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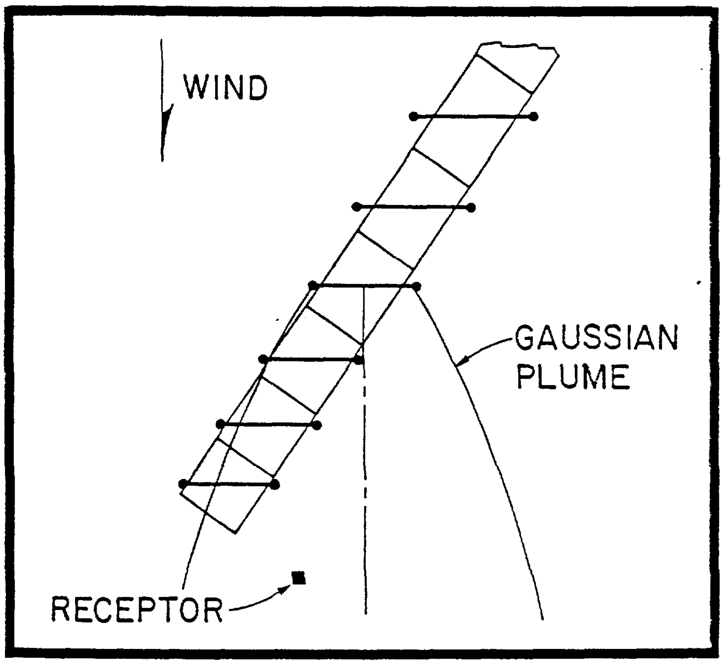
CALINE4 – A Dispersion Model For Predicting Air Pollutant Concentrations Near Roadways



FINAL REPORT
NOV. 1984
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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF NEW TECHNOLOGY AND RESEARCH

CALINE4 - A DISPERSION MODEL FOR PREDICTING AIR POLLUTION CONCENTRATIONS NEAR ROADWAYS

REVISED NOVEMBER 1986
REVISED JUNE 1989*

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16. ABSTRACT
A description of the California Line Source Dispersion Model, CALINE4, is given. The model uses traffic emissions, site geometry and meteorology to predict air pollutant concentrations near roadways. Predictions can be made for carbon monoxide, nitrogen dioxide and suspended particles. Options for modeling near intersections, parking lots, elevated or depressed freeways, and within canyons are given. A modal emissions model developed for the CALINE4 intersection link option is described. Also, an adjustment for transient emissions is developed. Computer documentation and user instructions for CALINE4 are included in the report.

Sensitivity of the model to various input parameters is illustrated in a series of model response curves. The model is verified using data from five separate field studies. Two of the studies were conducted as part of this research and are described in detail. Data from one of these, a highway tracer gas release experiment, are presented in an appendix to the report.

17. KEY WORDS Air pollution, highways, air quality, transportation, line source, dispersion model, carbon monoxide, suspended particles, nitrogen dioxide.

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mmm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2) acres	.09290 .4047	square metres (m^2) hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) kips (1000 lbs)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (ft-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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1. INTRODUCTION

CALINE4 is the last in a series of line source air quality models developed by the California Department of Transportation (Caltrans). It is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion over the roadway.

The purpose of the model is to assess air quality impacts near transportation facilities. Given source strength, meteorology and site geometry, CALINE4 can predict pollutant concentrations for receptors located within 500 meters of the roadway. In addition to predicting concentrations of relatively inert pollutants such as carbon monoxide (CO), the model can predict nitrogen dioxide (NO2) and suspended particle concentrations. It also has special options for modeling air quality near intersections, street canyons and parking facilities.

Historically, the CALINE series of models required relatively minimal input from the user. Spatial and temporal arrays of wind direction, wind speed and diffusivity were not needed by the models. While CALINE4 uses more input parameters than its predecessors, it must still be considered an extremely easy model to implement. For most applications, optional inputs can be bypassed and many other inputs can be assigned assumed worst-case values.

More complex approaches to dispersion modeling are unnecessary for most applications because of the uncertainties in estimating emission factors and traffic volumes for future years. CALINE4's accuracy is well balanced with the accuracy of state of the art predictive models for emissions and traffic. The new model also possesses greater flexibility than earlier versions at little cost to the user in terms of input complexity.

This report is meant to help the potential user of CALINE4 understand and apply the model. The user should become thoroughly familiar with the workings of the model and, particularly, its limitations. This knowledge will help one decide when and how to use CALINE4. The user should also become familiar with the response of the model to changes in various input parameters. This information is contained in the sensitivity analysis portion of this report. A model verification analysis using data from five separate field studies is also summarized in the report. User instructions have been added along with several examples of CALINE4 applications illustrating use of the model in a variety of situations. A companion report containing recommended worst-case meteorological input parameters for CALINE4 will be issued soon.

2. BACKGROUND

In response to the National Environmental Policy Act of 1969, Caltrans published its first line source dispersion model for inert gaseous pollutants in 1972(1). Model verification using the rudimentary field observations then available was inconclusive.

In 1975, the original model was replaced by a second generation model, CALINE2(2). The new model was able to compute concentrations for depressed sections and for winds parallel to the highway alignment. The two models were compared using 1973 CO bag sampling data from Los Angeles, and CALINE2 proved superior.

Sometime after the dissemination of CALINE2, users began to report suspiciously high predictions by the model for stable, parallel wind conditions. As a result, a more complete verification of the model was undertaken by Caltrans using the 1974-75 Caltrans Los Angeles Data Base(3), the 1975 General Motors Sulfate Experiment Data Base(4), and the 1974-75 Stanford Research Institute Data Base(5). Comparison of predicted and measured results showed that the predicted concentrations near the roadway were two to five times greater than measured values for stable, parallel wind conditions(6). An independent study by Noll concluded that CALINE2 overpredicted for parallel winds by an average of 66% for all stabilities(7).

Overpredictions by CALINE2 for the stable, parallel wind case were particularly significant. This configuration was usually selected as the worst-case condition for predicting highway impacts on air quality in the microscale region. Beneficial highway projects could be delayed or even cancelled on the basis of inaccurate results from CALINE2.

Additional inadequacies in the CALINE2 model also needed rectification. The inability to specify line source length and surface roughness severely limited the number of situations in which the model could be properly applied. Also, to predict impacts from multiple sources, a series of runs with varying receptor distances were required. Such an unwieldy procedure was time consuming and could lead to erroneous results.

A federally-funded research project entitled, "Distribution of Air Pollutants Within the Freeway Corridor", was initiated by Caltrans in 1978 to correct these deficiencies. As part of this project, an interim report was issued in 1979 implementing a completely new version of the model, CALINE3(8). The new model retained the basic Gaussian dispersion methodology, but used new vertical and horizontal dispersion curves modified for the effects of surface roughness, averaging time and vehicle-induced turbulence. It also replaced the virtual point source formulation used in CALINE2 with an equivalent finite line source formulation, and added multiple link capabilities to the model format.

A second interim report issued in 1980 gave a detailed account of the background and development of CALINE3(9). It also contained a thorough literature review on applications of the Gaussian method to line source modeling. Most of this background material is still relevant to the CALINE4 model.

This document represents the final report for the research project initiated in 1978. It contains background and user documentation for the CALINE4 model, as well as a description of the two field studies undertaken as part of the research project. Results from one of these field studies are summarized in tabular form at the back of the report. The data base for the second study is available on request from Caltrans.

CALINE4 should be thought of as an updated and expanded version of CALINE3. While the models use different methods for developing their vertical and horizontal dispersion curves, the final results differ very little by air quality modeling standards. For the most part, the technical differences between the two models represent "fine tuning" of the Gaussian method (as applied to line source modeling) and the mixing zone model. The real differences between the two models are in the areas of improved input/output flexibility and expanded capabilities. These improved and expanded features of CALINE4 are described in detail in the body of this report.

3. CONCLUSIONS AND RECOMMENDATIONS

The comparisons of CALINE3 and CALINE4 made in the verification analysis portion of this report demonstrate improved performance by the new model. It is concluded that the technical refinements contained in CALINE4 better describe the dispersion process near roadways. In addition, the greater flexibility and extended capabilities of the new model make it adaptable to many modeling applications not appropriate for CALINE3. For these reasons, it is recommended that CALINE4 replace CALINE3 as the official line source air quality model used by Caltrans.

4. IMPLEMENTATION

1. The CALINE4 program described in this report is operational and available to all Caltrans personnel through the California statewide VM/CMS timesharing computer system. It may be accessed via the Caltrans library disk (TRCLIB).

2. An air quality training course covering CALINE4 and other new assessment procedures is available for state personnel. In addition, this report will be distributed statewide to the Districts.

3. A report containing recommended worst-case meteorological scenarios is in preparation. It should be available some three to six months after issuance of this report. The scenarios will help the user determine appropriate input values for CALINE4 based on geography, land use and time of day.

5. MODEL DESCRIPTION

5.1 Link-Element Algorithm

CALINE4 divides individual highway links into a series of elements from which incremental concentrations are computed and then summed to form a total concentration estimate for a particular receptor location (Figure 1). The receptor distance is measured along a perpendicular from the receptor to the link centerline. The first element, $\varepsilon 0$ is formed as a square with sides equal to the highway width. Its location is determined by the roadway-wind angle, PHI. For PHI>45°, the center of the first element is located directly upwind of the receptor. For PHI<45°, the location of $\varepsilon 0$ remains constant and equal to its position at PHI=45°. This positional adjustment for $\varepsilon 0$ helps achieve smooth model response for receptors very near the link. The positions and lengths of subsequent elements are determined by the following formula:

$$EL = W*BASE^{NE}, \tag{5-1}$$

where EL = Element Length

W = Highway Width

NE = Element Number

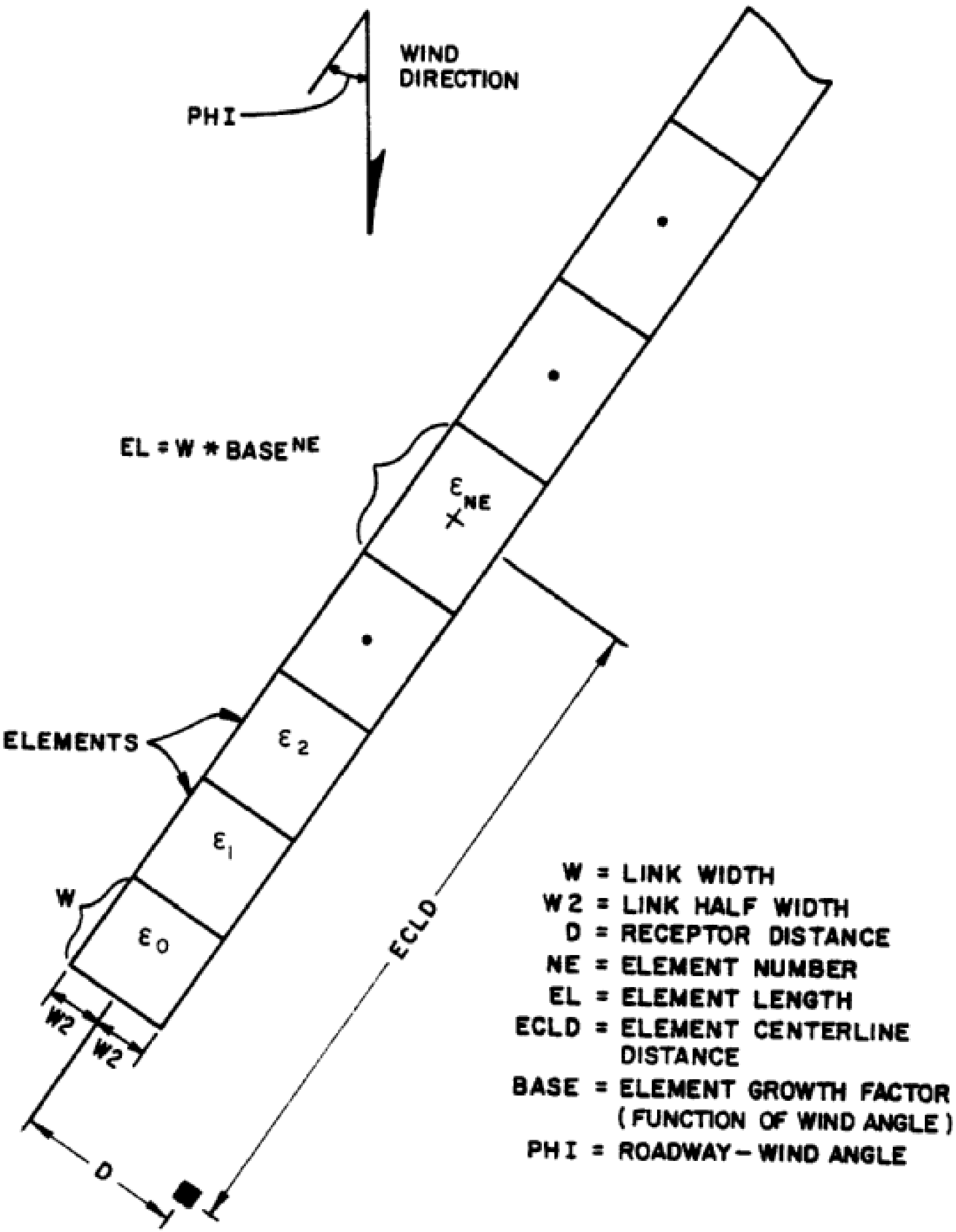
BASE = Element Growth Factor

and

$$BASE = 1.1 + \frac{PHI^3}{2.5 \times 10^5} \tag{5-2}$$

with PHI in degrees.

(Note: Capitalized variables shown in text and figures are identical to those used in the computer coding.)



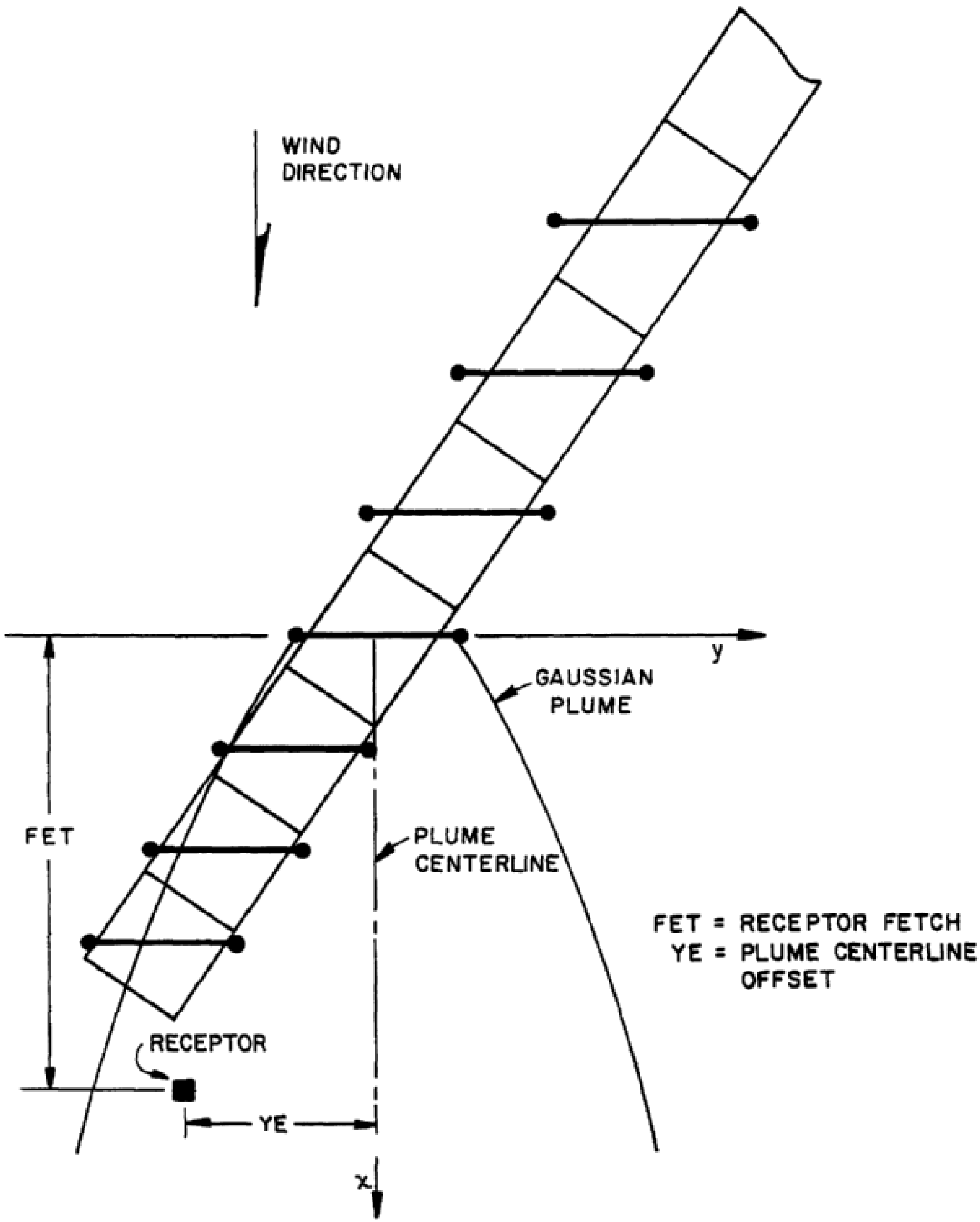
ELEMENT SERIES USED BY CALINE 4

FIGURE 1

As element resolution becomes less important at greater distances from the receptor, elements become large in accordance with Equation 5-1. The element growth factor, described by Equation 5-2, represents a compromise between accuracy and computational efficiency. Any inaccuracies generated by this approximation fall well below the level of significance reported by the model. The square shape the initial element is consistent with the vertical dispersion curves used in CALINE4. These have been calibrated for an initial distance equal to the link half-width (W2).

