency of the method used to integrate the point source equation. Concentrations at receptors which were located well above ground level and near the line source increased significantly as wind angle decreased.

The ground level concentrations at 25m or further downwind of the source were not affected significantly by changing wind angle. However, the concentration profiles at these downwind distances flattened considerably as wind angle decreased.

Surface Roughness Sensitivity Analysis

Surface roughness is the most difficult input parameter to estimate. Surface roughness values should be estimated from a table of suggested values presented by Pasquill (1974) which is included in Table 3 of the Appendix. Although the model will predict results when the input surface roughness value is greater than one meter, Pasquill recommended an upper limit of one metre. Surface roughness in the immediate vicinity of a roadway is probably never lower than 0.20

metres, because the vehicles on the roadway are significant obstacles to the wind flow. The sensitivity analysis does include lower surface roughness values, but the use of a surface roughness value which is less than 0.20m is not recommended.

A preliminary sensitivity analysis for surface roughness indicated that the ground level concentrations were very sensitive to changes in surface roughness. For this reason, ground level (z = 0.01m) predictions were included in the results presented in Table 5. This table showed that the pollutant seems to 'hug' the ground when the surface roughness is low. As surface roughness increased, vertical dispersion increased, resulting in a 'flattening' of the vertical concentration profiles.

Concentration predictions for receptors near ground level and within 10 metres of the line source were very high for the low surface roughness cases but decreased rapidly as receptor height increased. Unrealistic ground level concentration predictions within 10m of the roadway can be expected for two reasons; (1) one of the boundary conditions used to solve the general diffusion equation was that the concentration of the line source equals infinity; and (2) the assumed form of the wind speed profile results in zero wind speed at ground level. Since unrealistically high predicted concentrations occur only near the roadway when the surface roughness is very low, this problem should not be a concern in most roadway applications. However, as a precaution, the TXLINE Model should not be used to predict concentrations within one metre of ground level (below z = 1m).

Source Height Sensitivity Analysis

The source height sensitivity analysis results are presented in Table 6. The maximum concentration at the closest downwind distance (5 metres) was expected to occur near the same height as the source. This expectation is verified by the table for source heights of 1.0, 2.0, and 4.0 metres. For source heights of 8.0 and 12.0 metres, the maximum also occurs near the source height, but can not be seen in the table, since receptors at the source heights were not modelled for these cases. All concentrations near ground level are considerably lowered as source height is raised.

Continuity and Consistency Check

The TXLINE Model has already been shown to be continuous for changes in all input variables when the source is at ground level. For wind angles less than 70 degrees, when the source is elevated, the model uses the elevated point source equation, which restricts the value of the power law exponent, m. Since the unrestricted, infinite, elevated line source solution is used for any wind angle greater than 70 degrees, the continuity and consistency of the model for elevated sources was investigated. A review of the conditions under which these equations are used within the final version of the model is presented in Table 7. This table clearly shows that continuity should be examined across two dividing lines; (1) wind angle of 70 degrees (elevated source and (2) source height of 0.10m (wind angle $<$ 70°).

The basic input parameters for the continuity checks were kept the same as for the sensitivity analysis. In order to examine continuity along the first dividing line, two computer runs were made which varied source height; one for a wind angle of 69°, and the other for 70°. The results of these runs are presented in Tables 8 and 9, respectively. Concentration predictions are slightly lower than would be expected for the 69° wind angle case.

Results of computer runs with the source height equal to 0.15m for several wind angles less than seventy degrees are presented in Table 10. This table was used to examine the continuity of the model along the dividing line of source height equal to 0.10 metres, which was illustrated in Table 7. The results were compared to the results of the wind angle sensitivity analysis (Tables 3 and 4) which used the ground level point source solution. For the same wind angle, concentration predictions given in Table 10 were generally slightly lower than the predictions presented in Tables 3 and 4.

As expected, discontinuities do exist between the restricted elevated point source equation and the general elevated solution. However, these discontinuities are not large enough to significantly affect the model's performance.

TABLE 7. Summary of the Solutions Applied Within the TXLINE Model

	Source Height $\leq$ 0.10m	Source Height $>$ 0.10m
Wind Angle $\geq$ 70°	Infinite Line Source (Ground Level) Equation (Equation (3-6))	Infinite Line Source (Elevated) Equation (Equation (3-5))
	(1) both equations derived for perpendicular wind angles (2) both equations derived for general values of m, the power law exponent (3) equations are consistent with each other.	
Wind Angle $<$ 70°	Integration of the Point Source (Ground Level) Equation (Equation (3-33)) (1) general wind angle (2) derived for general values of m, the power law exponent (3) consistent and continuous with the Infinite Line Source Equations.	Integration of the Point Source (Elevated) Equation (Equation (3-35)) (1) general wind angle (2) derived for $m=\frac{1}{2}$ (general solution has not yet been found) (3) consistency and continuity discussed in this section.

TABLE 8. Continuity Check of the TXLINE Elevated Source Solution (wind angle = 69°)

HEIGHT (M)	DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE 5.00	10.00	25.00	50.00	75.00	100.00
	CONCENTRATION (PPM)					
	SOURCE HEIGHT = 1.00 M					
20.00	0.00	0.00	0.00	0.00	0.00	0.00
15.00	0.00	0.00	0.00	0.00	0.01	0.03
10.00	0.00	0.00	0.01	0.06	0.10	0.11
5.00	0.03	0.15	0.33	0.34	0.30	0.27
3.00	0.58	0.74	0.65	0.48	0.38	0.32
1.50	1.86	1.44	0.88	0.56	0.42	0.35
	SOURCE HEIGHT = 2.00 M					
20.00	0.00	0.00	0.00	0.00	0.00	0.00
15.00	0.00	0.00	0.00	0.01	0.02	0.03
10.00	0.00	0.00	0.02	0.07	0.10	0.11
5.00	0.12	0.25	0.34	0.33	0.29	0.26
3.00	0.89	0.78	0.61	0.46	0.37	0.31
1.50	1.38	1.14	0.78	0.52	0.40	0.33
	SOURCE HEIGHT = 4.00 M					
20.00	0.00	0.00	0.00	0.00	0.00	0.01
15.00	0.00	0.00	0.00	0.01	0.03	0.04
10.00	0.00	0.01	0.06	0.10	0.12	0.12
5.00	0.64	0.51	0.37	0.30	0.27	0.24
3.00	0.73	0.60	0.46	0.37	0.32	0.27
1.50	0.27	0.42	0.48	0.40	0.34	0.29
	SOURCE HEIGHT = 8.00 M					
20.00	0.00	0.00	0.00	0.01	0.01	0.02
15.00	0.00	0.00	0.02	0.05	0.06	0.07
10.00	0.10	0.25	0.21	0.17	0.14	0.13
5.00	0.08	0.17	0.20	0.19	0.18	0.17
3.00	0.00	0.03	0.11	0.16	0.17	0.17
1.50	0.00	0.01	0.07	0.14	0.17	0.17
	SOURCE HEIGHT = 12.00 M					
20.00	0.00	0.00	0.01	0.03	0.04	0.05
15.00	0.00	0.02	0.14	0.12	0.11	0.10
10.00	0.00	0.22	0.19	0.15	0.13	0.11
5.00	0.00	0.00	0.03	0.06	0.08	0.09
3.00	0.00	0.00	0.01	0.04	0.06	0.08
1.50	0.00	0.00	0.00	0.03	0.05	0.07

TABLE 9. Continuity Check of the TXLINE Elevated Source Solution (wind angle = 70°)

HEIGHT (M)	DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE 5.00	10.00	25.00	50.00	75.00	100.00
	CONCENTRATION (PPM)					
	SOURCE HEIGHT = 1.00 M					
20.00	0.00	0.00	0.00	0.01	0.02	0.04
15.00	0.00	0.00	0.00	0.04	0.07	0.09
10.00	0.00	0.00	0.06	0.16	0.19	0.19
5.00	0.09	0.29	0.48	0.45	0.38	0.33
3.00	0.82	0.96	0.82	0.59	0.46	0.38
1.50	2.20	1.74	1.08	0.68	0.51	0.41
	SOURCE HEIGHT = 2.00 M					
20.00	0.00	0.00	0.00	0.01	0.02	0.04
15.00	0.00	0.00	0.01	0.04	0.08	0.10
10.00	0.00	0.01	0.09	0.17	0.19	0.19
5.00	0.29	0.44	0.49	0.43	0.37	0.32
3.00	1.19	0.99	0.76	0.56	0.44	0.37
1.50	1.70	1.38	0.95	0.63	0.48	0.40
	SOURCE HEIGHT = 4.00 M					
20.00	0.00	0.00	0.00	0.02	0.03	0.05
15.00	0.00	0.00	0.02	0.07	0.09	0.10
10.00	0.01	0.07	0.16	0.19	0.20	0.19
5.00	0.89	0.69	0.49	0.39	0.34	0.30
3.00	1.00	0.79	0.59	0.47	0.39	0.33
1.50	0.48	0.63	0.63	0.51	0.42	0.35
	SOURCE HEIGHT = 8.00 M					
20.00	0.00	0.00	0.02	0.05	0.06	0.07
15.00	0.00	0.04	0.11	0.13	0.13	0.12
10.00	0.45	0.41	0.30	0.23	0.20	0.18
5.00	0.27	0.35	0.32	0.27	0.25	0.23
3.00	0.03	0.13	0.24	0.26	0.26	0.24
1.50	0.00	0.04	0.18	0.25	0.26	0.25
	SOURCE HEIGHT = 12.00 M					
20.00	0.00	0.02	0.08	0.10	0.10	0.09
15.00	0.00	0.27	0.22	0.17	0.15	0.13
10.00	0.16	0.37	0.27	0.20	0.17	0.16
5.00	0.00	0.03	0.11	0.15	0.16	0.16
3.00	0.00	0.00	0.06	0.12	0.14	0.15
1.50	0.00	0.00	0.03	0.10	0.13	0.15

TABLE 10. Continuity Check of the TXLINE Elevated Source Solution (source height = 0.15m)

HEIGHT (M)	DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE 5.00	10.00	25.00	50.00	75.00	100.00
	CONCENTRATION (PPM)					
	WIND ANGLE = 1. DEGREE					
20.00	0.91	0.99	0.96	0.73	0.46	0.24
15.00	1.36	1.40	1.17	0.81	0.49	0.26
10.00	2.13	1.98	1.37	0.88	0.52	0.27
5.00	3.50	2.66	1.52	0.92	0.54	0.28
3.00	4.22	2.89	1.56	0.93	0.54	0.28
1.50	4.67	3.00	1.57	0.93	0.54	0.28
	WIND ANGLE = 15. DEGREES					
20.00	0.00	0.00	0.01	0.05	0.08	0.10
15.00	0.00	0.01	0.06	0.14	0.17	0.17
10.00	0.03	0.11	0.28	0.32	0.29	0.26
5.00	0.69	0.88	0.74	0.52	0.40	0.33
3.00	1.78	1.49	0.91	0.57	0.43	0.34
1.50	2.85	1.88	1.00	0.60	0.44	0.35
	WIND ANGLE = 30. DEGREES					
20.00	0.00	0.00	0.00	0.00	0.02	0.03
15.00	0.00	0.00	0.00	0.04	0.07	0.09
10.00	0.00	0.01	0.09	0.17	0.19	0.19
5.00	0.19	0.42	0.54	0.44	0.36	0.30
3.00	1.07	1.12	0.80	0.53	0.41	0.33
1.50	2.46	1.72	0.95	0.58	0.43	0.34
	WIND ANGLE = 45. DEGREES					
20.00	0.00	0.00	0.00	0.00	0.00	0.01
15.00	0.00	0.00	0.00	0.01	0.03	0.05
10.00	0.00	0.00	0.03	0.11	0.15	0.16
5.00	0.06	0.25	0.45	0.42	0.35	0.31
3.00	0.75	0.97	0.79	0.55	0.43	0.35
1.50	2.40	1.76	1.00	0.62	0.46	0.37
	WIND ANGLE = 60. DEGREES					
20.00	0.00	0.00	0.00	0.00	0.00	0.00
15.00	0.00	0.00	0.00	0.00	0.02	0.03
10.00	0.00	0.00	0.01	0.07	0.11	0.12
5.00	0.02	0.14	0.35	0.36	0.32	0.28
3.00	0.50	0.78	0.70	0.51	0.40	0.33
1.50	2.11	1.60	0.94	0.58	0.44	0.36

D. COMPARISON OF DISPERSION MODELS USING EXISTING DATA

The following models were compared to the experimental data discussed in Chapter 2; TXLINE (with the wind speed correction factor); TXLINE (without the wind speed correction factor); HIWAY-2, CALINE-3, and TRAPS-IIM. Each of these models was also discussed in Chapter 2. The only model which does not contain empirical adjustments based on the GM data base is the version of the TXLINE Model without the wind speed correction factor.

Several statistics were calculated for comparisons to each data base, including: average error; average squared error; slope and intercept of a linear regression analysis; regression coefficient; percent within 2 parts per million (2 ppb for SF_6), and percent within 1 ppm (1 ppb for SF_6). Regression lines were also plotted for each comparison. Scatter plots were prepared for several representative comparisons. Comparisons to each data base are discussed in this section.

Comparisons to the GM Data

The results from the comparisons to the GM data are presented in Figure 19 and in Table 11. Only downwind receptors were compared. All input parameters except surface roughness were determined from the GM final report by Cadle (1976). A wind speed reference height of 4.4m was used for the TXLINE Model. A surface roughness value of 0.30m was used for all models except for TRAPS-IIM and HIWAY-2 (surface roughness

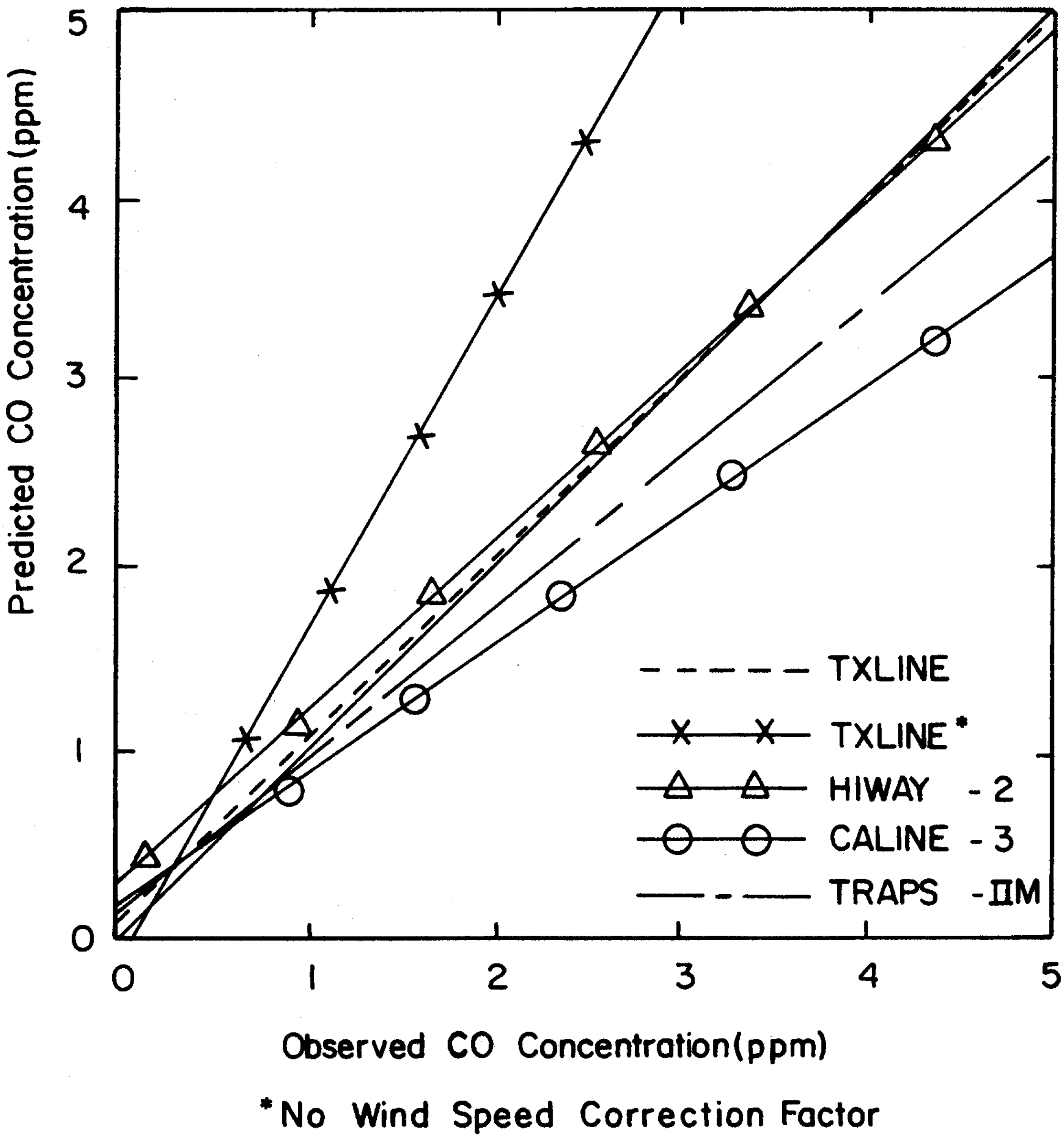


Fig. 19. Regression lines of various models for the GM SF_6 data.

TABLE 11. Statistical Comparisons of Model Results to the GM Data

Statistic	TXLINE*	TXLINE**	TRAPS II-M	HIWAY-2	CALINE-3
Average Error (ppb)	-0.10	-0.68	0.04	-0.26	0.11
Average Squared Error $(ppb)^2$	0.15	2.18	0.32	0.30	0.32
Intercept (ppb)	0.12	-0.06	0.13	0.35	0.19
Slope	0.97	1.75	0.82	0.91	0.69
R^2	0.79	0.55	0.56	0.67	0.47
% within ±2	100	93	NA	99	NA
% within ±1	97	80	NA	93	NA
number of points	561	561	561	561	561

* Final version - low wind speed correction factor was applied.

** Preliminary version - without wind speed correction factor.

is not an input parameter for HIWAY-2). The TRAPS-IIM results were taken from Green (1980), who assumed a surface roughness value of 0.12m. This value was considered to be too low based on the site description presented in the GM report. Since TRAPS-IIM was developed using this value, the model was not rerun for the GM data.

Statistical comparisons are presented in Table 11 and the regression lines are plotted in Figure 19. TXLINE clearly predicted the GM data far more accurately than any of the other models. The average error was slightly better for the TRAPS-IIM model, but average squared error for TXLINE was less than half that of the closest model, HIWAY-2. The slope and intercept for TXLINE were very close to the ideal values of 1.0 and 0.0. The regression coefficient of 0.79 further indicated the high degree of accuracy with which TXLINE predicted the GM data. 100.% of the TXLINE predictions were within 2 ppb of the data, while 97% were within 1 ppb.

TXLINE consistently overpredicted when the wind speed correction factor was not applied, but the regression coefficient was comparable to both TRAPS-IIM and CALINE-3. The HIWAY-2 Model predicted the data more accurately than these models, but not as well as the final version of TXLINE.

The two models which most accurately predicted the GM data, TXLINE (with wind speed correction factor) and HIWAY-2, were compared to the data using scatterplots as shown in Figures 20 and 21. TXLINE showed less scatter and fewer stray points than HIWAY-2.

To further compare HIWAY-2 and TXLINE, several more scatterplots were prepared which divided the comparisons into several subgroups by wind speed and wind angle. Each receptor location was plotted using a unique symbol, so that individual receptor locations could be identified. Table 12 is a symbols key for the scatterplots presented in Figures 22 through 25. Error bars were drawn on the figures to indicate 1 and 2 ppb deviations from observed values.

Close examination of Figures 22 through 25 reveals that TXLINE exhibits considerably less scatter than does HIWAY-2 for almost every wind speed/wind angle classification. The most marked difference was seen in the low wind angle classifications (0°-30°) where HIWAY-2 overpredicted most of the points. The corresponding TXLINE plots show far less scatter.

HIWAY-2 underpredicted concentrations for the cases when the wind speed was greater than 2 m/sec and the wind angle was greater than 30 degrees. TXLINE performed significantly better than HIWAY-2 in all of these cases. TXLINE also exhibited less scatter for all of the low wind speed cases (less than 2 m/sec).

The most important result of the scatterplot comparison was found by studying the symbols used in the plots. The HIWAY-2 Model consistently underpredicted the receptor located 4m downwind of the road edge at the 1.5m level (symbol 3),

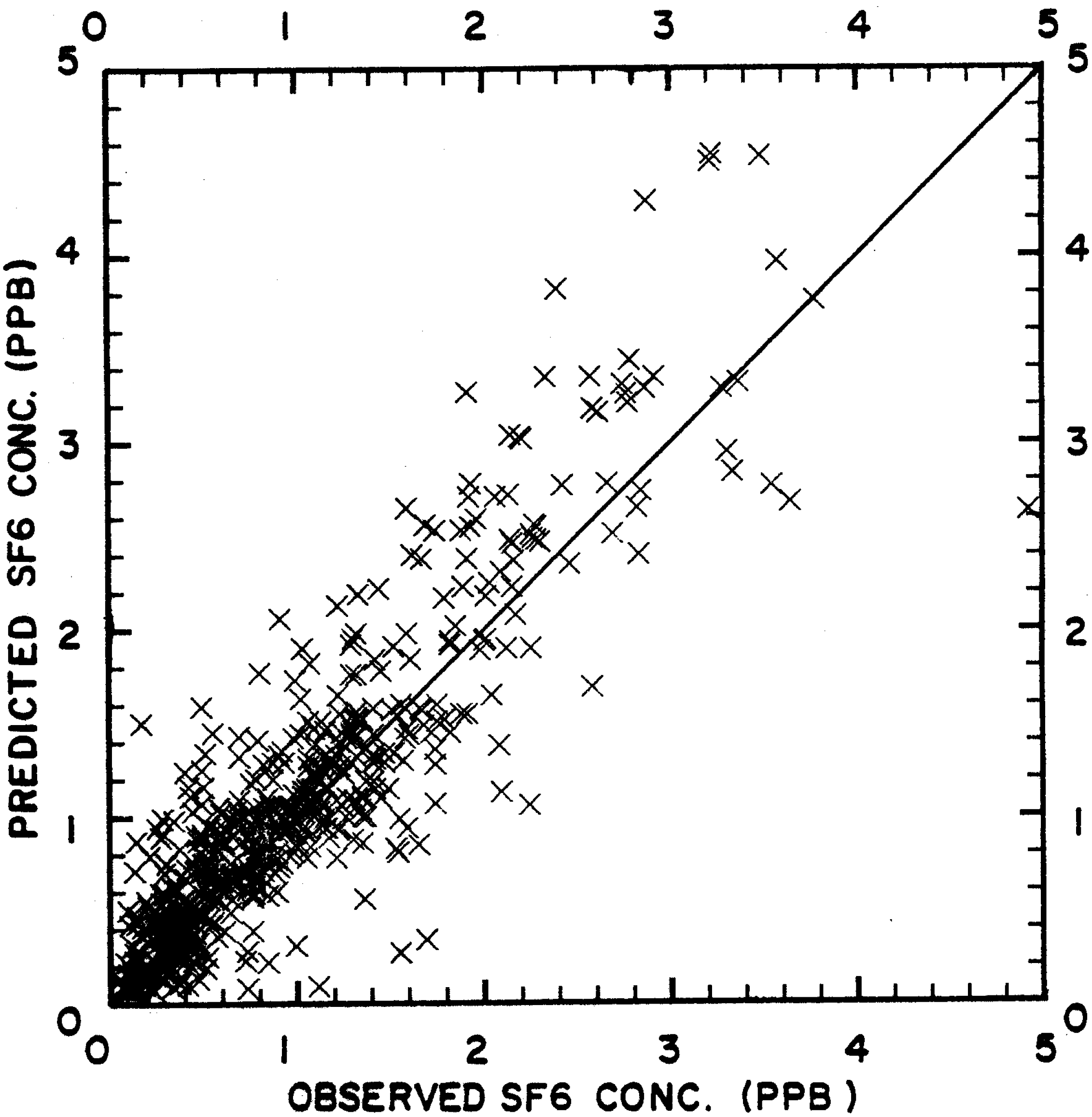


Fig. 20. Scatterplot of TXLINE (final version) predictions vs. observed SF_6 concentrations for the General Motors experiment.

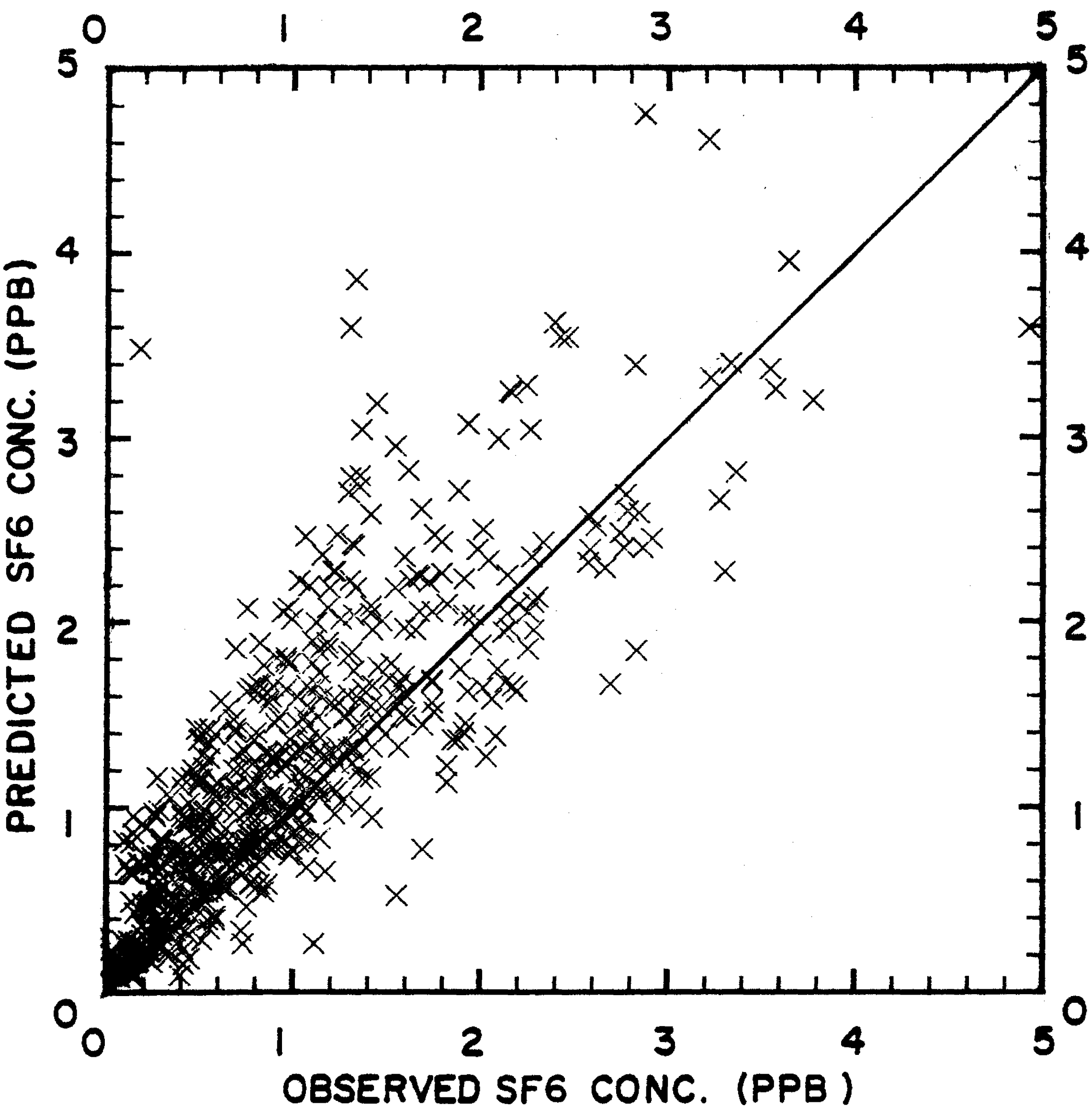


Fig. 21. Scatterplot of HIWAY-2 predictions vs. observed SF_6 concentrations for the General Motors experiment.

TABLE 12. Symbols Key for Figures 22 through 25

SYMBOL NUMBER	SYMBOL	TOWER* NUMBER	RECEPTOR HEIGHT, Z (meters)
1		2 or 4	9.6
2		2 or 4	3.6
3		2 or 4	0.6
4		1 or 5	9.6
5		1 or 5	3.6
6		1 or 5	0.6
7		6	9.6
8		6	3.6
9		6	0.6
10		7	0.6
11		8	0.6

* see Fig. 3. for tower locations (only down-wind locations were modelled)

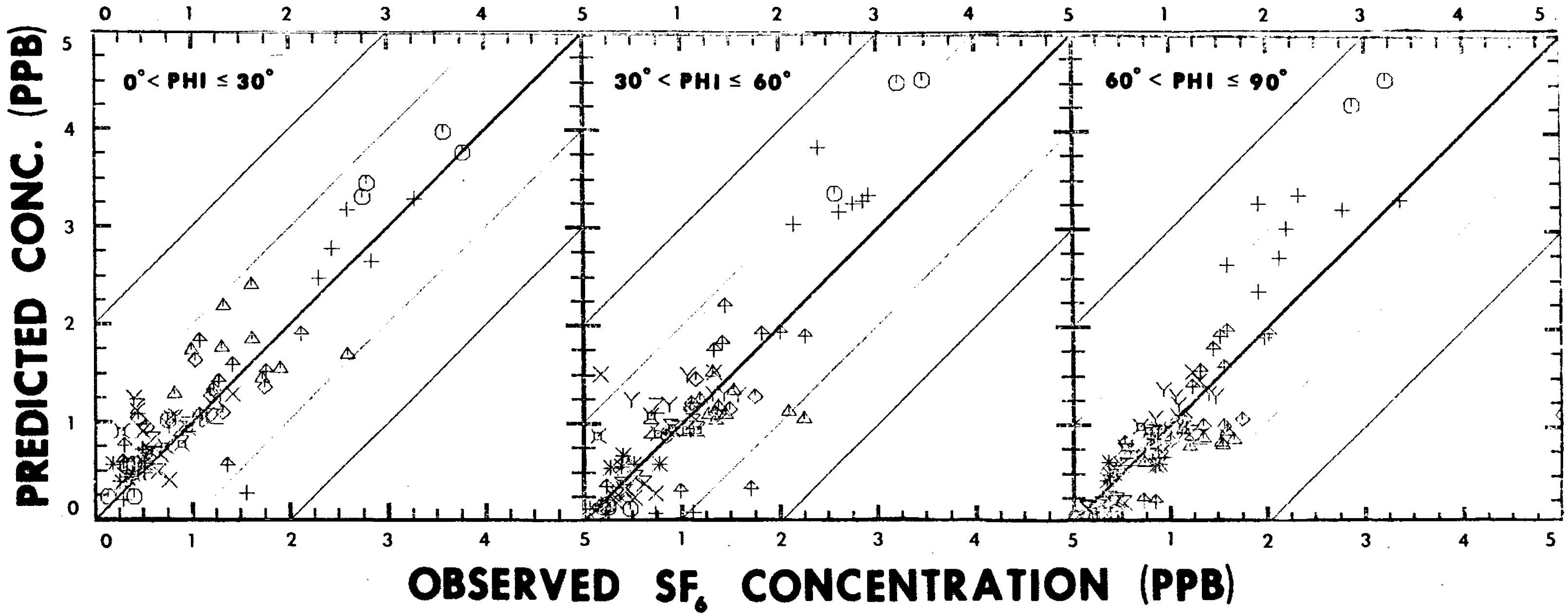


Fig. 22. Scatterplots of TXLINE (final version) predictions vs. observed SF_6 concentrations for the General Motors data when the wind speed was less than or equal to 2 m/s (classified by wind angle and receptor location - see TABLE 12).