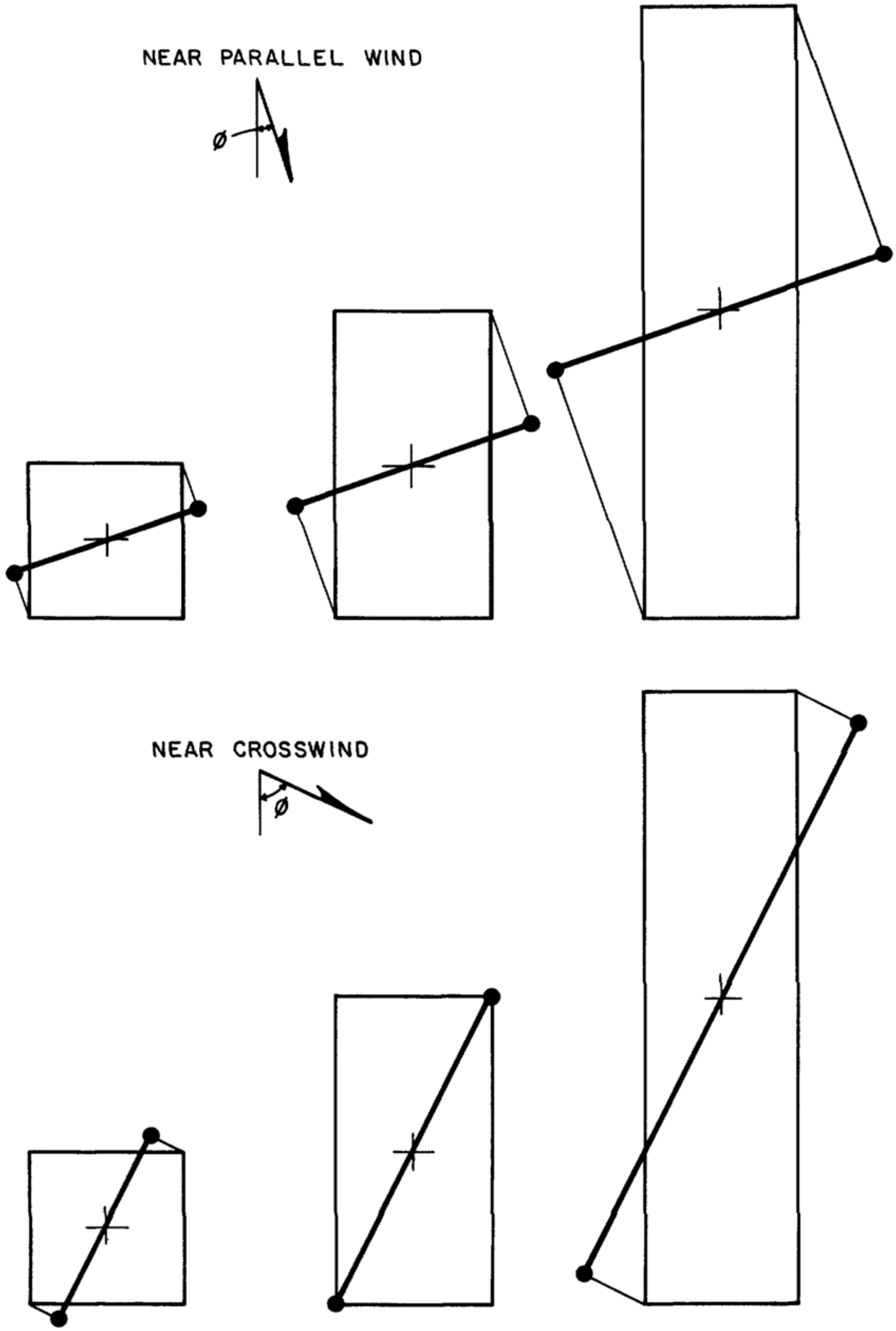
Each element is modeled as an "equivalent" finite line source (FLS) positioned normal to the wind direction and centered at the element midpoint (Figure 2). A local x-y coordinate system aligned with the wind direction and originating at the element midpoint is defined for each element. The emissions occurring within an element are assumed to be released along the FLS representing the element. The emissions are then assumed to disperse in a Gaussian manner downwind from the element. The length and orientation of the FLS are functions of the element size and roadway-wind angle (Figure 3).

In order to distribute emissions in an equitable manner, each element is divided into three sub-elements: a central sub-element and two peripheral sub-elements (Figure 4). These are referred to as ZON1, ZON2 and ZON3 in the computer program. The geometry of the sub-elements is a function of element size and roadway-wind angle. A lineal source strength (QE) for the central sub-element is computed using the geometry shown in Figure 5. The emission rate is assumed to be uniform throughout the element for purposes of this computation. Emissions for the peripheral sub-elements are modeled as decreasing linearly to zero at the ends of the FLS.

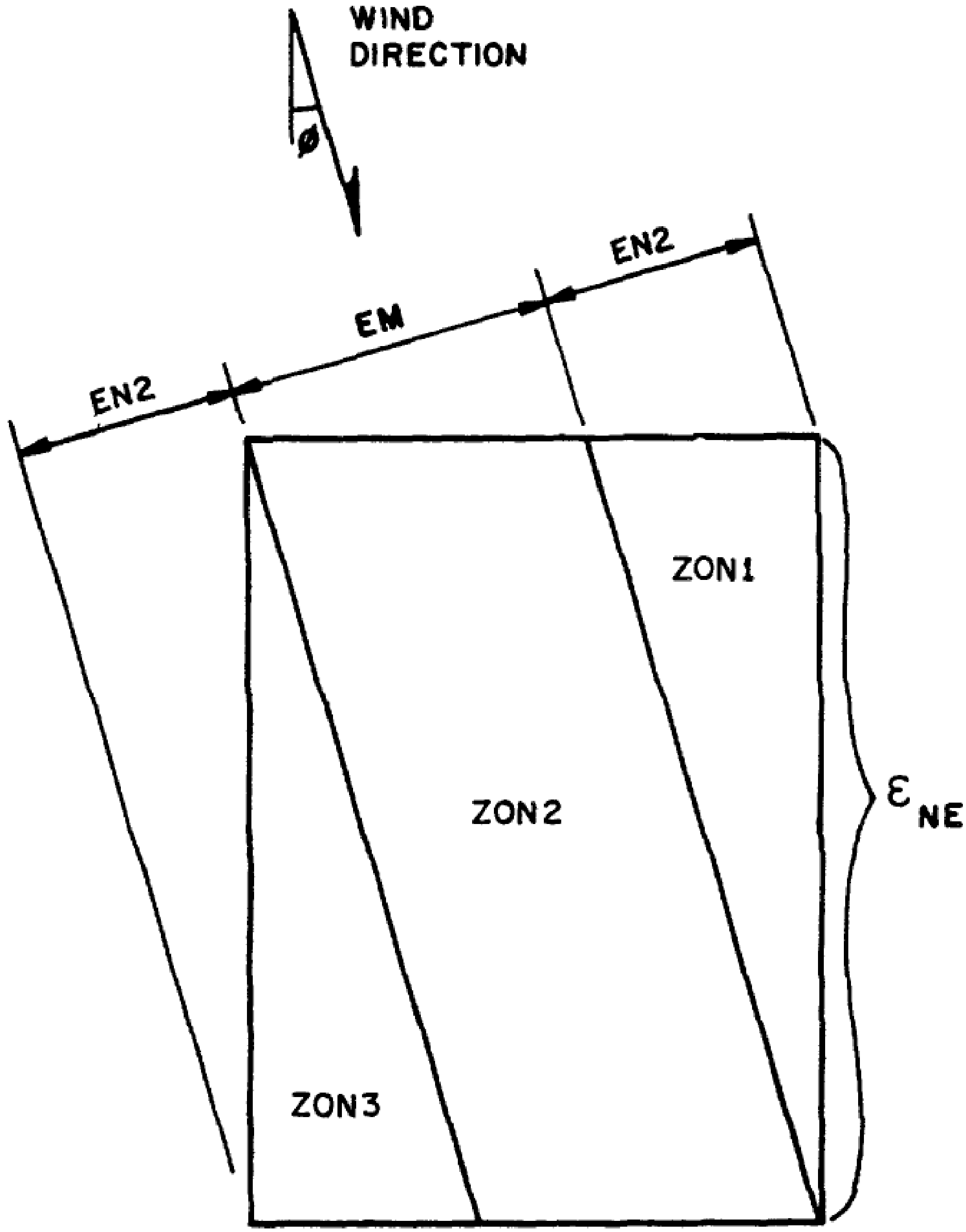


ELEMENT SERIES REPRESENTED BY
SERIES OF EQUIVALENT FINITE LINE SOURCES

FIGURE 2

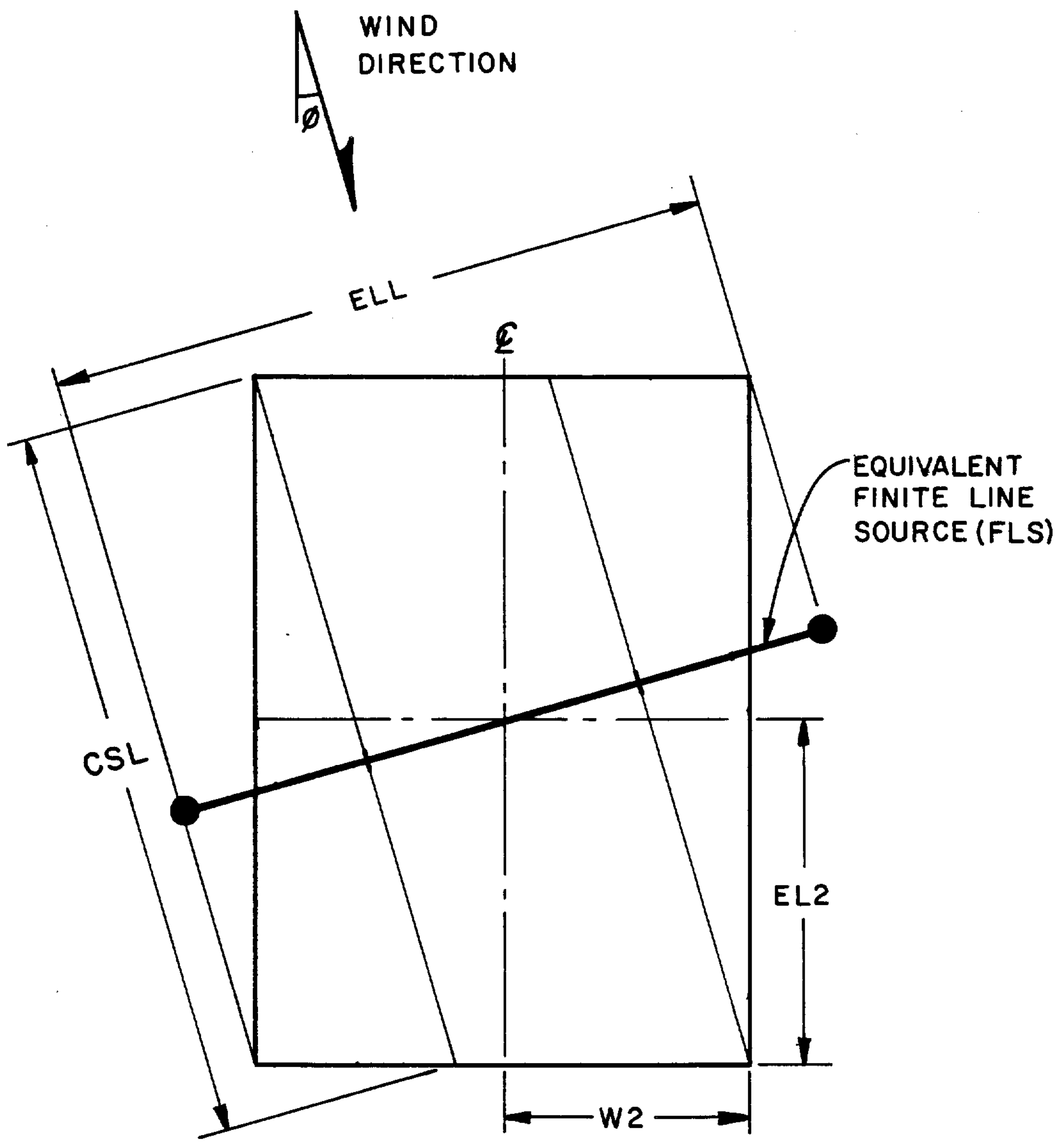


EQUIVALENT FINITE LINE SOURCE REPRESENTATION FOR
VARIOUS ELEMENT SIZES AND WIND ANGLES
FIGURE 3



CALINE 4 SUB-ELEMENTS

FIGURE 4



ELL = EQUIVALENT LINE LENGTH
CSL = CENTRAL SUB-ELEMENT LENGTH

CALINE 4 FINITE LINE SOURCE
ELEMENT REPRESENTATION

FIGURE 5

Downwind concentrations from the element are modeled using the crosswind FLS Gaussian formulation. Consider the receptor concentration attributable to an infinitesimal FLS segment, dy, shown in Figure 6:

$$dC = \frac{q\,dy}{2\pi u \sigma_y \sigma_z}\left[\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\right]\left\{\exp\left[\frac{-(z-H)^2}{2\sigma_z^2}\right] + \exp\left[\frac{-(z+H)^2}{2\sigma_z^2}\right]\right\}, \qquad (5\text{-}3)$$

where

dC = Incremental Concentration

q = Lineal Source Strength

u = Wind Speed

H = Source Height

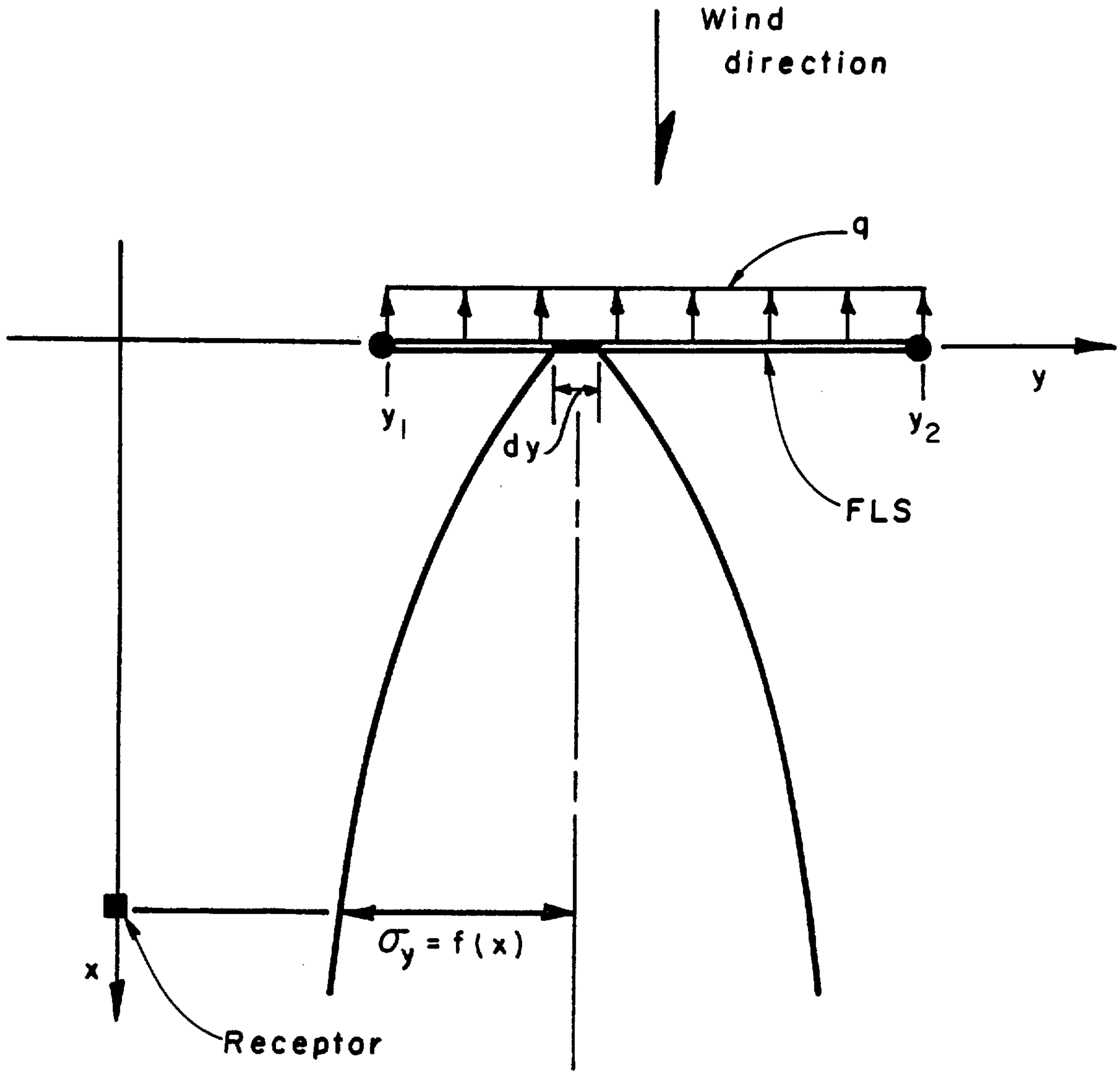
σ_y, σ_z = Horizontal and Vertical Dispersion Parameters.