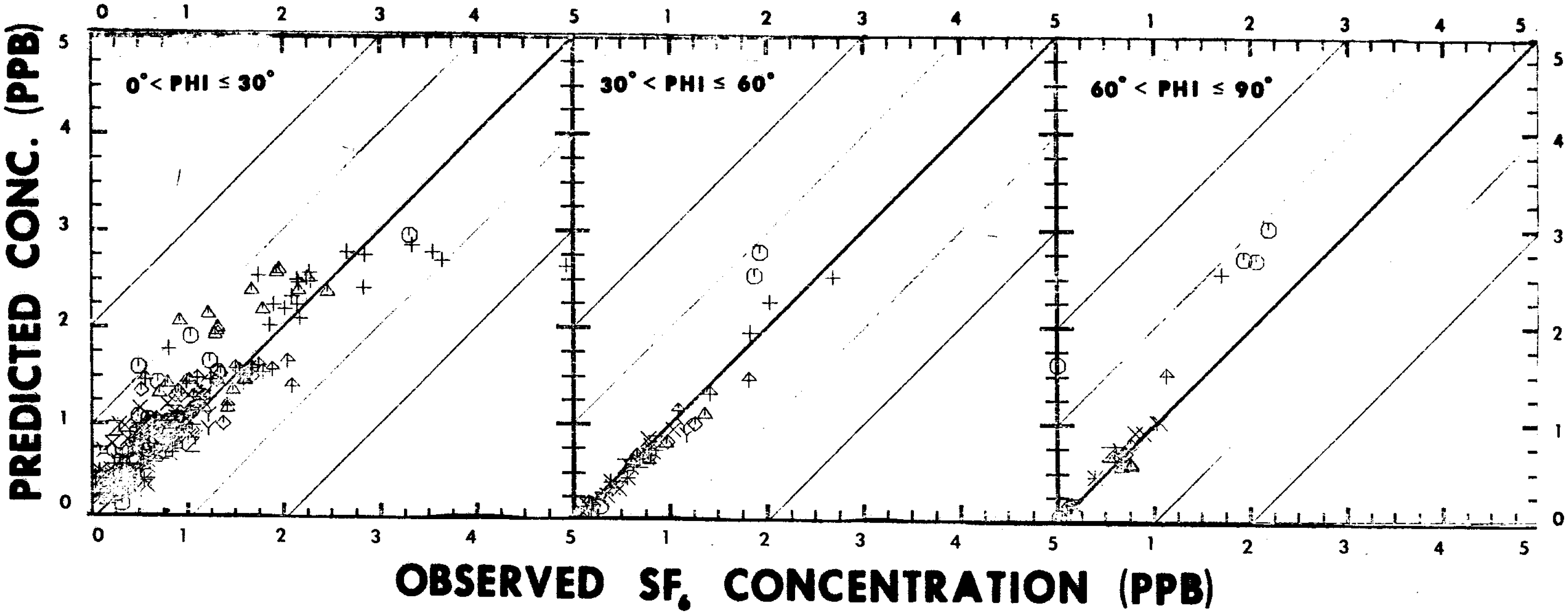


Fig. 23. Scatterplots of TXLINE (final version) predictions vs. observed SF_6 concentrations for the General Motors data when the wind speed was greater than 2 m/s (classified by wind angle and receptor location - see TABLE 12).

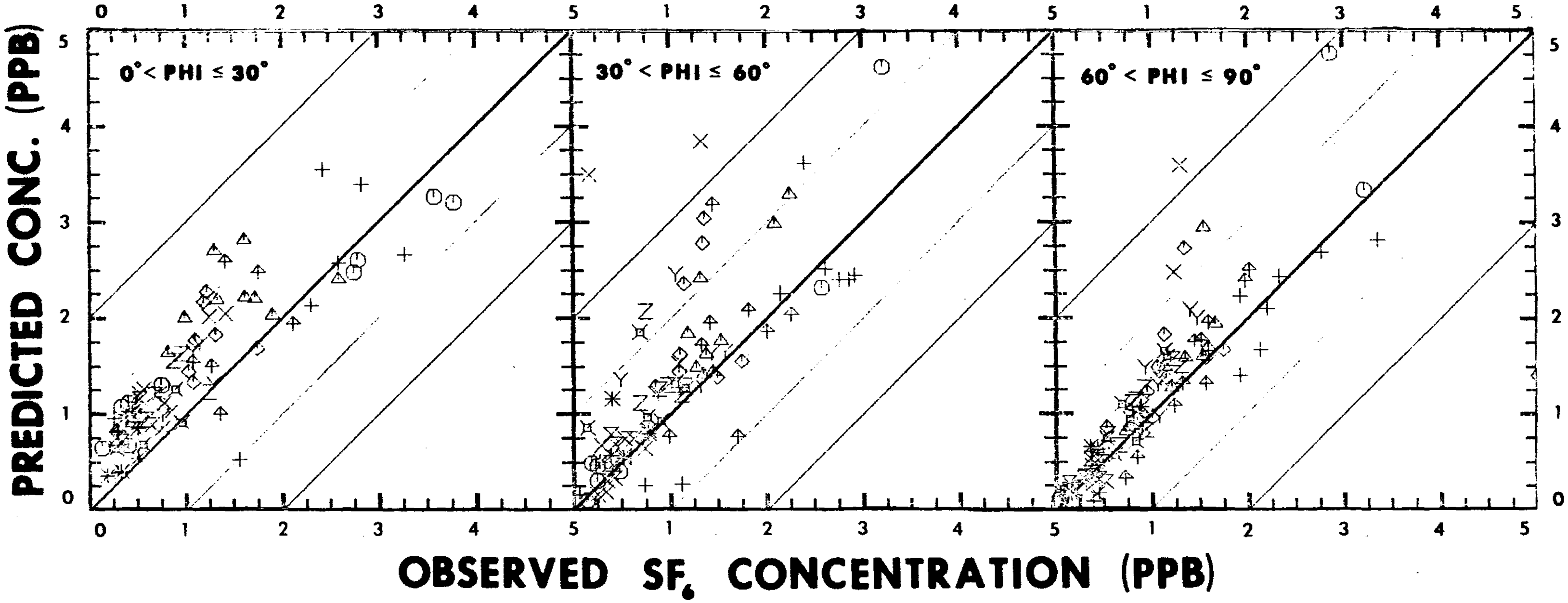


Fig. 24. Scatterplots of HIWAY-2 predictions vs. observed SF_6 concentrations for the General Motors data when the wind speed was less than or equal to 2 m/s (classified by wind angle and receptor location - see TABLE 12).

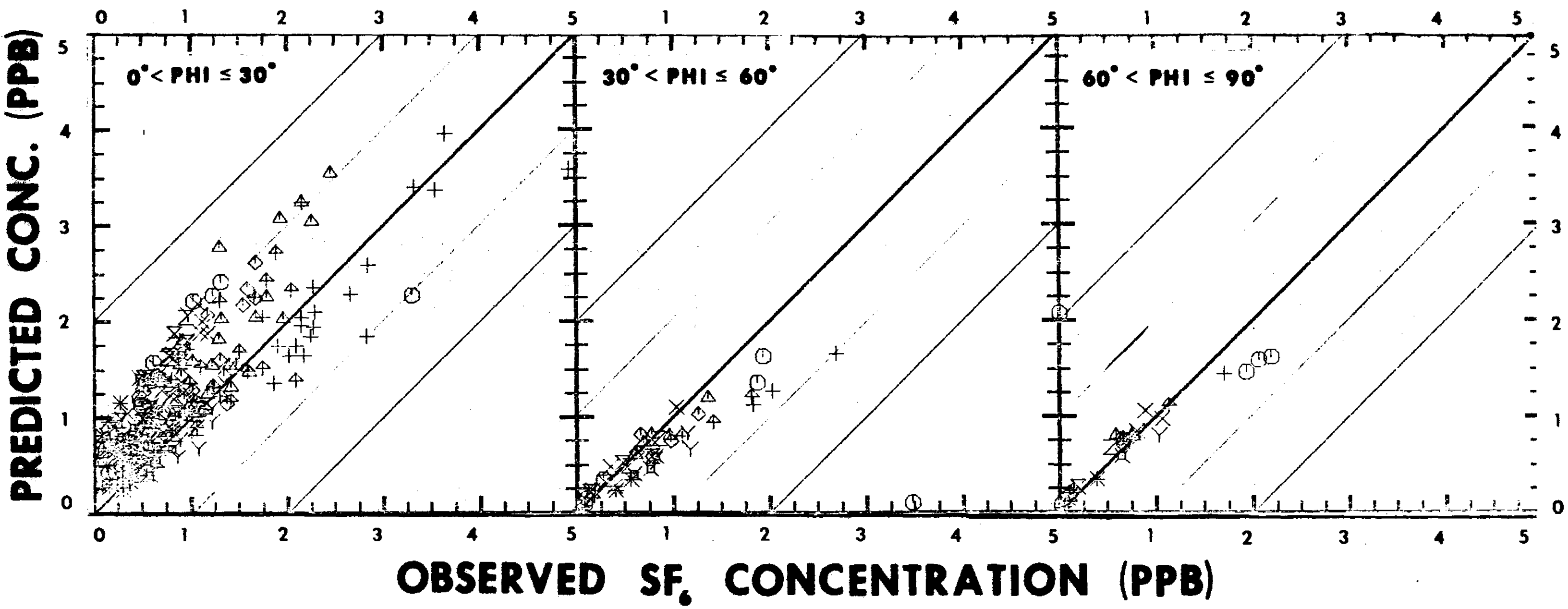


Fig. 25. Scatterplots of HIWAY-2 predictions vs. observed SF_6 concentrations for the General Motors data when the wind speed was greater than 2 m/s (classified by wind angle and receptor location - see TABLE 12).

while TXLINE slightly overpredicted the same points. Model performance at this particular receptor location is very important, because it is the location most often used in EPA 'worst case' analysis studies. This receptor is nearest the road at normal breathing level. Even though HIWAY-2 overpredicted most points, it underpredicted these most vital points. The consistent slight overprediction of these same points by TXLINE indicated a major advantage of the TXLINE Model.

Comparisons to the Texas Data

The Texas data base provided an unbiased test for all of the models except TRAPS-IIM, which was developed using the Texas data. Separate comparisons were made for each of the following at-grade sites; San Antonio, Dallas, El Paso, and Houston. The TRAPS-IIM results, and all input parameters required for the other models, were taken from Green (1980). Statistical comparisons are presented in Tables 13 - 16 and the regression lines are plotted in Figures 26 - 29.

The comparisons to the San Antonio data presented in Table 13 and Figure 26 are fairly indicative of all comparisons to actual roadway carbon monoxide dispersion data. Regression coefficients are all significantly lower than in the GM experiment. On the average, TRAPS-IIM and the uncorrected (for low wind speed) version of TXLINE overpredicted. The final TXLINE Model (with wind speed correction factor) had the lowest average error and average squared error, but slope

TABLE 13. Statistical Comparisons of Model Results to the San Antonio Data

Statistic	TXLINE*	TXLINE**	TRAPS II-M	HIWAY-2	CALINE-3
Average Error (ppm)	0.01	-0.25	0.29	0.03	0.14
Average Squared Error $(ppm)^2$	1.02	1.41	1.57	1.08	1.05
Intercept (ppm)	0.67	0.82	0.58	0.64	0.52
Slope	0.46	0.55	0.77	0.46	0.47
R^2	0.25	0.23	0.31	0.23	0.25
% within ±2	96	88	88	95	95
% within ±1	66	65	69	68	71
number of points***	352	352	352	352	352

* Final version - low wind speed correction factor was applied.

** Preliminary version - without wind speed correction factor.

*** 26 points were negative after being adjusted for background concentration

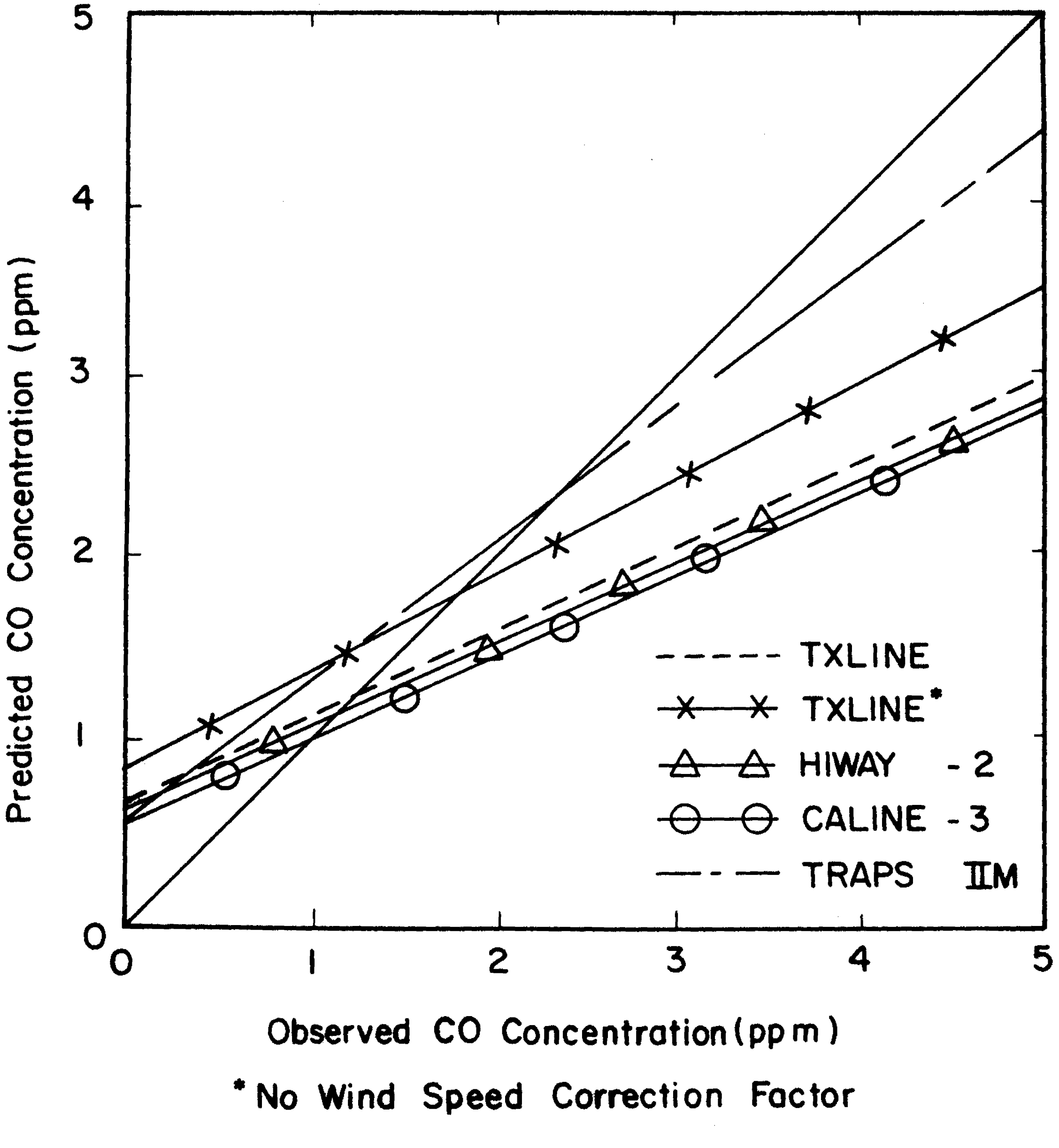


Fig. 26. Regression lines of various models for the San Antonio data.

TABLE 14. Statistical Comparisons of Model Results to the Dallas Data

Statistic	TXLINE*	TXLINE**	TRAPS II-M	HIWAY-2	CALINE-3
Average Error (ppm)	0.35	0.32	0.43	0.55	0.60
Average Squared Error $(ppm)^2$	1.45	1.50	1.27	1.19	1.22
Intercept (ppm)	0.63	0.67	0.49	0.31	0.25
Slope	-0.23	-0.25	-0.15	-0.08	-0.06
R^2	0.16	0.17	0.17	0.23	0.17
% within ±2	91	90	92	92	92
% within ±1	57	57	70	71	70
number of points***	98	98	98	98	98

* Final version - low wind speed correction factor was applied.

** Preliminary version - without wind speed correction factor.

*** 15 points were negative after being adjusted for background concentration

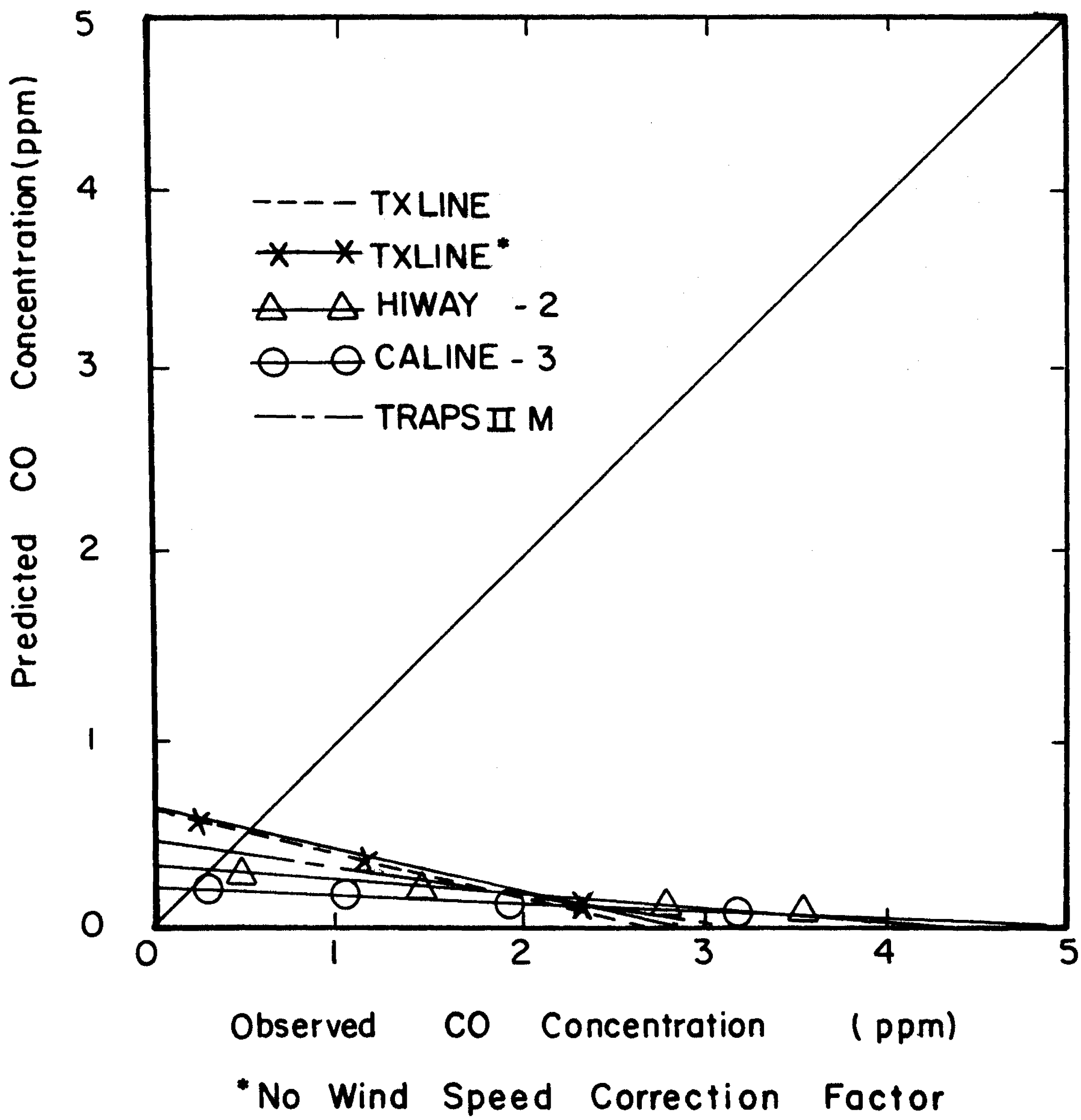


Fig. 27. Regression lines of various models for the Dallas data.

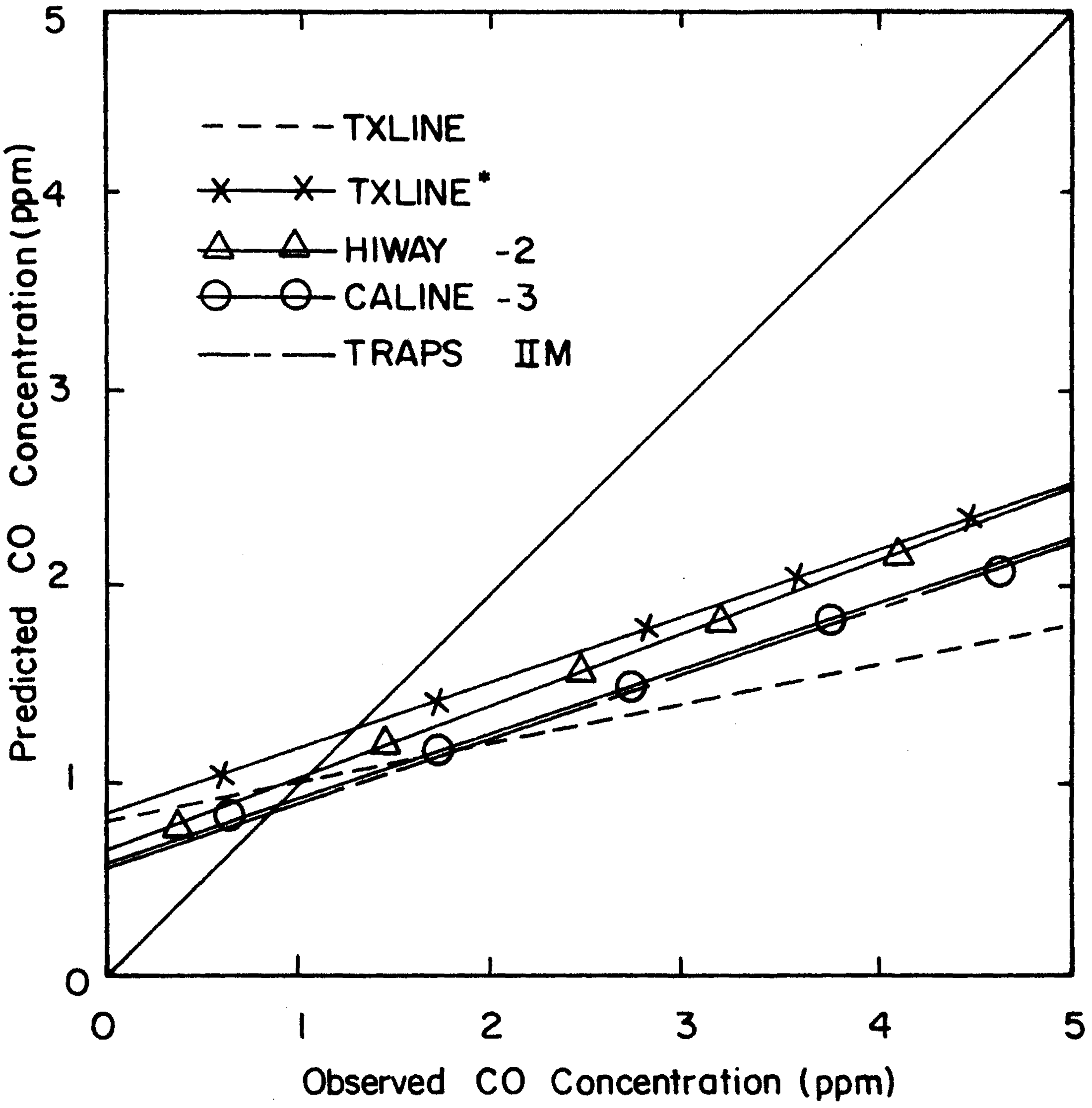
TABLE 15. Statistical Comparisons of Model Results to the El Paso Data

Statistic	TXLINE*	TXLINE**	TRAPS II-M	HIWAY-2	CALINE-3
Average Error (ppm)	0.30	0.05	0.37	0.25	0.20
Average Squared Error $(ppm)^2$	3.01	2.94	2.76	2.82	2.65
Intercept (ppm)	0.78	0.87	0.58	0.62	0.58
Slope	0.22	0.34	0.33	0.38	0.33
R^2	0.31	0.29	0.37	0.34	0.37
% within ±2	78	78	80	80	80
% within ±1	44	44	48	50	47
number of points***	704	704	704	704	704

* Final version - low wind speed correction factor was applied.

** Preliminary version - without wind speed correction factor.

*** 163 points were negative after being adjusted for background concentration



*No Wind Speed Correction Factor

Fig. 28. Regression lines of various models for the El Paso data.

TABLE 16. Statistical Comparisons of Model Results to the Houston Data

Statistic	TXLINE*	TXLINE**	TRAPS II-M	HIWAY-2	CALINE-3
Average Error (ppm)	0.30	0.30	0.53	0.42	0.20
Average Squared Error (ppm)^2	1.03	1.00	1.08	1.21	1.19
Intercept (ppm)	0.61	0.60	0.25	0.50	0.52
Slope	0.34	0.35	0.43	0.33	0.48
R^2	0.39	0.40	0.48	0.32	0.32
% within ±2	96	96	97	94	95
% within ±1	67	68	64	64	59
number of points***	195	195	195	195	195

* Final version - low wind speed correction factor was applied.

** Preliminary version - without wind speed correction factor.

*** 23 points were negative after being adjusted for background concentration

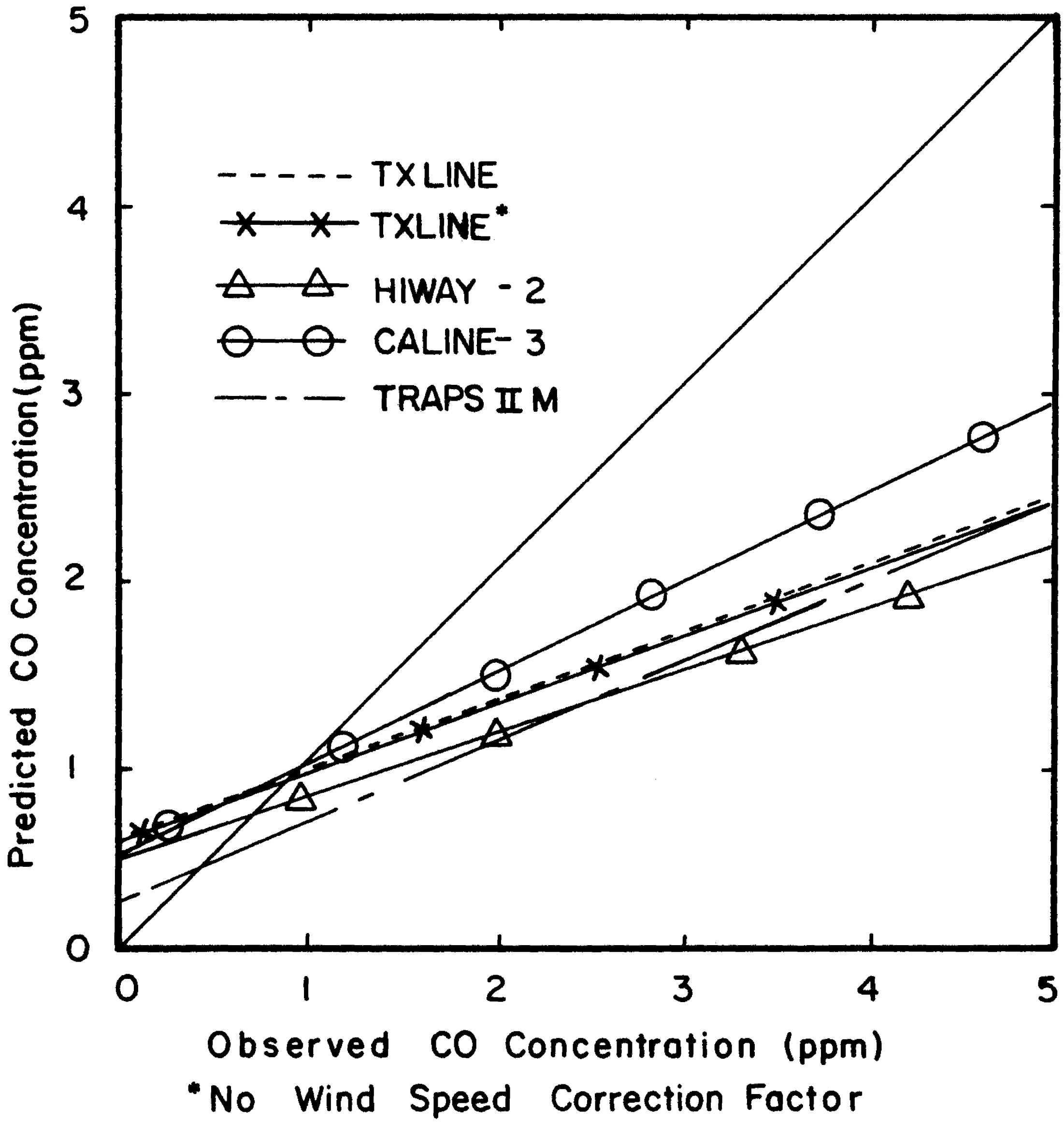


Fig. 29 Regression lines of various models for the Houston data.

and intercept were similar to the other models. Despite their many theoretical differences, the results for HIWAY-2 and TXLINE were very similar.

Each model severely underpredicted the Dallas data (Table 14 and Figure 27). This data set primarily contained high wind speed cases. The Dallas data illustrated how difficult the problem of modelling carbon monoxide dispersion near a roadway can be.

The El Paso comparisons presented in Table 15 and Figure 28 were much more encouraging. With the exception of the uncorrected version of TXLINE, all models underpredicted the data. The regression lines shown in Figure 28 are closely bunched. A significantly large number of points in this data base were negative after being adjusted for background concentration. This problem was addressed in Chapter 2.

The Houston comparisons presented in Table 16 and Figure 29 were once again similar for all of the models, but regression coefficients were slightly higher for this data set. The two versions of TXLINE predicted nearly identical results since the wind speed correction factor does not apply to wind speeds above 4 m/sec, and most of the Houston data were taken at greater wind speeds.

The Texas data comparisons did not show one model to be clearly superior or inferior to the others, but did indicate that each model had a tendency to underpredict the data.

Comparisons to the SRI Data

The SRI data base was described in detail in Chapter 2. The models were tested by comparing concentration predictions of both a tracer gas and carbon monoxide to the data. These comparisons were an unbiased test of all of the models except for CALINE-3. The SRI data was used in the development of CALINE-3.

SRI Elevated Site

The comparisons to the data from the SRI elevated site were used to evaluate the performance of the models when the source was well above ground level. The site geometry is described in detail in Chapter 2. Surface roughness was estimated to be 0.20m, using Table 3 of the Appendix. Wind speeds were averaged at the reference height of 14.0m (see Figure 11). The wind speed measurements taken at levels below this height appeared to be very inconsistent; probably due to interference from the bridge itself. Stability class was determined using a table by Pasquill (1974) which gave stability class as a function of wind speed and incoming solar radiation.

Source strength was measured directly and included in the data for the SF_6 tracer gas experiment. The source strength for carbon monoxide was estimated using cruise mode estimates from EPA report APTD-1497 (see Dabberdt, et al. (1981)) and was also recorded in the data base.

Comparisons of model predictions to the SRI elevated source SF_6 data are presented in Table 17 and Figure 30. All of the models performed poorly for this data set. The regression coefficient (r^2 = 0.16) was slightly better for CALINE-3 than for the other models. This was expected, since CALINE-3 had been developed with the SRI data. The average squared error was only slightly higher for TXLINE than for CALINE-3, but both models underpredicted the data, as exhibited by the positive average error values. The average error for HIWAY-2 was negligible, but the average squared error was very high. The TXLINE Model, without the wind speed correction factor, overpredicted considerably.

Comparisons of model predictions to the SRI elevated source carbon monoxide data are presented in Table 18 and Figure 31. The accuracy of the predictions was once again poor. TXLINE and CALINE-3 statistics were nearly identical and showed lower average squared error than the other models. All models underpredicted, although TXLINE exhibited a respectable average error of 0.14 when the wind speed correction factor was not applied. The regression lines were all closely bunched and near parallel, except for the uncorrected version of TXLINE.

As a whole, the model predictions of the SRI elevated data indicated that none of the models could accurately predict the data. Since all of the data was taken fairly near the roadway (see Figure 11), this comparison may not be indicative of each model's ability to predict dispersion from an elevated source.

TABLE 17. Statistical Comparisons of Model Results to the SRI Elevated Source SF_6 Data

Statistic	TXLINE*	TXLINE**	HIWAY-2	CALINE-3
Average Error (ppb)	0.41	-1.02	-0.09	0.32
Average Squared Error $(ppb)^2$	4.62	21.30	10.60	3.87
Intercept (ppb)	0.94	1.66	1.24	0.82
Slope	0.09	0.57	0.22	0.23
R^2	0.04	0.07	0.03	0.16
% within ±2	82	73	80	82
% within ±1	66	62	66	66
number of points	336	336	336	336

* Final version - low wind speed correction factor was applied.

** Preliminary version - without wind speed correction factor.

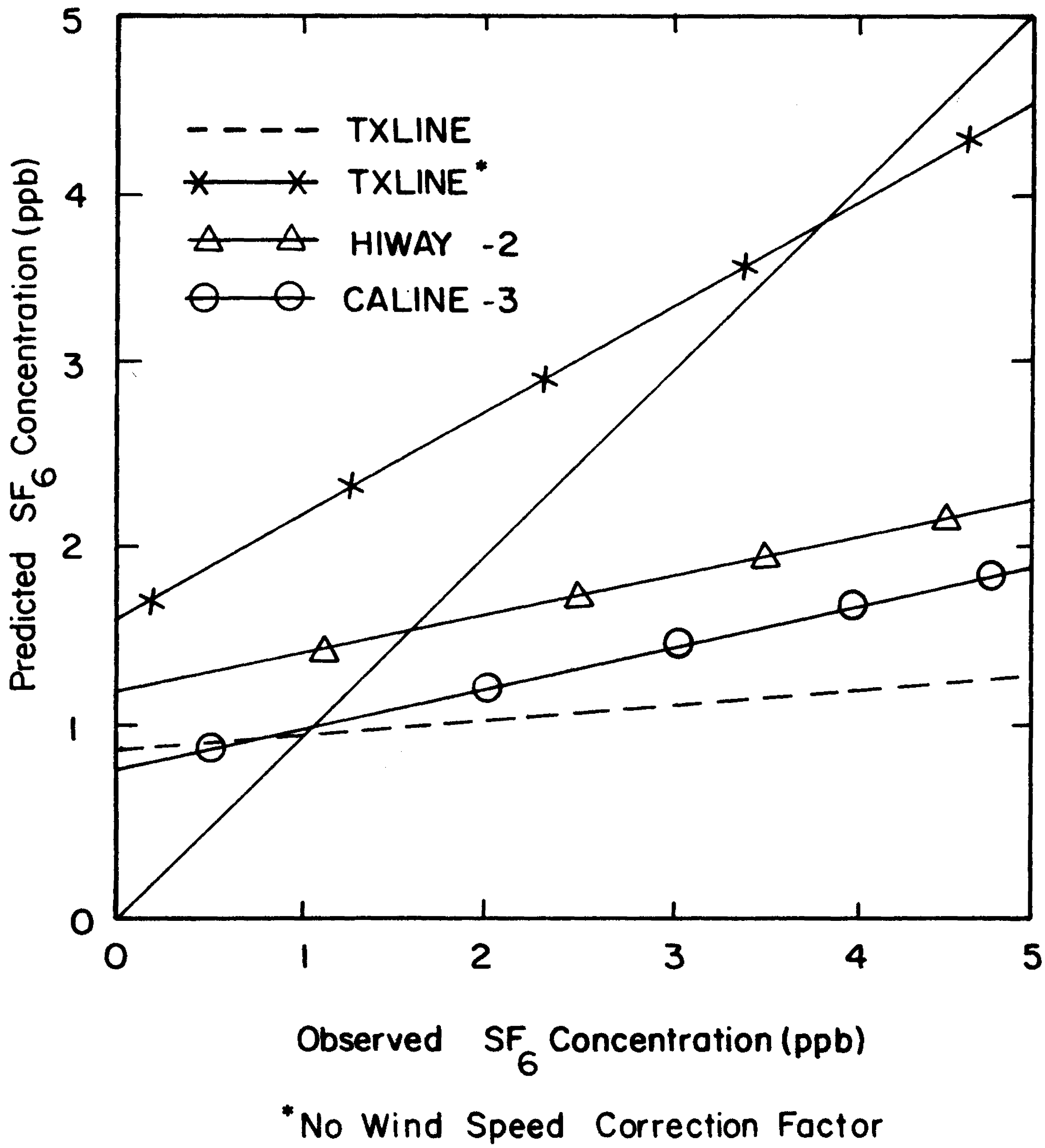


Fig. 30. Regression lines of various models for the SRI elevated SF_6 data.

TABLE 18. Statistical Comparisons of Model Results to the SRI Elevated Source CO Data

Statistic	TXLINE*	TXLINE**	HIWAY-2	CALINE-3
Average Error (ppm)	0.67	0.14	0.54	0.67
Average Squared Error $(ppm)^2$	1.57	2.69	2.15	1.59
Intercept (ppm)	0.39	0.54	0.47	0.38
Slope	0.09	0.42	0.13	0.10
R^2	0.08	0.09	0.02	0.07
% within ±2	93	90	91	92
% within ±1	70	66	70	68
number of points	359	359	359	359

* Final version -low wind speed correction factor was applied.

** Preliminary version - without wind speed correction factor.

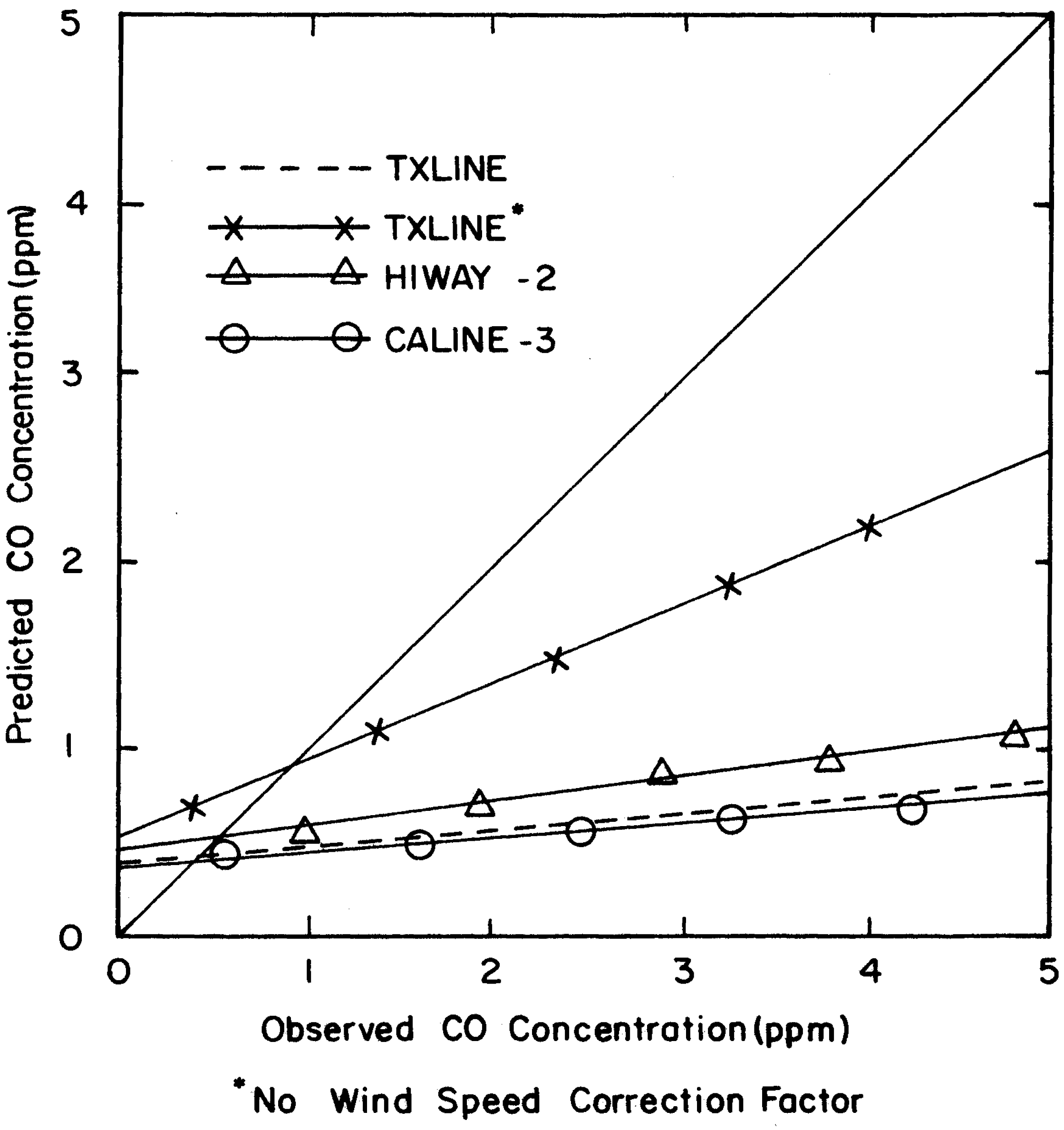


Fig. 31. Regression lines of various models for the SRI elevated CO data.

SRI At-Grade Site

Site geometry for the SRI at-grade experiment was described in detail in Chapter 2. Surface roughness was estimated to be 0.20m, using Table 3 of the Appendix. Wind speeds were averaged at the reference height of 7.50m (see Figure 11). Once again, only downwind receptors were modelled. Stability class and source strength were determined using the same methods described in the SRI elevated data section.

Comparisons of model predictions to the SRI at-grade SF_6 data are presented in Table 19 and Figure 32. Each of the models predicted a nearly parallel regression line. The intercept for the version of TXLINE without the wind speed correction factor was again much higher than the intercepts for the other models. The final version of TXLINE was the superior model based on nearly every statistic, but results were still poor. The unreasonably large average squared error for each of the models further indicated the inability of the models to predict this data set.

The model comparisons to the SRI at-grade carbon monoxide data differentiated the models more than any other data base, except for the GM data. Statistical comparisons and regression lines are presented in Table 20 and Figure 33. Based on these comparisons TXLINE and HIWAY-2 clearly outperformed the other models. TXLINE had a considerably lower average error (0.05 ppm) than HIWAY-2 and also showed slightly better performance in every other statistical comparison.

TABLE 19. Statistical Comparisons of Model Results to the SRI At-grade Source SF_6 Data

Statistic	TXLINE*	TXLINE**	HIWAY-2	CALINE-3
Average Error (ppb)	0.49	-1.11	0.73	0.90
Average Squared Error $(ppb)^2$	19.23	28.83	19.82	21.30
Intercept (ppb)	1.33	2.69	1.13	0.99
Slope	0.10	0.22	0.08	0.06
R^2	0.09	0.06	0.08	0.04
% within ±2	85	68	81	76
% within ±1	65	49	62	50
number of points	479	479	479	479

* Final version - low wind speed correction factor was applied.

** Preliminary version - without wind speed correction factor.

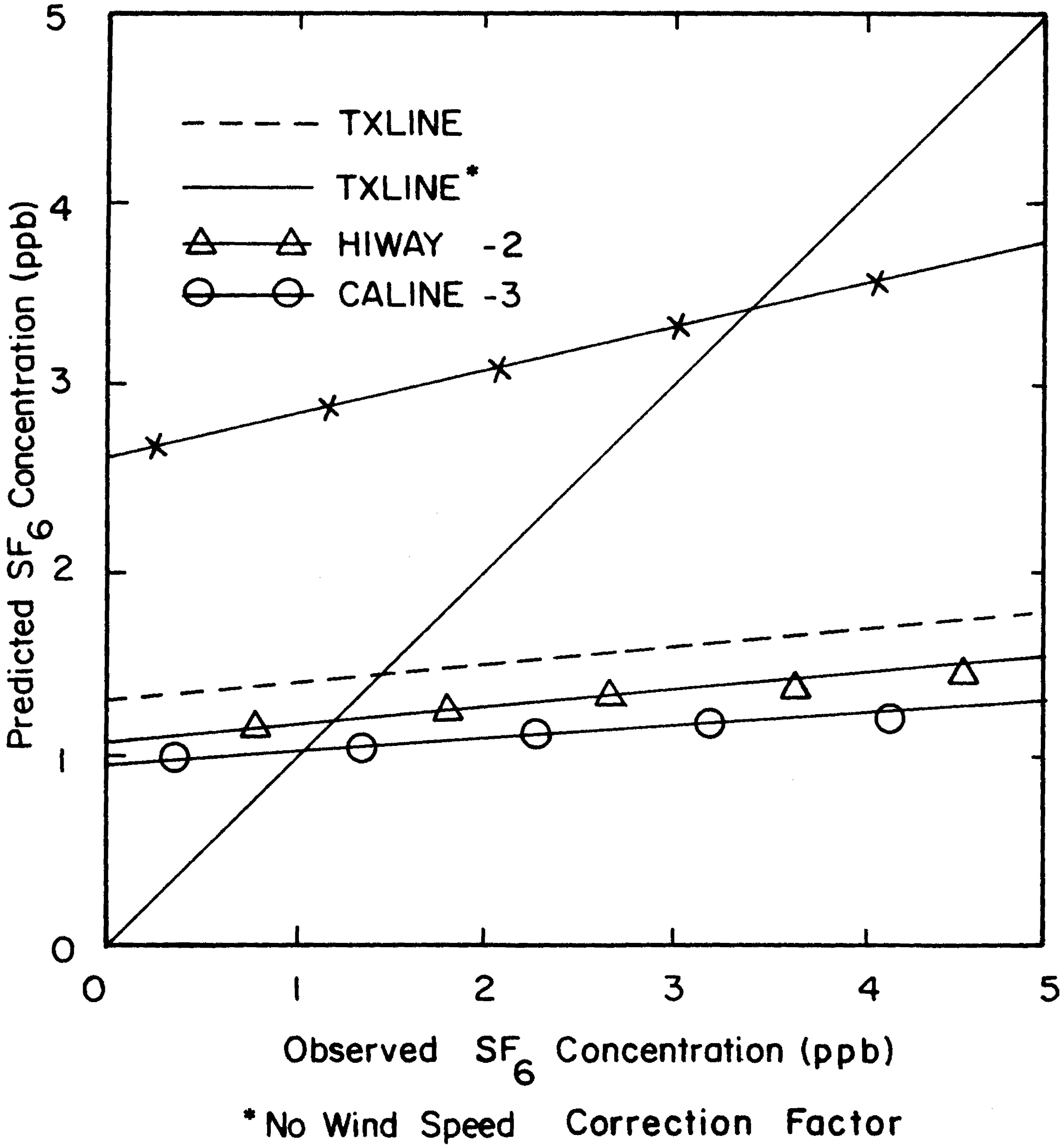


Fig. 32. Regression lines of various models for the SRI at-grade SF_6 data.

TABLE 20. Statistical Comparisons of Model Results to the SRI At-grade Source CO Data

Statistic	TXLINE*	TXLINE**	HIWAY-2	CALINE-3
Average Error (ppm)	0.05	-1.28	0.30	0.48
Average Squared Error $(ppm)^2$	1.54	9.66	1.68	2.80
Intercept (ppm)	0.73	1.71	0.63	0.65
Slope	0.47	0.71	0.37	0.24
R^2	0.37	0.13	0.33	0.10
% within ±2	93	72	91	84
% within ±1	67	54	65	60
number of points	463	463	463	463

* Final version - low wind speed correction factor was applied.

** Preliminary version - without wind speed correction factor.

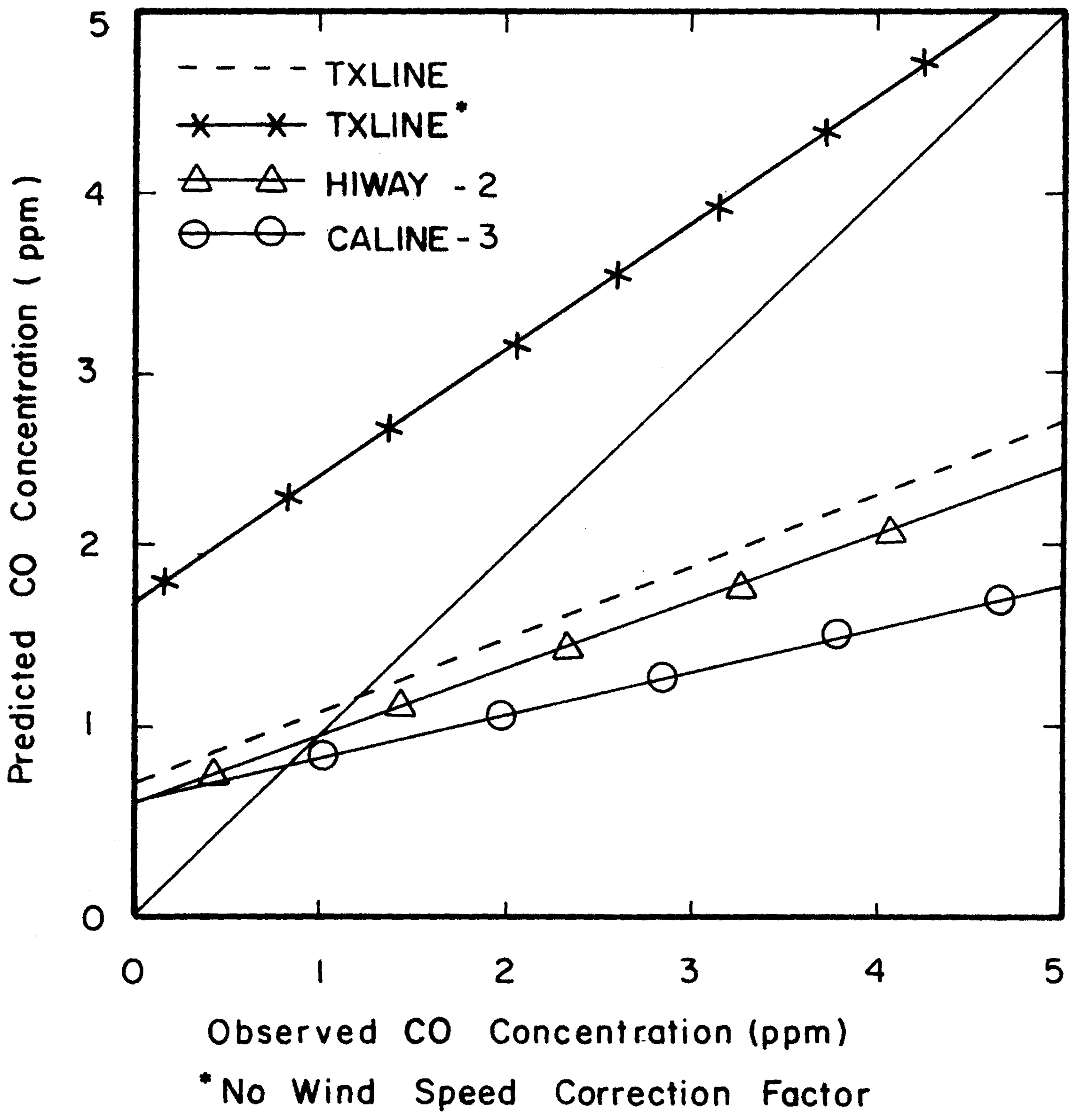


Fig. 33 Regression lines of various models for the SRI at-grade CO data.

In order to further differentiate the performance of the models for the SRI at-grade carbon monoxide data, a scatter plot of predicted vs. observed values was presented for each model. The individual receptor locations were differentiated using different symbols. The symbols key is presented in Table 21 and the scatter plots are presented in Figures 34-37. The general inferences which were drawn from the statistics are easily visualized in these plots. TXLINE (without the wind speed correction factor) severely overpredicted the data while CALINE-3 severely underpredicted the data. The statistical comparisons of the models had given a slight edge to TXLINE over HIWAY-2, but this edge is much more pronounced in the scatter plots. The points are much more tightly bunched around the 45° line for TXLINE than for HIWAY-2. Examination of the individual symbol revealed trends similar to those observed in the GM comparisons. The 1m level receptors nearest the roadway (represented by Symbols 4 and 9), were severely underpredicted by CALINE-3 and HIWAY-2. As discussed in the section on the GM comparisons, these receptor locations would by far be the most important if these results were being used for an environmental impact analysis. The TXLINE Model predicted these receptors much more accurately than the other models, without overpredicting. The ability to accurately predict concentrations at these critical receptor locations was a distinct advantage of TXLINE.

TABLE 21. Symbols Key for Figures 34 through 37

SYMBOL NUMBER	SYMBOL	DOWNWIND DISTANCE, X* (meters)	HEIGHT, Z (meters)
1		29.0	13.6
2		29.0	6.1
3		29.0	3.0
4		29.0	1.0
5		48.8	13.6
6		48.8	6.1
7		48.8	3.0
8		48.8	1.0
9		25.0	1.0
10		39.0	1.0
11		64.0	1.0
12		95.0	1.0

* see Fig. 10. for receptor locations - downwind distances were measured from the center of the median.

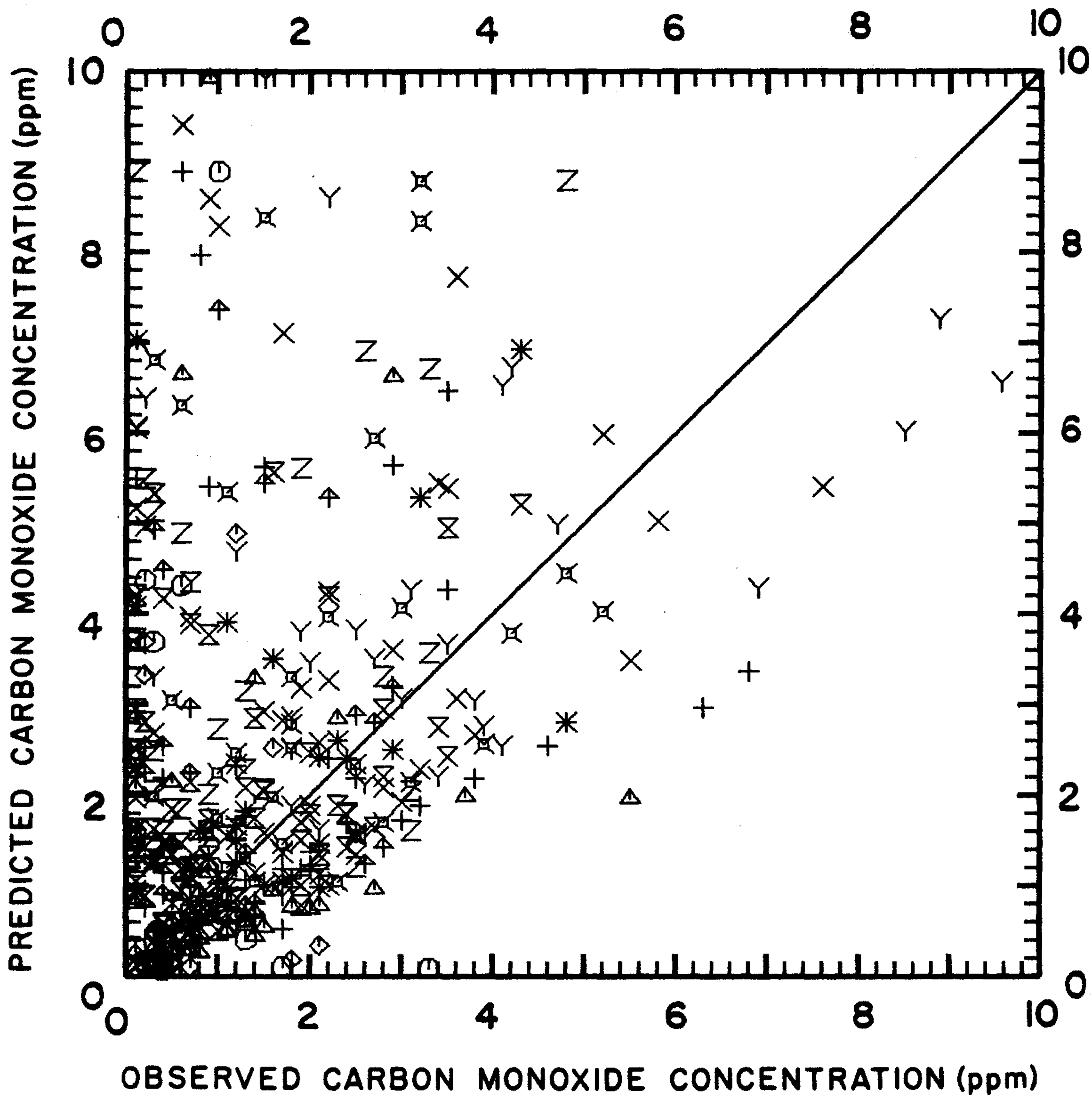


Fig. 34. Scatterplot of TXLINE (without wind speed correction factor) predictions vs. observed carbon monoxide concentrations for the SRI at-grade experiment.

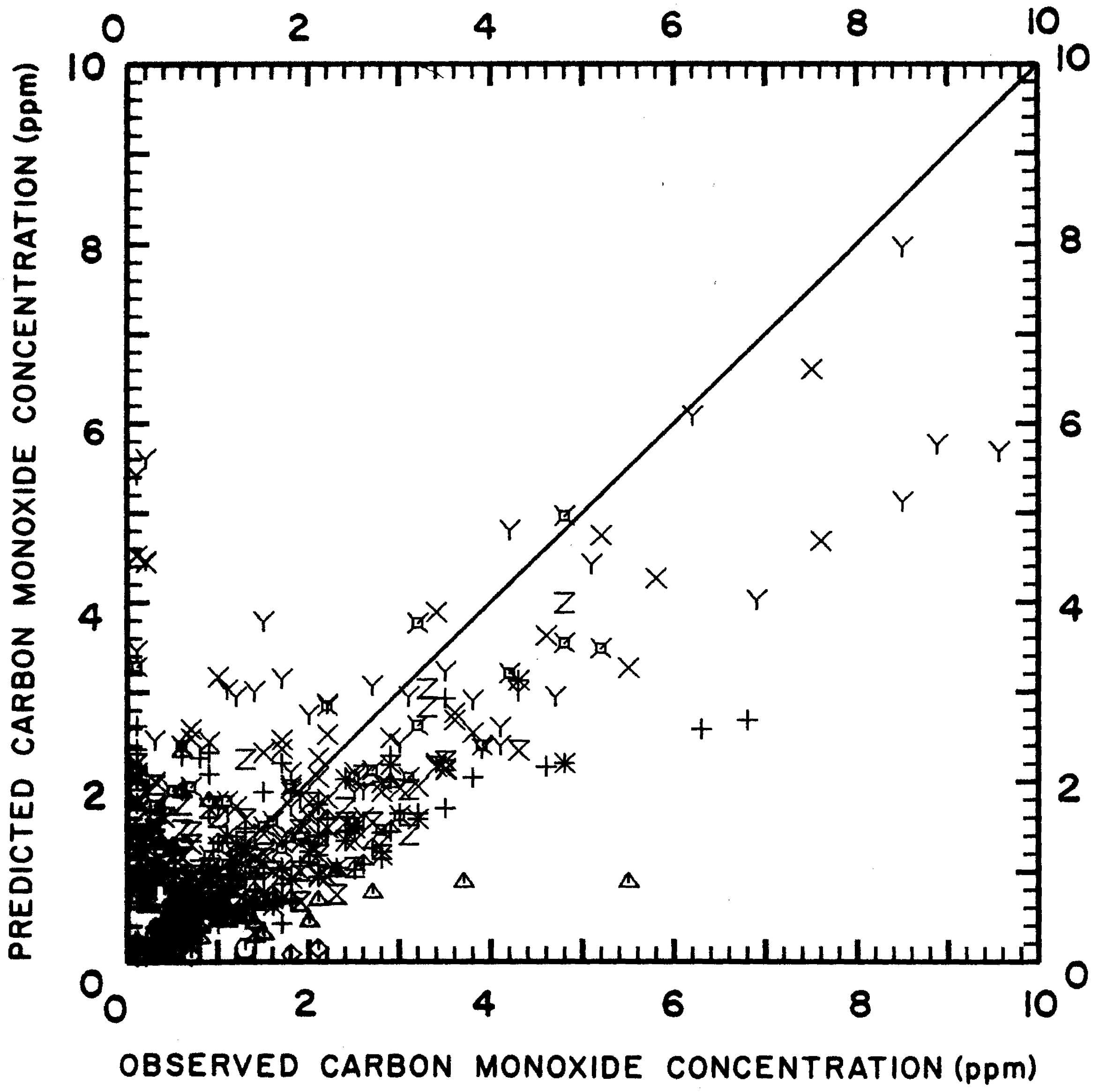


Fig. 35. Scatterplot of TXLINE (final version - with wind speed correction factor) predictions vs. observed carbon monoxide concentrations for the SRI at-grade experiment.