Since σ_z is constant with respect to y, let

$$A = \exp\left[\frac{-(z-H)^2}{2\sigma_z^2}\right] + \exp\left[\frac{-(z+H)^2}{2\sigma_z^2}\right] . \qquad (5\text{-}4)$$

Integrating over the FLS length yields

$$C = \frac{Aq}{2\pi u \sigma_y \sigma_z}\int_{y_1}^{y_2} \exp\left(\frac{-y^2}{2\sigma_y^2}\right) dy . \qquad (5\text{-}5)$$



q = UNIFORM LINE SOURCE STRENGTH
σ_y = HORIZONTAL DISPERSION PARAMETER

GENERALIZED FINITE LINE SOURCE (FLS)

FIGURE 6

Note that σ_y and σ_z are functions of x, not y. Substituting $p=y/\sigma y$ and $dp=dy/\sigma y$ gives

$$C = \frac{Aq}{2\pi u \sigma_y \sigma_z} \int_{y_1/\sigma_y}^{y_2/\sigma_y} \exp\left(\frac{-p^2}{2}\right) \sigma_y \, dp \; . \qquad (5\text{-}6)$$

Backsubstituting for A and removing σy from the integral leaves

$$C = \frac{q}{2\pi \sigma_z u} \left\{ \exp\left[\frac{-(z-H)^2}{2\sigma_z^2}\right] + \exp\left[\frac{-(z+H)^2}{2\sigma_z^2}\right] \right\} \int_{y_1/\sigma_y}^{y_2/\sigma_y} \exp\left(\frac{-p^2}{2}\right) dp \, . \qquad (5\text{-}7)$$

This can be rewritten as

$$C = \frac{q}{\sqrt{2\pi}\, \sigma_z u} \left\{ \exp\left[\frac{-(z-H)^2}{2\sigma_z^2}\right] + \exp\left[\frac{-(z+H)^2}{2\sigma_z^2}\right] \right\} \cdot PD, \qquad (5\text{-}8)$$

where

$$PD = \frac{1}{\sqrt{2\pi}} \int_{y_1/\sigma_y}^{y_2/\sigma_y} \exp\left(\frac{-p^2}{2}\right) \, dp = \text{Normal Probability Density Function.} \qquad (5\text{-}9)$$

CALINE4 computes receptor concentrations as a series of incremental contributions from each element FLS. The FLS is divided into segments of length equal to σy or a fraction thereof (Figure 7). The source strength for each segment is determined by multiplying QE by a weighting factor (WT). This factor accounts for the linear decrease of emissions across the peripheral sub-elements. The effect of horizontal dispersion is quantified by Equation 5-9. This integral represents a portion of the area under the unit normal curve with standard deviation equal to σy as pictured in Figure 7. The model computes FLS contributions for a maximum of six segments within $\pm 3\sigma y$ of the receptor. Results beyond this range are insignificant and would add appreciably to computation time. The total receptor concentration (C) from a particular roadway link is computed as follows:

$$C = \frac{1}{\sqrt{2\pi}U} * \sum_{i=1}^{n} \left\{ \frac{1}{SGZ_i} * \sum_{k=-CNT}^{CNT} \left[\exp\left(\frac{-(Z-H+2*k*L)^2}{2*SGZ_i^2} \right) + \exp\left(\frac{-(Z+H+2*k*L)^2}{2*SGZ_i^2} \right) \right] * \sum_{j=1}^{6} (WT_j * QE_i * PD_{ij}) \right\}, \quad (5\text{-}10)$$

where

n = Total number of elements

CNT = Number of multiple reflections required for convergence

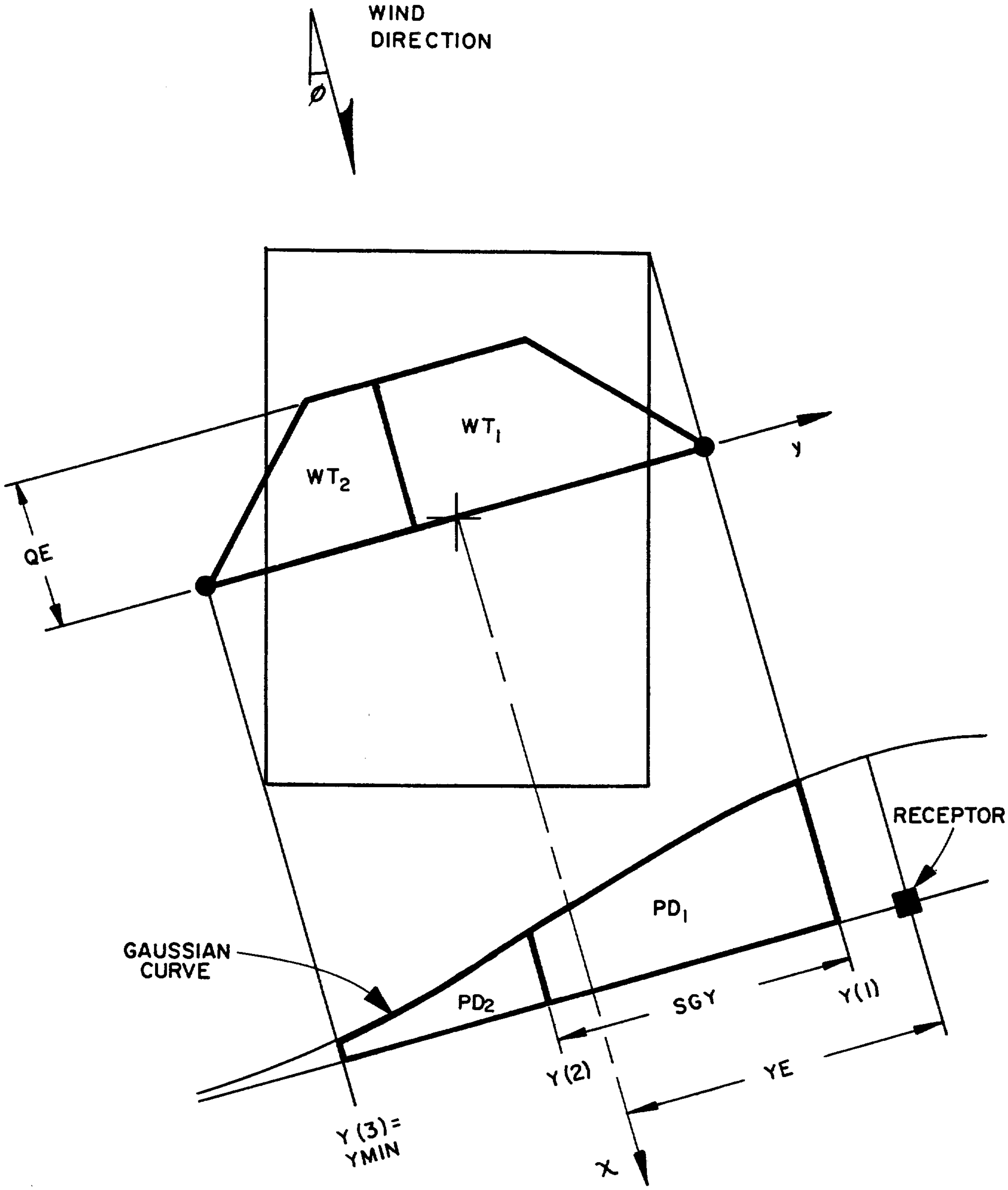
U = Wind speed

L = Mixing height (MIXH in coding)

SGZ_i = σ_z as f(x) for ith element

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

WT_j = Source strength weighting factor for jth FLS segment



QE = EQUIVALENT LINE SOURCE STRENGTH
PD = PROBABILITY DENSITY
SGY = HORIZONTAL DISPERSION PARAMETER
YE = PLUME CENTERLINE OFFSET

CALINE4 INTEGRATED FINITE LINE SOURCE AND
SUB-ELEMENT MODEL
F1GURE 7

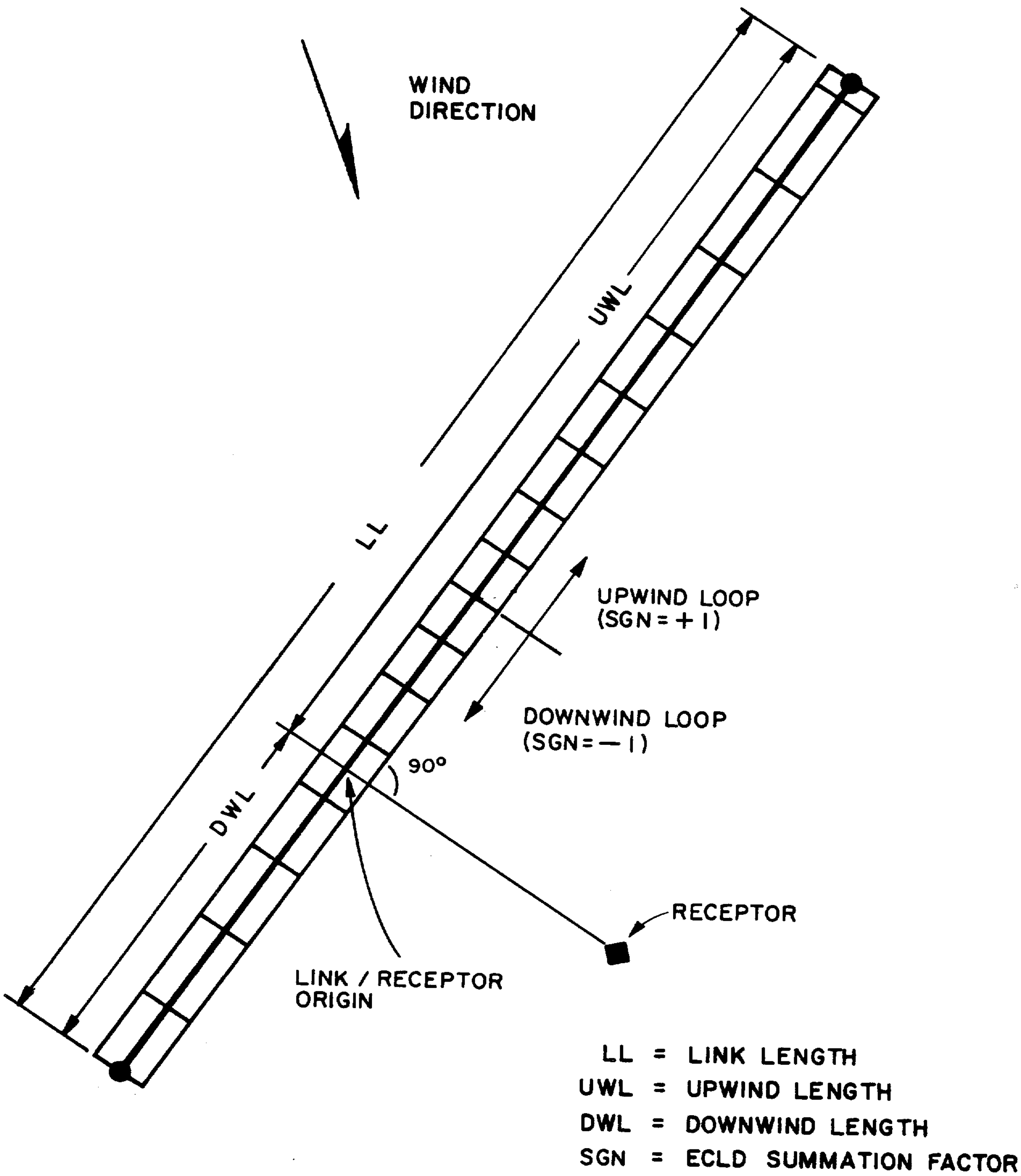
$$PD_{ij} = \frac{1}{\sqrt{2\pi}} \int_{\frac{Y_j}{SGY_i}}^{\frac{Y_{j+1}}{SGY_i}} \exp\left(\frac{-p^2}{2}\right) dp$$

Y_j, Y_j+1 = Offset distances for jth FLS segment

SGY_i = σ_y as f(x) for ith element.

In the computer coding, the offset distances, Yj, are expressed in increments of σy. PDij is calculated by use of a fifth order polynomial (10). Equation 5-10 is computed in the program as three separate factors: FAC1, FAC2 and FAC5. FAC1 accounts for dilution and vertical dispersion by including the effects of wind speed and σz. FAC2 accounts for the horizontal dispersion of the FLS plume. FAC5 contains multiple reflection terms which account for restricted mixing height. These terms are represented in Equation 5-10 by non-zero k indices.

The element summation of the FLS equation is actually initiated twice for each link (Figure 8). The computation takes place first in an upwind direction beginning with ε0. It ends when the element limits go beyond the upwind length (UWL), or when the element contributions fall outside the horizontal dispersion limit of 3σy. In the former case, the length of the last element is modified to conform with the link endpoint. The program then proceeds in the downwind direction starting with an initial square element immediately downwind of ε0, and proceeding until the downwind length (DWL) is exceeded. As soon as a negative receptor fetch (FET, Figure 2) is encountered,



CALINE 4 LINK – ELEMENT REPRESENTATION

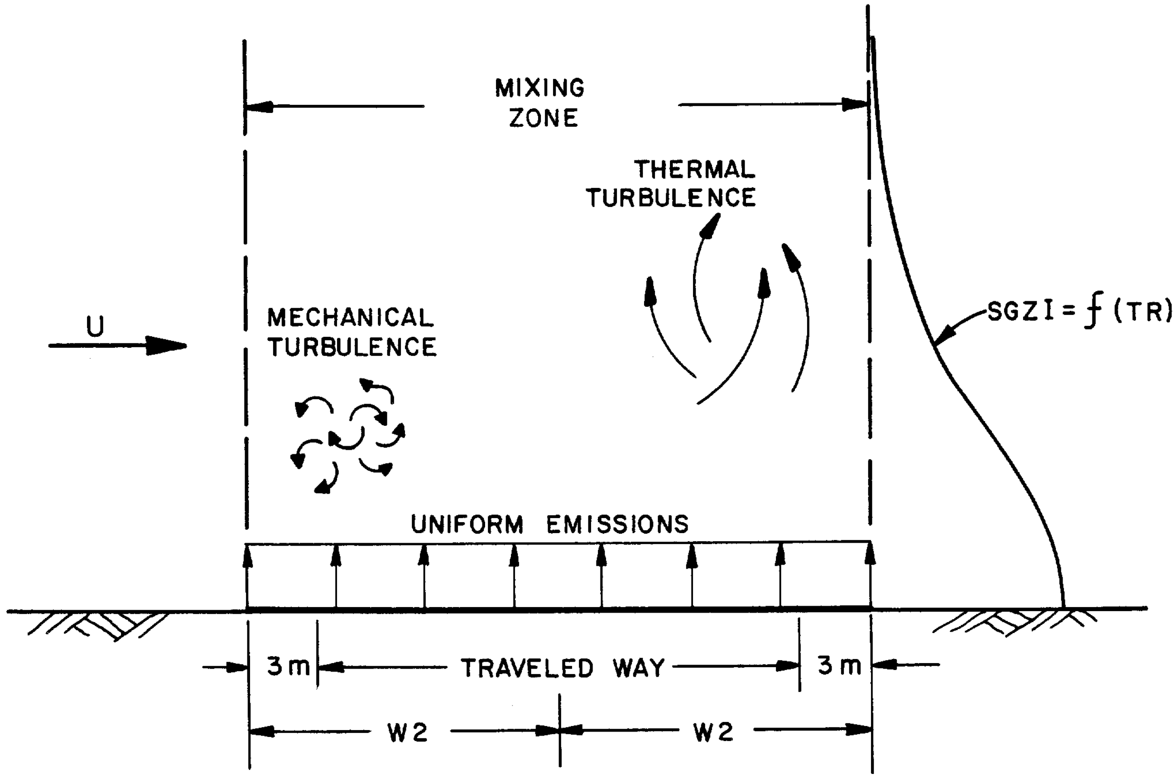
FIGURE 8

the program automatically concludes the downwind loop computations. If a receptor is located within an element or downwind from part of an element, only the upwind portion of the element is used to determine the source strength. All distances along the link, including UWL and DWL, are measured from the intersection of the link centerline and a perpendicular line drawn from the receptor to the link.

5.2 Mixing Zone Model

CALINE4 treats the region directly over the highway as a zone of uniform emissions and turbulence. This is designated as the mixing zone, and is defined as the region over the traveled way (traffic lanes - not including shoulders) plus three meters on either side (Figure 9). The additional width accounts for the initial horizontal dispersion imparted to pollutants by the vehicle wake.