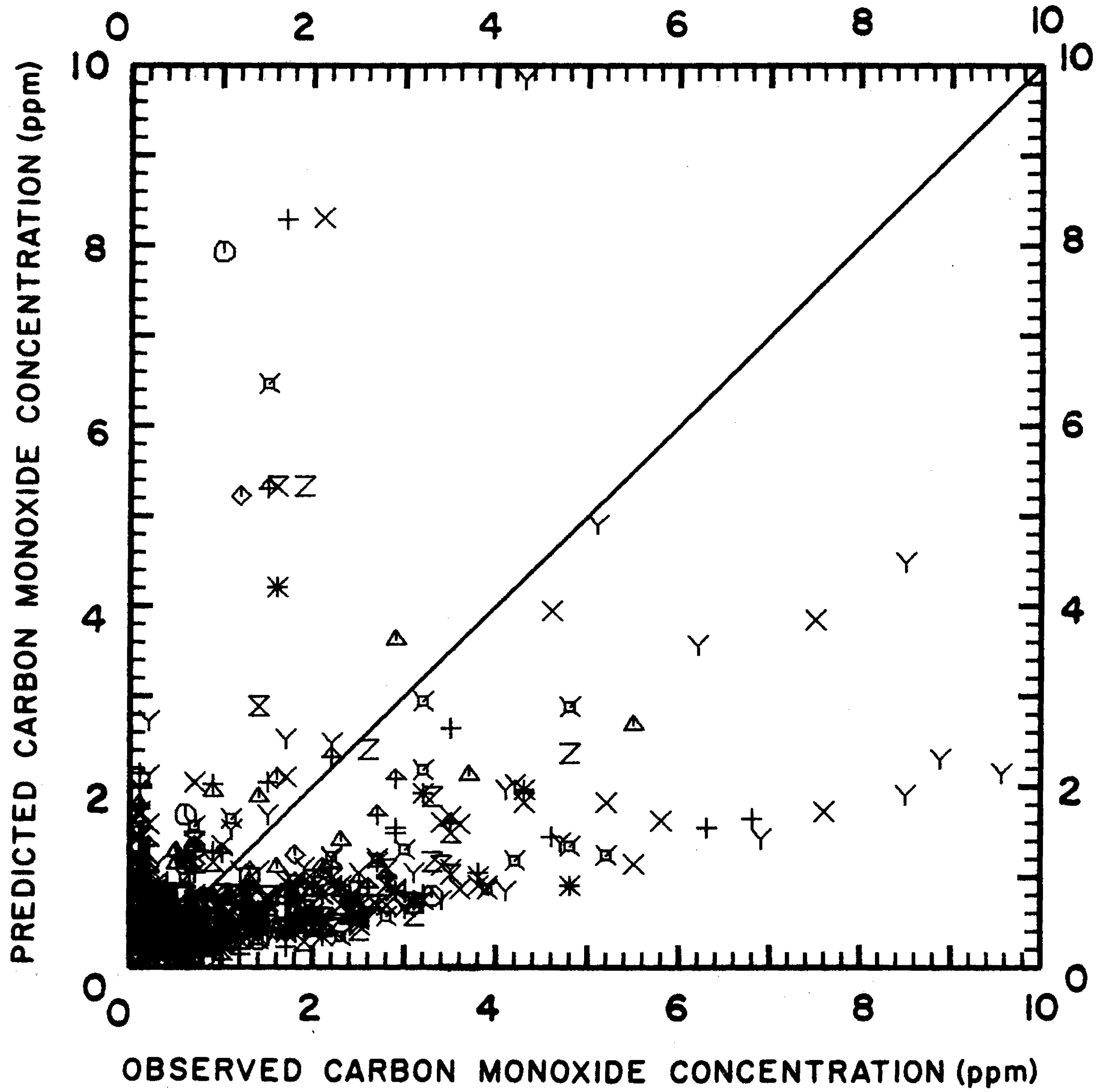


Fig. 36. Scatterplot of CALINE-3 predictions vs. observed carbon monoxide concentrations for the SRI at-grade experiment.

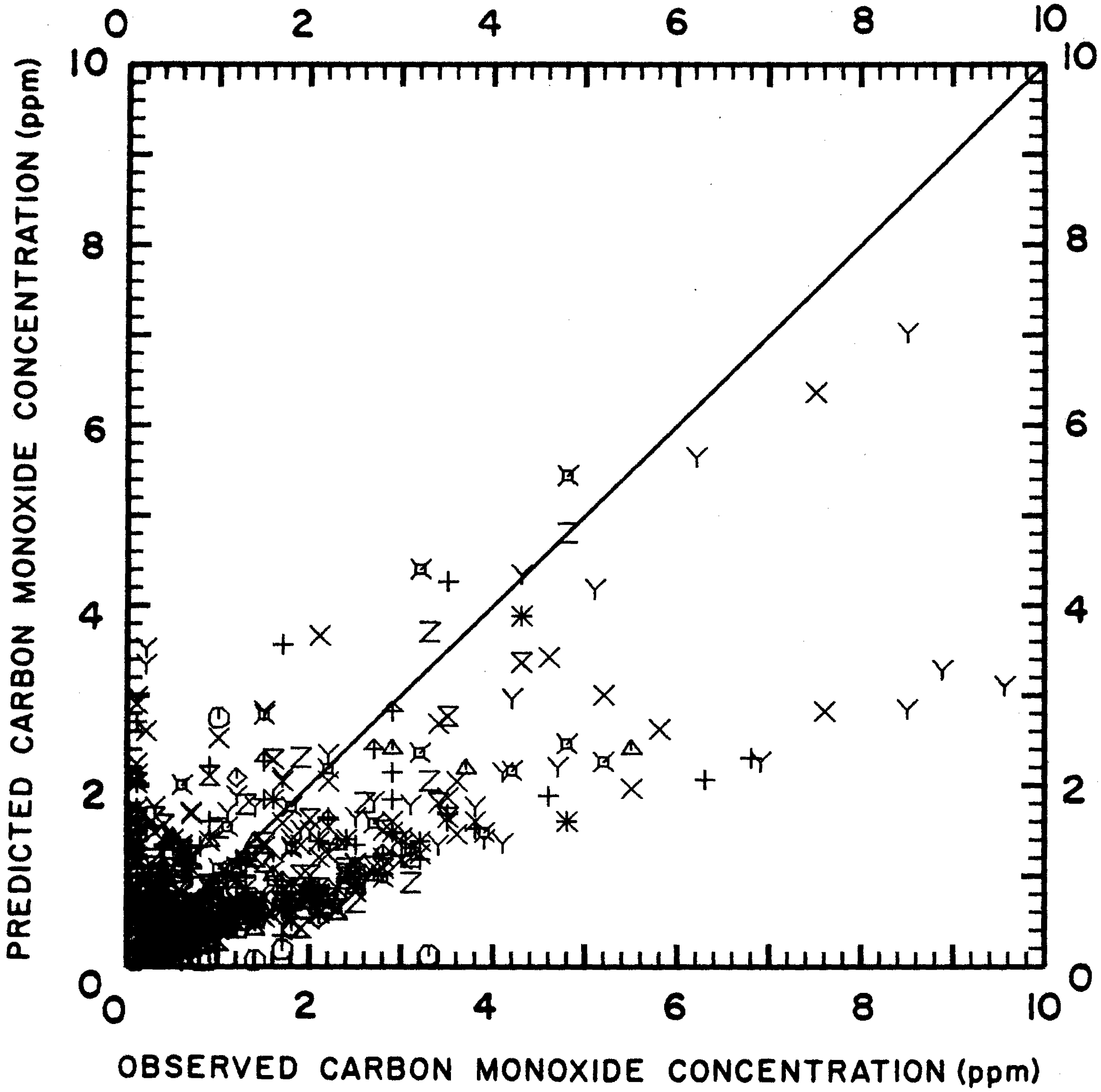


Fig. 37. Scatterplot of HIWAY-2 predictions vs. observed carbon monoxide concentrations for the SRI at-grade experiment.

Another interesting observation can be made by comparing all of the regression line plots for the SRI data. These plots include Figure 30 for SF_6 at the elevated site, Figure 31 for CO at the elevated site, Figure 32 for SF_6 at the at-grade site and Figure 33 for CO at the at-grade site. In all of these figures, the models consistently underpredict the data by about a factor of two in the concentration range of 2 to 5 ppb or ppm. This observation is consistent with the roadway mass balance work of Bullin, Green and Polasek (1980). In this work, the amount of pollutants flowing past the towers downwind of the roadway was shown to be about twice the measured emission rate for the tracer gases and about twice the estimated emission rate for carbon monoxide.

E. COMPARISON OF COMPUTER TIME REQUIREMENTS

In this section, the computer time requirements for TXLINE, CALINE-3, and HIWAY-2 are compared. The SRI at-grade SF_6 simulations were chosen for the comparison. A minimum of 560 concentration predictions were required from each model. Since the TXLINE Model calculates a concentration prediction for every combination of input receptor coordinates (see the Appendix), several more concentration predictions were made. Both HIWAY-2 and CALINE-3 require individual receptor coordinates as input, and therefore, the minimum requirement of 560 concentration predictions was not exceeded by either of these models.

The results of the computer time comparison are presented in Table 22. The computer comparisons were run on an Amdahl 470/V6/V8 computer using a FORTRAN-H (Extended) compiler. On the average, TXLINE took less than half as much computer time to execute a single simulation as CALINE-3 and HIWAY-2. In other words, even though TXLINE predicted concentrations at nearly twice the number of downwind locations as the other models, it took less time to execute.

TABLE 22. Computer Time Requirements for the Models

Dispersion Model	Number of simulations	Total computer time (C.P.U. sec)	Time per simulation (C.P.U. sec)
TXLINE	1,080	18.6	0.017
CALINE-3	560	23.0	0.040
HIWAY-2	560	33.4	0.060

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

A new model to predict the dispersion of pollutants from roadways was developed. The new model, called TXLINE, was compared to experimental data and to the previous models, CALINE-2, HIWAY-2 and TRAPS-IIM. An extensive literature review indicated that the commonly used Gaussian dispersion models were based on several unjustified assumptions. The most erroneous assumption was that wind speed was constant with height. TRAPS-IIM did not assume a constant wind speed with height. However, it used an inaccurate fit of the log-law wind profile. In addition, the solution to the general diffusion equation used in the TRAPS-IIM Model required several restrictive conditions.

The TXLINE Model was developed from more general solutions to the diffusion equation. The TXLINE Model has several advantages over previous models, including; an accurate fit of the widely accepted log-law wind profile; a mathematical treatment of wind angle; a theoretical basis for the assumed form of the eddy diffusivity profile; excellent agreement with mass balance theory; and a limited amount of empiricism.

TXLINE assumes negligible atmospheric stability and applies a wind speed correction factor as the only parameter which had been fit to experimental data. When compared to the General Motors data, TXLINE clearly outperformed the other models. Comparisons to the Texas and SRI data showed that TXLINE is at least as accurate as the other models. The TXLINE Model requires only about one-half as much computer time as the other models. Future improvements to the model could probably result in a far superior dispersion model.

Recommendations For Future Work

The major disadvantage of the TXLINE Model is that it can not be applied to complicated roadway geometries such as intersections. Since the model uses finite elements, it could easily be extended to a 'link' model. As more data becomes available, TXLINE could also be improved for elevated sources and extended to apply to street canyons.

The model could also be improved by including the effects of traffic and atmospheric stability on the dispersion process. By modifying the wind speed and eddy diffusivity profiles to account for these effects, the need for the low wind speed adjustment factor would probably be eliminated.

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APPENDIX

USER'S GUIDE FOR THE TXLINE MODEL

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USER'S GUIDE FOR THE TXLINE MODEL

The Texas Line Source (TXLINE) Model is a FORTRAN computer program intended to provide improved evaluation of pollution impacts in the vicinity of straight roadways. This User's Guide briefly describes the TXLINE Model and its use. The input procedures are discussed in detail and several illustrative examples are presented. The FORTRAN listing of TXLINE is also included and contains an abbreviated version of this user's guide in comment form.

MODEL DESCRIPTION

TXLINE is a FORTRAN computer program which estimates pollutant concentrations downwind of a singular line source or several parallel line sources of any elevation. The model is primarily intended for use in predicting carbon monoxide concentrations, but can also be used to simulate the dispersion of other gaseous pollutants. TXLINE is a microscale model, and therefore should only be used to predict concentrations in the near vicinity of a roadway.

There are several major differences between TXLINE and other dispersion models currently in use. TXLINE is the only current model which does not assume a flat wind profile. Instead, TXLINE uses a power law wind speed profile. The power law parameters have been

----

The Texas Line Source (TXLINE) Model was developed by the Chemical Engineering Department and the Texas Transportation Institute at Texas A&M University. The model was developed in partial fulfillment of Contract Number 2-8-80-283 for the Texas State Department of Highways and Public Transportation in cooperation with the Federal Highway Administration. A complete discussion of the development and validation of the TXLINE Model is presented in the Texas Transportation Institute final research report 2-2-80-283 "TXLINE: A Computer Model for Estimating Pollutant Concentrations Downwind of a Roadway." Questions or comments concerning the model should be directed to Professor J.A. Bullin, Chemical Engineering Department, Texas Transportation Institute, Texas A&M University, College Station, Texas, 77843, Phone (409)845-3306 or to Mr. Roderick Moe, Texas State Department of Highways and Public Transportation, File D-8P, 11th & Brazos, Austin, Texas, 78701, Phone (512) 465-6170.

fitted to approximate the log-law wind speed profile, which is commonly accepted by meteorologists to describe wind flow in the lower atmosphere under neutral stability conditions.

Unlike other recent models such as CALINE-3 (1979) and HIWAY-2 (1980), TXLINE does not use the simple form of the dispersion equation which assumes a Gaussian concentration distribution. Since this equation is not used, the difficulties which arise in estimating the Gaussian dispersion parameters are avoided. The equations used in the TXLINE Model were derived by Smith (1957) from the fundamental partial differential equations of diffusion which depend on eddy diffusivity and a non-uniform wind profile. The form of the eddy diffusivity profile follows directly from the power law wind profile as was shown by Calder (1949).

TXLINE incorporates Smith's solutions to both the infinite line source equation and the point source equation. The infinite line source equation is used when the wind angle is perpendicular or near perpendicular. In the case of an oblique wind angle, the point source equation is integrated along the length of the line segment. This numerical integration provides a theoretical treatment of the oblique wind angle case.

The only empirical feature of TXLINE is a low wind speed correction factor. Comparison of the TXLINE results by Rodden (1983), to both the GM data (1976) and the Texas

A&M data reported by Bullin, et al. (1978) showed that TXLINE overpredicted concentrations as wind speed and/or wind angle were decreased. A wind speed correction factor was fit through analysis of the GM data to better represent these cases. This factor becomes negligible (approaches a value of one) as the wind speed approaches 4 metres/second and as the wind angle approaches 90 degrees (perpendicular to the road). The correction factor is recommended for all highway pollution dispersion modelling, but the user is given the option to override the factor and use the more theoretical version of TXLINE.

The user should find the TXLINE Model quite simple to implement. Input parameters have been kept to a minimum and numerous self-explanatory error and warning messages have been included. Due to the complex nature of the equations used in TXLINE, a great deal of effort was made throughout the development stage of the model to minimize execution time. The program (Appendix A) was written as several documented subroutines. The specific function of each subroutine is outlined in Appendix B.

INPUT PROCEDURE

The TXLINE Model requires six types of input cards. They are in order:

(1) Heading and/or Comments card (one card)
(2) Input/Output Information card (one card)
(3) Wind Profile card (one card)
(4) Line Source Description card(s) (one card per line source)
(5) X-Coordinates of Receptors card (one card)
(6) Z-Coordinates of Receptors card (one card)

The input variable names, types, column locations, formats, and units are given in Table A1. As shown in the table, all of the input data are formatted according to standard FORTRAN conventions. The input variables are described in detail below. Most input variables must be within a certain range to prevent an error or warning message. A detailed description of the recommended ranges of these variables is presented in Table A2.

Heading and/or Comments Card. The first type of input card is the Heading and Comments card (see Table 1). The first 68 columns of this card are for any desired heading, comments, or identification codes.
Any combination of accepted FORTRAN alphanumeric characters may be used. The variable read from this card is:

COMM - Heading and/or Comments

TABLE A1. Input Variables for TXLINE

Card Type	Variable Name	Variable Type	FORTRAN Format	Card Columns	Variable Units
1	COMM	Real	17A4	01-68	---
2	CTYPE	Int.	A4	01-04	---
2	IN	Int.	A3	06-08	---
2	OUT	Int.	A3	10-12	---
2	NLINES	Int.	A1	14	---
2	AMB*	Real	F10.2	20-29	spec. by OUT
2	TCENT*	Real	F10.2	30-39	C
2	MOWT*	Real	F10.2	40-49	gram/mole
3	CTYPE	Int.	A4	01-04	---
3	LWADJ	Int.	I1	06	---
3	UREF	Real	F10.3	10-19	metre/s
3	REFZ	Real	F10.3	20-29	metre
3	PHI	Real	F10.0	30-39	degrees
3	Z0	Real	F10.3	40-49	metre
4	CTYPE	Int.	A4	01-04	---
4	XLIN	Real	F10.2	10-19	metre
4	HLIN	Real	F10.2	20-29	metre
4	QLIN**	Real	F10.5	30-39	g/km/s
4	VPH**	Real	F10.0	30-39	veh/hr
4	EFAC**	Real	F10.5	40-49	g/veh/mile
5	CTYPE	Int.	A4	01-04	---
5	NX	Int.	I1	06	---
5	X***	Real	6F10.2	10-69	metre
6	CTYPE	Int.	A4	01-04	---
6	NZ	Int.	I1	06	---
6	Z***	Real	6F10.2	10-69	metre

* These variables are not always required. See descriptions of these variables for explanation.

** Either QLIN or the combination of VPH and EFAC is required. See descriptions of these variables for explanation.

*** These variables are arrays. See variable descriptions.

TABLE A2. Limitations on the Ranges of TXLINE Input Variables

Variable Name	Range	Result of Violation	Explanation
NLINES	$1 \le NLINES \le 8$	Fatal Error	Program is dimensioned to handle a maximum of eight parallel line sources.
TCENT	$-30 \le TCENT \le 50$	Fatal Error	Reasonable temperature range.
MOWT	$10 \le MOWT \le 300$	Fatal Error	Reasonable limits on molecular weight of pollutants where the assumption of negligible settling velocity is valid.
UREF	$0 \le UREF \le 20$	Fatal Error	Program not tested outside this range.
	$0.44 \le UREF$	Warning	Windspeeds less than 0.44 m/sec are assumed equal to 0.44 m/sec for calculational purposes.
REFZ	$REFZ > 10$	Warning	Program not tested outside this range.
	$(Z0+1.5) \le REFZ \le 30$	Fatal Error	The power law parameters cannot be fit properly when outside of this range.
PHI	$0 \le PHI \le 90$	Fatal Error	Complete range of possible wind angles.
	$0 < PHI < 1$	Warning	If a value between zero and one is entered, PHI is assumed to be equal to one in order to avoid numerical difficulties.

TABLE A2 (continued)

Z0	$0 \leq Z0 \leq 4$	Fatal Error	Reasonable physical limitations on surface roughness.
	$Z0 < 0.01$	Warning	Program assumes Z0=0.01 to avoid division by a very small number.
	$Z0 > 1.0$	Warning	Surface roughness greater than 1m is greater than the maximum limit recommended by Pasquill (see Table A3).
HLIN	$0 \leq HLIN \leq 30$	Fatal Error	Range of accurate wind profile fit.
NX	$1 \leq NX \leq 6$	Fatal Error	Program is dimensioned to handle a maximum of six x-coordinates.
X	$3 \leq (X-XLIN)$	Fatal Error	If a receptor is placed closer than 3 meters from a source, calculational difficulties may arise.
	$(X-XLIN) \leq 250$	Warning	Program not tested outside this range. TXLINE is a microscale model, and is not intended to accurately predict distant concentrations.
NZ	$1 \leq NZ \leq 6$	Fatal Error	Program is dimensioned to handle a maximum of six z-coordinates.
Z	$0 \leq Z \leq 30$	Fatal Error	Range of accurate profile fit.

Input/Output Information Card. The second type of input card is the Input/Output Information card (see Table A1). This card and every card thereafter must begin with a card identifier code (see descriptions below). This card contains information which specifies input and output formats and variables which are necessary only when certain format options are specified. The variables located on this card are:

CTYPE - This is the 4-character card identifier code. The code for this card must be the letters 'IOUT'.

IN - This is a 3-character code which specifies the manner in which source strength is being entered. Two options are available:

(1) 'VPH' - If vehicles/hour and emission factor are to be entered on cards of type 4. (See explanation of the Line Source Description card).

(2) 'GKS' - If source strength is to be entered in units of g/km/sec on cards of type 4. (See explanation of the Line Source Description card).

OUT - This is a 3-character code which specifies the units desired for the output concentrations. Three options are available:

(1) 'PPM' - If concentration units of parts per million are desired.

(2) 'PPB' - If concentration units of parts per billion are desired.

(3) 'GM3' - If concentration units of grams per cubic metre are desired.

NLINES - A one digit integer specifying the number of line sources being modelled. The value of NLINES must agree with the number of Line Source Description cards.

AMB - The ambient or background concentration. If entered, the units must agree with the units specified by variable OUT and this background value will be added to all concentration predictions. If no value is entered, the ambient concentration is set to zero.

TCENT - The ambient temperature in units of degrees centigrade. (This variable is not required if the output option 'GM3' is specified - see description of variable OUT).

MOWT - The molecular weight of the pollutant being modelled. (This variable is not required if the output option 'GM3' is specified - see description of variable OUT). NOTE: For carbon monoxide, MOWT=28.

Wind Profile Card. The third type of input card is the Wind Profile card (see Table A1). This card contains all information needed by the model to determine the wind speed profile. The variables required on this card are:

CTYPE - This is the card identifier code. The code for this card must be the letters 'WIND'.

LWADJ - This is an integer code which is be used to specify the low wind speed correction factor option (see MODEL DESCRIPTION section). Two options are available:

(1) If a zero is entered or the field is left blank, the wind speed correction factor will be applied, if applicable. The correction is applicable if the windspeed is below 4 m/s.

(2) If the number nine (or any integer other than zero) is entered, the wind speed correction factor will not be applied and the completely theoretical version of the model will be used.

NOTE: For normal applications to highway dispersion modelling, it is recommended that the low wind speed correction factor option be used. (Enter a zero or a blank).

UREF - Reference wind speed.

REFZ - Height (z-coordinate) of the reference wind speed

PHI - Wind angle with respect to the line sources. The angle must be between zero and ninety (zero = parallel to the line sources; ninety = perpendicular to the line sources).

Z0 - Surface roughness. Pasquill's (1974) table of suggested surface roughness values (Table A3) is recommended to estimate this parameter.

Line Source Description Cards. The fourth type of card is the Line Source Description card (see Table A1). One card of this type is required for each line source being modelled. Therefore the total number of Line

TABLE A3. Suggested Surface Roughness (z_o) Values for TXLINE (from Pasquill (1974))*

z_o (cm)	Surface
0.1	very closely mown grass
1	short grass ($<$ 10cm)
3	long grass
20	rural-agricultural complex
100	forests, urban areas

* Rodden (1983) suggests that since the wind profile in the near downwind vicinity of a roadway is significantly influenced by the vehicles themselves, surface roughness values lower than about 20cm are rarely encountered near a roadway during typical traffic conditions.

Source Description cards must agree with the value of NLINES (see explanation of the Input/Output Information card). The variables on each Line Source Description card are:

CTYPE - This is the card identifier code. Each card of this type must begin with the character string 'LINE'.

XLIN - X-coordinate of the line source. Any arbitrary datum line parallel to the line sources may be assigned the value of x=0. The x-coordinate of each line source is then measured relative to this zero line. The coordinate of the line source should normally be the center of the actual roadway or lane. The receptor coordinates are also inputted relative to this coordinate system. For further description of this coordinate system see the example cases.

HLIN - The height (z-coordinate) of the line source, referred to ground level.

The following variable(s) on the Line Source Description card depend on the value of the variable IN which was entered on the Input/Output Information card.

If IN was entered as 'VPH', the following two variables should be entered on each Line Source Description card:

(1) VPH - Vehicles per hour.

(2) EFAC - Emission factor. If this factor is not measurable, it is recommended that it be estimated using the EPA program MOBILE-2 (1981).

If IN was entered as 'GKS,' the following one variable must be entered (do not enter values for VPH and EFAC):

QLIN - The source strength of the line source (in units of grams/km/sec).

X-Coordinates of Receptors Card. The fifth type of card contains the horizontal coordinates of the receptors. These coordinates must be relative to the same datum line as the line source coordinates. Since there are limitations on the values of the receptor x-coordinates, it is especially important that the user study Table A2 and the example cases. The variables read from this card are:

NX - Number of x-receptor coordinates.

X(i) - The ith x-coordinate. The number of coordinates entered should agree with the value of NX. (i = 1, 2, 3, ..., NX)

Z-Coordinates of Receptors Card. The sixth and final type of card contains the vertical coordinates of the receptors. The variables read from this card are:

NZ - Number of z-receptor coordinates.

Z(j) - The jth z-coordinate. The number of coordinates entered should agree with the value of NZ. (j = 1, 2, 3, ..., NZ)

LIMITATIONS AND RECOMMENDATIONS

The TXLINE Model will handle a wide variety of straight highway configurations, but does have some limitations. The present version cannot be used to model a street canyon or tunnel. TXLINE is capable of modelling a gradual cut or fill section, where the cut or fill is 45 degrees or less, as is illustrated in Example Three. Elevated sources such as bridges can also be modelled, provided there are no major obstructions to the wind flow under the roadway.

One major advantage of TXLINE is the ability to model several parallel line sources simultaneously with a minimum of input. Examples Two and Three illustrate this feature of the model.

The user should be aware that each lane of traffic need not always be modelled as a separate line source. In most cases, it is sufficient to model each direction of traffic as a single line source, with the source located in the center of the group of lanes. If the road has a narrow median and nearly equal traffic volumes in each direction, the entire road can be modelled as one line source with the source located at the center of the median. The only cases where it is recommended that each lane be modelled as separate line sources are (1) when the traffic (source strength) differs significantly from lane to lane; and/or (2) when the lanes are separated by large distances.

EXAMPLES

Three comprehensive examples have been prepared and are presented in order to further the user's understanding of the TXLINE model. Complete listings of the input and output files are presented along with a complete discussion of the parameters involved.

Example 1A. The first example is the simple case of a two lane highway without a median. The input cards for Example 1A are presented on FORTRAN coding paper in Figure A1. The first card is the Headings and/or Comments Card. The following characters have been entered on this card: 'EXAMPLE 1A - TWO LANE HIGHWAY'.

The second card is the Input/Output Information Card. The value of CTYPE must thus be entered as 'IOUT'. The input option code (IN) entered is 'VPH', indicating that values for vehicles/hour and emission factor will be entered on the Line Source Description Card. The output option code (OUT) entered is 'PPM' to specify that the output concentrations should be in units of parts per million. NLINES is given a value of one, since the road is very narrow and the traffic volumes in each lane are approximately equal. (The road could be modelled as two parallel line sources if desired, but this is not necessary for this case. See the LIMITATIONS AND RECOMMENDATIONS). The ambient con-

C COMMENT / CONTINUATION	DATA PROCESSING CENTER TEXAS A & M UNIVERSITY	PROBLEM: TXLINE INPUT - EXAMPLE 1A	PAGE 1 OF 1
		PROGRAMMER: J. B. RODDEN	DATE 11-22-82

FORTRAN STATEMENT

```
                         COMM
USER'S GUIDE EXAMPLE 1A  -  TWO LANE HIGHWAY

CTYPE IN  OUT  NLINES   AMB      TCENT     MOWT
IOUT VPH PPM 1         0.2      30.1      28.0

CTYPE LWADJ   UREF      REFZ     PHI        ZO
WIND 0       2.1       6.0      13.0       0.60

CTYPE         XLIN      HLIN   VPH         EFAC
LINE         0.0       0.0    1500.       27.8

CTYPE NX      X(1)     X(2)      X(3)      X(4)      X(5)     X(6)
XREC 6       5.0      10.0      25.0      50.0      75.0     100.0

CTYPE NZ      Z(1)     Z(2)      Z(3)      Z(4)
ZREC 4      15.0      10.0       5.0       2.0
```

Fig. A1. Input for TXLINE Example 1A on FORTRAN coding form.

centration, AMB, is given the value of 0.2 ppm. Since concentration units of parts per million were specified, values must be entered for TCENT and MOWT. TCENT is the temperature in degrees Centigrade and is equal to 30.1. The pollutant being modelled is carbon monoxide, so MOWT is given the value of 28.0 g/mole.

The third card is the Wind Profile Card. CTYPE is entered as 'WIND'. The low wind speed correction factor is desired, so a zero is entered for LWADJ. The wind speed is known to be 2.1 m/sec at a height of six metres. (UREF = 2.1, and REFZ = 6.0). The wind angle, PHI, is 13. degrees (see Figure A1). Since this road cuts through an area with several small trees, the site roughness is estimated to be 0.60 metres (see Table A3).

The fourth card is the Line Source Description Card. Since the road is being modelled as a single line source, only one card of this type is entered. The value of CTYPE is 'LINE'. The arbitrary line where x = 0 has been chosen for convenience as the center line between the two lanes. Since this is also the location of the line source, XLIN = 0.0. The road is at ground level, so HLIN = 0.0. Traffic was estimated to be approximately 700 veh/hr in the northbound direction and 800 veh/hr in the southbound direction. The total vehicles per hour is entered (VPH = 1500). The cruise emission factor (EFAC) was estimated as 27.8 grams/vehicle/mile using the MOBILE-2 program. Note that since the input option 'VPH' was specified, a value of QLIN should be entered for this example.