Within the mixing zone, the mechanical turbulence created by moving vehicles and the thermal turbulence created by hot vehicle exhaust are assumed to be the dominant dispersive mechanisms. Evidence indicates that this is a valid assumption for all but the most unstable atmospheric conditions (6). Vehicle emissions are released and rapidly dispersed within the trailing wake of each vehicle. Further initial dispersion occurs through the action of turbulence generated by other passing vehicles. This active release condition differs significantly from the passive release assumed by the standard Gaussian dispersion methodology. To adjust for this, CALINE4 models the initial vertical dispersion parameter (SGZI) as a function of pollutant residence time within the mixing zone.



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

CALINE 4 MIXING ZONE

FIGURE 9

A number of studies have noted a correlation between cross-road wind speed and initial vertical dispersion (5,6,11). Each of these studies has concluded that lower wind speeds result in greater initial vertical dispersion. In CALINE4, it is assumed that the longer a parcel of air resides in the turbulent mixing zone, the greater the amount of initial vertical dispersion the parcel will undergo. The residence time (TR) can be readily defined in terms of the average wind speed. CALINE4 defines mixing zone residence time as

$$TR = \begin{cases} W2/(U*SIN(PHI)), & PHI \geq 45^\circ \\ W2/(U*SIN(45^\circ)), & PHI < 45^\circ \end{cases} \qquad (5\text{-}11)$$

This definition accounts for the additional distance traversed under oblique roadway-wind angles up to 45°. The 45° limitation is imposed because the effects of vehicle induced mechanical turbulence are limited in vertical extent (12). Thermal effects are more persistent, however, and are dealt with through the use of a heat flux adjustment described in Section 5.3.

The equation used by CALINE4 to relate SGZI to TR is

$$\underset{(m)}{SGZI} = 1.5+(\underset{(secs.)}{TR}/10). \qquad (5\text{-}12)$$

This relationship was derived empirically from the General Motors Sulfate Experiment Data Base (4). It differs slightly from the CALINE3 version because of the modified residence time definition (Equation 5-11).

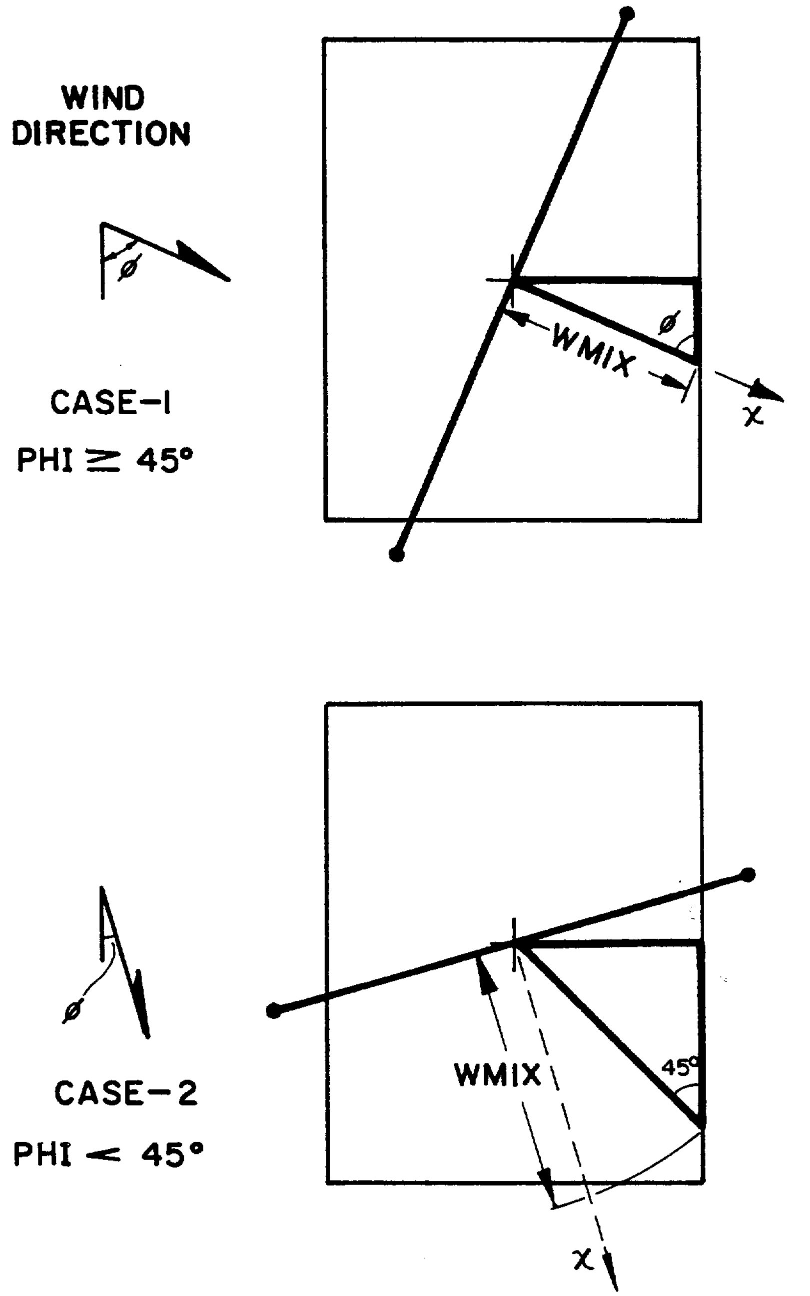
SGZI is treated by CALINE4 as completely independent of surface roughness and atmospheric stability class. Its use provides a way of linking the FLS element approximation to the actual two-dimensional nature of the emissions release.

5.3 Vertical Dispersion Parameter, σz

CALINE4 uses a modified version of the Pasquill-Smith (P-S) vertical dispersion curves (13) to describe the Gaussian vertical dispersion parameter, σz, downwind from roadways. The modified version evolved from an earlier prototype (14), to include the thermal effects of vehicular emissions. The curves are constructed using SGZI from the mixing zone model, a modified value of σz at 10 kilometers incorporating thermal effects (SGZM), and a final value of σz at 10 kilometers for a passive release under ambient stability conditions (SGZF). The reference distance of 10 kilometers (DREF) was chosen as the distance at which the type of release (i.e., active versus passive) would have little effect on the vertical extent of the plume. It is also the maximum distance recommended by Pasquill for power curve approximations to the vertical dispersion curves, and it goes well beyond the distances normally needed for line source dispersion calculations.

The vertical dispersion parameter is assumed to be constant and equal to SGZI over the mixing zone to a distance WMIX from the centerpoint of the FLS (Figure 10) with

$$WMIX = \begin{cases} W2/SIN(PHI) & PHI \geq 45° \\ W2/SIN(45°) & PHI < 45° \end{cases} . \qquad (5\text{-}13)$$



ELEMENT GEOMETRY FOR DETERMINING WMIX

FIGURE 10

At this point, the rate of vertical plume growth follows a modified power curve of the form

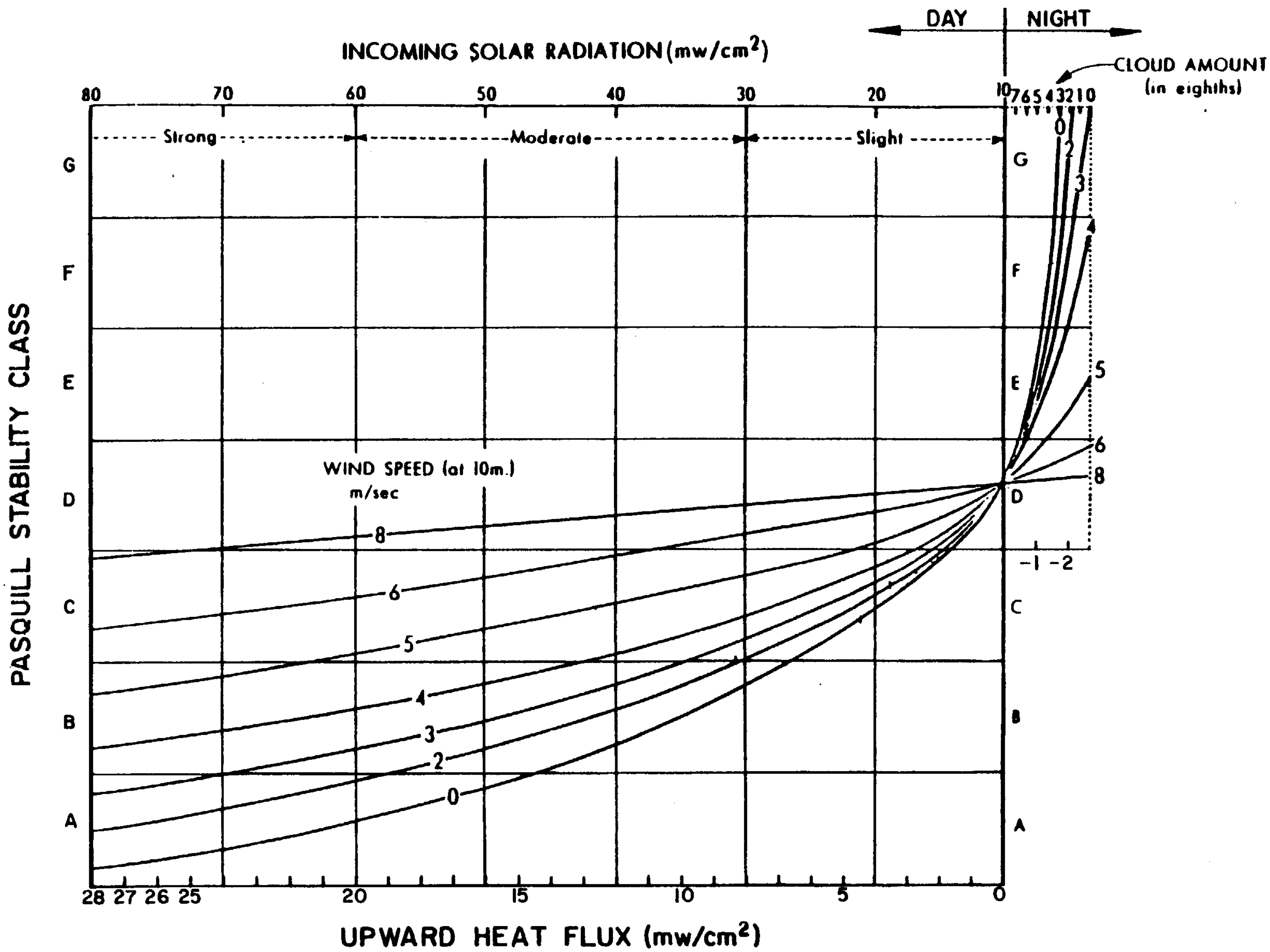
$$SGZ = PZ1*FET^{PZ2}, \qquad (5\text{-}14)$$

where PZ1 and PZ2 are power curve coefficients consistent with SGZI at WMIX and SGZM at DREF, and SGZ is the vertical dispersion parameter, σz, at a distance equal to the downwind fetch (FET) from each element. SGZI comes from the mixing zone model (Equation 5-12). SGZM is the P-S value for σz at DREF adjusted for surface roughness (ZO) and vehicular heat flux. The heat flux adjustment is accomplished by applying a heat flux factor (HFF) to the traffic volume, and using the resulting augmented sensible heat flux in conjunction with Smith's stability nomograph(15), shown in Figure 11, to predict a modified stability class (MCLAS) for use within the mixing zone.

The value used by CALINE4 for HFF is 6.82 mw-hr/cm-vehicle. This is based on an assumed composite fuel economy of 20 miles/gallon, a 0.6 heat loss factor, and a specific energy of 1.25x105 BTU/gallon for gasoline. When multiplied by the traffic volume in vehicles/hour and divided by the mixing zone width in centimeters, HFF yields the sensible heat flux contributed by vehicle emissions in units consistent with Figure 11.

The rate of vertical plume spread is assumed by the model to follow the modified stability curve for a distance DMIX downwind of the FLS. DMIX is defined as the lesser of either the distance traversed by the FLS plume centerline over the mixing zone, or the distance at which

$$W2 = 0.6744*\sigma_y. \qquad (5\text{-}15)$$



ATMOSPERIC STABILITY NOMOGRAPH (AFTER SMITH, 15)

FIGURE 11

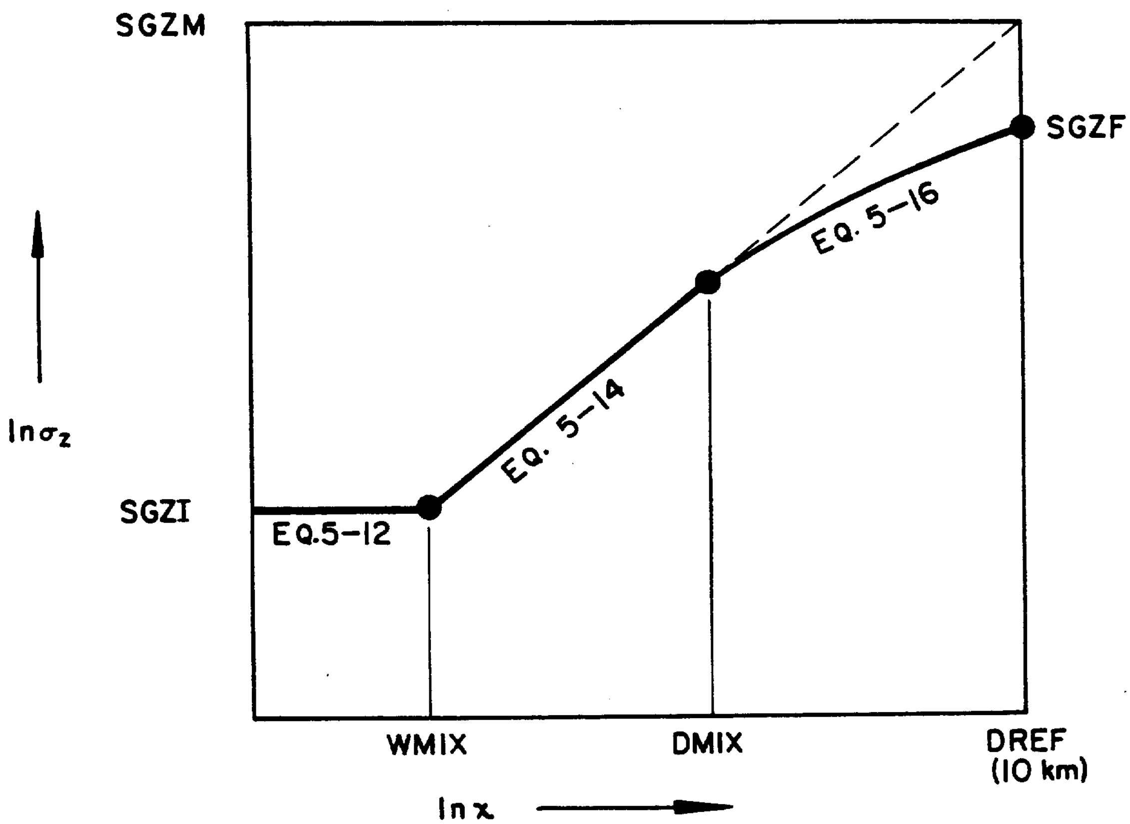
The latter case accounts for near-parallel wind conditions at distances where one-half or more of the plume is no longer influenced by the thermal turbulence within the mixing zone. In either case, DMIX is not allowed to be less than WMIX.

Beyond DMIX, the diminishing influence of mixing zone turbulence is dealt with by returning the curve to SGZF at DREF. This is accomplished by adding a third term, PZ3, to Equation 5-14 so that

$$SGZ = PZ1 * FET^{PZ2} * (FET/DMIX)^{PZ3 * \ln(FET/DMIX)}. \qquad (5\text{-}16)$$

PZ3 is defined by equating the first derivatives of SGZ with respect to FET for Equations 5-14 and 5-16 at DMIX, and holding SGZ equal to SGZF at DREF. A representation of the composite vertical dispersion curve used in CALINE4 is shown in Figure 12.

In some cases where DMIX approaches DREF, or there is a large difference between SGZM and SGZF, Equation 5-16 reaches a maximum value at a distance less than DREF. If this occurs, the model adjusts PZ3 so that $d\sigma z/dx=0$ at DREF. This results in somewhat higher value for SGZ at DREF than SGZF. The rationale for this adjustment is that the effects of the thermal turbulence generated within the mixing zone are sometimes of enough strength to influence the vertical plume spread at distances as great as 10 kilometers.



COMPOSITE VERTICAL DISPERSION CURVE–CALINE4

FIGURE 12

5.4 Horizontal Dispersion Parameter, σy

CALINE4 uses a method developed by Draxler to compute values for the Gaussian horizontal dispersion parameter, σy (16). The method states that

$$\sigma_y \simeq \sigma_\theta x f_1(T/t_L) \quad , \qquad (5\text{-}17$$

where

σ_θ = Horizontal wind angle standard deviation in radians,

x = Downwind distance

and f1 is a universal function of the diffusion time, T, and the Lagrangian time scale, tL. The function, f (denoted F1 in the program), is computed as follows:

$$F1 = \frac{1}{1+0.9(TT/TI)^{0.5}} \quad , \qquad (5\text{-}18)$$

where TT=FET/U (diffusion time) and TI is the diffusion time required for F1 to equal 0.5. In Draxler's method, TI is assumed to be proportional to tL. For ground level sources, a value of 300 seconds is used for TI when TT is less than 550 seconds. When TT exceeds 550 seconds, TI is adjusted for the effect of wind shear as follows,

$$TI = 0.001\ TT^2. \qquad (5\text{-}19)$$

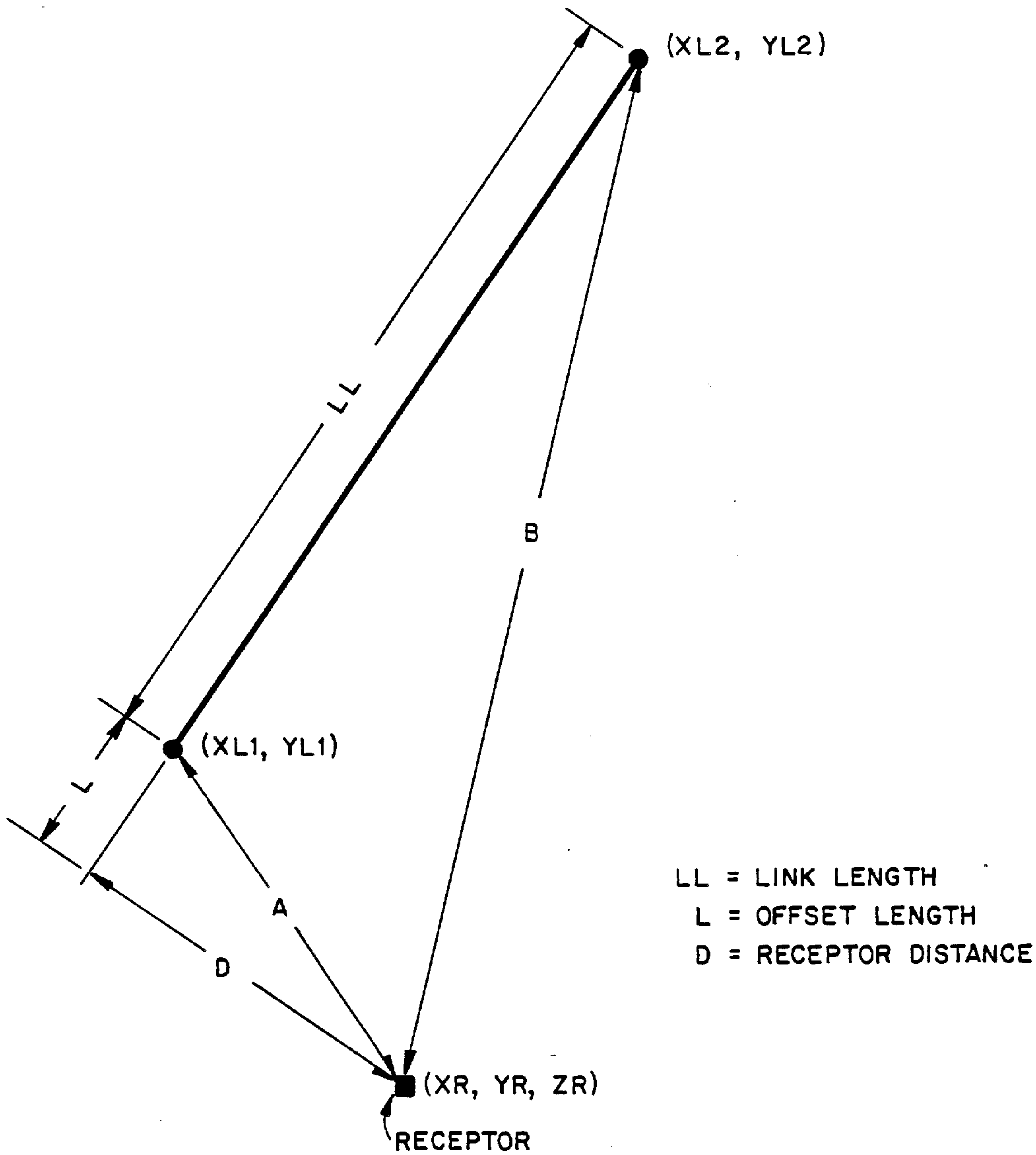
The effect of averaging time on horizontal dispersion is implicit in the value assigned to $\sigma\theta$. Therefore, it is no longer needed as an input to the model.

5.5 Roadway Geometry

CALINE4 permits the specification of up to 20 links and 20 receptors† within an X-Y plane (not to be confused with the local x-y coordinate system associated with each element). A link is defined as a straight segment of roadway having a constant width, height, traffic volume, and vehicle emission factor. The location of the link is specified by the endpoint coordinates of its centerline (Figure 13). The location of a receptor is specified in terms of X, Y, Z coordinates. Thus, CALINE4 can be used to model multiple sources and receptors, curved alignments, or roadway segments with varying emission factors. The wind angle (BRG) is given in terms of an azimuth bearing (0 to 360º). If the Y-axis is aligned with due north, then wind angle inputs to the model will follow accepted meteorological convention (e.g., 90º equivalent to a wind directly from the east).

The program automatically sums the contributions from each link to each receptor. After this has been completed for all receptors, an ambient or background value (AMB) assigned by the user is added. Surface roughness is assumed to be reasonably uniform throughout the study area. The meteorological variables of atmospheric stability, wind speed, and wind direction are also taken as constant over the study area. The user should keep this assumption of horizontal homogeneity in mind when assigning link lengths. For instance, assigning a 10 kilometer link over a region with a terrain induced wind shift after the first 2 kilometers would be inappropriate.

† Several organizations have recompiled CALINE4 with different array limits, allowing more than 20 receptors and links to be specified, for use where substantial computer resources are available. An executable that has been redimensioned for 100 links & receptors is available at the Caltrans web site (http://www.dot.ca.gov/hq/env/air/). –M. J. Brady, 11/2010.



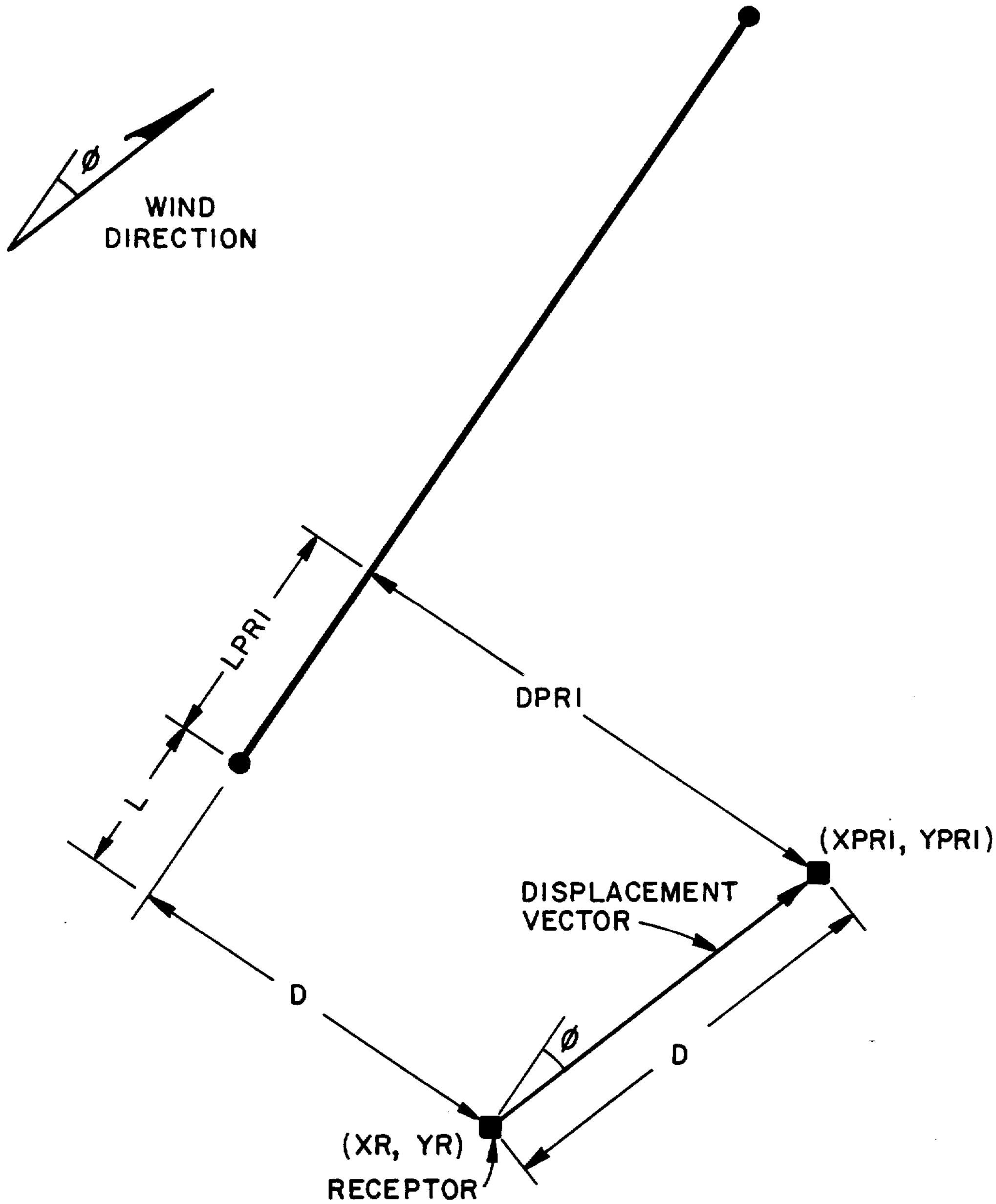
CALINE4 LINK GEOMETRY

FIGURE 13

The elements for each link are constructed as a function of receptor location as described in Section 5.1. This scheme assures that the finest element resolution within a link will occur at the point having the greatest impact on the receptor. An imaginary displacement of the receptor in the direction of the wind is used by CALINE4 to determine whether the receptor is upwind or downwind of the link (Figure 14).

For each highway link specified, CALINE4 requires an input for highway width (W) and height (H). The width is defined as the width of the traveled way (traffic lanes only) plus 3 meters on each side. This 3 meter allowance accounts for the wake-induced horizontal plume dispersion behind a moving vehicle. The height is defined as the vertical distance above or below the local ground level or datum. The model should not be used for links with values of H greater than 10 meters or less than -10 meters.

Elevated highway sections may be of either the fill or bridge type. For a bridge, air will flow above and below the source in a relatively undisturbed manner. This sort of uniform flow with respect to height is an assumption of the Gaussian formulation. For bridge sections, H is specified as the height of the roadway above the surrounding terrain. For fill sections, however, the model automatically sets H equal to zero. This assumes that the air flow streamlines follow the terrain in an undisturbed manner. This is a reasonable assumption to make given moderate fill slopes and stable atmospheric conditions(17).



IF DPRI < D THEN D=-D
IF LPRI < L THEN tUWL--DW L

IMAGINARY DISPLACEMENT SCHEME USED BY CALINE 4

FIGURE 14

For depressed sections, the model is patterned after the results of a study conducted in 1973/74 by Caltrans along a section of the Santa Monica Freeway in Los Angeles(3). Compared to equivalent at-grade and elevated sites, greater values for initial vertical dispersion were observed in this study concurrently with higher mixing zone concentrations. It was concluded that channeling and eddying effects effectively decreased the rate of pollutant transport out of the depressed section mixing zone. This increased the residence time, thus elevating the mixing zone concentration. Lower concentrations downwind of the highway were attributed to more extensive vertical mixing occurring within the mixing zone because of the longer residence time. Consequently, the residence time was adjusted to yield higher values for concentrations within or close to the mixing zone, and somewhat lower values for receptors outside of the depressed section. If the depressed section is greater than 1.5 meters deep, CALINE4 increases the residence time within the mixing zone by the following factor empirically derived from the Los Angeles data:

$$DSTR = 0.72 * ABS(H)^{0.83}. \qquad (5\text{-}20)$$

This leads to a higher value of SGZI at the edge of the highway. The increased residence time, characterized in the model as a lower average wind speed, yields relatively high concentrations within the mixing zone. The wind speed is linearly adjusted back to the ambient value at a distance of 3R downwind from the edge of the mixing zone. At this point, the effect of the higher value for SGZI dominates, yielding lower concentrations than an equivalent at-grade section. Except for these adjustments, CALINE4 treats depressed sections computationally the same as at-grade sections.

It is also possible to use CALINE4 to model microscale impacts from an at-grade parking facility. This is done by modeling the planned accessways as a series of links and then determining an overall link emission factor (including excess transient cold start emissions). The links should be identified as parking lot links when input to the model. This will cause the model to disengage the residence time algorithm and automatically set SGZI to 1 meter. The purpose for this adjustment is to account for the fact that slow moving, cold start vehicles will contribute much less turbulent energy to the initial dispersion of their exhaust gases. For this same reason, mixing zone widths should not include the usual horizontal dispersion adjustment of 3 meters on each side.

Further discussion on parking lot analysis can be found in Section 6.3.

5.6 Topographic Effects

The Gaussian formulation used in CALINE4 is based on two somewhat restrictive assumptions: 1) horizontally homogeneous wind flow, and 2) steady-state meteorological conditions. Complex topography can bring the validity of each of these assumptions into question. Winds can be redirected or channeled by topographic elements, resulting in significant spatial variability of wind direction and speed. Locations situated near hills and valleys are also likely to have frequent shifts in wind direction caused by differential surface heating. For these reasons, use of CALINE4 in complex terrain should be approached with care.

An algorithm suggested by Turner(18) has been incorporated into the model to handle bluff and canyon situations. The algorithm computes the effect of single or multiple horizontal reflections for each FLS plume in much the same way as mixing height reflections are handled. The roadway and wind direction are assumed to be parallel to the horizontal topographic boundary. This assumption is not particularly restrictive since upslope and drainage flows naturally follow topographic alignment. As far as CALINE4 is concerned, a winding canyon or bluff will be modeled as a straight link with PHI=0º. For canyons, the model will also alter the vertical dispersion curve to account for vehicle-related heat flux distributed over the width of the canyon. This is of particular significance if modeling a narrow urban street canyon.

In complex topographic situations where the bluff or canyon options are not applicable, use of the model is restricted to small areas which can be reasonably expected to experience horizontally homogeneous wind flow. Thus, the model might be appropriate for an intersection hot-spot analysis in complex terrain because the bulk of the emissions are confined to a small area. Conversely, a freeway application in the same region with links 1 to 2 kilometers long would be inappropriate because of the inability to assign a single representative wind direction to a large area in complex terrain.

5.7 Deposition and Settling Velocity

Deposition velocity (VD) is a measure of the rate at which a pollutant can be adsorbed or assimilated by a surface. It involves a molecular, not turbulent, diffusive process through the laminar sublayer covering the surface. Settling velocity (VS) is the rate at which a particle falls with respect to its immediate surroundings. It is an actual physical velocity of the particle in the downward direction. For most situations, a class of particles with an assigned settling velocity will also be assigned the same deposition velocity.

CALINE4 contains a method by which predicted concentrations for suspended particles may be adjusted for pollutant deposition and settling. This procedure, developed by Ermak(19), is fully compatible with the Gaussian formulation of CALINE4. It allows the model to include such factors as the settling rate of lead particulates near roadways(20) or dust transport from unpaved roads. A review paper by McMahon and Denison(21) on deposition parameters provides an excellent reference.