The final two cards contain the receptor coordinate information. The locations of the receptors being modelled are shown in Figure A2. A receptor is located at each of the following 17 (x,z) coordinates (metres):

```
 (5, 2),    (5, 5),    (5, 10)
(10, 2),  (10, 5),  (10, 10)
(25, 2),  (25, 5),  (25, 10)
(50, 2),  (50, 5),  (50, 10)
(75, 2),            (75, 10)
        (100, 5), (100, 10), (100, 15)
```

TXLINE was written to predict concentrations at all possible combinations of x and z coordinates. Receptor coordinates are NOT entered individually. Instead, each unique x-coordinate is entered and each unique z-coordinate is entered. The six x-coordinates are: 5, 10, 25, 50, 75, and 100 metres. The four z-coordinates are: 15, 10, 5, and 2 metres. Although not required, it is recommended that the x-coordinates be entered in ascending order and the z-coordinates be entered in descending order. Card type five contains the x-coordinate information. This card begins with 'XREC', the required value for CTYPE. Following this variable is the one digit integer NX which specifies the number of unique x-coordinates. For this example, NX = 6. Following this variable is the list of six

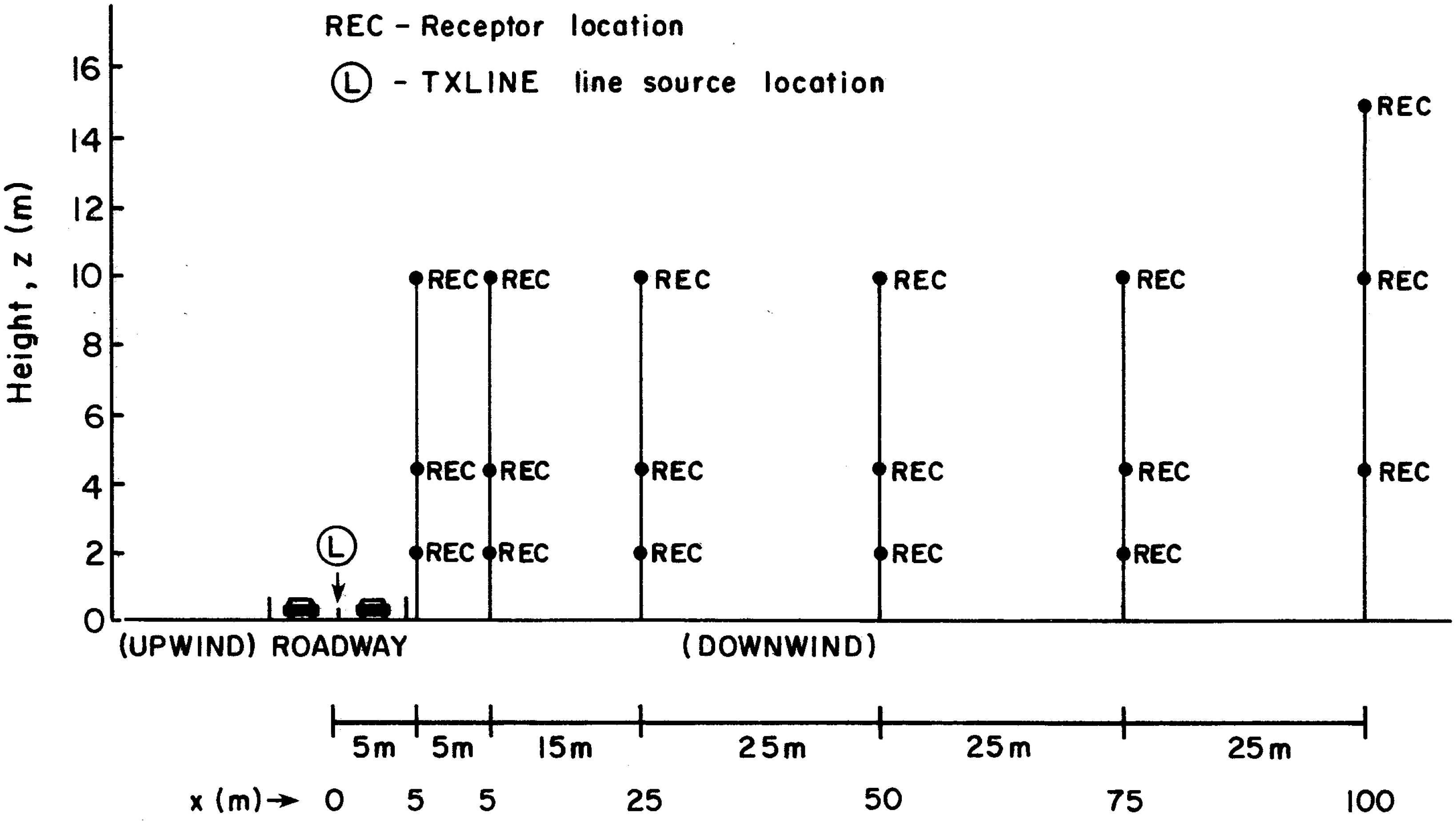

Fig. A2. Receptor locations for TXLINE Example I (a two-lane highway).

x-coordinates in ascending order. Card type six contains the z-coordinate information. The following variables are entered on this card: CTYPE = 'ZREC', NZ = 4, and the four z-receptor coordinates in descending order.

Figure A3 shows the output from Example 1A. The first section gives the run description exactly as it was entered on the first input card. Section Two is a summary of all of the input meteorological parameters and the third section contains the x-coordinate, height, and source strength for each line source. Since source strength was entered in units of vehicles/hour and emission factor, the values of these variables are also given in Section Three. Section Four is the concentration array. Concentrations are presented in tabular form as a function of receptor height (z) and distance from the nearest line source. Since the line source was assigned a coordinate of x = 0, the distances from the nearest line source are equal to the x-coordinates entered on card type five. This is not always the case, as seen in Example Two.

Example 1B. Example 1B is identical to Example 1A except for the fact that the low wind speed adjustment factor has been overridden. The single digit '9' was entered on the third card for the value of LWADJ. All other input was identical to Figure A1. This example was included to illustrate the possibility of using the

```
*************************************************************************************
* TXLINE - TEXAS LINE SOURCE AIR POLLUTION DISPERSION SIMULATOR (AUG., 1982 ) *
*************************************************************************************

  I.  RUN DESCRIPTION
      --- -----------

         USER'S GUIDE EXAMPLE 1A   -  TWO LANE HIGHWAY


 II.  METEOROLOGICAL PARAMETERS
      -------------- ----------

         WIND SPEED  =  2.10 M/SEC        *    REFERENCE HEIGHT  =  6.00 M
         WIND ANGLE  = 13.   DEGREES      *    SURFACE ROUGHNESS =  0.60 M
         TEMPERATURE = 30.10 C            *    POLLUTANT MOWT    = 28.00 G/MOLE

         NOTE: WIND SPEED CORRECTION FACTOR WAS APPLIED AS REQUESTED.


III.  LINE SOURCE INFORMATION
      ---- ------ -----------

         LINE * X COORDINATE * HEIGHT *  E FACTOR  *   VPH     * SOURCE STRENGTH
           #  *      (M)     *  (M)   * (G/VEH/MI) * (VEH/HR)  *   (G/KM/SEC)
         -----*--------------*--------*------------*-----------*-----------------
           1  *      0.0     *  0.00  *    27.80   *   1500.   *     7.1974


 IV.  CONCENTRATION ARRAY
      ------------- -----

         HEIGHT (M) *    DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE
                    *     5.00     10.00     25.00     50.00     75.00    100.00
         -----------*------------------------------------------------------------
                    *              C O N C E N T R A T I O N    ( P P M )
             15.00  *     0.28      0.34      0.39      0.40      0.37      0.35
             10.00  *     0.47      0.53      0.52      0.45      0.40      0.37
              5.00  *     1.01      0.82      0.66      0.50      0.43      0.38
              2.00  *     1.42      0.99      0.71      0.52      0.43      0.38
                    *
                    *              AMBIENT CONCENTRATION =  0.20

*************************************************************************************
* TXLINE  *  END OF RUN  *  NUMBER OF WARNINGS =  0  *  END OF RUN  *  TXLINE *
*************************************************************************************
```

Fig. A3. FORTRAN output for TXLINE Example 1A.

more theoretical version of TXLINE, although this version is NOT considered to be the most accurate for normal highway air pollution dispersion modelling.

The output from Example 1B is given in Figure A4. Note that the concentration predictions are slightly higher than those of Example 1A.

Example Two. Example Two illustrates the ability of TXLINE to model elevated roadways. This site has two parallel bridges each carrying four lanes of traffic. Note that the bridges are not at the same elevation. Since Example One was explained in great detail, minor details were not included in this example in order to avoid repetition.

The input cards are shown in Figure A5. Note that on card two the input option code specified is 'VPH', and the output code specified is 'PPM'. NLINES is given a value of two, since each four-lane bridge will be modelled as a separate line source. The background concentration (AMB) was estimated as 0.6 parts per million. Note that this value will be added to all of the concentration predictions. The last two variables entered on this card are TCENT = 21.0 and MOWT = 28.0 (carbon monoxide dispersion is being modelled).

The values entered on the Wind Profile Card are: LWADJ = 0, UREF = 1.1 metres/sec, REFZ = 7.2 metres, PHI = 88 degrees, and Z0 = 0.20 metres. Z0 was estimated from Table A3. (The land near the bridges is covered with tall weeds.)

```
*************************************************************************************
* TXLINE - TEXAS LINE SOURCE AIR POLLUTION DISPERSION SIMULATOR (AUG., 1982 ) *
*************************************************************************************

 I.  RUN DESCRIPTION
     --- -----------

       USER'S GUIDE EXAMPLE 1B  -  TWO LANE HIGHWAY


 II.  METEOROLOGICAL PARAMETERS
      -------------- ----------

       WIND SPEED  =  2.10 M/SEC      *   REFERENCE HEIGHT  =  6.00 M
       WIND ANGLE  = 13.   DEGREES    *   SURFACE ROUGHNESS =  0.60 M
       TEMPERATURE = 30.10 C          *   POLLUTANT MOWT    = 28.00 G/MOLE

       NOTE: WIND SPEED CORRECTION FACTOR OPTION WAS OVERRIDDEN BY THE USER.


 III.  LINE SOURCE INFORMATION
       ---- ------ -----------

       LINE * X COORDINATE * HEIGHT *  E FACTOR  *    VPH     * SOURCE STRENGTH
         #  *      (M)     *  (M)   * (G/VEH/MI) * (VEH/HR)   *    (G/KM/SEC)
       -----*--------------*--------*------------*------------*-----------------
         1  *      0.0     * 0.00   *   27.80    *   1500.    *      7.1974


 IV.  CONCENTRATION ARRAY
      ------------- -----

       HEIGHT (M) *    DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE
                  *     5.00     10.00     25.00     50.00     75.00    100.00
       -----------*------------------------------------------------------------
                  *            C O N C E N T R A T I O N    ( P P M )
          15.00   *     0.33     0.42      0.51      0.51      0.47     0.44
          10.00   *     0.64     0.72      0.71      0.61      0.52     0.47
           5.00   *     1.50     1.19      0.93      0.68      0.56     0.49
           2.00   *     2.16     1.46      1.02      0.71      0.57     0.50
                  *
                  *             AMBIENT CONCENTRATION.=  0.20

*************************************************************************************
* TXLINE  *  END OF RUN  *  NUMBER OF WARNINGS =  0  *  END OF RUN  *  TXLINE *
*************************************************************************************
```

Fig. A4. FORTRAN output for TXLINE Example 1B.

```
USER'S GUIDE EXAMPLE 2  -  TWO PARALLEL BRIDGES
IOUT  VPH PPM 2         0.6       21.0      28.0
WIND  0       1.1       7.2       43.0       0.20
LINE          0.0      12.0     3910.       29.8
LINE         30.0       9.5     4990.       31.6
XREC 5       45.0      55.0       75.0     150.0     200.0
ZREC 5       24.3      15.0        9.5       5.0       2.1
```

Fig. A5. FORTRAN input for TXLINE Example 2.

Following the Wind Profile Card are the two Line Source Description Cards. The coordinate system has been chosen so that the x = 0 datum line is down the center of Bridge 1 (see Figure A6). All x-receptor coordinates and the x-coordinate of Bridge 2 must also be in reference to this line. The following values have been entered on the first Line Source Description Card: XLIN = 0.0, HLIN = 12.0 metres (the elevation of Bridge 1), VPH = 3910 vehicles/hr, and EFAC = 29.8 g/vehicle/mile (from MOBILE-2). The second line source (Bridge 2) is not only at a different elevation, but has a significantly different traffic volume and emission factor. The following values have been entered on the second Line Source Description Card: XLIN = 30.0, HLIN = 9.5 metres, VPH = 4990 vehicles/hour, and EFAC = 31.6 g/vehicle/mile.

The final two cards contain the coordinates of the receptors. The receptor locations can be seen in Figure A6. The X-Coordinates of the Receptors Card contains the number of x-coordinates, NX = 5, followed by the x-coordinates of the receptors; 45, 55, 75, 155, and 200 metres. The final card contains the number of z-coordinates, NZ = 5, followed by the z-coordinates of the receptors; 24.3, 15.0, 9.5, 5.0, and 2.1 metres.

The output of Example Two is presented in Figure A7 and is very similar to the previous examples. One maj-

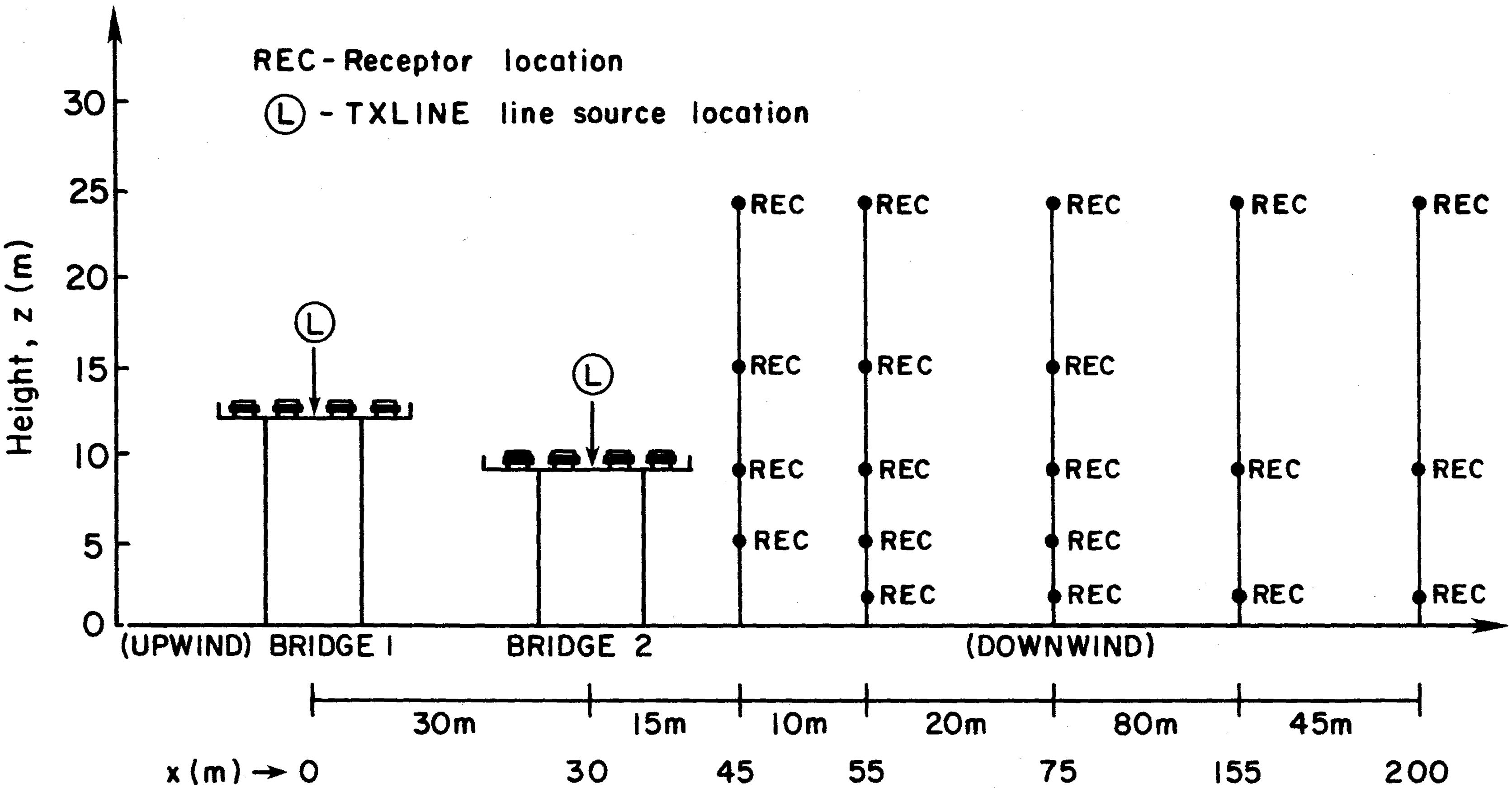

Fig. A6. Receptor locations for TXLINE Example 2 (two parallel bridges).

```
***************************************************************************************
* TXLINE - TEXAS LINE SOURCE AIR POLLUTION DISPERSION SIMULATOR (AUG., 1982 ) *
***************************************************************************************

  I.  RUN DESCRIPTION
      --- -----------

        USER'S GUIDE EXAMPLE 2  -  TWO PARALLEL BRIDGES


 II.  METEOROLOGICAL PARAMETERS
      -------------- ----------

        WIND SPEED  =  1.10 M/SEC     *   REFERENCE HEIGHT  =  7.20 M
        WIND ANGLE  = 43.   DEGREES   *   SURFACE ROUGHNESS =  0.20 M
        TEMPERATURE = 21.00 C         *   POLLUTANT MOWT    = 28.00 G/MOLE

        NOTE: WIND SPEED CORRECTION FACTOR WAS APPLIED AS REQUESTED.


III.  LINE SOURCE INFORMATION
      ---- ------ -----------

        LINE * X COORDINATE * HEIGHT *  E FACTOR  *   VPH     * SOURCE STRENGTH
         #   *     (M)      *  (M)   * (G/VEH/MI) * (VEH/HR)  *   (G/KM/SEC)
        -----*--------------*--------*------------*-----------*-----------------
         1   *     0.0      * 12.00  *   29.80    *   3910.   *    20.1110
         2   *    30.0      *  9.50  *   31.60    *   4990.   *    27.2162


 IV.  CONCENTRATION ARRAY
      ------------- -----

        HEIGHT (M) *   DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE
                   *     15.00     25.00     45.00    120.00    170.00
        -----------*-----------------------------------------------------
                   *          C O N C E N T R A T I O N    ( P P M )
          24.30    *     0.61      0.62      0.64      0.75      0.80
          15.00    *     1.25      1.36      1.44      1.35      1.30
           9.50    *     2.95      2.53      2.13      1.67      1.56
           5.00    *     1.26      1.50      1.65      1.69      1.65
           2.10    *     0.73      0.90      1.23      1.66      1.67
                   *
                   *             AMBIENT CONCENTRATION =  0.60

***************************************************************************************
* TXLINE  *  END OF RUN  *  NUMBER OF WARNINGS =  0  *  END OF RUN  *  TXLINE *
***************************************************************************************
```

Fig. A7. FORTRAN output for TXLINE Example 2.

or difference is that multiple line sources were modelled. The concentration predictions are the result of the combined contributions of the two line sources plus the ambient concentration. Note that the downwind distances given in the final section of output are not the same numbers as were entered for the x-coordinates of the receptors, but are the downwind distances from the nearest line source (in this case, the center of Bridge 2).

Example 3A. The final example is a cut section of roadway. TXLINE should be used to model cuts ONLY when the cut or fill is less than 45 degrees. All input parameters can be found in Figure A8. Only those variables which warrant further explanation will be discussed below.

The area surrounding the road consists of tall grass and several small shrubs and trees. Using Table A1, the site roughness, z_o, was estimated to be 0.40 metres.

In this case, the dispersion of a tracer gas, sulfur hexaflouride (SF_6) will be modelled instead of carbon monoxide. There are eight parallel lanes in the cut, and it is assumed that the gas was released at a known rate in each lane. Since the release rates were all measured in units of g/km/sec, the input option code 'GKS' was specified on the second card. Concentrations of SF_6 are normally measured in parts per

```
USER'S GUIDE EXAMPLE 3A  -  SHALLOW CUT SECTION - SF6 TRACER GAS
IOUT GKS PPB 8        0.0       9.0     146.0
WIND 0          3.2   6.5      52.0       0.40
LINE          -42.0   0.0       0.0392
LINE          -38.0   0.0       0.0324
LINE          -34.0   0.0       0.0318
LINE          -30.0   0.0       0.0368
LINE          -12.0   0.0       0.0349
LINE           -8.0   0.0       0.0397
LINE           -4.0   0.0       0.0381
LINE            0.0   0.0       0.0362
XREC 6          5.0   9.6      16.0      29.7      63.0      128.0
ZREC 3         11.1   5.9       1.8
```

Fig. A8. FORTRAN input for TXLINE Example 3A.

billion, so the output option code 'PPB' was specified. The molecular weight, MOWT = 146, is that of sulfur hexaflouride. The roadway was modelled as eight separate line sources (NLINES = 8), because the release rates varied from lane to lane.

All x-coordinates for the cut were handled in exactly the same manner as in the previous examples. The x = 0 datum line has been chosen as the road edge nearest the receptors. Note that in this case the line sources have negative x-coordinates. The coordinate system and the receptor locations can be seen in Figure A9.

The z-coordinates of the receptors and the source heights are measured with reference to the actual ground level, NOT as actual elevations with respect to the bottom of the cut. This method assumes that when the cut is gradual, the effect that the cut has on the wind profile is negligible.

The output from Example 3A is presented in Figure A10. Note that values are not given for vehicles/hour and emission factor, since source strength was entered directly. The output concentrations are reported in units of parts per billion as was specified on the second input card. The ambient concentration is zero since SF_6 is not normally found in the atmosphere.

Example 3B. Example 3B is identical to Example 3A except that the output option 'GM3' was specified on

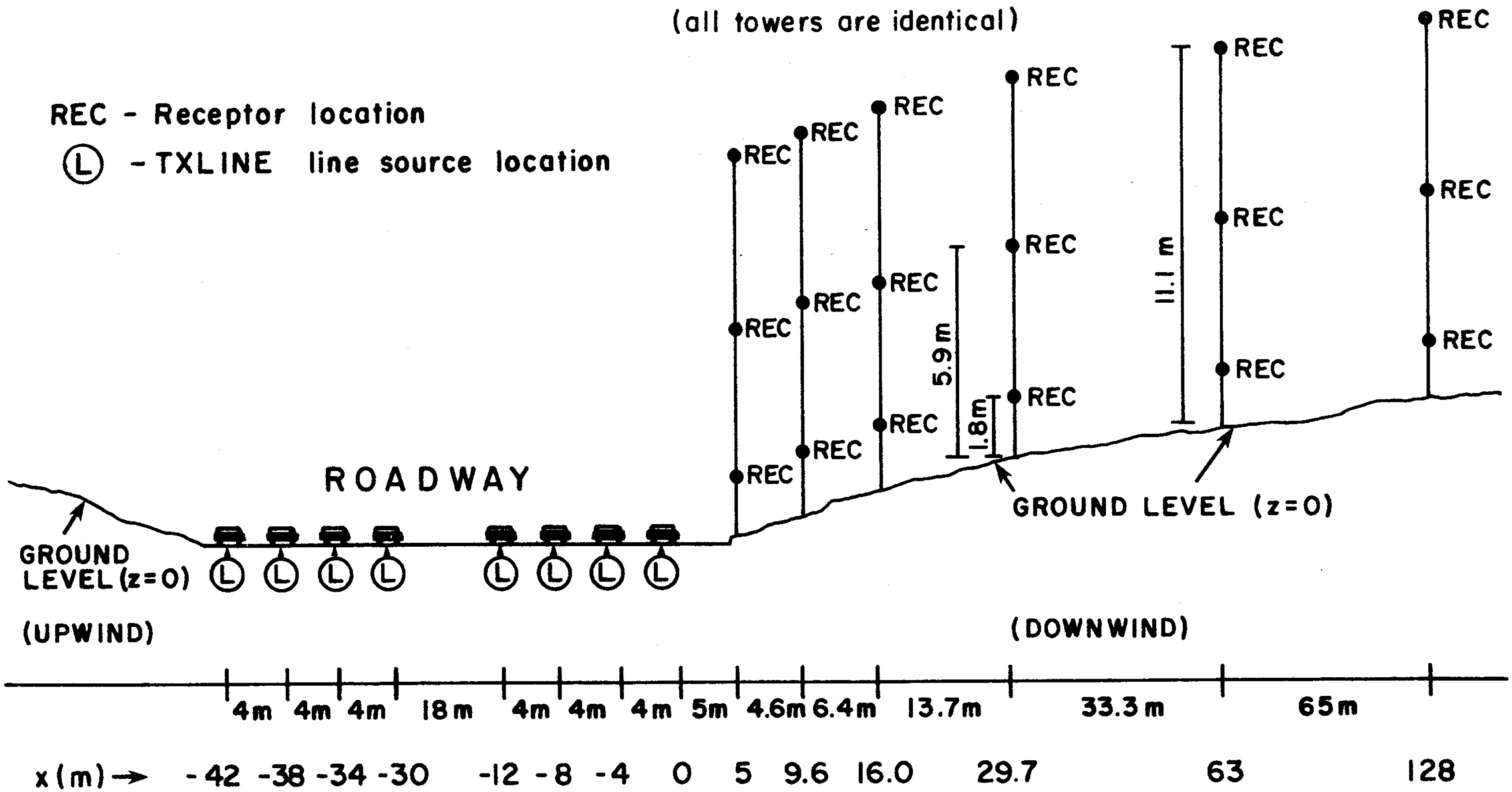

Fig. A9. Receptor locations for TXLINE Example 3 (cut-section).

```
*************************************************************************************
* TXLINE - TEXAS LINE SOURCE AIR POLLUTION DISPERSION SIMULATOR (AUG., 1982 ) *
*************************************************************************************


  I.  RUN DESCRIPTION
      --- -----------

        USER'S GUIDE EXAMPLE 3A  -  SHALLOW CUT SECTION - SF6 TRACER GAS


 II.  METEOROLOGICAL PARAMETERS
      -------------- ----------

        WIND SPEED  =  3.20 M/SEC      *    REFERENCE HEIGHT  =  6.50 M
        WIND ANGLE  = 77.   DEGREES    *    SURFACE ROUGHNESS =  0.40 M
        TEMPERATURE =  9.00 C          *    POLLUTANT MOWT    =146.00 G/MOLE

        NOTE: WIND SPEED CORRECTION FACTOR WAS APPLIED AS REQUESTED.


III.  LINE SOURCE INFORMATION
      ---- ------ -----------

        LINE * X COORDINATE * HEIGHT *  E FACTOR   *   VPH    * SOURCE STRENGTH
         #   *     (M)      *   (M)  * (G/VEH/MI)  * (VEH/HR) *    (G/KM/SEC)
        -----*--------------*--------*-------------*----------*-----------------
          1  *    -42.0     *  0.00  *     NA      *    NA    *      0.0392
          2  *    -38.0     *  0.00  *     NA      *    NA    *      0.0324
          3  *    -34.0     *  0.00  *     NA      *    NA    *      0.0318
          4  *    -30.0     *  0.00  *     NA      *    NA    *      0.0368
          5  *    -12.0     *  0.00  *     NA      *    NA    *      0.0349
          6  *     -8.0     *  0.00  *     NA      *    NA    *      0.0397
          7  *     -4.0     *  0.00  *     NA      *    NA    *      0.0381
          8  *      0.0     *  0.00  *     NA      *    NA    *      0.0362


 IV.  CONCENTRATION ARRAY
      ------------- -----

        HEIGHT (M) *    DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE
                   *     5.00      9.60     16.00     29.70     63.00    128.00
        -----------*-----------------------------------------------------------
                   *            C O N C E N T R A T I O N    ( P P B )
           11.10   *     0.17      0.20      0.26      0.38      0.54      0.54
            5.90   *     0.89      1.04      1.18      1.24      1.07      0.79
            1.80   *     3.93      3.46      2.92      2.23      1.48      0.94
                   *
                   *               AMBIENT CONCENTRATION =  0.00


*************************************************************************************
* TXLINE  *  END OF RUN  *  NUMBER OF WARNINGS =  0  *  END OF RUN  *  TXLINE *
*************************************************************************************
```

Fig. A10. FORTRAN output for TXLINE Example 3A.

the Input/Output Information card. Values for TCENT and MOWT are not required, since the output concentrations will be in units of grams per cubic metre. The output to Example 3B is shown in Figure A11. Concentrations are reported in exponential format due to their small numerical values.

```
*******************************************************************************
* TXLINE - TEXAS LINE SOURCE AIR POLLUTION DISPERSION SIMULATOR (AUG., 1982 ) *
*******************************************************************************

   I.  RUN DESCRIPTION
       --- -----------

         USER'S GUIDE EXAMPLE 3B  -  SHALLOW CUT SECTION - SF6 TRACER GAS


  II.  METEOROLOGICAL PARAMETERS
       -------------- ----------

         WIND SPEED  =  3.20 M/SEC     *    REFERENCE HEIGHT  =  6.50 M
         WIND ANGLE  = 52.   DEGREES   *    SURFACE ROUGHNESS =  0.40 M

         NOTE: WIND SPEED CORRECTION FACTOR WAS APPLIED AS REQUESTED.


 III.  LINE SOURCE INFORMATION
       ---- ------ -----------

         LINE * X COORDINATE * HEIGHT *  E FACTOR  *   VPH    * SOURCE STRENGTH
          #   *     (M)      *  (M)   * (G/VEH/MI) * (VEH/HR) *    (G/KM/SEC)
         -----*--------------*--------*------------*----------*-----------------
           1  *    -42.0     *  0.00  *     NA     *    NA    *     0.0392
           2  *    -38.0     *  0.00  *     NA     *    NA    *     0.0324
           3  *    -34.0     *  0.00  *     NA     *    NA    *     0.0318
           4  *    -30.0     *  0.00  *     NA     *    NA    *     0.0368
           5  *    -12.0     *  0.00  *     NA     *    NA    *     0.0349
           6  *     -8.0     *  0.00  *     NA     *    NA    *     0.0397
           7  *     -4.0     *  0.00  *     NA     *    NA    *     0.0381
           8  *      0.0     *  0.00  *     NA     *    NA    *     0.0362


  IV.  CONCENTRATION ARRAY
       ------------- -----

         HEIGHT (M) *    DOWNWIND DISTANCE (M) FROM THE NEAREST LINE SOURCE
                    * 0.50E 01  0.96E 01  0.16E 02  0.30E 02  0.63E 02  0.13E 03
         -----------*-------------------------------------------------------------
                    *           C O N C E N T R A T I O N   ( G / M**3 )
            11.10   * 0.17E-05  0.21E-05  0.27E-05  0.37E-05  0.44E-05  0.40E-05
             5.90   * 0.76E-05  0.88E-05  0.96E-05  0.94E-05  0.77E-05  0.55E-05
             1.80   * 0.28E-04  0.24E-04  0.20E-04  0.15E-04  0.99E-05  0.63E-05
                    *
                    *              AMBIENT CONCENTRATION = 0.00E 00

*******************************************************************************
* TXLINE  *  END OF RUN  *  NUMBER OF WARNINGS =  0  *  END OF RUN  *  TXLINE *
*******************************************************************************
```

Fig. A11. FORTRAN output for TXLINE Example 3B.

References

Benson, P.E., "CALINE-3: A Versatile Dispersion Model for Predicting Air Pollution Levels Near Highways and Arterial Streets," California Department of Transportation, Sacramento, California, 1979.

Bullin, J.A., J.C. Polasek, and N.J. Green, "Analytical and Experimental Assessment of Highway Impact on Air Quality," Texas Transportation Institute Research Report 218-4, Chemical Engineering Department, Texas A&M University, College Station, TX, 77843, 1978.

Cadle, S.H., et al., "Results of the General Motors Sulfate Dispersion Experiments," General Motors Research Laboratories, GMR-2107, 1976.

Calder, K.L., "Eddy diffusion and evaporation over aerodynamically smooth and rough surfaces: a treatment based on laboratory laws of turbulent flow with special reference to conditions in the lower atmosphere," Quart. J. Mech. and Applied Math., II, 153, (1949).

Pasquill, F., Atmospheric Diffusion, 2nd ed., Ellis Horwood Ltd., Sussex, England (1974).

Peterson, W.B., "User's Guide for HIWAY-2, a Highway Air Pollution Model," U.S. EPA, Research Triangle Park, N.C., EPA-600/8-80-018, 1980.

Rodden, J.B., "A Non-Fickian Gradient Transport Model to Predict Air Pollution Dispersion From Roadways," M.S. Thesis, Texas A&M University, 1983.

U.S. Environmental Protection Agency, "User's Guide to MOBILE-2 (Mobile Source Emissions Model)," Office of Mobile Source Air Pollution Control, U.S. EPA, Ann Arbor, Michigan, EPA-460/13-81-006, 1981.

APPENDIX A.1

FORTRAN LISTING OF TXLINE

```
C***********************************************************************
C*                                                                    *
C*   TTTTTTT    X      X     L           IIIIIII    N      N    EEEEEEE  *
C*      T        X    X      L              I       NN     N    E        *
C*      T         X X        L              I       N N    N    E        *
C*      T          X         L              I       N  N   N    EEEEEEE  *
C*      T         X X        L              I       N   N N     E        *
C*      T        X    X      L              I       N    NN     E        *
C*      T       X      X     LLLLLLL     IIIIIII    N      N    EEEEEEE  *
C*                                                                    *
C***********************************************************************
C*                                                                    *
C*  TEXAS LINE SOURCE AIR POLLUTION DISPERSION SIMULATOR (NOV. 1982)  *
C*                                                                    *
C***********************************************************************
C*                                                                    *
C*  DEVELOPER: JOHN B. RODDEN                                         *
C*             CHEMICAL ENGINEERING DEPARTMENT                        *
C*             TEXAS TRANSPORTATION INSTITUTE                         *
C*             TEXAS A&M UNIVERSITY                                   *
C*                                                                    *
C***********************************************************************
C*                                                                    *
C*  AGENCY: TEXAS TRANSPORTATION INSTITUTE                            *
C*          PREPARED UNDER CONTRACT NUMBER 2-8-80-283 FOR THE         *
C*          TEXAS STATE DEPT. OF HIGHWAYS AND PUBLIC TRANSPORTATION   *
C*          IN COOPERATION WITH                                       *
C*          THE FEDERAL HIGHWAY ADMINISTRATION                        *
C*          PROJECT OFFICER: RODERICK MOE - TEXAS SDHPT               *
C*                                                                    *
C***********************************************************************
C*                                                                    *
C*  QUESTIONS CONCERNING THIS PROGRAM SHOULD BE DIRECTED TO:          *
C*                                                                    *
C*          DR. J.A. BULLIN, DR. A.D. MESSINA,                        *
C*          OR J.B. RODDEN                                            *
C*          C/O CHEMICAL ENGINEERING DEPARTMENT                       *
C*          TEXAS A&M UNIVERSITY                                      *
C*          COLLEGE STATION, TEXAS  77843                             *
C*          (409)-845-3361                                            *
C*                                                                    *
C***********************************************************************
C*                                                                    *
C*  TXLINE ESTIMATES POLLUTANT CONCENTRATIONS DOWNWIND OF A SINGULAR  *
C*  LINE SOURCE OR SEVERAL PARALLEL LINE SOURCES.  THE MODEL IS PRI-  *
C*  MARILY INTENDED FOR USE IN PREDICTING CARBON MONOXIDE CONCEN-     *
C*  TRATIONS, BUT WAS WRITTEN IN A GENERAL FASHION IN ORDER TO ALLOW  *
C*  SIMULATION OF THE DISPERSION OF OTHER GASEOUS POLLUTANTS.         *
C*                                                                    *
C*  TXLINE IS THE ONLY CURRENT AIR POLLUTION DISPERSION MODEL WHICH   *
C*  DOES NOT ASSUME A FLAT WIND PROFILE.  INSTEAD TXLINE USES A POWER *
C*  LAW WIND PROFILE WHICH APPROXIMATES THE COMMONLY ACCEPTED LOG-LAW *
C*  WIND PROFILE.  TXLINE IS ALSO THE ONLY MODEL WHICH DOES NOT USE   *
C*  THE SIMPLIFIED 'GAUSSIAN' EQUATION OF DISPERSION.  THE DISPERSION *
C*  EQUATIONS USED IN TXLINE ARE PRIMARILY THE RESULTS OF WORK DONE   *
C*  INDEPENDENTLY BY F.B. SMITH AND K.L. CALDER.  FOR A COMPLETE      *
C*  REVIEW OF THE MODEL DEVELOPMENT, SEE THE PROJECT REPORT.          *
C*                                                                    *
C*  A MINI - USER'S GUIDE FOLLOWS THIS SECTION.  THIS GUIDE IS NOT    *
C*  INTENDED TO FULLY EXPLAIN THE USE OF TXLINE, BUT IS INCLUDED AS A *
C*  REFERENCE FOR THE USER WHO IS ALREADY FAMILIAR WITH THE PROGRAM.  *
C*  (REFER TO THE COMPLETE USER'S GUIDE FOR DETAILED INSTRUCTIONS ON  *
C*  THE USE OF THE MODEL.)  NOTE THAT TXLINE SHOULD NOT BE USED TO    *
C*  MODEL DEEP CUT SECTIONS OF ROADWAY, STREET CANYONS, UPWIND        *
C*  RECEPTORS, OR RECEPTORS WHICH ARE DIRECTLY ABOVE THE ROADWAY.     *
C*                                                                    *
C***********************************************************************
C***********************************************************************
C*                                                                    *
C*  TXLINE    *     M I N I  -  U S E R ' S   G U I D E    *    TXLINE  *
C*                                                                    *
C***********************************************************************
```

```
C*                                                                        *
C*  SIX TYPES OF INPUT CARDS ARE REQUIRED FOR EACH RUN.  CARD BY CARD     *
C*  TABULAR DESCRIPTIONS OF THE REQUIRED INPUT VARIABLES ARE GIVEN,       *
C*  INCLUDING FORMAT SPECIFICATIONS, COLUMN FIELDS, AND UNITS.            *
C*                                                                        *
C**************************************************************************
C*                                                                        *
C*  CARD TYPE ONE: HEADINGS AND/OR COMMENTS CARD                          *
C*                                                                        *
C*  INPUT VARIABLES:                                                      *
C*                                                                        *
C*  NAME      FORMAT   COLUMNS   DESCRIPTION                  UNITS       *
C*  ----      ------   -------   -----------                  -----       *
C*  COMM       17A4     01-68    HEADING AND/OR COMMENTS        -         *
C*                                                                        *
C**************************************************************************
C*                                                                        *
C*  CARD TYPE TWO: INPUT/OUTPUT INFORMATION CARD                          *
C*                                                                        *
C*  INPUT VARIABLES:                                                      *
C*                                                                        *
C*  NAME      FORMAT   COLUMNS   DESCRIPTION                  UNITS       *
C*  ----      ------   -------   -----------                  -----       *
C*  CTYPE       A4      01-04    CARD TYPE CODE:                -         *
C*                               MUST BE EQUAL TO 'IOUT'                  *
C*                                                                        *
C*  IN          A3      06-08    INPUT OPTION CODE:             -         *
C*                               (1) ENTER 'VPH' IF VEH/HR                *
C*                                   AND EFACTOR ARE TO BE                *
C*                                   ENTERED AS INPUT DATA.               *
C*                               (2) ENTER 'GKS' IF SOURCE                *
C*                                   STRENGTH IS TO BE                    *
C*                                   ENTERED DIRECTLY IN                  *
C*                                   UNITS OF G/KM/SEC.                   *
C*                                                                        *
C*  OUT         A3      10-12    OUTPUT OPTION CODE:            -         *
C*                               (1) ENTER 'PPM' FOR OUTPUT               *
C*                                   CONCENTRATION UNITS OF               *
C*                                   PARTS PER MILLION.                   *
C*                               (2) ENTER 'PPB' FOR OUTPUT               *
C*                                   CONCENTRATION UNITS OF               *
C*                                   PARTS PER BILLION.                   *
C*                               (3) ENTER 'GM3' FOR OUTPUT               *
C*                                   CONCENTRATION UNITS OF               *
C*                                   GRAMS PER CUBIC METER.               *
C*                                                                        *
C*  NLINES      I1      14       NUMBER OF LINE SOURCES         -         *
C*                               (NO GREATER THAN 8)                      *
C*                                                                        *
C*  AMB       F10.5     20-29    AMBIENT CONCENTRATION       UNITS MUST   *
C*                                                           AGREE WITH   *
C*                                                           OUTPUT CODE  *
C*                                                                        *
C*  TCENT     F10.2     30-39    AMBIENT TEMPERATURE         CENTIGRADE   *
C*                                                                        *
C*  MOWT      F10.2     40-49    MOL. WT. OF POLLUTANT       G/MOLE       *
C*                               (MOWT=28. FOR CO)                        *
C*                                                                        *
C*                                                                        *
C*  NOTE: IF THE OUTPUT OPTION CODE 'GM3' IS SPECIFIED, IT IS NOT         *
C*        NECESSARY TO INPUT VALUES OF THE VARIABLES TCENT AND MOWT.      *
C*                                                                        *
C**************************************************************************
C*                                                                        *
C*  CARD TYPE THREE: WIND PROFILE CARD                                    *
C*                                                                        *
C*  INPUT VARIABLES:                                                      *
C*                                                                        *
C*  NAME      FORMAT   COLUMNS   DESCRIPTION                  UNITS       *
C*  ----      ------   -------   -----------                  -----       *
C*  CTYPE       A4      01-04    CARD TYPE CODE:                -         *
C*                               MUST BE EQUAL TO 'WIND'                  *
```

```
C*                                                                    * TXL0725
C*  LWADJ       I1     06        LOW WIND SPEED ADJUSTMENT    -       * TXL0730
C*                               FACTOR OPTION CODE:                  * TXL0735
C*                               (1) IF A ZERO OR A BLANK;            * TXL0740
C*                                   THE FACTOR IS APPLIED.           * TXL0745
C*                               (2) IF ANY OTHER INTEGER;            * TXL0750
C*                                   IT IS NOT APPLIED.               * TXL0755
C*                                                                    * TXL0760
C*  UREF      F10.3    10-19     REFERENCE WIND SPEED        M/SEC    * TXL0765
C*                                                                    * TXL0770
C*  REFZ      F10.3    20-29     HT. OF WSPEED MEASUREMENT     M      * TXL0775
C*                                                                    * TXL0780
C*  PHI       F10.0    30-39     WIND ANGLE                  DEGREES  * TXL0785
C*                               (O=PARALLEL; 90=PERP.)               * TXL0790
C*                                                                    * TXL0795
C*  ZO        F10.3    40-49     SURFACE ROUGHNESS             M      * TXL0800
C*                                                                    * TXL0805
C********************************************************************** TXL0810
C*                                                                    * TXL0815
C*  CARD TYPE FOUR: LINE SOURCE DESCRIPTON CARD(S) - (THE NUMBER OF   * TXL0820
C*                  CARDS OF THIS TYPE MUST AGREE WITH THE VALUE OF   * TXL0825
C*                  THE VARIABLE NLINES ON CARD TYPE TWO.)            * TXL0830
C*                                                                    * TXL0835
C*  INPUT VARIABLES:                                                  * TXL0840
C*                                                                    * TXL0845
C*  NAME      FORMAT   COLUMNS   DESCRIPTION                 UNITS    * TXL0850
C*  ----      ------   -------   -----------                 -----    * TXL0855
C*  CTYPE       A4     01-04     CARD TYPE CODE:               -      * TXL0860
C*                               MUST BE EQUAL TO 'LINE'              * TXL0865
C*                                                                    * TXL0870
C*  XLIN      F10.2    10-19     X COOR. OF THE LINE SOURCE    M      * TXL0875
C*                                                                    * TXL0880
C*  HLIN      F10.2    20-29     HT. OF THE LINE SOURCE        M      * TXL0885
C*                                                                    * TXL0890
C*  QLIN      F10.5    30-39     LINE SOURCE STRENGTH        G/KM/SEC * TXL0895
C*   OR                                                               * TXL0900
C*  VPH       F10.0    30-39     TRAFFIC ON THE LINE SOURCE VEH/HR    * TXL0905
C*   &                                                                * TXL0910
C*  EFAC      F10.5    40-49     EMISSION FACTOR             G/VEH/MILE * TXL0915
C*                                                                    * TXL0920
C*                                                                    * TXL0925
C*  NOTE: ENTER EITHER QLIN OR THE COMBINATION OF VPH AND EFAC,       * TXL0930
C*        DEPENDING ON THE INPUT OPTION CODE WHICH WAS ENTERED ON     * TXL0935
C*        THE INPUT/OUTPUT INFORMATION CARD (CARD TYPE TWO).          * TXL0940
C*                                                                    * TXL0945
C********************************************************************** TXL0950
C*                                                                    * TXL0955
C*  CARD TYPE FIVE: X COORDINATES OF THE RECEPTORS CARD               * TXL0960
C*                                                                    * TXL0965
C*  INPUT VARIABLES:                                                  * TXL0970
C*                                                                    * TXL0975
C*  NAME      FORMAT   COLUMNS   DESCRIPTION                 UNITS    * TXL0980
C*  ----      ------   -------   -----------                 -----    * TXL0985
C*  CTYPE       A4     01-04     CARD TYPE CODE:               -      * TXL0990
C*                               MUST BE EQUAL TO 'XREC'              * TXL0995
C*                                                                    * TXL1000
C*  NX          I1     06        NUMBER OF X COORDINATES       -      * TXL1005
C*                               TO BE ENTERED.                       * TXL1010
C*                                                                    * TXL1015
C*  XINP     6F10.2    10-69     X COORDINATES OF THE          M      * TXL1020
C*                               RECEPTORS.                           * TXL1025
C*                                                                    * TXL1030
C*                                                                    * TXL1035
C*  NOTE: THE NUMBER OF X COORDINATES APPEARING ON THIS CARD MUST     * TXL1040
C*        BE EQUAL TO THE VALUE OF THE VARIABLE NX.  THE TOTAL XINP   * TXL1045
C*        INPUT FIELD (COL. 10-69) SHOULD BE FILLED ONLY IF NX=6.     * TXL1050
C*                                                                    * TXL1055
C********************************************************************** TXL1060
C*                                                                    * TXL1065
C*  CARD TYPE SIX: Z COORDINATES OF THE RECEPTORS CARD                * TXL1070
C*                                                                    * TXL1075
C*  INPUT VARIABLES:                                                  * TXL1080
```

```
C*                                                                          *
C*  NAME      FORMAT   COLUMNS   DESCRIPTION                    UNITS       *
C*  ----      ------   -------   -----------                    -----       *
C*  CTYPE       A4      01-04    CARD TYPE CODE:                  -         *
C*                               MUST BE EQUAL TO 'ZREC'                    *
C*                                                                          *
C*  NZ          I1      06       NUMBER OF Z COORDINATES          -         *
C*                               TO BE ENTERED.                             *
C*                                                                          *
C*  Z         6F10.2    10-69    Z COORDINATES OF THE             M         *
C*                               RECEPTORS.                                 *
C*                                                                          *
C*                                                                          *
C*  NOTE: THE NUMBER OF Z COORDINATES APPEARING ON THIS CARD MUST           *
C*        BE EQUAL TO THE VALUE OF THE VARIABLE NZ.  THE TOTAL Z            *
C*        INPUT FIELD (COL. 10-69) SHOULD BE FILLED ONLY IF NZ=6.           *
C*                                                                          *
C****************************************************************************
C****************************************************************************
C
      REAL X(6),XINP(6),Z(6),CHI(6,6),TCONC(6,6),COMM(17),MOWT,KO,
     >     XLIN(8),HLIN(8),QLIN(8),VPH(8),EFAC(8),QALL(6)
      INTEGER WFLAG(6)
C
C**   INTEGER*4 VARIABLES USED FOR CHARACTER STRINGS.
      INTEGER*4 IN,OUT,CTYPE
      INTEGER*4 ICHAR(2)/' VPH',' GKS'/,OCHAR(3)/' PPM',' PPB',' GM3'/
      INTEGER*4 TCHAR(6)/'    ','IOUT','WIND','LINE','XREC','ZREC'/
C
C** ALL OF THE COMMON BLOCKS ARE LISTED IN MAIN, BUT NOT ALL OF THESE
C** BLOCKS ARE REQUIRED BY MAIN.  THE FUNCTION OF EACH IS DESCRIBED
C** HERE IN ORDER TO AVOID REPETITION OF COMMENTS IN THE SUBROUTINES.
C
C** COMMON BLOCK INFO CONTAINS GENERAL INTEGER VARIABLES USED BY MOST
C** OF THE SUBROUTINES.  THE VARIABLE JUMP IS A CODE WHICH ALLOWS
C** CERTAIN SECTIONS OF THE PROGRAM TO BE SKIPPED IF THEY CONTAIN
C** REPETITIVE CALCULATIONS.  KILL AND KILTOW ARE ARRAYS WHICH
C** INDICATE THE COMPLETION STATUS OF CALCULATIONS FOR EACH RECEPTOR
C** AND RECEPTOR TOWER.  (A VALUE OF 9 INDICATES THAT CALCULATIONS
C** HAVE BEEN COMPLETED FOR THE GIVEN RECEPTOR OR RECEPTOR TOWER.)
      COMMON /INFO/NX,NZ,KILL(6,6),JUMP,KILTOW(6)
C
C** SKIP1 AND SKIP2 CONTAIN VARIABLES WHICH ARE SAVED IN COMMON SO THAT
C** THEY ARE NOT LOST WHEN SECTIONS OF THE PROGRAM ARE SKIPPED.
      COMMON /SKIP1/A,B,GA,GB,CONIN,CONSP,H2,ZTERM(6)
      COMMON /SKIP2/TOP1,DENOM1,BX2,BP1,BPA
C
C** COMMON BLOCK MXGINL IS SHARED BY SUBROUTINES MXGRND AND INLINE.
      COMMON /MXGINL/EXARGC(6)
C
C** COMMON BLOCK MXGJRL IS SHARED BY SUBROUTINES MXGRND AND JRLINE.
      COMMON /MXGJRL/PSIN,PCOS
C
C** COMMON BLOCK MXGPOI IS SHARED BY SUBROUTINES MXGRND AND POINT.
      COMMON /MXGPOI/C1(6,6),C2(6,6)
C
C** COMMON BLOCK MXGSPR IS SHARED BY SUBROUTINES MXGRND AND SPREAD.
      COMMON /MXGSPR/TERM2(6),EDA(6)
C
C** READ HEADING AND/OR COMMENTS CARD
    5 READ(5,1000,END=9999)COMM
C
C** RESET VALUES TO ZERO
      JUMP=0
      IWCOU=0
      XLMAX=-9999.
      DO 8 I=1,6
      WFLAG(I)=0
      DO 7 J=1,6
      TCONC(I,J)=0.
    7 CONTINUE
    8 CONTINUE
```

```
C
C***********************************************************************
C** READ INPUT/OUTPUT CARD AND CHECK VALUES OF THE INPUT VARIABLES
      READ(5,1100)CTYPE,IN,OUT,NLINES,AMB,TCENT,MOWT
      IF(CTYPE.EQ.TCHAR(2))GO TO 10
      WRITE(6,2010)TCHAR(2)
      GO TO 9999
   10 IF((NLINES.GE.1).OR.(NLINES.LE.8))GO TO 12
      WRITE(6,2020)
      GO TO 9999
   12 IF(IN.EQ.ICHAR(1))IN=1
      IF(IN.EQ.ICHAR(2))IN=2
      IF((IN.EQ.1).OR.(IN.EQ.2))GO TO 15
      WRITE(6,2030)
      GO TO 9999
   15 IF(OUT.EQ.OCHAR(1))OUT=1
      IF(OUT.EQ.OCHAR(2))OUT=2
      IF(OUT.EQ.OCHAR(3))OUT=3
      IF((OUT.GE.1).AND.(OUT.LE.3))GO TO 16
      WRITE(6,2040)
      GO TO 9999
   16 GO TO (17,17,20),OUT
   17 IF((TCENT.GE.-30.).AND.(TCENT.LE.50.))GO TO 18
      WRITE(6,2050)
      GO TO 9999
   18 TKELV=TCENT+273.15
      IF((MOWT.GE.10.).AND.(MOWT.LE.300.))GO TO 20
      WRITE(6,2060)
      GO TO 9999
C
C***********************************************************************
C** READ WIND PROFILE CARD AND CHECK VALUES OF THE INPUT VARIABLES
   20 READ(5,1200)CTYPE,LWADJ,UREF,REFZ,PHI,ZO
      IF(CTYPE.EQ.TCHAR(3))GO TO 25
      WRITE(6,2010)TCHAR(3)
      GO TO 9999
   25 IF((UREF.GT.O.).AND.(UREF.LE.20.))GO TO 28
      WRITE(6,2070)
      GO TO 9999
   28 IF(UREF.GT.O.44)GO TO 30
      UREF=O.44
      WFLAG(1)=9
      IWCOU=IWCOU+1
   30 IF((REFZ.GT.(ZO+1.5)).AND.(REFZ.LE.30.))GO TO 35
      WRITE(6,2080)
      GO TO 9999
   35 IF(REFZ.LT.11.)GO TO 40
      WFLAG(2)=9
      IWCOU=IWCOU+1
   40 IF((PHI.GE.O.).AND.(PHI.LE.90.))GO TO 45
      WRITE(6,2090)
      GO TO 9999
   45 IF(PHI.GE.1.)GO TO 50
      PHI=1.
      WFLAG(3)=9
      IWCOU=IWCOU+1
   50 IF((ZO.GE.O.).AND.(ZO.LE.4.))GO TO 55
      WRITE(6,2100)
      GO TO 9999
   55 IF(ZO.GE.O.01)GO TO 56
      ZO=O.01
      WFLAG(4)=9
      IWCOU=IWCOU+1
   56 IF(ZO.LE.1.)GO TO 60
      WFLAG(5)=9
      IWCOU=IWCOU+1
C
C***********************************************************************
C** READ ALL LINE SOURCE DESCRIPTION CARDS AND
C** CHECK VALUES OF THE INPUT VARIABLES.
   60 DO 99 L=1,NLINES
      GO TO (65,70),IN
```

```
   65 READ(5,1300)CTYPE,XLIN(L),HLIN(L),VPH(L),EFAC(L)
      QLIN(L)=VPH(L)*EFAC(L)*1.726E-07
      GO TO 75
   70 READ(5,1350)CTYPE,XLIN(L),HLIN(L),QLIN(L)
      QLIN(L)=QLIN(L)/1000.
   75 IF(CTYPE.EQ.TCHAR(4))GO TO 80
      WRITE(6,2010)TCHAR(4)
      GO TO 9999
   80 IF(QLIN(L).GT.0.0)GO TO 95
      GO TO (85,90),IN
   85 WRITE(6,2110)L
      GO TO 9999
   90 WRITE(6,2120)L
      GO TO 9999
   95 IF((HLIN(L).GE.0.).AND.(HLIN(L).LE.30.))GO TO 97
      WRITE(6,2130)
      GO TO 9999
C
C** FIND THE LINE SOURCE WHICH IS CLOSEST TO THE RECEPTORS.
   97 IF(XLIN(L).GE.XLMAX)XLMAX=XLIN(L)
   99 CONTINUE
C
C**********************************************************************
C** READ THE X COORDINATES OF THE RECEPTORS CARD AND
C** CHECK VALUES OF THE INPUT VARIABLES.
      READ(5,1400)CTYPE,NX,(X(I),I=1,NX)
      IF(CTYPE.EQ.TCHAR(5))GO TO 100
      WRITE(6,2010)TCHAR(5)
      GO TO 9999
  100 IF((NX.GE.1).AND.(NX.LE.6))GO TO 105
      WRITE(6,2140)
      GO TO 9999
C
C**********************************************************************
C** READ THE Z COORDINATES OF THE RECEPTORS CARD AND
C** CHECK VALUES OF THE INPUT VARIABLES.
  105 READ(5,1400)CTYPE,NZ,(Z(J),J=1,NZ)
      IF(CTYPE.EQ.TCHAR(6))GO TO 110
      WRITE(6,2010)TCHAR(6)
      GO TO 9999
  110 IF((NZ.GE.1).AND.(NZ.LE.6))GO TO 115
      WRITE(6,2150)
      GO TO 9999
  115 DO 125 J=1,NZ
      IF((Z(J).GE.0.).AND.(Z(J).LE.30.))GO TO 120
      WRITE(6,2160)
      GO TO 9999
  120 IF(Z(J).LT.0.01)Z(J)=0.01
  125 CONTINUE
C
C**********************************************************************
C
      DO 200 L=1,NLINES
      H=HLIN(L)
      IF(L.EQ.1)GO TO 130
      IF((PHI.GE.70.).OR.(H.EQ.HLIN(L-1)))GO TO 135
      IF((H.LE.0.10).AND.(HLIN(L-1).LE.0.10))GO TO 135
C
C** CALCULATE THE WIND AND EDDY DIFFUSIVITY PROFILE PARAMETERS
  130 CALL URWIND(UREF,REFZ,ZO,PHI,LWADJ,    ALPHA,UO,KO)
C
C** COMPUTE THE ACTUAL DISTANCE TO EACH RECEPTOR AND
C** CHECK IF A WARNING IS NECESSARY.
  135 DO 145 I=1,NX
      XINP(I)=X(I)-XLIN(L)
      IF((XINP(I).GE.3.).AND.(XINP(I).LE.500.))GO TO 140
      WRITE(6,2170)
      GO TO 9999
  140 IF(XINP(I).LE.250.)GO TO 145
      WFLAG(6)=9
      IWCOU=IWCOU+1
  145 CONTINUE
```

```
C
C** CALCULATE LINE SOURCE CONCENTRATION PREDICTIONS.
      IF(PHI.GE.70.)GO TO 150
      CAPQ=QLIN(L)
      CALL URLINE(XINP,Z,H,CAPQ,ZO,ALPHA,UO,KO,PHI,    CHI)
      GO TO 155
  150 DO 151 I=1,NX
      QALL(I)=QLIN(L)
  151 CONTINUE
      CALL INLINE(XINP,Z,H,QALL,    ALPHA,UO,KO,        CHI)
C
C** ADD CURRENT LINE SOURCE CONTRIBUTION TO THE TOTAL CONCENTRATION.
  155 DO 175 I=1,NX
      DO 160 J=1,NZ
      TCONC(I,J)=TCONC(I,J)+CHI(I,J)
  160 CONTINUE
  175 CONTINUE
C
  200 CONTINUE
      DO 300 I=1,NX
C
C** CALCULATE RECEPTOR DISTANCES TO THE NEAREST LINE SOURCE.
      X(I)=X(I)-XLMAX
C
C** CONVERT FINAL CONC. PREDICTIONS TO THE REQUESTED UNITS
C** AND ADD THE AMBIENT (BACKGROUND) CONCENTRATION TO THE TOTAL.
      DO 280 J=1,NZ
      GO TO (250,260,270),OUT
  250 TCONC(I,J)=TCONC(I,J)/MOWT*82.057*TKELV+AMB
      GO TO 280
  260 TCONC(I,J)=TCONC(I,J)/MOWT*82057.*TKELV+AMB
      GO TO 280
  270 TCONC(I,J)=TCONC(I,J)+AMB
  280 CONTINUE
C
  300 CONTINUE
      WRITE(6,3000)COMM
      WRITE(6,3010)UREF,REFZ,PHI,ZO
C
C** TEMPERATURE AND MOLECULAR WEIGHT ARE WRITTEN ONLY IF REQUIRED.
      IF(OUT.EQ.3)GO TO 305
      WRITE(6,3015)TCENT,MOWT
C
C** WRITE NOTE REGARDING THE LOW WINDSPEED ADJUSTMENT FACTOR.
  305 IF(LWADJ.GT.O)GO TO 313
      IF(UREF.GT.4.)GO TO 312
      WRITE(6,3021)
      GO TO 314
  312 WRITE(6,3022)
      GO TO 314
  313 WRITE(6,3023)
  314 WRITE(6,3030)
C
C** WRITE LINE SOURCE INFORMATION.
      DO 350 L=1,NLINES
      QLIN(L)=QLIN(L)*1000.
      IF(IN.EQ.2)GO TO 320
      WRITE(6,3040)L,XLIN(L),HLIN(L),EFAC(L),VPH(L),QLIN(L)
      GO TO 350
  320 WRITE(6,3042)L,XLIN(L),HLIN(L),QLIN(L)
  350 CONTINUE
C
      WRITE(6,3050)
      WRITE(6,3060)
C
C** WRITE RECEPTOR DISTANCES TO THE NEAREST LINE SOURCE.
      GO TO (370,370,373),OUT
  370 WRITE(6,3070)(X(I),I=1,NX)
      GO TO 375
  373 WRITE(6,3075)(X(I),I=1,NX)
  375 WRITE(6,3080)
C
```

```
C** WRITE HEADING FOR THE CONCENTRATION TABLE.
      GO TO (380,385,390),OUT
  380 WRITE(6,3081)
      GO TO 395
  385 WRITE(6,3082)
      GO TO 395
  390 WRITE(6,3083)
C
C** WRITE CONCENTRATION PREDICTIONS IN TABULAR FORM.
  395 DO 400 J=1,NZ
      GO TO (396,396,398),OUT
  396 WRITE(6,3090)Z(J),(TCONC(I,J),I=1,NX)
      GO TO 400
  398 WRITE(6,3095)Z(J),(TCONC(I,J),I=1,NX)
  400 CONTINUE
C
C** WRITE AMBIENT CONCENTRATION.
      GO TO (401,401,403),OUT
  401 WRITE(6,3100)AMB
      GO TO 405
  403 WRITE(6,3103)AMB
C
C** WRITE WARNINGS IF APPLICABLE.
  405 DO 599 M=1,6
      IF(WFLAG(M).LT.9)GO TO 599
      GO TO (510,520,530,540,550,560),M
  510 WRITE(6,2510)
      GO TO 599
  520 WRITE(6,2520)
      GO TO 599
  530 WRITE(6,2530)
      GO TO 599
  540 WRITE(6,2540)
      GO TO 599
  550 WRITE(6,2550)
      GO TO 599
  560 WRITE(6,2560)
  599 CONTINUE
C
C** WRITE TRAILER (INCLUDES THE NUMBER OF WARNINGS ISSUED).
      WRITE(6,3110)IWCOU
C
      GO TO 5
C
C** STATEMENT NUMBER 9999 IS THE FINAL EXECUTABLE STATEMENT.
 9999 WRITE(6,4000)
C
C** FORMAT NUMBERS FOR READ STATEMENTS ALL BEGIN WITH 1
 1000 FORMAT(17A4)
 1100 FORMAT(3A4,T14,I1,T20,F10.5,2F10.2)
 1200 FORMAT(A4,T6,I1,T10,2F10.3,F10.0,F10.3)
 1300 FORMAT(A4,T10,2F10.2,F10.0,F10.5)
 1350 FORMAT(A4,T10,2F10.2,F10.5)
 1400 FORMAT(A4,T6,I1,T10,6F10.2)
C
C** FATAL ERROR FORMAT NUMBERS ARE ALL BETWEEN 2000 AND 2200.
 2010 FORMAT(T2,'** FATAL ERROR **  IMPROPER CARD TYPE CODE;',
     >' EXPECTING ',A4,' IN COL. 01-04.')
 2020 FORMAT(T2,'** FATAL ERROR **  NLINES MUST BE BETWEEN',
     >' 1 AND 8 INCLUSIVE.')
 2030 FORMAT(T2,'** FATAL ERROR **  INVALID INPUT OPTION CODE ',
     >'ENTERED.')
 2040 FORMAT(T2,'** FATAL ERROR **  INVALID OUTPUT OPTION CODE ',
     >'ENTERED.')
 2050 FORMAT(T2,'** FATAL ERROR **  TEMP. OUT OF RANGE;',
     >' RANGE ALLOWED IS: -30.<TCENT<50. C.')
 2060 FORMAT(T2,'** FATAL ERROR **  MOWT IS OUT OF RANGE;',
     >' RANGE ALLOWED IS: 10<MOWT<300 G/MOLE.')
 2070 FORMAT(T2,'** FATAL ERROR **  UREF OUT OF RANGE;',
     >' RANGE ALLOWED IS: 0.<UREF<20. M/SEC.')
 2080 FORMAT(T2,'** FATAL ERROR **  REFZ OUT OF RANGE;',
     >' RANGE ALLOWED IS: (ZO+1.5)<REFZ<30. M.')
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 2090 FORMAT(T2,'** FATAL ERROR **  PHI IS OUT OF RANGE;',
     >' RANGE ALLOWED IS: O.<PHI<90. DEGREES.')
 2100 FORMAT(T2,'** FATAL ERROR **  ZO IS OUT OF RANGE;',
     >' RANGE ALLOWED IS: O.<ZO<4. M.')
 2110 FORMAT(T2,'** FATAL ERROR **  VPH OR EFAC IS LESS THAN',
     >' OR EQUAL TO O. FOR LINE SOURCE NUM. ',I1)
 2120 FORMAT(T2,'** FATAL ERROR **  QLIN IS LESS THAN OR EQUAL TO',
     >' O. FOR LINE SOURCE NUM. ',I1)
 2130 FORMAT(T2,'** FATAL ERROR **  HLIN IS NOT BETWEEN O. AND',
     >' 30. FOR LINE SOURCE NUM. ',I1)
 2140 FORMAT(T2,'** FATAL ERROR **  NX MUST BE BETWEEN 1 AND 6 ',
     >'INCLUSIVE.')
 2150 FORMAT(T2,'** FATAL ERROR **  NZ MUST BE BETWEEN 1 AND 6 ',
     >'INCLUSIVE.')
 2160 FORMAT(T2,'** FATAL ERROR **  AT LEAST ONE Z COOR. IS',
     >' NOT BETWEEN O AND 30 M')
 2170 FORMAT(T2,'** FATAL ERROR **  AT LEAST ONE RECEPTOR IS WITHIN',
     >'3. M  OF A LINE SOURCE.')
C
C** WARNING MESSAGE FORMAT NUMBERS ARE ALL BETWEEN 2500 AND 2600.
 2510 FORMAT(//,T2,'** WARNING **  WIND SPEED WAS LESS THAN 0.44 M/SEC',
     >' (1 MPH).',/,T17,'TXLINE ASSUMED THE INPUT WSPD = 0.44 M/SEC.')
 2520 FORMAT(//,T2,'** WARNING **  THE REFERENCE HT. WAS GREATER THAN',
     >' 10. M.',/,T17,'NOT RECOMMENDED - POOR WIND PROFILE FIT',
     >' COULD RESULT.')
 2530 FORMAT(//,T2,'** WARNING **  WIND ANGLE WAS LESS THAN 1. DEGREE.',
     >/,T17,'TXLINE ASSUMED PHI=1. DEGREE TO AVOID CALC. DIFFICULTIES.')
 2540 FORMAT(//,T2,'** WARNING **  SURFACE ROUGHNESS WAS LESS THAN ',
     >'0.01 M.',/,T17,'TXLINE ASSUMED ZO=0.01M TO AVOID CALC. ERRORS.')
 2550 FORMAT(//,T2,'** WARNING **  SURFACE ROUGHNESS IS GREATER THAN ',
     >'1 METER.',/,T17,'OUT OF RECOMMENDED RANGE - SEE USERS GUIDE.')
 2560 FORMAT(//,T2,'** WARNING **  AT LEAST 1 REC. IS FURTHER THAN 250',
     >'M FROM A LINE SOURCE.',/,T17,'NOT RECOMMENDED - TXLINE IS A ',
     >'MICROSCALE MODEL.')
C
C** STANDARD OUTPUT FORMAT NUMBERS ALL BEGIN WITH A 3
 3000 FORMAT(1H1,T2,79('*'),/,T2,'* TXLINE - TEXAS LINE SOURCE',
     >' AIR POLLUTION DISPERSION SIMULATOR (NOV., 1982 ) *',
     >/,T2,79('*'),///,T4,'I.  RUN DESCRIPTION',/,T8,3('-'),1X,11('-'),
     >//,T10,17A4)
 3010 FORMAT(///,T3,'II.  METEOROLOGICAL PARAMETERS',/,T8,14('-'),1X,
     >10('-'),//,T10,'WIND SPEED  =',F6.2,' M/SEC',T41,'*',T46,
     >'REFERENCE HEIGHT  = ',F5.2,' M',/,T10,'WIND ANGLE  =',F4.0,
     >'    DEGREES',T41,'*',T46,'SURFACE ROUGHNESS =',F6.2,' M')
 3015 FORMAT(T10,'TEMPERATURE = ',F5.2,' C',T41,'*',T46,'POLLUTANT',
     >' MOWT    =',F6.2,' G/MOLE')
 3021 FORMAT(/,T10,'NOTE: WIND SPEED CORRECTION FACTOR WAS APPLIED AS',
     >' REQUESTED.')
 3022 FORMAT(/,T10,'NOTE: WIND SPEED CORRECTION FACTOR DOES NOT',
     >' APPLY WHEN WSPD > 4. M/SEC.')
 3023 FORMAT(/,T10,'NOTE: WIND SPEED CORRECTION FACTOR OPTION WAS',
     >' OVERRIDDEN BY THE USER.')
 3030 FORMAT(///,T2,'III.  LINE SOURCE INFORMATION',/,T8,
     >4('-'),1X,6('-'),1X,11('-'),//,
     >T10,'LINE * X COORDINATE * HEIGHT *  E FACTOR  *   VPH    *',
     >' SOURCE STRENGTH',/,T11,' #  *         (M)',T30,'*  (M)    ',
     >'* (G/VEH/MI) * (VEH/HR) *    (G/KM/SEC)',/,T10,5('-'),'*',14('-')
     >,'*',8('-'),'*',12('-'),'*',10('-'),'*',17('-'))
 3040 FORMAT(T12,I1,T15,'*  ',F7.1,T30,'* ',F5.2,T39,
     >'*  ',F7.2,T52,'*  ',F6.0,T63,'* ',F11.4)
 3042 FORMAT(T12,I1,T15,'*   ','NA',T30,'* ',F5.2,T39,
     >'*     ','NA',T52,'*    ','NA',T63,'* ',F11.4)
 3050 FORMAT(///,T3,'IV.  CONCENTRATION ARRAY',/,T8,13('-'),1X,5('-'),/)
 3060 FORMAT(T10,'HEIGHT (M) *    DOWNWIND DISTANCE (M) FROM THE ',
     >'NEAREST LINE SOURCE')
 3070 FORMAT(T21,'*',6F9.2)
 3075 FORMAT(T21,'*',E9.2,5E10.2)
 3080 FORMAT(T10,11('-'),'*',59('-'))
 3081 FORMAT(T21,'*',T33,'C O N C E N T R A T I O N  ( P P M )')
 3082 FORMAT(T21,'*',T33,'C O N C E N T R A T I O N  ( P P B )')
 3083 FORMAT(T21,'*',T33,'C O N C E N T R A T I O N  ( G / M**3 )')
 3090 FORMAT(T8,F10.2,T21,'*',6F9.2)
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 3095 FORMAT(T8,F10.2,T21,'*',E9.2,5E10.2)
 3100 FORMAT(T21,'*',/,T21,'*',T36,'AMBIENT CONCENTRATION =',F6.2)
 3103 FORMAT(T21,'*',/,T21,'*',T36,'AMBIENT CONCENTRATION =',E9.2)
 3110 FORMAT(//,T2,79('*'),/,T2,'* TXLINE   *   END OF RUN   *   NUMBER',
     >' OF WARNINGS = ',I2,'  *  END OF RUN  *  TXLINE *',
     >/,T2,79('*'))
 4000 FORMAT(1H1)
      STOP
      END
C
      SUBROUTINE URWIND(UREF,REFZ,ZO,PHI,LWADJ,     ALPHA,UO,KO)
C
C***********************************************************************
C*                                                                     *
C*   SUBROUTINE URWIND WAS DEVELOPED BY J.B. RODDEN TO CALCULATE THE   *
C*   METEOROLOGICAL PARAMETERS ALPHA, KO, AND UO.  THE FUNCTIONS WHICH *
C*   DESCRIBE QP AND ALPHA WERE DEVELOPED BY MINIMIZING THE ERROR      *
C*   BETWEEN THE POWER LAW WIND SPEED PROFILE PROPOSED BY K.L. CALDER  *
C*   (U=USTAR*QP*(Z/ZO)**ALPHA) AND THE TRADITIONALLY ACCEPTED LOG LAW *
C*   PROFILE (U=USTAR/VANK*ALOG(Z/ZO)).  ONCE QP AND ALPHA ARE DETER-  *
C*   MINED, THE BASE WIND SPEED, UO, AND BASE EDDY DIFFUSIVITY, KO,    *
C*   ARE CALCULATED USING CALDER'S THEORY.                             *
C*                                                                     *
C*   AN OPTIONAL FEATURE OF THE SUBROUTINE IS A WIND SPEED ADJUSTMENT  *
C*   FACTOR WHICH MAY BE APPLIED TO LOW WIND SPEED CASES.  THE EQUA-   *
C*   TIONS WHICH PREDICT THIS FACTOR WERE DEVELOPED BY COMPARING MODEL *
C*   PREDICTIONS TO DATA FROM THE GENERAL MOTORS SULFATE DISPERSION    *
C*   EXPERIMENT.  THE FACTOR SLIGHTLY INCREASES LOW WIND SPEED VALUES  *
C*   IN ORDER TO AVOID THE PREDICTION OF UNREASONABLY HIGH CONCENTRA-  *
C*   TIONS.  THIS OPTION IS THE ONLY EMPIRICAL FEATURE OF TXLINE.      *
C*                                                                     *
C***********************************************************************
C*                                                                     *
C*   ARGUMENTS:                                                        *
C*                                                                     *
C*   NAME      IN/OUT     TYPE     DESCRIPTION                UNITS    *
C*   ----      ------     ----     -----------                -----    *
C*   UREF        IN        R       REFERENCE WIND SPEED       M/SEC    *
C*   REFZ        IN        R       HT. OF UREF MEASUREMENT      M      *
C*   ZO          IN        R       SURFACE ROUGHNESS            M      *
C*   PHI         IN        R       WIND ANGLE (O. TO 90.)     DEGREES  *
C*   LWADJ       IN        I       WSPD. ADJ. FLAG (O=YES)      -      *
C*   ALPHA       OUT       R       POWER LAW EXPONENT <-        -      *
C*   UO          OUT       R       WIND SPEED AT Z=1M         M/SEC    *
C*   KO          OUT       R       EDDY DIFF. AT Z=1M         M**2/SEC *
C*                                                                     *
C***********************************************************************
C*                                                                     *
C*  USES: -                                                            *
C*  USED BY: MAIN, MXGRND                                              *
C*                                                                     *
C***********************************************************************
C
      REAL KO
C
C** SET VALUE OF VAN KARMAN'S CONSTANT
      DATA VANK/0.4/
C
      ZO2=ZO*ZO
      ZO3=ZO2*ZO
      ZO4=ZO3*ZO
      ZO5=ZO4*ZO
      IF(ZO.GT.O.30)GO TO 5
C
C** POLYNOMIALS TO CALCULATE POWER LAW PARAMETERS WHEN ZO<O.30M
      ALPHA=O.1429+1.9011*ZO-15.618*ZO2+83.237*ZO3-224.37*ZO4+235.96*ZO5
      QP=5.8183-46.123*ZO+416.41*ZO2-2162.3*ZO3+5670.6*ZO4-5830.1*ZO5
C
      GO TO 15
    5 ZO6=ZO5*ZO
      ZO7=ZO6*ZO
C
```

```
C** POLYNOMIALS TO CALCULATE POWER LAW PARAMETERS WHEN ZO>0.30M
      ALPHA=0.2292+0.3057*ZO-0.1221*ZO2+0.0401*ZO3-0.0066*ZO4+0.0004*ZO5
      QP=3.8272-4.3854*ZO+4.4999*ZO2-2.8816*ZO3+1.1016*ZO4-
     >   0.2446*ZO5+0.0290*ZO6-0.0014*ZO7
C
C** CHECK IF LOW WIND SPEED CORRECTION FACTOR SHOULD BE APPLIED
   15 IF((LWADJ.LT.1).AND.(UREF.LT.4.))GO TO 18
C
C** CALCULATE FRICTION VELOCITY (WHEN NO CORRECTION FACTOR APPLIED)
      USTAR=UREF*VANK/ALOG(REFZ/ZO)
C
      GO TO 20
C
C
C** WIND SPEED CORRECTION SECTION (OPTIONAL) **************************
C
   18 UREF2=UREF*UREF
      THI=PHI
      IF(THI.LT.10.)THI=10.
      IF(THI.GT.45.)THI=45.
      F1=0.3431+2.8337/UREF-0.2297/UREF2
      F2=0.8918+0.4946/UREF+0.3037/UREF2