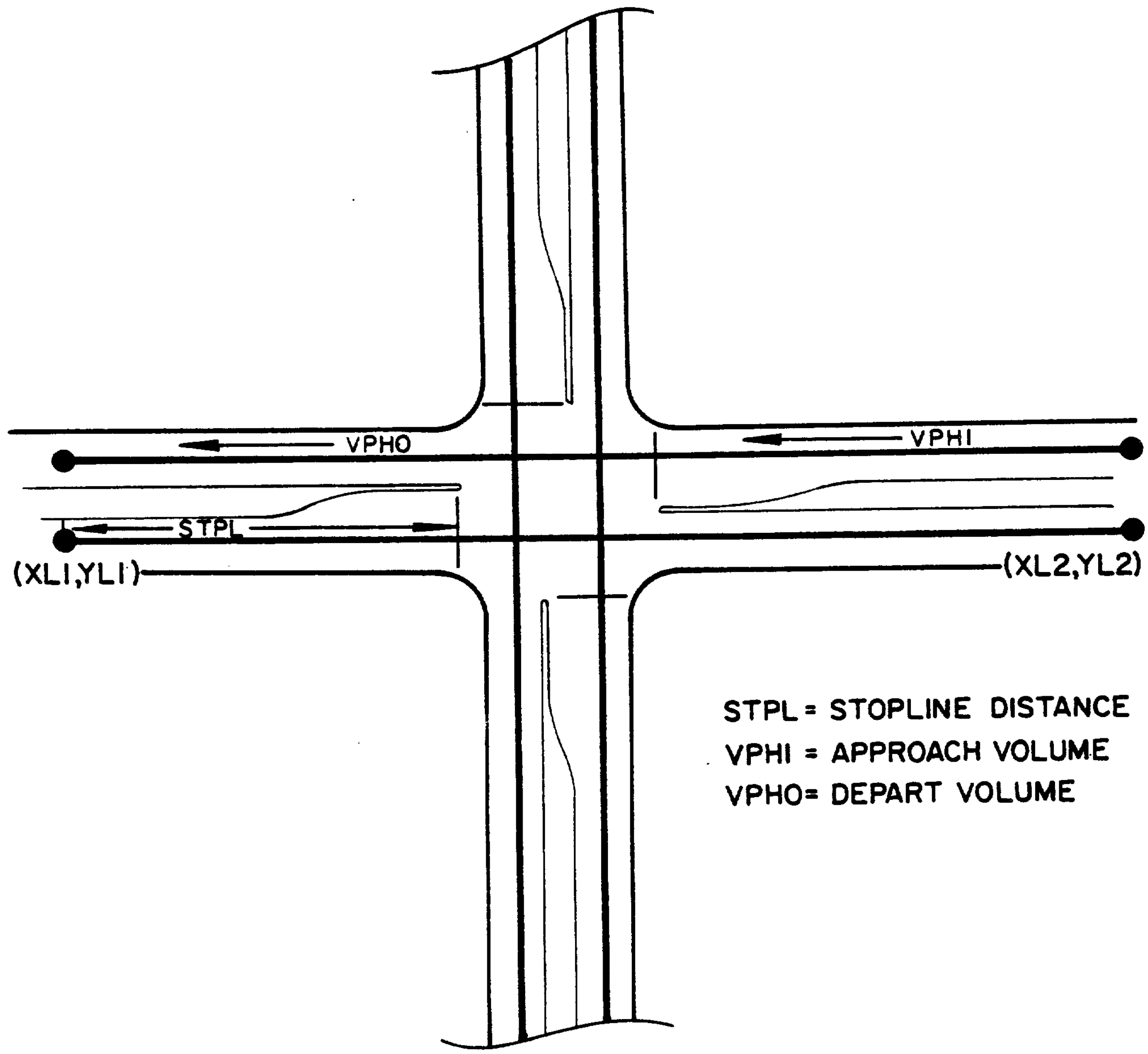
Most studies have indicated that CO deposition is negligible. Both deposition and settling velocity adjustments can be easily bypassed by assigning a value of 0.0 to VD and VS.

5.8 Intersection Link Option

The CALINE4 program is designed to recognize different link types representing different roadway sections (at-grade, depressed, fill, bridge and parking lot). For each of these link types, the assigned emission factor is assumed to be a constant over the length of the link. As long as vehicle travel along the link can be adequately represented by an average speed, this assumption is entirely appropriate. At controlled intersections, however, vehicle operations are modal in nature, and the assumption of uniform emissions is no longer valid. The operational modes of deceleration, idle, acceleration and cruise have a significant effect on the rate of vehicle emissions. Traffic parameters such as queue length and average vehicle delay define the location and duration of these emissions. The net result is a concentration of emissions at and near the intersection which, for microscale applications, cannot be adequately modeled using emission factors derived from average route speeds. For this reason, a specialized intersection link has been added to CALINE4.

Several other models dealing specifically with the intersection modeling problem have been developed recently. One of these models, TEXIN(22), is actually an adaptation of CALINE3, incorporating minor revisions to the dispersion algorithms. The other model, MICRO(23), was developed from Stanford Research Institute's APRAC-2 intersection sub-model. Both TEXIN and MICRO contain detailed subroutines for determining queue length and vehicle delay from traffic volume and signal phasing information. The CALINE4 intersection option includes modal emissions and dispersion components, but does not include a traffic model component. However, the traffic parameters required by CALINE4 are basic, and need only be as accurate as the element resolution of the model itself.

A CALINE4 intersection link must encompass the acceleration and deceleration zones created by the presence of the intersection. Each link can treat only one direction of traffic flow, so that four links are required to model a full intersection (Figure 15). Traffic is assumed to flow from a link endpoint 1 to endpoint 2. The stopline distance (STPL) is always referenced to link endpoint 1.



CALINE4 INTERSECTION LINKS

FIGURE 15

Input and output traffic volumes (YPHI and VPHO) are assigned to account for potential volume differences on either side of the stopline. The mixing zone width is defined as the width of the "thru" lanes plus 3 meters on each side. Because of the need to resolve the spatial distribution of emissions at and near the intersection, the element growth factor is held to unity. The point of origin for the resulting square elements is at the stopline for all intersection link applications.

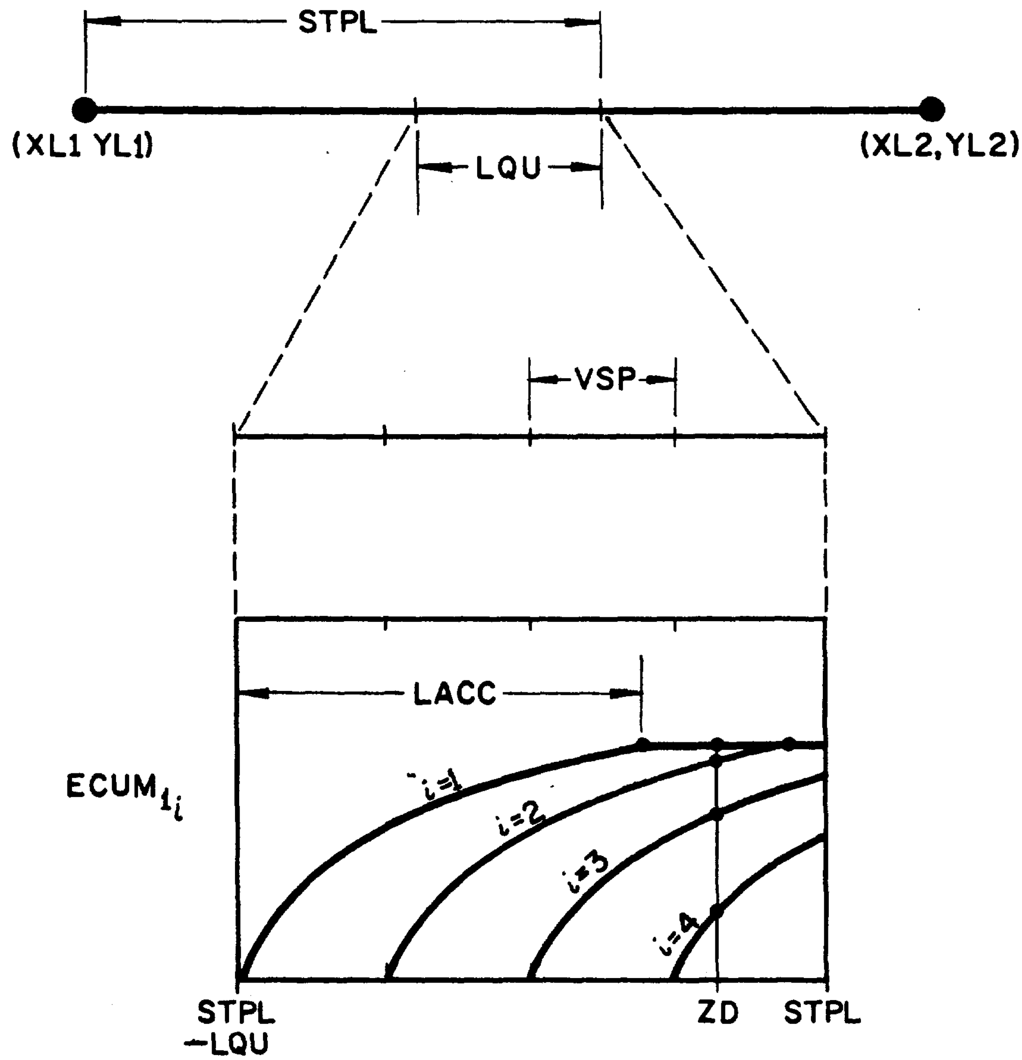
Four cumulative modal emission profiles representing the deceleration, idle, acceleration and cruise modes of operation are constructed for each intersection link. These profiles are determined using the following input variables:

SPD = Cruise speed (mph)
ACCT = Acceleration time (seconds)
DCLT = Deceleration time (seconds)
IDT1 = Maximum idle time (seconds)
IDT2 = Minimum idle time (seconds)
NCYC = Number of vehicles entering the intersection per cycle per lane
NDLA = Number of vehicles delayed per cycle per lane.

NCYC and NDLA are chosen to represent the dominant movement for the link. NDLA may exceed NCYC in cases where some or all of the vehicles will require more than one cycle to clear the intersection. The model assumes uniform, steady-state vehicle arrival and departure rates, constant acceleration and deceleration rates, and full stops for all delayed vehicles. Acceleration and deceleration rates (ACCR, DCLR) and acceleration and deceleration lengths (LACC, LDCL) are determined using the input values for SPD, ACCT and DCLT. By assuming an "at rest" vehicle spacing (VSP) of 7 meters, the average queue length (LQU) is also determined. STPL must be greater than or equal to the sum of LQU and LDCL. IDT1 represents the delay at full stop experienced by the first vehicle in the queue. Similarly, IDT2 represents this same measure for the last vehicle. IDT2 is used to model a platooned arrival and should be assigned a value of zero for non-platooned applications.

The time rate modal emission factors are computed by a method described in Section 6.2. To develop these factors, the model must be provided with composite emission rates for average route speeds of 0 (idle) and 16 mph. The resulting time rate factors are denoted as EFA (acceleration), EFD (deceleration), EFC (cruise) and EFI (idle).

The cumulative emission profile for a given mode is developed by determining the time in mode per cycle for each vehicle as a function of distance from link endpoint 1 (ZD), multiplying the time by the respective modal emission rate and summing the results over the number of vehicles. The elementary equations of motion are used to relate time to ZD for each mode. The assumed vehicle spacing (VSP) is used to specify the positional distribution of the vehicles in the queue. The total cumulative emissions per cycle per lane at distance ZD from XL1, YL1 are denoted as ECUMk(ZD) in the CALINE4 coding, where the subscript signifies the mode (1=accel., 2=decel., 3=cruise, 4=idle). Figure 16 illustrates how a series of distributed cumulative emissions profiles are combined for the acceleration mode. The individual profiles are based on the assumption that the time rate emission factor (EFA) is constant throughout the modal event. This means that the cumulative modal emissions from a vehicle are directly proportional to the time the vehicle has spent in the mode.



$$ECUM_1\ (ZD) = \left\{ EFA * (2 / ACCR)^{1/2} * \sum_{i=2}^{4} \left[ZD' - (i-1) * VSP \right]^{1/2} + EFA * 1 * ACCT \right\}$$

DETERMINATION OF TOTAL CUMULATIVE ACCELERATION EMISSIONS PER CYCLE PER LANE (ECUM1) fOR A CALINE4 INTERSECTION LINK [ZD’= ZD-(STPL-LQU)]

FIGURE 16

In the case of a constant acceleration starting from an "at rest" position, the cumulative emissions for the ith vehicle are given as

$$ECUM1_i = EFA*(2*X/ACCR)^{1/2}, \qquad (5\text{-}21)$$

where X equals the distance from the start of the acceleration. Equation 5-21 dictates the shape of the individual cumulative emission profiles shown in Figure 16. Similar reasoning is used for developing the other modal profiles. A complete mathematical description of this algorithm is contained in Appendix A.

To obtain the average lineal emission rate over an element (Q1), CALINE4 computes the total cumulative emissions for the 4 modes at each end of the element (ZD1 and ZD2). The difference between these amounts divided by the element length and multiplied by the ratio between the traffic volume and NCYC yields Q1 for the element. This can be written as

$$Q1 = \frac{VPH(ECLD)}{NCYC} * \left\{ \frac{\sum_{k=1}^{4} ECUM_k(ZD2) - \sum_{k=1}^{4} ECUM_k(ZD1)}{ZD2 - ZD1} \right\}, \qquad (5\text{-}22)$$

where the subscript k denotes the mode and,

$$VPH(ECLD) = \begin{cases} VPHI, & ECLD \leq STPL \\ VPHO, & ECLD > STPL. \end{cases} \qquad (5\text{-}23)$$

Turn movements are not dealt with explicitly by CALINE4. Instead, the cumulative emissions profile per cycle per lane for the dominant approach movement is prorated by the approach or depart volume, depending on the relative location of the stopline. This method implicitly assigns a turning vehicle's deceleration, idle and part of its acceleration emissions to its approach link. The remainder of its modal emissions are assigned to its depart link. The method assumes that the acceleration patterns for turning and "thru" vehicles are roughly similar. While this simplifying assumption may not be exactly correct, it is reasonable in light of the overall precision of the model.

5.9 NO2 Option

A number of analytical methods have been developed to facilitate use of the Gaussian plume formulation with simple reactive plume chemistries(24). For NO2 computations, these include the exponential decay, ozone limiting and photostationary state methods. An unfortunate weakness of these methods is their assumption that reactants mix instantaneously as they disperse, and that the resulting time-averaged concentrations determine the reaction rates (25,26,27,28). This assumption usually leads to overestimates of NO2 production since the component reactants, NO and ambient O3, are not mixed instantaneously by the relatively large-scale dispersive processes of the atmosphere(29,30). Instead, the plume and ambient components remain isolated as concentration-rich parcels until sufficient time has past for molecular diffusion to mix them on a scale commensurate with the reaction kinetics.

In CALINE4, a different computational scheme called the Discrete Parcel Method is used to model NO2 concentrations. As with the preceding methods, a simplified set of controlling reactions is assumed:

$$NO_2 + h\nu \rightarrow NO + O \quad (A)$$

$$O + O_2 + M \rightarrow O_3 + M \quad (B)$$

$$NO + O_3 \rightarrow NO_2 + O_2 \quad (C)$$

Because of the relatively high concentration of O2, it is further assumed that reaction B occurs instantaneously. The other assumptions of the Discrete Parcel Method used in CALINE4 are: 1) that emissions and ambient reactants are fully mixed within the mixing zone to a height of 3.5 meters, 2) that initial tailpipe NOx emissions are 92.5% NO and 7.5% NO2 by mass, and 3) that parcels of the mixed reactants retain their identity relative to molecular scales for a distance of $U\tau m$, where τm equals the time-scale for molecular diffusion (about 300 meters for U=1 m/s).

The Discrete Parcel Method fixes the initial mixing zone concentrations of the reactants on the basis of the ambient and vehicular contributions as follows:

$$[O_3]_i = [O_3]_a \quad (5\text{-}24)$$

$$[NO]_i = [NO]_a + \frac{(0.925)*Q1}{3.5*U}*FPPM_{NO} \quad (5\text{-}25)$$

$$[NO_2]_i = [NO_2]_a + \frac{(0.075)*Q1*FPPM_{NO_2}}{3.5*U} \quad (5\text{-}26)$$

where Q1 is the NOx vehicle emission factor in µgm/m-s FPPM is a factor which converts mass concentration to volumetric concentration, and the bracketed subscripted constituents represent initial (i) and ambient (a) volumetric concentrations. These initial concentrations and the time of travel from element to receptor (TT) are used to compute the final concentration of NO2 within each discrete parcel in accordance with the first-order reaction rates governing reactions A and C.

The reactions within each parcel are assumed to proceed independent of the dispersion process. This assumption is justified by the fact that the reaction rates are controlled by the reactant concentrations within a small neighborhood (on the scale of the mean free path of the molecules), while the dispersion process acts on a much larger scale. The reaction dynamics can therefore be modeled as a first-order process until concentration gradients are reduced to the extent that molecular diffusion becomes a significant part of the dispersion process. For most microscale modeling applications, travel times are not long enough for this to occur. Also, because the reactions are assumed to occur as isolated processes within each discrete parcel, complications arising from overlapping plumes are avoided.

Discrete parcel NO2 concentrations are computed by CALINE4 for each element-receptor combination because of the variable travel times involved. These concentrations are not, of course, the same as time-averaged NO2 concentrations. To arrive at time-averaged values, the dispersion process must be accounted for. To accomplish this, the link source strength, Q1, is adjusted to yield an initial NO2 mixing zone concentration equal to the discrete parcel concentration after time t, [NO2]t, for each element-receptor combination. The following formula is used in CALINE4 to make this adjustment:

$$Q1 = \frac{[NO_2]_t - [NO_2]_a}{FPPM} * 3.5 * U. \qquad (5\text{-}27)$$

The model then proceeds to compute the time-averaged concentration just as with a non-reactive species such as CO.

In summary, the discrete parcels are dispersed across the FLS plume in accordance with the Gaussian methodology. The reactions take place within the parcels at rates governed by the initial mixing zone concentrations and independent of the dispersion mechanism. A full mathematical description of the Discrete Parcel Method is given in Appendix B.

5.10 Volumetric Concentrations

CALINE4 initially computes all concentrations in mass per unit volume. These results are converted to a volumetric equivalent (i.e., parts per million) for gaseous pollutants. The conversion is accomplished by multiplying the concentration in $\mu g/m^3$ by FPPM where

$$FPPM = \frac{0.02241}{MOWT} * \left(\frac{T}{273}\right) * \exp\left(\frac{0.03417 * ALT}{T}\right) \qquad (5\text{-}28)$$

With MOWT = Molecular weight of the pollutant

T = Temperature (°K)

ALT = Altitude (m).