      UFACT=F1-(THI-10.)/35.*(F1-F2)
      UCOR=UREF*UFACT
C
C*********************************************************************
C
C** CALCULATE FRICTION VELOCITY (WHEN CORRECTION FACTOR IS APPLIED)
      USTAR=UCOR*VANK/ALOG(REFZ/ZO)
C
C** CALCULATE BASE WIND SPEED AND BASE EDDY DIFFUSIVITY
   20 UO=QP*USTAR*(1./ZO)**ALPHA
      KO=ZO**(2.*ALPHA)*UO/(ALPHA*QP**2)
C
   99 RETURN
      END
C
      SUBROUTINE INLINE(X,Z,H,Q,ALPHA,UO,KO,  C1)
C
C*********************************************************************
C*                                                                   *
C*  SUBROUTINE INLINE IS USED TO CALCULATE POLLUTANT CONCENTRATIONS  *
C*  DOWNWIND FROM AN INFINITE LINE SOURCE WITH A PERPENDICULAR WIND. *
C*  THE EQUATIONS USED IN THIS ROUTINE WERE DERIVED BY F.B. SMITH.   *
C*                                                                   *
C*  FOR OBLIQUE WIND ANGLES WITH THE SOURCE AT GROUND LEVEL, THE     *
C*  RESULTS OF THIS SUBROUTINE ARE USED AS PART OF THE POINT SOURCE  *
C*  SOLUTION (SEE SUBROUTINE POINT).                                 *
C*                                                                   *
C*********************************************************************
C*                                                                   *
C*  ARGUMENTS:                                                       *
C*                                                                   *
C*  NAME     IN/OUT     TYPE     DESCRIPTION               UNITS     *
C*  ----     ------     ----     -----------               -----     *
C*  X          IN        R       X COORDINATE ARRAY          M       *
C*  Z          IN        R       Z COORDINATE ARRAY          M       *
C*  H          IN        R       SOURCE HEIGHT               M       *
C*  Q          IN        R       SOURCE STRENGTH ARRAY     G/M/SEC   *
C*  ALPHA      IN        R       POWER LAW EXPONENT          -       *
C*  UO         IN        R       WIND SPEED AT Z=1M        M/SEC     *
C*  KO         IN        R       EDDY DIFF. AT Z=1M        M**2/SEC  *
C*  C1         OUT       R       CONCENTRATION ARRAY       G/M**3    *
C*                                                                   *
C*  IMPORTANT NOTE: C1 IS THE FINAL CONCENTRATION PREDICTION ONLY    *
C*                  WHEN INLINE IS CALLED BY MAIN.  IN ALL OTHER     *
C*                  CASES C1 HAS UNITS OF G/M**2 AND THE SOURCE      *
C*                  STRENGTH (Q) HAS UNITS OF G/SEC.                 *
C*                                                                   *
C*********************************************************************
C*                                                                   *
C*  USES: BESSEL                                                     *
```

```
C*  USED BY: MAIN, POINT, MXGRND                                            *
C*                                                                          *
C****************************************************************************
C
      REAL X(6),Z(6),C1(6,6),KO,Q(6)
      COMMON /INFO/NX,NZ,KILL(6,6),JUMP,KILTOW(6)
      COMMON /SKIP1/A,B,GA,GB,CONIN,CONSP,H2,ZTERM(6)
      COMMON /MXGINL/EXARGC(6)
C
C** JUMP IF JUMP=9 TO AVOID REDUNDANT CALCULATIONS (JUMP CAN NEVER
C** EQUAL 9 IF THE ELEVATED INFINITE LINE SOURCE EQUATION IS USED).
      IF(JUMP.EQ.9)GO TO 60
C
      AX2P1=ALPHA*2.+1.
      ORDER=-1.*ALPHA/AX2P1
      TCOM=UO/(KO*AX2P1**2)
    5 IF(H.LE.0.10)GO TO 50
C
C
C** ELEVATED INFINITE LINE SOURCE SECTION *********************************
C
      HPOW=H**AX2P1
      DO 40 J=1,NZ
      CNUM=AX2P1*((Z(J)-H)*H+H*H)**(ALPHA/2.)*TCOM/UO
      EXNUM=-1.*(Z(J)**AX2P1+HPOW)*TCOM
      BESNUM=2.*((Z(J)-H)*H+H*H)**(AX2P1/2.)*TCOM
      DO 30 I=1,NX
      BESARG=BESNUM/X(I)
      EXPARG=EXNUM/X(I)
C
C** CHECK VALUE OF EXPARG TO AVOID UNDERFLOW ERROR
      IF(EXPARG.LT.-100.)EXPARG=-100.
C
C** CALCULATE THE INFINITE LINE SOURCE CONCENTRATON FUNCTION
      C1(I,J)=Q(I)*CNUM/X(I)*EXP(EXPARG)*BESSEL(ORDER,BESARG)
C
C** LIMIT RANGE OF C1 TO PREVENT POSSIBLE ERRORS IN FUTURE CALCULATIONS
      IF(C1(I,J).LT.1.E-25)C1(I,J)=1.E-25
      IF(C1(I,J).GT.1.E+25)C1(I,J)=1.E+25
C
   30 CONTINUE
   40 CONTINUE
C
C****************************************************************************
C
C
      GO TO 99
C
C
C** GROUND LEVEL INFINITE LINE SOURCE SECTION *****************************
C
   50 CONIN=1./(UO*AX2P1**(1./AX2P1)*GAMMA(ORDER+1.))
      A=(1.+ALPHA)/AX2P1
      DO 55 J=1,NZ
      ZTERM(J)=Z(J)**AX2P1*TCOM
   55 CONTINUE
   60 DO 75 I=1,NX
      IF(KILTOW(I).EQ.9)GO TO 75
      CNUM=Q(I)*(X(I)*KO/UO)**(-1.*A)
      DO 74 J=1,NZ
      IF(KILL(I,J).EQ.9)GO TO 74
C
C** EXARGC ARRAY IS SAVED IN COMMON FOR USE IN SUBROUTINE MXGRND.
C** (EXARGC ARRAY IS 1-D BECAUSE NZ=1 WHEN MXGRND CALLS INLINE.)
      EXARGC(I)=-1.*ZTERM(J)/X(I)
C
C** CHECK VALUE OF EXARGC TO AVOID UNDERFLOW ERROR
      IF(EXARGC(I).LT.-100.)EXARGC(I)=-100.
C
C** CALCULATE INFINITE LINE SOURCE CONCENTRATION FUNCTION
      C1(I,J)=CONIN*CNUM*EXP(EXARGC(I))
C
```

```
C** LIMIT RANGE OF C1 TO PREVENT POSSIBLE ERRORS IN FUTURE CALCULATIONS
      IF(C1(I,J).LT.1.E-25)C1(I,J)=1.E-25
      IF(C1(I,J).GT.1.E+25)C1(I,J)=1.E+25
   74 CONTINUE
   75 CONTINUE
C
C*********************************************************************
C
C
   99 CONTINUE
      RETURN
      END
C
      SUBROUTINE JRLINE(X,Z,H,CAPQ,ZO,ALPHA,UO,KO,PHI,     CHI)
C
C*********************************************************************
C*                                                                   *
C*  SUBROUTINE JRLINE WAS DEVELOPED BY J.B. RODDEN TO MODEL A LINE   *
C*  SOURCE BY COMBINING A FINITE NUMBER OF POINT SOURCES.  THIS METHOD *
C*  ALLOWS A THEORETICAL TREATMENT OF OBLIQUE WIND ANGLE CASES.      *
C*                                                                   *
C*  THE LOCATION OF THE STARTING POINT IS SELECTED BY SUBROUTINE     *
C*  MXGRND.  THE SPACING TO BE USED BETWEEN INDIVIDUAL POINT SOURCES *
C*  IS THEN DETERMINED AS A FUNCTION OF X AND PHI.  FINALLY, POINT   *
C*  SOURCE CONCENTRATIONS ARE SUMMED IN BOTH DIRECTIONS FROM THE     *
C*  STARTING POINT UNTIL THE EFFECT OF SUMMING ANY MORE POINTS WOULD *
C*  BE NEGLIGIBLE  (OR UNTIL THE LENGTH OF THE ACTUAL SOURCE HAS     *
C*  BEEN EXCEEDED).                                                  *
C*                                                                   *
C*********************************************************************
C*                                                                   *
C*  ARGUMENTS:                                                       *
C*                                                                   *
C*  NAME     IN/OUT    TYPE    DESCRIPTION                UNITS      *
C*  ----     ------    ----    -----------                -----      *
C*  X          IN       R      X COORDINATE ARRAY           M        *
C*  Z          IN       R      Z COORDINATE ARRAY           M        *
C*  H          IN       R      SOURCE HEIGHT                M        *
C*  CAPQ       IN       R      SOURCE STRENGTH            G/M/SEC    *
C*  ALPHA      IN       R      POWER LAW EXPONENT           -        *
C*  UO         IN       R      WIND SPEED AT Z=1M         M/SEC      *
C*  KO         IN       R      EDDY DIFF. AT Z=1M         M**2/SEC   *
C*  PHI        IN       R      WIND ANGLE (0. TO 90.)     DEGREES    *
C*  CHI       OUT       R      CONCENTRATION ARRAY        G/M**3     *
C*                                                                   *
C*********************************************************************
C*                                                                   *
C*  USES: MXGRND, POINT                                              *
C*  USED BY: MAIN                                                    *
C*                                                                   *
C*********************************************************************
C
      REAL X(6),Z(6),XPT(6),YPT(6),CHI(6,6),KO,ORIG(6),D1CHI(6,6),
     >     OSEG(6),SEGLEN(6),PTCHI(6,6),STPT(6)
      COMMON /INFO/NX,NZ,KILL(6,6),JUMP,KILTOW(6)
      COMMON /MXGJRL/PSIN,PCOS
      JUMP=0
      NXNZ=NX*NZ
C
C** ARGUMENTS OF TRIGONOMETRIC FUNCTIONS ARE IN RADIANS
      PSIN=SIN(PHI/90.*3.141593/2.)
      PCOS=COS(PHI/90.*3.141593/2.)
C
C** SUBROUTINE MXGRND RETURNS STARTING POINT ARRAY
      CALL MXGRND(X,ZO,     STPT)
C
      DO 30 I=1,NX
      XACT=X(I)
      IF(X(I).GT.100.)X(I)=100.
C
C
C** SEGMENT LENGTH CALCULATION SECTION ********************************
```

```
C** SEGLEN IS THE DISTANCE BETWEEN POINT SOURCES.  THE FOLLOWING FUN-
C** TIONS WERE FITTED TO PREDICT THE MAXIMUM ALLOWABLE SEGMENT LENGTH.
C
      IF(PHI.GE.20.)GO TO 5
      SEG=2.2565*X(I)-0.0226*X(I)**2+0.00012*X(I)**3-3.2159
      IF(PHI.GT.10.)GO TO 4
      SEGLEN(I)=SEG
      GO TO 20
    4 PSI=0.34202
      PCO=0.93969
      GO TO 6
    5 PSI=PSIN
      PCO=PCOS
    6 IP(ALPHA.LT.0.3562)GO TO 10
      AFAC=2.5
      GO TO 15
   10 AFAC=0.44829+1.5359*ALPHA+11.8596*ALPHA**2
   15 SEGLEN(I)=AFAC*(8.6917+1./PSI*(0.00667*X(I)-10.3599+1./PSI*
     >(X(I)*(0.0478-0.000106*X(I))+2.1047))-PCO*(2.3824-PCO*8.4284))
      IF(PHI.GE.20.)GO TO 20
      SEGLEN(I)=SEGLEN(I)+(20.-PHI)/10.*(SEG-SEGLEN(I))
C
C***********************************************************************
C
C
C** CALCULATE SOURCE STRENGTH OF THE LINE SEGMENT (G/SEC)
   20 QSEG(I)=CAPQ*SEGLEN(I)
C
      DO 25 J=1,NZ
C
C** SET INITIAL VALUE OF D1CHI; THE CONCENTRATION ARRAY FOR IDIR=1
      D1CHI(I,J)=0.
C
   25 CONTINUE
      X(I)=XACT
   30 CONTINUE
C
C** IDIR INDICATES THE DIRECTION IN WHICH POINTS ARE BEING SUMMED
C** IDIR=1 WHEN MOVING IN A POSITIVE DIRECTION AWAY FROM STPT
C** IDIR=2 WHEN MOVING IN A NEGATIVE DIRECTION AWAY FROM STPT
      DO 200 IDIR=1,2
C
      KILCOU=0
      DO 55 I=1,NX
      KILTOW(I)=0
C
C** CHECK IF STPT IS WITHIN A REASONABLE DISTANCE OF THE RECEPTORS
      IF(STPT(I).GT.-500.)GO TO 31
      IF(STPT(I).LT.-2500.)STPT(I)=-2500.
      IF(PHI.GT.20.)STPT(I)=-500.
C
C** SET INITIAL VALUE OF THE POINT SOURCE ORIGIN
   31 GO TO (35,40),IDIR
   35 ORIG(I)=-0.5*SEGLEN(I)+STPT(I)
      GO TO 45
   40 ORIG(I)=0.5*SEGLEN(I)+STPT(I)
C
   45 DO 50 J=1,NZ
C
C** SET INITIAL VALUES OF THE KILL ARRAY AND THE CONCENTRATION ARRAY
      KILL(I,J)=0
      CHI(I,J)=0.
C
   50 CONTINUE
   55 CONTINUE
   60 CONTINUE
   65 DO 95 I=1,NX
      IF(KILTOW(I).EQ.9)GO TO 95
C
C** INCREMENT POINT SOURCE ORIGIN
      GO TO (70,75),IDIR
   70 ORIG(I)=ORIG(I)+SEGLEN(I)
```

```
      GO TO 80
   75 ORIG(I)=ORIG(I)-SEGLEN(I)
C
C** PREVENT POINTS FROM BEING SUMMED MORE THAN 5000M FROM THE RECEPTORS
   80 IF(ABS(ORIG(I)).GT.5000.)GO TO 85
C
C** CALCULATE RECEPTOR COORDINATES W/R TO THE PT. SOURCE COORD. SYSTEM
      XPT(I)=X(I)*PSIN-ORIG(I)*PCOS
      YPT(I)=X(I)*PCOS+ORIG(I)*PSIN
C
C** SUMMING IS TERMINATED IF XPT IS LESS THAN 1 METER
      IF(XPT(I).GT.1.00)GO TO 95
C
   85 KILTOW(I)=9
      DO 90 J=1,NZ
      IF(KILL(I,J).EQ.9)GO TO 90
      KILCOU=KILCOU+1
      GO TO (86,87),IDIR
   86 D1CHI(I,J)=CHI(I,J)
   87 IF(KILCOU.EQ.NXNZ)GO TO 125
      KILL(I,J)=9
   90 CONTINUE
   95 CONTINUE
C
C** SUBROUTINE POINT RETURNS THE POINT SOURCE CONCENTRATION ARRAY
      CALL POINT(XPT,YPT,Z,H,QSEG,ALPHA,UO,KO,    PTCHI)
C
C** 'JUMPS' ARE NOW PERMITTED
      JUMP=9
C
      DO 120 I=1,NX
      IF(KILTOW(I).EQ.9)GO TO 120
      DO 115 J=1,NZ
      IF(KILL(I,J).EQ.9)GO TO 115
C
C** ADD POINT SOURCE CONTRIBUTION TO THE TOTAL CONCENTRATION
      CHI(I,J)=CHI(I,J)+PTCHI(I,J)
C
C** TERMINATE SUMMING IF THE POINT SOURCE CONTRIBUTION DID NOT
C** SIGNIFICANTLY INCREASE THE TOTAL CONCENTRATION.
      IF(PHI.GT.15.)GO TO 96
      IF((PTCHI(I,J)/SEGLEN(I)/CHI(I,J)).GT.0.0001)GO TO 115
      GO TO 97
   96 IF((PTCHI(I,J)/SEGLEN(I)/CHI(I,J)).GT.0.001)GO TO 115
C
   97 KILCOU=KILCOU+1
      KILTOW(I)=KILTOW(I)+1
      IF(KILTOW(I).EQ.NZ)KILTOW(I)=9
      GO TO (100,105),IDIR
  100 D1CHI(I,J)=CHI(I,J)
  105 IF(KILCOU.EQ.NXNZ)GO TO 125
      KILL(I,J)=9
  115 CONTINUE
  120 CONTINUE
      GO TO 60
  125 CONTINUE
  200 CONTINUE
      DO 900 I=1,NX
      KILTOW(I)=0
      DO 800 J=1,NZ
      KILL(I,J)=0
C
C** TOTAL CONCENTRATION = (DIRECTION 2 TOTAL) + (DIRECTION 1 TOTAL)
      CHI(I,J)=CHI(I,J)+D1CHI(I,J)
C
  800 CONTINUE
  900 CONTINUE
      JUMP=0
      RETURN
      END
C
      SUBROUTINE MXGRND(X,ZO,    STPT)
```

```
C
C***********************************************************************
C*                                                                     *
C*  SUBROUTINE MXGRND WAS DEVELOPED BY J.B. RODDEN.  THIS ROUTINE IS   *
C*  USED TO FIND A STARTING POINT FOR SUBROUTINE JRLINE. THE POINT     *
C*  WHICH IS RETURNED IS THE POINT THAT GIVES THE MAXIMUM GROUND LEVEL *
C*  CONCENTRATION AT THE SPECIFIED DISTANCE FROM THE ROAD.  (IN ORDER  *
C*  TO CONSERVE COMPUTER TIME, IT IS DESIRABLE TO BEGIN SUMMING POINTS *
C*  NEAR THE POINT ON THE ROADWAY WHICH CONTRIBUTES THE MAXIMUM CON-   *
C*  CENTRATION TO A GIVEN RECEPTOR.)                                   *
C*                                                                     *
C*  A FUNCTION WAS FITTED TO GIVE A VERY APPROXIMATE FIRST GUESS OF    *
C*  THE STARTING POINT.  THE ACTUAL LOCATION OF THE STARTING POINT IS  *
C*  FOUND BY USING NEWTON'S METHOD TO SOLVE FOR THE ZERO OF THE FIRST  *
C*  DERIVATIVE (WITH RESPECT TO LENGTH ALONG THE ROAD) OF THE POINT    *
C*  SOURCE EQUATION.                                                   *
C*                                                                     *
C***********************************************************************
C*                                                                     *
C*  ARGUMENTS:                                                         *
C*                                                                     *
C*  NAME    IN/OUT    TYPE    DESCRIPTION                 UNITS        *
C*  ----    ------    ----    -----------                 -----        *
C*  X         IN       R      X COORDINATE ARRAY            M          *
C*  ALPHA     IN       R      POWER LAW EXPONENT            -          *
C*  ZO        IN       R      SURFACE ROUGHNESS             M          *
C*  STPT      OUT      R      STARTING PT. COORD. ARRAY     M          *
C*                                                                     *
C***********************************************************************
C*                                                                     *
C*  USES: INLINE, SPREAD, KUMMER, V, JRWIND                            *
C*  USED BY: JRLINE                                                    *
C*                                                                     *
C***********************************************************************
C
      REAL X(6),XPT(6),YPT(6),KUMMER,ZGR(6),Q(6),STPT(6)
      COMMON /INFO/NX,NZ,KILL(6,6),JUMP,KILTOW(6)
      COMMON /SKIP1/A,B,GA,GB,CONIN,CONSP,H2,ZTERM(6)
      COMMON /MXGINL/EXARGC(6)
      COMMON /MXGSPR/TERM2(6),EDA(6)
      COMMON /MXGJRL/PSIN,PCOS
      COMMON /MXGPOI/C1(6,6),C2(6,6)
C
C** INITIALIZE COUNTERS
      KILCOU=0
      ISTOP=0
C
C** ALL CALCULATIONS IN THIS ROUTINE ARE FOR GROUND LEVEL (SEE REPORT)
      NZTEM=NZ
      NZ=1
      ZGR(1)=0.10
C
C** NEWTON'S METHOD WILL NOT ALWAYS CONVERGE WHEN ZO > 1.5M (SEE REPORT)
      ZOTEM=ZO
      IF(ZO.GT.1.5)ZO=1.5
C
C** THE STARTING POINT IS A VERY WEAK FUNCTION OF WIND SPEED; UREF
C** AND REFZ WERE ASSIGNED VALUES WHICH ARE KNOWN TO LEAD TO CONVERGENCE
      CALL JRWIND(4.0,5.0,ZO,45.,9,  DUMALP,DUMUO,DUMKO)
C
      DO 2 I=1,NX
C
C** Q IS A CONSTANT WHEN THE DERIVATIVES ARE TAKEN: AN ARBITRARY
C** VALUE OF 1000. IS ASSIGNED TO AVOID NUMERICAL DIFFICULTIES.
      Q(I)=1000.
C
      KILTOW(I)=0
      KILL(I,1)=0
C
C***********************************************************************
C** THIS SECTION GIVES AN APPROXIMATE FIRST GUESS OF STPT.
C** SEE THE PROJECT REPORT FOR A COMPLETE EXPLANATION.
```

```
C
      IF(PSIN.LT.0.2588)GO TO 1
      STPT(I)=-X(I)*PCOS/PSIN*EXP(.0005-(1.08/X(I)-8.47/X(I)**2+
     >        28.13/X(I)**3)/PSIN)
      GO TO 2
    1 STPT(I)=-X(I)*PCOS/PSIN*EXP(-.0656-(1.18/X(I)-12.63/X(I)**2+
     >        39.37/X(I)**3)/PSIN)
C
C*****************************************************************************
C
    2 CONTINUE
    3 ISTOP=ISTOP+1
C
C** CALCULATE COORDINATES RELATIVE TO THE POINT SOURCE LOCATIONS
      DO 4 I=1,NX
      XPT(I)=X(I)*PSIN-STPT(I)*PCOS
      IF(XPT(I).LT.0.001)STPT(I)=X(I)*PSIN/PCOS-0.001
      XPT(I)=X(I)*PSIN-STPT(I)*PCOS
      YPT(I)=X(I)*PCOS+STPT(I)*PSIN
    4 CONTINUE
C
C** CALL INLINE AND SPREAD TO GET C1 AND C2 ARRAYS
      CALL INLINE(XPT,ZGR,0.,Q,DUMALP,DUMUO,DUMKO,  C1)
      CALL SPREAD(XPT,ZGR,Q,DUMALP,DUMUO,DUMKO,  C2)
C
      IF(ISTOP.GT.1)GO TO 10
      JUMP=9
      BMA=B-A
      BM1=B-1.
      BP1=B+1.
      AP1=A+1.
      CKMR=GB/GA*B/A
   10 DO 40 I=1,NX
      IF(KILTOW(I).EQ.9)GO TO 40
      W1=C1(I,1)
      W2=C2(I,1)
      Y2=YPT(I)**2/2.
      PCXP=PCOS/XPT(I)
      ETA=EDA(I)
      BMAETA=BMA+ETA
C
C** GET FIRST DERIVATIVE OF THE V FUNCTION
      DV=V(1,B,A,ETA)
C
C** CALCULATE 1ST DERIVATIVES OF C1 AND C2
      DC1=W1*PCXP*(EXARGC(I)+A)
      DC2=PCXP*(TERM2(I)*(CKMR*ETA*KUMMER(BP1,AP1,ETA)-
     >    ETA**B*(B+ETA*DV))-W2*BMAETA)
C
C** CALCULATE 2ND DERIVATIVES OF C1 AND C2
      DDC1=W1*PCXP**2*EXARGC(I)+DC1*(PCXP+DC1/W1)
      DDC2=PCXP*(2.*DC2*(1.-BMAETA)+PCXP*(W2*(BMAETA*(1.-BMAETA)-ETA)+
     >      TERM2(I)*ETA*(CKMR*BP1/AP1*ETA*KUMMER(B+2.,A+2.,ETA)-
     >      ETA**B*(B*DV+ETA*V(2,B,A,ETA)+B/ETA*BM1))))
C
      C1C2=W1/W2
      C2C1=W2/W1
C
C** F IS THE FUNCTION OBTAINED BY SETTING THE 1ST DERIVATIVE
C** OF THE POINT SOURCE EQUATION EQUAL TO ZERO.
      F=DC1*(1.5*C2C1-Y2)+DC2*(Y2*C1C2-0.5)-W1*PSIN*YPT(I)
C
C** DF IS THE DERIVATIVE OF F (DF IS NEEDED FOR NEWTON'S METHOD).
      DF=DDC1*(1.5*C2C1-Y2)+DC1*(1.5/W1*(DC2-DC1*C2C1)-2.*YPT(I)*PSIN)+
     >   DDC2*(Y2*C1C2-0.5)+DC2*(Y2/W2*(DC1-DC2*C1C2)+C1C2*YPT(I)*PSIN)-
     >   W1*PSIN**2
C
C** NEWTON'S METHOD GIVES THE NEXT GUESS OF STPT.
      STP=STPT(I)-F/DF
C
C** CHECK IF CONVERGENCE CRITERION HAS BEEN SATISFIED
      IF(ABS(F/DF/STPT(I)).GT.0.01)GO TO 25
```

```
C
      IF(STP.LT.O.)GO TO 20
      STP=O.01
      GO TO 25
   20 KILTOW(I)=9
      KILCOU=KILCOU+1
   25 STPT(I)=STP
   40 CONTINUE
C
C** STOP CALC. IF CONVERGENCE HAS NOT BEEN REACHED AFTER 100 TRIALS
      IF(ISTOP.GT.100)GO TO 50
C
C** CHECK IF ALL CALCULATIONS HAVE BEEN COMPLETED
      IF(KILCOU.NE.NX)GO TO 3
C
C** RESET ORIGINAL VALUES OF NZ AND ZO
   50 NZ=NZTEM
      ZO=ZOTEM
C
      JUMP=O
      RETURN
      END
C
      SUBROUTINE POINT(X,Y,Z,H,Q,ALPHA,UO,KO,  PTCHI)
C
C*********************************************************************
C*                                                                   *
C*  SUBROUTINE POINT IS USED TO CALCULATE THE CONCENTRATION DUE TO THE *
C*  EFFECT OF A SINGLE POINT SOURCE.  THE EQUATIONS USED IN THIS      *
C*  ROUTINE WERE DEVELOPED BY F.B. SMITH.                             *
C*                                                                   *
C*  WHEN THE POINT SOURCE IS AT GROUND LEVEL, THE SOLUTION REQUIRES   *
C*  BOTH THE INFINITE LINE SOURCE SOLUTION (SUBROUTINE INLINE), AND   *
C*  THE SPREAD FUNCTION SOLUTION (SUBROUTINE SPREAD).                 *
C*                                                                   *
C*  THE EQUATION USED TO SOLVE THE CASE OF THE ELEVATED POINT SOURCE  *
C*  ASSUMES THAT ALPHA IS EQUAL TO 0.5. (THE EQUATION FOR GENERAL     *
C*  VALUES OF ALPHA HAS NOT YET BEEN DERIVED.)                        *
C*                                                                   *
C*********************************************************************
C*                                                                   *
C*  ARGUMENTS:                                                        *
C*                                                                   *
C*  NAME     IN/OUT    TYPE     DESCRIPTION               UNITS       *
C*  ----     ------    ----     -----------               -----       *
C*  X          IN       R       X COORDINATE ARRAY          M         *
C*  Y          IN       R       Y COORDINATE ARRAY          M         *
C*  Z          IN       R       Z COORDINATE ARRAY          M         *
C*  H          IN       R       SOURCE HEIGHT               M         *
C*  Q          IN       R       SOURCE STRENGTH ARRAY     G/SEC       *
C*  ALPHA      IN       R       POWER LAW EXPONENT          -         *
C*  UO         IN       R       WIND SPEED AT Z=1M        M/SEC       *
C*  KO         IN       R       EDDY DIFF. AT Z=1M        M**2/SEC    *
C*  PTCHI      OUT      R       PT. SOURCE CONC. ARRAY    G/M**3      *
C*                                                                   *
C*  IMPORTANT NOTE: THE INPUT X AND Y COORDINATES TO THIS SUBROUTINE  *
C*                  ARE THE COORDINATES OF THE RECEPTORS WITH RESPECT *
C*                  TO EACH INDIVIDUAL POINT SOURCE COORDINATE SYSTEM. *
C*                  THEY SHOULD NOT BE CONFUSED WITH THE ORIGINAL     *
C*                  RECEPTOR COORDINATES.                             *
C*                                                                   *
C*********************************************************************
C*                                                                   *
C*  USES: SPREAD, INLINE, BESSEL                                      *
C*  USED BY: URLINE                                                   *
C*                                                                   *
C*********************************************************************
C
      REAL X(6),Y(6),Z(6),Q(6),KO,PTCHI(6,6)
      COMMON /INFO/NX,NZ,KILL(6,6),JUMP,KILTOW(6)
      COMMON /SKIP1/A,B,GA,GB,CONIN,CONSP,H2,ZTERM(6)
      COMMON /MXGPOI/C1(6,6),C2(6,6)
```

```
      IF(H.LE.O.10)GO TO 30
C
C** 'JUMP' IF JUMP=9 TO AVOID REDUNDANT CALCULATIONS
      IF(JUMP.EQ.9)GO TO 6
C
      H2=H*H
      DO 5 J=1,NZ
      ZTERM(J)=(Z(J)-H)*H+H2
    5 CONTINUE
    6 CONTINUE
C
C
C** ELEVATED POINT SOURCE SECTION ************************************
C
      DO 20 I=1,NX
      IF(KILTOW(I).EQ.9)GO TO 20
      Y2=Y(I)**2
      T1=Q(I)/7.09/(KO*X(I))**1.5
      T2=2.*KO*X(I)/UO
      DO 10 J=1,NZ
      IF(KILL(I,J).EQ.9)GO TO 10
      BESARG=ZTERM(J)/T2
      EXPARG=-1.*(Y2+H2+Z(J)**2)/(2.*T2)
C
C** CHECK VALUE OF EXPARG TO AVOID UNDERFLOW ERROR
      IF(EXPARG.LT.-100.)EXPARG=-100.
C
C** CALCULATE CONCENTRATION RESULTING FROM POINT SOURCE
      PTCHI(I,J)=T1*ZTERM(J)**0.25*EXP(EXPARG)*BESSEL(-0.25,BESARG)
C
   10 CONTINUE
   20 CONTINUE
C
C*********************************************************************
C
C
      GO TO 99
C
C
C** GROUND LEVEL POINT SOURCE SECTION ********************************
C
C** C1 AND C2 ARE BOTH NEEDED IN THE POINT SOURCE EQUATION
   30 CALL INLINE(X,Z,H,Q,ALPHA,UO,KO,   C1)
      CALL SPREAD(X,Z,Q,ALPHA,UO,KO,   C2)
C
      DO 60 I=1,NX
      IF(KILTOW(I).EQ.9)GO TO 60
      Y2=Y(I)**2
      DO 50 J=1,NZ
      IF(KILL(I,J).EQ.9)GO TO 50
      EXPARG=-1.*Y2/(2.*C2(I,J)/C1(I,J))
C
C** CHECK VALUE OF EXPARG TO AVOID UNDERFLOW ERROR
      IF(EXPARG.LT.-100.)EXPARG=-100.
C
C** CALCULATE CONCENTRATION RESULTING FROM POINT SOURCE
      PTCHI(I,J)=C1(I,J)*(C1(I,J)/(6.2832*C2(I,J)))**0.5*EXP(EXPARG)
C
   50 CONTINUE
   60 CONTINUE
C
C*********************************************************************
C
C
   99 RETURN
      END
C
      SUBROUTINE SPREAD(X,Z,Q,ALPHA,UO,KO,   C2)
C
C*********************************************************************
C*                                                                   *
C*  SUBROUTINE SPREAD CALCULATES THE 'SPREAD FUNCTION' DERIVED BY    *
```

```
C*   F.B. SMITH.  THIS FUNCTION (C2) IS COMBINED WITH THE INFINITE          *
C*   LINE SOURCE EQUATION (C1) IN SUBROUTINE POINT TO GIVE THE POINT        *
C*   SOURCE EQUATION.                                                       *
C*                                                                          *
C*   THE RATIO OF C2 TO C1 IS A MEASURE OF THE 'SPREAD' IN THE Y            *
C*   DIRECTION.  THIS RATIO IS SIMILAR IN NATURE TO THE LATERAL CONCEN-     *
C*   TRATION VARIANCE WHICH IS USED AS A DISPERSION PARAMETER BY MOST       *
C*   OTHER AIR POLLUTION MODELS.  BOTH ARE A MEASURE OF THE CONCEN-         *
C*   TRATION SPREAD IN THE LATERAL DIRECTION AND BOTH HAVE DIMENSIONS       *
C*   OF LENGTH SQUARED.                                                     *
C*                                                                          *
C****************************************************************************
C*                                                                          *
C*   ARGUMENTS:                                                             *
C*                                                                          *
C*   NAME      IN/OUT      TYPE      DESCRIPTION               UNITS        *
C*   ----      ------      ----      -----------               -----        *
C*   X           IN         R        X COORDINATE ARRAY          M          *
C*   Z           IN         R        Z COORDINATE ARRAY          M          *
C*   Q           IN         R        SOURCE STRENGTH ARRAY     G/SEC        *
C*   ALPHA       IN         R        POWER LAW EXPONENT          -          *
C*   UO          IN         R        WIND SPEED AT Z=1M        M/SEC        *
C*   KO          IN         R        EDDY DIFF. AT Z=1M        M**2/SEC     *
C*   C2          OUT        R        SPREAD FUNCTION ARRAY       G          *
C*                                                                          *
C****************************************************************************
C*                                                                          *
C*   USES: V, KUMMER                                                        *
C*   USED BY: POINT, MXGRND                                                 *
C*                                                                          *
C****************************************************************************
C
      REAL X(6),Z(6),C2(6,6),KO,KUMMER,EDAZ(6),Q(6)
      COMMON /INFO/NX,NZ,KILL(6,6),JUMP,KILTOW(6)
      COMMON /SKIP1/A,B,GA,GB,CONIN,CONSP,H2,ZTERM(6)
      COMMON /MXGSPR/TERM2(6),EDA(6)
C
C** 'JUMP' IF JUMP=9 TO AVOID REDUNDANT CALCULATIONS
      IF(JUMP.EQ.9)GO TO 7
C
      AX2P1=2.*ALPHA+1.
      A=(1.+ALPHA)/AX2P1
      B=2./AX2P1
C
C** THE GAMMA FUNCTION IS A BUILT IN FORTRAN FUNCTION.
      GA=GAMMA(A)
      GB=GAMMA(B)
      CONSP=2.*KO**(B-A)/UO**(B-A+1)*AX2P1**((3.*B-4.)/2.)*GB/GA*
     >      GAMMA(B+A-1.)/GAMMA(2.*B)
C
      TCOM=UO/(KO*AX2P1**2)
C
    5 DO 6 J=1,NZ
      ZTERM(J)=Z(J)**AX2P1*TCOM
    6 CONTINUE
C
    7 CONTINUE
      DO 20 I=1,NX
      IF(KILTOW(I).EQ.9)GO TO 20
      TERM1=Q(I)*CONSP*X(I)**(B-A)
      DO 10 J=1,NZ
      IF(KILL(I,J).EQ.9)GO TO 10
C
C** EDA AND TERM2 ARRAYS ARE SAVED IN COMMON FOR USE IN SUBROUTINE
C** MXGRND.  THESE ARRAYS ARE 1-D BECAUSE NZ=1 WHEN MXGRND CALLS SPREAD.
      EDA(I)=ZTERM(J)/X(I)
C
      ETA=EDA(I)
C
C** CHECK VALUE OF ETA TO AVOID POSSIBLE ERRORS.
C** (ETA**POWER, WHERE ETA<O, AND OVERFLOW)
      IF(ETA.LT.1.E-10)ETA=1.E-10
```

```
      IF(ETA.GT.100.)ETA=100.
C
      TERM2(I)=TERM1*EXP(-1.*ETA)
C
C** CALCULATE SPREAD FUNCTION
      C2(I,J)=TERM2(I)*(GB/GA*KUMMER(B,A,ETA)-ETA**B*V(0,B,A,ETA))
C
C** LIMIT RANGE OF C2 TO AVOID POSSIBLE ERRORS IN FUTURE CALCULATIONS.
      IF(C2(I,J).LT.1.E-25)C2(I,J)=1.E-25
      IF(C2(I,J).GT.1.E+25)C2(I,J)=1.E+25
C
   10 CONTINUE
   20 CONTINUE
      RETURN
      END
C
      FUNCTION BESSEL(ORDER,ARG)
C
C*********************************************************************
C*                                                                   *
C*  FUNCTION BESSEL IS A MODIFIED BESSEL FUNCTION OF THE FIRST KIND.  *
C*  THIS FUNCTION IS REQUIRED TO SOLVE THE INFINITE LINE SOURCE      *
C*  EQUATION (SEE SUBROUTINE INLINE).  FUNCTION BESSEL IS ALSO A PART *
C*  OF THE ELEVATED POINT SOURCE SOLUTION (SEE SUBROUTINE POINT).  THE *
C*  FORM OF THIS FUNCTION IS AN INFINITE SERIES WITH RAPID CONVERGENCE *
C*  PROPERTIES.                                                      *
C*                                                                   *
C*********************************************************************
C*                                                                   *
C*  ARGUMENTS:                                                       *
C*                                                                   *
C*  NAME     IN/OUT    TYPE    DESCRIPTION               UNITS       *
C*  ----     ------    ----    -----------               -----       *
C*  ORDER      IN       R      ORDER OF THE FUNCTION       -         *
C*  ARG        IN       R      ARGUMENT OF THE FUNCTION    -         *
C*                                                                   *
C*  IMPORTANT NOTE: FUNCTION BESSEL IS INTENDED ONLY FOR USE WITH A  *
C*                  NEGATIVE FRACTIONAL ORDER. (THIS IS ALWAYS THE   *
C*                  CASE WITHIN TXLINE).                             *
C*                                                                   *
C*********************************************************************
C*                                                                   *
C*  USES: -                                                          *
C*  USED BY: INLINE, POINT                                           *
C*                                                                   *
C*********************************************************************
C
C
C** THE GAMMA FUNCTION IS A FORTRAN BUILT IN FUNCTION.
      GAMM=GAMMA(ORDER+1.)
C
      P=0.
      PFACT=1.
C
C** CALCULATE VALUE OF 1ST TERM IN SERIES
      BESSEL=(ARG/2.)**(ORDER+2.*P)/(PFACT*GAMM)
C
   10 P=P+1.
      PFACT=PFACT*P
C
C** RECURSIVE PROPERTY OF THE GAMMA FUNCTION IS USED
      GAMM=(P+ORDER)*GAMM
C
      EX=ALOG(ARG/2.)*(ORDER+2.*P)
C
C** CHECK VALUE OF EX TO PREVENT UNDERFLOW OR OVERFLOW
      IF(EX.GT.100.)EX=100.
      IF(EX.LT.-100.)EX=-100.
C
C** CALCULATE THE VALUE OF THE NEXT TERM IN THE SERIES
      TERM=EXP(EX)/(PFACT*GAMM)
C
```

```
C** ADD TERM TO THE TOTAL SUM
      BESSEL=BESSEL+TERM
C
C** SUMMATION IS ENDED AFTER 30 TERMS IF CONVERGENCE CRITERION HAS NOT
C** YET BEEN SATISFIED.
      IF(P.GT.30.)GO TO 30
C
C** CONVERGENCE CHECK
      IF((ABS(TERM)/BESSEL).GT.0.0001)GO TO 10
C
   30 RETURN
      END
C
      REAL FUNCTION KUMMER(B,A,ETA)
C
C*********************************************************************
C*                                                                   *
C*  THE FUNCTION KUMMER IS A CONFLUENT HYPERGEOMETRIC FUNCTION WHICH *
C*  IS A SOLUTION TO KUMMER'S EQUATION.  THIS FUNCTION APPEARS IN THE *
C*  SOLUTION OF THE 'SPREAD' FUNCTION (SEE SUBROUTINE SPREAD).  THE   *
C*  FORM OF THE KUMMER FUNCTION IS AN INFINITE SERIES WITH RAPID CON- *
C*  VERGENCE PROPERTIES.                                              *
C*                                                                   *
C*********************************************************************
C*                                                                   *
C*  ARGUMENTS:                                                       *
C*                                                                   *
C*  NAME      IN/OUT     TYPE     DESCRIPTION                 UNITS  *
C*  ----      ------     ----     -----------                 -----  *
C*  B           IN         R      CONSTANT =                    -    *
C*                                2./(1.+2.*ALPHA)                   *
C*                                                                   *
C*  A           IN         R      CONSTANT =                    -    *
C*                                (1.+ALPHA)/(1.+2.*ALPHA)           *
C*                                                                   *
C*  ETA         IN         R      DIMENSIONLESS PARAMETER       -    *
C*                                (SEE PROJECT REPORT)               *
C*                                                                   *
C*********************************************************************
C*                                                                   *
C*  USES: -                                                          *
C*  USED BY: SPREAD, MXGRND                                          *
C*                                                                   *
C*********************************************************************
C
C
C** SET VALUE OF THE 1ST TERM IN THE SERIES
      KUMMER=1.
C
      AN=1.
      BN=1.
      NTERM=1
      NFACT=1
    5 AN=AN*(A+FLOAT(NTERM-1))
      BN=BN*(B+FLOAT(NTERM-1))
      ETAN=ETA**NTERM
C
C** CALCULATE THE VALUE OF THE NEXT TERM IN THE SERIES
      TERM=(BN*ETAN)/(AN*FLOAT(NFACT))
C
C** ADD TERM TO THE TOTAL SUM
      KUMMER=KUMMER+TERM
C
C** SUMMATION IS ENDED AFTER 20 TERMS IF CONVERGENCE CRITERION HAS
C** NOT YET BEEN SATISFIED.
      IF(NTERM.GT.20)GO TO 10
C
      NTERM=NTERM+1
      NFACT=NFACT*NTERM
C
C** CONVERGENCE CHECK
      IF((TERM/KUMMER).GT.0.001)GO TO 5
```

```
C
   10 CONTINUE
      RETURN
      END
C
      FUNCTION V(ID.B,A,ETA)
C
C*********************************************************************
C*                                                                   *
C*  FUNCTION V IS AN ALLIED FUNCTION TO THE KUMMER FUNCTION (SEE REAL *
C*  FUNCTION KUMMER).  V IS ALSO AN INFINITE SERIES WITH RAPID CON-   *
C*  VERGENCE PROPERTIES.  THIS FUNCTION IS A PORTION OF THE 'SPREAD'  *
C*  FUNCTION SOLUTION (SEE SUBROUTINE SPREAD).                        *
C*                                                                   *
C*  FUNCTION V MAY BE USED TO GIVE THE FIRST OR SECOND DERIVATIVE OF  *
C*  V (WITH RESPECT TO ETA).  THESE DERIVATIVES ARE BOTH NEEDED IN    *
C*  SUBROUTINE MXGRND.                                                *
C*                                                                   *
C*********************************************************************
C*                                                                   *
C*  ARGUMENTS:                                                       *
C*                                                                   *
C*  NAME     IN/OUT    TYPE    DESCRIPTION                 UNITS     *
C*  ----     ------    ----    -----------                 -----     *
C*  ID         IN        I     DERIVATIVE FLAG               -       *
C*                             O=ACTUAL FUNCTION                     *
C*                             1=1ST DER. W/R TO ETA                 *
C*                             2=2ND DER. W/R TO ETA                 *
C*                                                                   *
C*  B          IN        R     CONSTANT =                    -       *
C*                             2./(1.+2.*ALPHA)                      *
C*                                                                   *
C*  A          IN        R     CONSTANT =                    -       *
C*                             (1.+ALPHA)/(1.+2.*ALPHA)              *
C*                                                                   *
C*  ETA        IN        R     DIMENSIONLESS PARAMETER       -       *
C*                             (SEE PROJECT REPORT)                  *
C*                                                                   *
C*********************************************************************
C*                                                                   *
C*  USES: -                                                          *
C*  USED BY: SPREAD, MXGRND                                          *
C*                                                                   *
C*********************************************************************
C
      COMMON /INFO/NX,NZ,KILL(6,6),JUMP,KILTOW(6)
      COMMON /SKIP2/TOP1,DENOM1,BX2,BP1,BPA
C
C** JUMP IF JUMP=9 TO AVOID REDUNDANT CALCULATIONS
      IF(JUMP.EQ.9)GO TO 1
C
      BX2=2.*B
      BP1=B+1.
      BPA=B+A
C
C** THE GAMMA FUNCTION IS A FORTRAN BUILT IN FUNCTION.
      TOP1=GAMMA(BX2)
      DENOM1=GAMMA(BP1)*GAMMA(BPA)
C
    1 TOP=TOP1
      DENOM=DENOM1
      IDP1=ID+1
C
C*********************************************************************
C** THIS SECTION GIVES THE VALUE OF THE 1ST TERM IN THE SERIES.
C
      GO TO (3,2,2),IDP1
    2 V=O.
      GO TO 4
    3 V=TOP/DENOM
    4 R=1.
C
```

```
C***********************************************************************
C
C** THE RECURSIVE PROPERTY OF THE GAMMA FUNCTION IS USED HERE.
    5 TOP=TOP*(BX2+R-1.)
      DENOM=DENOM*(BP1+R-1.)*(BPA+R-1.)
C
C***********************************************************************
C** THIS SECTION CALCULATES THE VALUE OF EACH ADDITIONAL TERM.
C
      GO TO (8,7,6),IDP1
    6 TERM=(R-1.)*R*ETA**(R-2.)*TOP/DENOM
      GO TO 9
    7 TERM=R*ETA**(R-1.)*TOP/DENOM
      GO TO 9
    8 TERM=(TOP*ETA**R)/DENOM
C
C***********************************************************************
C
C** ADD TERM TO THE TOTAL SUM
    9 V=V+TERM
C
C** SUMMATION IS ENDED AFTER 20 TERMS IF CONVERGENCE CRITERION HAS NOT
C** YET BEEN SATISFIED.
      IF(R.GT.20.)GO TO 10
C
      R=R+1.
      IF(R.LT.3.)GO TO 5
C
C** CONVERGENCE CHECK
      IF(ABS(TERM/V).GT.0.001)GO TO 5
C
   10 RETURN
      END
```