FPPM accounts for the effects of both temperature and pressure on the volumetric concentration.

6. ESTIMATING MOBILE EMISSIONS FOR CALINE4

A composite vehicle emission factor in grams per vehicle-mile must be provided for each CALINE4 link. This factor is readily available from the computer programs discussed in Section 6.1. CALINE4 contains an algorithm which can convert a composite emission factor for carbon monoxide to a modal factor. The development of this algorithm is described in Section 6.2. An important component of either composite or modal emission factors is the transient nature of cold and hot-start vehicle emissions. This is discussed in Section 6.3.

6.1 Composite Emission Factors

An emission factor based on a vehicle distribution weighted by type, age and operating mode can be termed a composite emission factor. The Environmental Protection Agency (EPA) has developed a series of computer programs, the latest of which is called MOBILE2, for estimating composite mobile emission factors given average route speed, percent cold and hot-starts, ambient temperature, vehicle mix and prediction year(31). These programs were developed from certification and surveillance data, mandated emissions standards for future vehicles and special emissions studies. California has traditionally modified the EPA programs to account for the unique emissions standards imposed on the California fleet. This has resulted in the EMFAC series of models, the latest of which is EMFAC6(32). At this writing, the California equivalent of MOBILE2, EMFAC7, is nearing completion.

The final output from CALINE4 is directly proportional to the emission factors input to the program. Therefore, the accuracy of any microscale air quality impact analysis is heavily dependent on the accuracy of the composite emission factors used. Of those variables within the control of the user, average route speed, percent cold-start and ambient temperature are usually the most critical. Care should be taken to make accurate estimates of these variables. In cases where the average route speed is derived from a highly variable driving cycle, a modal analysis should be made.

6.2 Modal Emissions

Composite emission factors represent the average emission rate over a driving cycle. The cycle might include acceleration, deceleration, cruise and idle modes of operation. Emission rates specific to each of these modes are called modal emission factors. The speed correction factors used in composite emission factor models such as MOBILE2 and EMFAC7 are derived from variable driving cycles representative of typical urban trips. The 1975 Federal Test Procedure driving cycle (FTP-75) is the basis for most of this work. In locations such as intersections, significant variations in the spatial distribution of emissions are lost when the composite emission factor approach is used. The approach described in Section 5.8 allows CALINE4 to model the spatial distribution of emissions at and near intersections more accurately. To do this, the model must be able to convert composite emission factors to modal factors.

The first modal emission factor model was developed in 1974 by the EPA(33,34). This model was based on emissions data from 1020 light-duty vehicles, model years 1957 through

1971(35). Discrete modal emissions were available for each of these cars over a 37-mode driving cycle known as the Surveillance Driving Sequence (SDS). The results were used to determine the coefficients of a second-order emissions rate formula incorporating all combinations of acceleration rate and average speed. Separate coefficients were developed for 11 distinct model year/location groups.

A simpler modal emissions model was recently developed by the Colorado Department of Highways (CDOH),(23). This model was based on data from 45 light-duty, 1975 vehicles tested in Denver on the SDS cycle(36). Results were analyzed in terms of a normalized modal emission rate, defined as the ratio of the time rate of modal emissions to the average time rate of FTP-75 emissions. Use of this modal/FTP-75 ratio allowed the direct conversion of average route speed emission factors to modal emission rates.

The CDOH analysis revealed a strong correlation between the modal/FTP-75 emission rate ratio, called E in the report, and the modal acceleration-speed product (AS). For CO, this was expressed as

$$E = 0.182-0.00798(AS)+0.000362(AS)^2, \qquad (6\text{-}1)$$

with AS representing the product of the average acceleration and average speed for the acceleration event in units of ft^2/s^3. The CDOH report also furnished a logical explanation for the strong correlation between E and AS. Using the basic equations of motion, the report showed that the acceleration-speed product was equivalent to power per unit mass. This meant that the power expended by a vehicle during an acceleration event was directly related to the value of AS for the event. As power demand approached engine capacity, a vehicle would tend to burn fuel less efficiently, resulting in higher CO and hydrocarbon emissions. The relationship between E and AS was a direct consequence of this general behavior.

The modal emission model contained in CALINE4 is patterned after the CDOH model. As with the CDOH model, the time rate (not distance rate) of the emissions is used. The dependent variable remains the ratio of the modal to FTP-75 emission rates, although the latter rate is restricted to the BAG2 (Hot Stabilized) portion of the complete FTP-75 cycle. The independent variable, AS, is also retained in the CALINE4 version. However, the functional form of the relationship between the dependent and independent variables is different. Also, separate forms of the model are used depending upon initial conditions (vehicle at rest or moving), and modal operation (vehicle accelerating or cruising).

Modification of the CDOH approach was brought about by the need to develop a model based on California, catalyst - equipped vehicles. Two data bases containing SDS driving cycle measurements were used for this purpose. The first was collected as part of a nationwide surveillance study conducted by the EPA(36). Only the portion of this data base containing results for California, 1975 and 1976 light-duty automobiles, was used (62 vehicles). The second data base contained results from a California Air Resources Board (CARB) surveillance study conducted at Lake Tahoe in 1976(37). Again, the analysis was confined to 1975 and 1976 automobiles (19 vehicles). Unfortunately, reliable SDS data for more recent model year vehicles could not be found.

The modal models used in CALINE4 were developed from acceleration and cruise CO emission rates measured during the SDS driving cycle (Table 1). Instead of basing the model on overall average emission rates, as was done in the CDOH study, the CALINE4 model was based on a disaggregated analytical approach. Modal/BAG2 ratios were developed separately for each vehicle and then analyzed together with other vehicles from the same study.

Five vehicles from the EPA study were omitted from the final analysis because they exhibited significant inconsistencies for repeated acceleration modes over the course of the SDS cycle. Several erratic or zero value individual results were also omitted as outliers, but these amounted to less than 2% of the data studied.

The FTP-75, BAG2 driving sequence (867 seconds, 3.91 miles, 16.2 mph average speed) was simulated by compositing modal emission rates as summarized in Table 2. The actual FTP-75 results compared very poorly with the SDS composited results, sometime varying by as much as a factor of ten. Possible reasons for this include the more stressful nature of the SDS cycle and the different measurement techniques employed. Cumulative bag samples collected for all vehicles in both studies during the SDS test cycle compared favorably with the modal measurements. Because of this internal consistency displayed by the SDS data, it was decided to base the modal/BAG2 ratios exclusively on SDS measurements, relying on the simulated BAG2 results rather than the measured values.

TABLE 1

37-MODE SURVEILLANCE DRIVING SEQUENCE

Mode			Time in Mode	Average Acceleration rate	Distance	Acceleration Speed Product
No.	Type	Speed Range (mph)	(sec)	(mph/sec)	(miles)	(mi^2/hr^2-s)
1	Accel	0-30	12	2.50	0.0602	37.5
2	Decel	30-0	16	-1.88	0.0741	-
3	Accel	0-15	8	1.88	0.0201	14.1
4	Accel	15-30	11	1.36	0.0705	30.7
5	Accel	30-45	13	1.15	0.1360	43.3
6	Decel	45-30	12	-1.25	0.1268	-
7	Accel	30-60	17	1.76	0.2163	79.4
8	Decel	60-45	12	-1.25	0.1716	-
9	Accel	45-60	14	1.07	0.2043	56.2
10	Decel	60-15	30	-1.50	0.3367	-
11	Accel	15-60	26	1.73	0.3136	64.9
12	Decel	60-0	21	-2.86	0.1973	-
13	Accel	0-60	32	1.88	0.3313	56.3
14	Decel	60-30	23	-1.30	0.2994	-
15	Decel	30-15	9	-1.67	0.0579	-
16	Decel	15-0	8	-1.88	0.0173	-
17	Accel	0-45	22	2.05	0.1759	46.0
18	Decel	45-15	16	-1.88	0.1392	-
19	Accel	15-45	18	1.67	0.1528	50.0
20	Decel	45-0	19	-2.37	0.1304	-
21	Accel	0-60	25	2.40	0.2654	72.0
22	Decel	60-0	28	-2.14	0.2634	-
23	Accel	0-30	15	2.00	0.0737	30.0
24	Accel	30-60	25	1.20	0.3134	54.0
25	Decel	60-30	18	-1.67	0.2362	-
26	Decel	30-0	10	-3.00	0.0444	-
27	Accel	0-60	38	1.58	0.4009	47.4
28	Decel	60-0	35	-1.71	0.3293	-
29	Accel	0-30	18	1.67	0.0886	25.0
30	Accel	30-60	21	1.43	0.2599	64.3
31	Decel	60-30	14	-2.14	0.1813	-
32	Decel	30-0	13	-2.31	0.0592	-
33	Idle	0				
34	Cruise	15				
35	Cruise	30				
36	Cruise	45				
37	Cruise	60				

TABLE 2

Simulated FTP-75 (BAG2) Driving Sequence
Using SDS Modal Events

MODE			
No.	Type	Speed Range (mph)	Time in Mode (sec)
1	Accel	0-30	9
2	Decel	30-0	88
3	Accel	0-15	23
4	Accel	15-30	39
15	Decel	30-15	23
16	Decel	15-0	7
26	Decel	30-0	28
29	Accel	0-30	151
32	Decel	30-0	34
33	Idle	0	155
34	Cruise	15	51
35	Cruise	30	259
		Total:	867 seconds

The resultant acceleration models were developed from the combined EPA and CARB data sets (76 vehicles). The first model is valid for vehicles starting at rest and accelerating up to 45 mph. It is based on results from modes 1, 3, 17, 23 and 29. This is the model used in CALINE4 for converting the intersection link composite emission factor (EFL) to an acceleration emission factor (EFA). The conversion is made as follows:

$$EFA = BAG2*0.75*e^{0.0454*AS}, \qquad (6\text{-}2)$$

where BAG2 represents the time rate emission factor for the intersection link at an average route speed of 16.2 mph, and AS is in units of mi^2/hr^2-s. The conversion from the user supplied distance rate at 16.2 mph to the corresponding time rate (BAG2) is made internally by the program.

A second model was developed for vehicles moving at speeds of 15 mph (or greater) and accelerating up to 60 mph. The second model was based on results from modes 7, 9, 11, 24 and 30 of the EPA data set. CARB results for these modes were significantly different from the EPA data, and were therefore omitted. This difference was attributed to the high altitude effects of the Lake Tahoe test location used in the CARB study.

The second model can be used to handle special situations such as acceleration emissions along on-ramp or weave sections. The model takes the form,

$$EFA = BAG2*0.027*e^{0.098*AS}, \qquad (6\text{-}3)$$

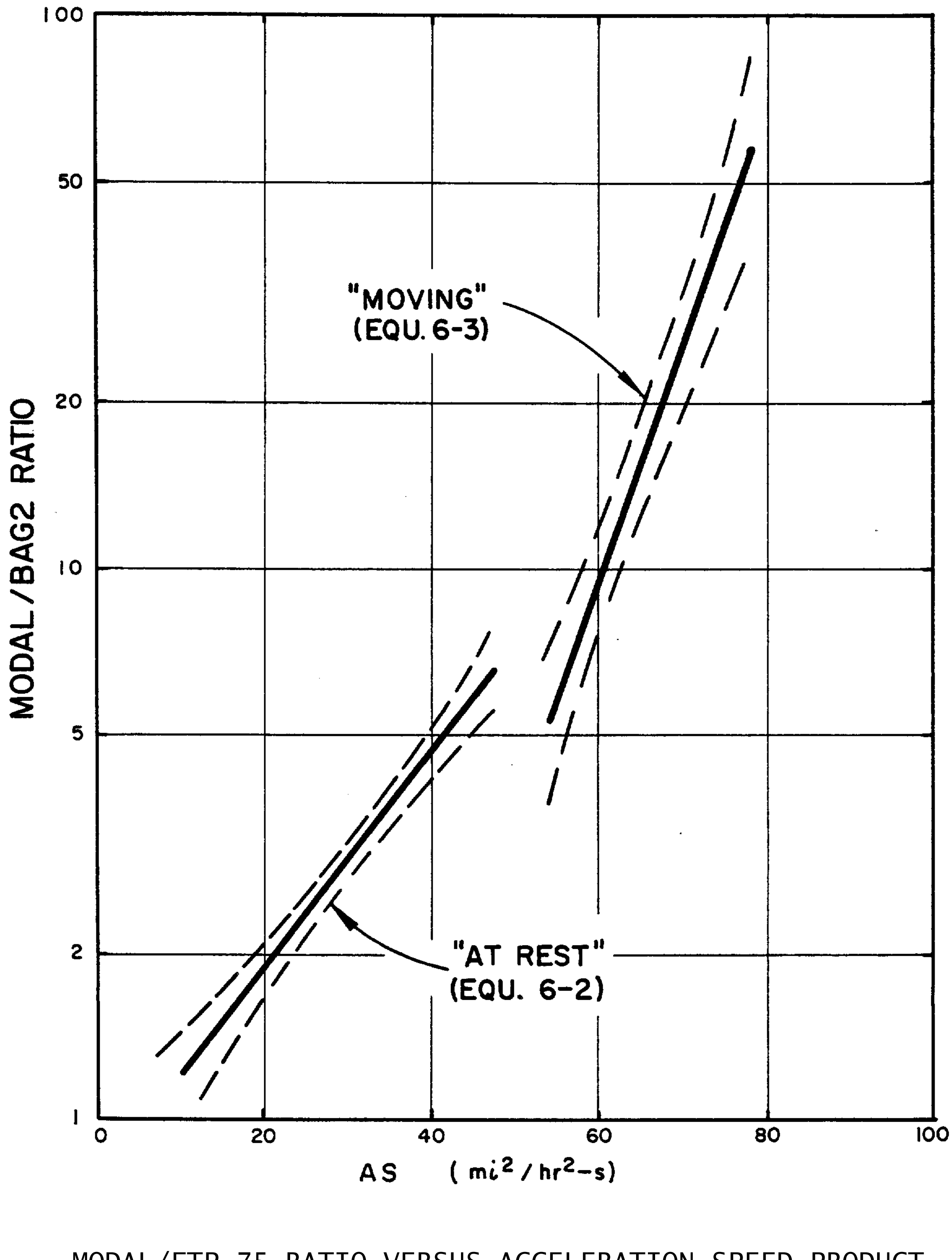
where the terms are defined in the same manner as for Equation 6-2.

Both acceleration models are shown with their 95% confidence limits in Figure 17. There is a clear difference between the "at rest" and "moving" acceleration modes. At the higher average speeds for the "moving" accelerations, drag forces add significantly to the power demands on the engine. This leads to higher modal/BAG2 ratios.

Cruise or steady-state modes were also included in the SDS test data. The EPA data set contained numerous zero or near zero entries for cruise mode, resulting in an erratic pattern for the modal/BAG2 ratios. This was most likely attributable to low exhaust concentrations which bordered on the range of sensitivity for the instruments used. The CARB data set showed more consistent results, and was therefore used as a basis for determining the cruise emission factor, EFC.

The aerodynamic drag force was assumed to be the controlling variable for the cruise model. This force is directly proportional to SPD2, where SPD is the vehicle cruise speed in mph. As expected, the CARB data showed a strong correlation between the modal/BAG2 ratio for cruise modes and SPD^2. This resulted in the following model:

$$EFC = BAG2*(0.494+0.000227*SPD^2). \qquad (6\text{-}4)$$



MODAL/FTP-75 RATIO VERSUS ACCELERATION-SPEED PRODUCT FOR "AT REST" AND "MOVING" CONDITIONS (95% CONFIDENCE LIMITS SHOWN AS DASHED LINES)

FIGURE 17

Cruise emission rates can also be estimated for vehicles climbing grades by using the "at rest" or "moving" acceleration models already developed. The acceleration-speed product can be shown to be equivalent to g*SPD*PG, where g is the gravitational acceleration constant (22 mph/s), SPD is the vehicle speed and PG is the roadway profile grade (in decimal form). Given SPD and PG, a value for AS can be determined for a vehicle moving at constant speed up a grade. A grade correction for the composite emission factor can then be determined using Equation 6-2 for speeds less than 30 mph and Equation 6-3 for speeds greater than 30 mph-. This assumes that the value for AS is within the range of validity for the equations as shown in Figure 17.

Deceleration emission rates for the two data sets were studied and compared to the idle emission rates. Results for the EPA data were inconclusive, again because of the numerous measurements of zero emissions. The CARB data set, which seemed to have more reliable steady-state measurements, contained deceleration emission rates that were relatively constant over the 16 modes studied. These rates were approximately 50% higher than the idle rates.

The slightly higher deceleration rates found in the CARB data are compatible with the normal practice of gradually releasing the accelerator pedal during a planned deceleration. The deceleration emission rate used in CALINE4 is therefore 1.5 times the idle emission rate.

All of the modal emissions models discussed in this report were developed using data from hot-stabilized, light-duty automobiles only. In the absence of evidence to the contrary, it is assumed that extension of these models to all operating modes and vehicle types is valid. Therefore, when using the CALINE4 intersection option, composite FTP-75 emission factors at 0 and 16.2 mph (including cold/hot starts and all vehicle types) should be used.