APPENDIX B

SUBROUTINE STRUCTURE OF THE TXLINE MODEL

SUBROUTINE STRUCTURE OF THE TXLINE MODEL *

MAIN - 1) checks validity of all input parameters (writes error or warning messages if necessary), and performs any necessary conversions,

2) calls SUBROUTINE JRWIND which returns the power law parameters,

3) calls the appropriate line source routine; if $\theta \geq 70°$ calls SUBROUTINE INLINE, if $\theta < 70°$ calls SUBROUTINE JRLINE,

4) repeats '3)' for every line source,

5) sums the concentration predictions for all line sources (assumes the 'superposition of concentration' principle),

6) converts concentrations to the desired units,

7) writes output.

JRWIND - 1) applies the low wind speed correction factor when applicable,

2) calculates the power law parameters so that the power law best fits the log-law.

INLINE - calculates C_o, the infinite line source concentration.

JRLINE - integrates the appropriate point source equation in the following manner:

1) calls SUBROUTINE MXGRND which returns the starting point of the integration,

2) calculates the maximum point source spacing, Δp_{max}.

3) adds point source concentrations in each direction until the effect of summing more points becomes negligible. (Point source concentrations are calculated by calling SUBROUTINE POINT).
NOTE: Point sources are placed Δp_{max} distance apart.

* see Rodden, J.B., "A Non-Fickian Gradient Transport Model to Predict Air Pollution Dispersion from Roadways," M.S. Thesis, Texas A&M University, 1983.

POINT - calculates either:

1) the concentration due to a ground level point source,

or 2) the concentration due to an elevated point source.

MXGRND - 1) determines a first guess, P_o^1, of the starting point for the numerical integration,

2) using P_o^1 as the first guess applies Newton's method to solve for P_o^N, the point where the numerical integration is started.

KUMMER* - calculates the value of Kummer's function.

V* - calculates the value of the V function. May also be used to calculate the 1st and 2nd derivatives of the V function.

BESSEL* - calculates the value of the modified Bessel function of the first kind for any arbitrary negative order using an infinite series. The recursive property of the gamma function was used in order to save computer time. Results of this subroutine were checked against values found in the literature** and found to be accurate to the fourth decimal place.

* called as needed by the other subroutines.

** Lowen, A.D., and Greenberg, L.M., "Tables of Bessel Functions of Fractional Order," Columbia University Press, New York, 1949.