6.3 Transient Emissions

Before an engine reaches hot-stabilized running temperature, it operates less efficiently because fuel is not readily vaporized in a cold engine. This results in excess CO and hydrocarbon emissions during the engine start-up phase. The problem is compounded for catalyst-equipped vehicles by the need for the catalyst to reach operating temperature before it can perform efficiently. Both these effects are temporary in nature, and therefore the resulting excess emissions are termed transient emissions. They are usually treated as trip-end contributions for mesoscale emission inventories, or as weighted components in a composited emission factor for microscale applications.

Two variables that have a direct effect on transient emissions are ambient temperature and soak time. The ambient temperature determines the initial temperature of the engine block and catalyst at start-up. The soak time is the elapsed time between engine operations. It controls the extent to which the system has been able to reach ambient temperature. Depending on the length of the soak and the type of vehicle (catalyst or non-catalyst), a start is categorized as either cold or hot. Both are transient states and result in excess emissions. Excess cold-start emissions are significantly greater than hot-start emissions.

Excess transient emissions are often a significant component of a composite emission factor. The conventional method of modeling transient emissions for microscale applications is to assume a fixed percentage of vehicles traveling in a transient operating mode, and to assign an average excess transient emission rate, $\bar{e}_{tr}$s to these vehicles. The value of $\bar{e}_{tr}$ is defined as

$$\bar{e}_{tr} = E_{tr}/R, \tag{6-5}$$

where E_{tr} equals the mass of excess transient emissions per vehicle-trip (aggregated over vehicle types) and R equals the total distance traveled during the transient cycle. For cold and hot-starts, R is defined by FTP-75 as 3.59 miles.

As long as vehicles operating in a transient mode are distributed equally by distance traveled (or time of travel) over the transient cycle, $\bar{e}_{tr}$ adequately characterizes the transient emission function. Vehicles in the early part of the transient cycle draw from a smaller area, but have a higher probability of passing the microscale location than vehicles near the end of the cycle. These two effects tend to offset each other in cases where the microscale location offers no special attraction and trip destinations are randomly distributed. Most urban streets fall into this category. However, heavily traveled urban freeways will attract vehicle trips at a more or less constant rate over distances equal to the transient cycle distance, R, provided competing freeways are not close by. In such situations, a greater proportion of vehicles in transient operating mode will be near the end of the transient cycle. These vehicles are drawn from a larger area of potential trip origins than vehicles that only travel a short distance. This principle can be illustrated using a simple model.

$$r = |x| + |y| , \qquad (6\text{-}6)$$

where r equals the trip length to a specific destination followed by a vehicle via the most direct route over a rectangular street grid. Assume a uniform trip generation per unit area. Now consider the elemental area, dA, shown in Figure 18. An elemental weighting factor, dw, representing the fraction of vehicles in transient operation which have traveled a distance r to a specific microscale location, (0,0), can be written as

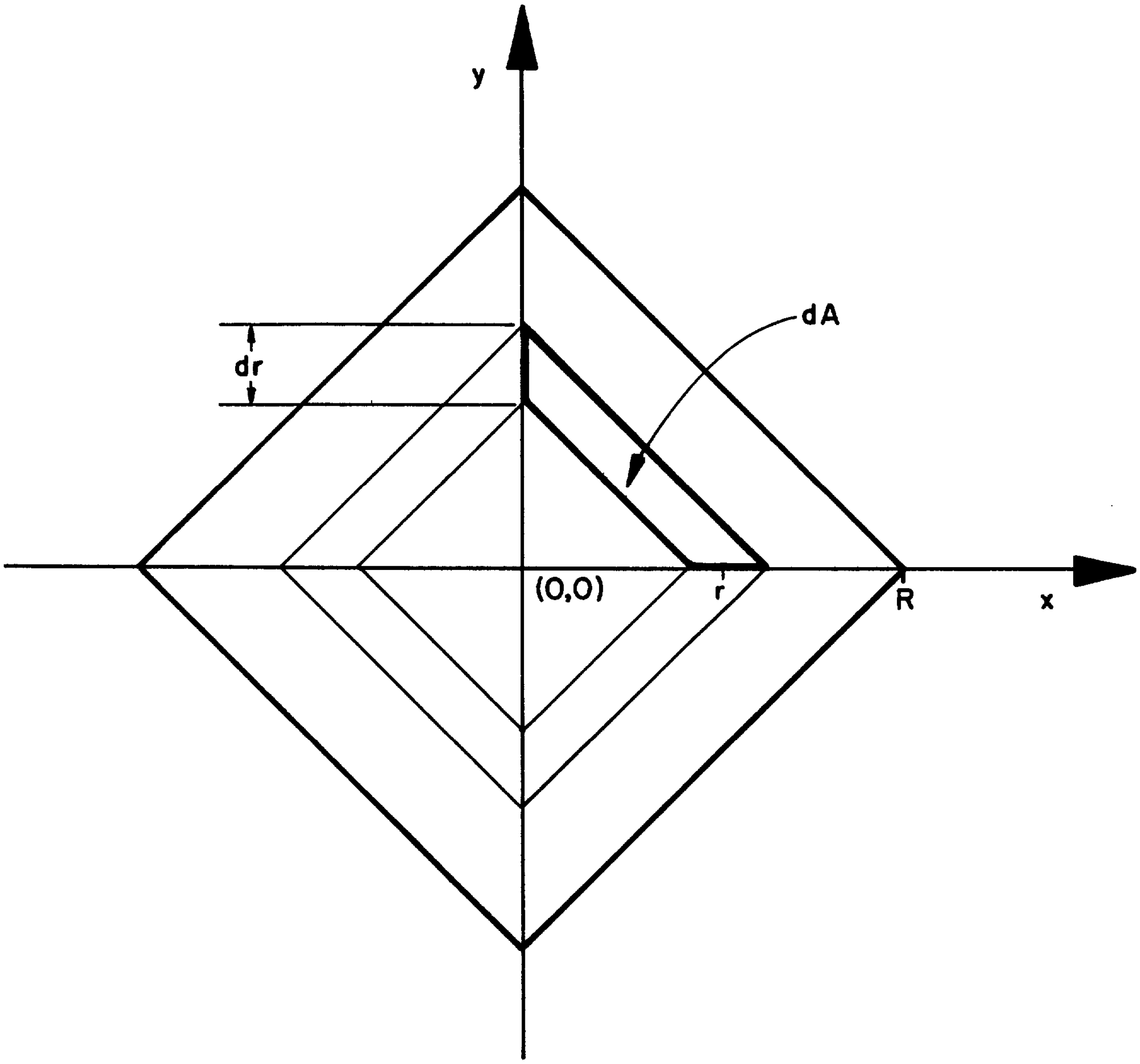
$$dw = \frac{4dA}{(\sqrt{2}\ R)^2} \quad . \qquad (6\text{-}7)$$

This assumes that the probability of a trip passing through (0,0) is constant over R. From Figure 18 it can be seen that

$$dA = \sqrt{2}\ r\ (dr/\sqrt{2}) \ . \qquad (6\text{-}8)$$

Combining Equations 6-7 and 6-8 yields,

$$dw = 2(r/R^2)dr. \qquad (6\text{-}9)$$



WEIGHTING FUNCTION MODEL FOR DISTANCE TRAVELED BY VEHICLES IN TRANSIENT OPERATING MODE AT (0,0).

FIGURE 18

Thus, dw increases in direct proportion to r. In this case, applying a constant $\bar{e}tr$ to all transient vehicles is only correct if each vehicle's excess transient emission rate is constant over the transient cycle. Such a situation is hardly likely since engine warm-up is a smooth, continuous process, not a discrete process.

A more realistic model of excess emissions during a transient cycle can easily be arrived at by establishing a set of boundary conditions consistent with the physics of the transient process. By definition, excess transient emissions will dissipate to zero by the end of the transient cycle so that,

$$e(r)\big|^{R} = 0, \qquad (6\text{-}10)$$

where e(r) represents the distance rate of excess emissions as a function of distance traveled, r. Futhermore, it is reasonable to assume that the rate of change of excess emissions with distance will be decreasing over the transient cycle, and will approach zero as a smooth function at the end of the cycle. Thus,

$$\frac{\partial e(r)}{\partial r}\bigg|^{R} = 0. \qquad (6\text{-}11)$$

A quadratic function,

$$e(r) = a + br + cr^2, \qquad (6\text{-}12)$$

is chosen as the simplest functional form to describe e(r) that will satisfy the boundary conditions given in Equations 6-10 and 6-11 (Figure 19).

A final boundary condition is needed to evaluate the coefficients in Equation 6-12. This is supplied by the definition of Etr:

$$E_{tr} = \int_0^R e(r)\, dr \quad . \qquad (6\text{-}13)$$

Simultaneous solution of Equations 6-10, 6-11 and 6-13 yields the following relationship for the excess transient emission rate:

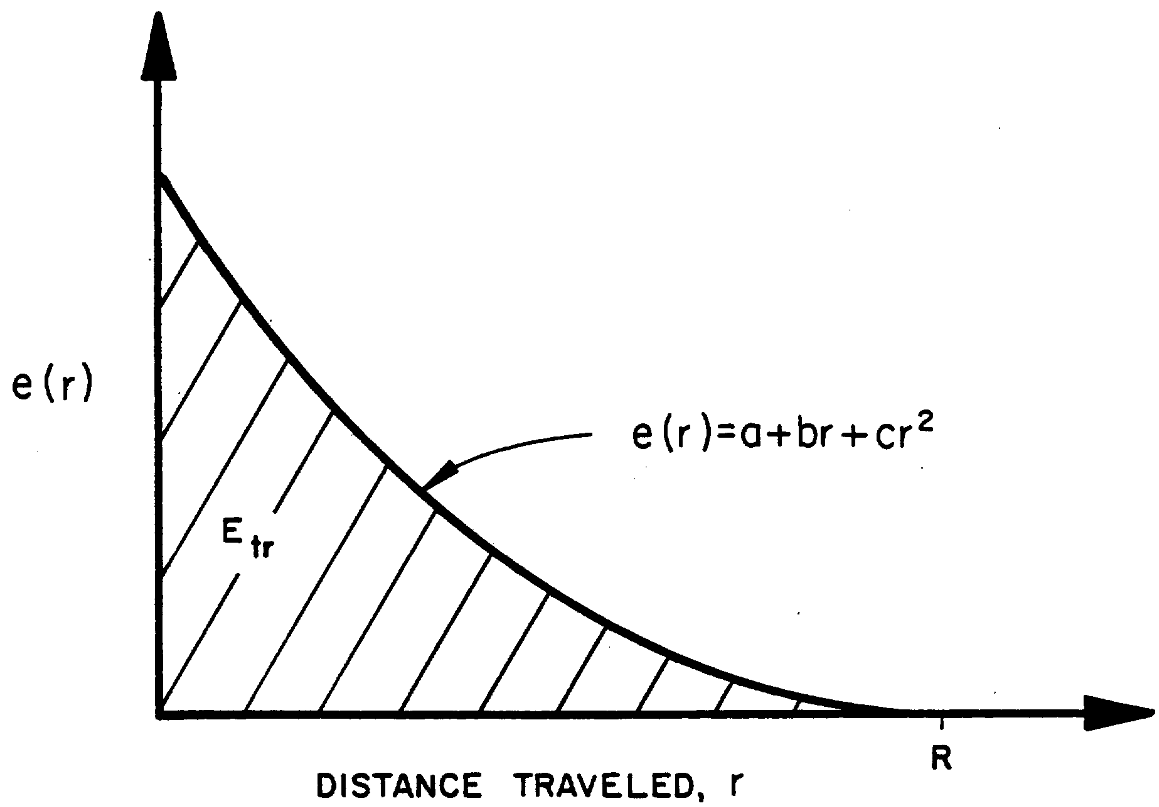
$$e(r) = \frac{3E_{tr}}{R} \left(1 - \frac{2}{R}r + \frac{1}{R^2}r^2 \right) \quad . \qquad (6\text{-}14)$$

Equation 6-14 may also be cast as a function of fraction of transient cycle completed, fr=r/R. This form of the equation leads to a generalized relation between the fraction excess transient emissions, fe and fr through the equation,

$$f_e = \frac{\int_0^{f_r} e(f_r)\, df_r}{E_{tr}} \quad . \qquad (6\text{-}15)$$

Performing the indicated integration and simplifying gives

$$f_e = f_r^3 - 3f_r^2 + 3f_r . \qquad (6\text{-}16)$$



EMISSION RATE FUNCTION FOR EXCESS TRANSIENT EMISSIONS.

FIGURE 19

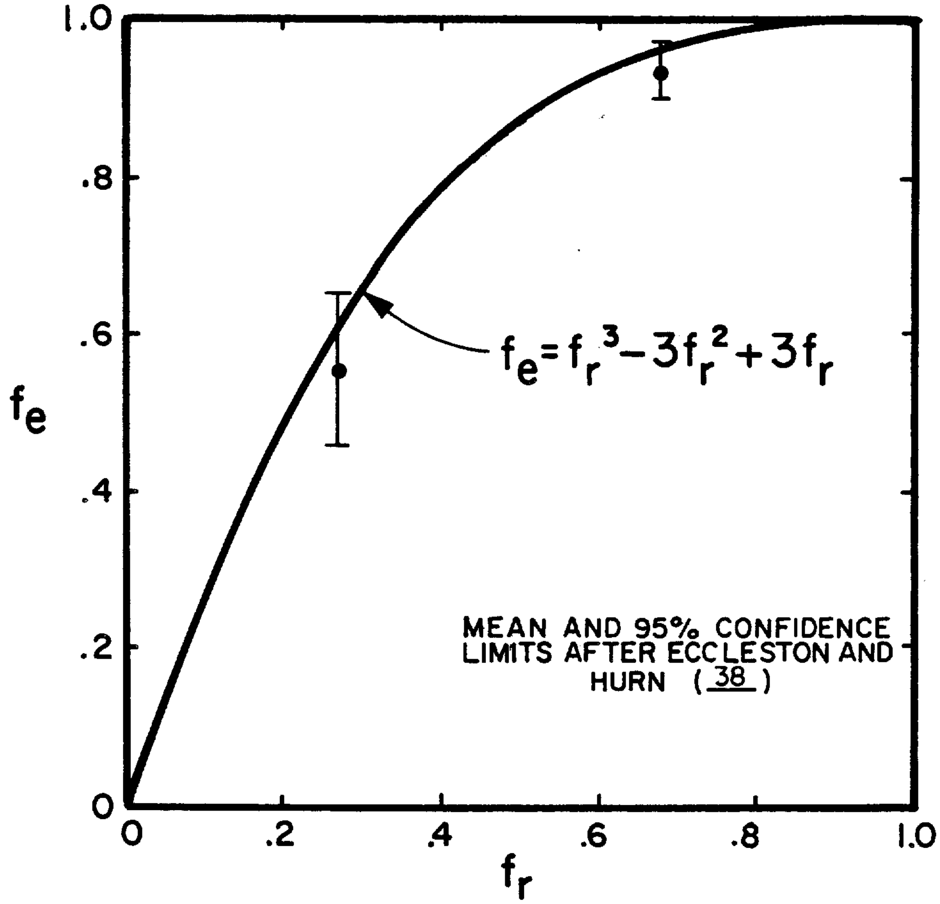
A plot of Equation 6-16 is shown in Figure 20. Superimposed on this plot are the results from an FTP-75 cold- start study conducted by Eccleston and Hurn(38). The mean and 95% confidence limits are shown for interim cold-start CO emissions from the 9 gasoline-powered vehicles studied. Equation 6-16 yields slightly higher fractions on average because of the boundary condition described in Equation 6-10. The measured results include both excess and running emissions so that e(r) will equal a value greater than zero at the end of the cycle. However, the running (or hot- stabilized) emission rate is typically much less than the excess cold-start emission rate, so that the difference is minor. The measured results, though few in number, give some degree of verification to Equation 6-14.

To find a properly weighted excess transient emission rate for urban freeways, one must multiply e(r) by the elemental weighting factor contained in Equation 6-9 and integrate over the complete transient cycle. Using **Y** to represent the correction factor for $\bar{e}tr$, this can be stated as

$$\gamma \bar{e}_{tr} = \frac{2}{R^2} \int_0^R e(r) \cdot r \, dr \quad . \qquad (6\text{-}17)$$

Substituting Equation 6-14 yields

$$\gamma \bar{e}_{tr} = \frac{6E_{tr}}{R^3} \int_0^R \left(r - \frac{2}{R} r^2 + \frac{1}{R^2} r^3 \right) dr \quad . \qquad (6\text{-}18)$$



FRACTION EXCESS TRANSIENT EMISSIONS, fe . VERSUS FRACTION OFTRANSIENT CYCLE COMPLETED, fr

FIGURE 20

Integrating Equation 6-18 and simplifying gives

$$\gamma \bar{e}_{tr} = \frac{E_{tr}}{2R} \quad . \qquad (6\text{-}19)$$

By definition, $\bar{e}tr = Etr/R$. Therefore, $\gamma = 1/2$ for conditions consistent with the assumptions of the foregoing derivation. This means that cold and hot-start excess emission rates should be reduced by 50% for microscale analyses in cases where trip generation and the probability of attracting trips is uniformly distributed over a distance R from the microscale location. In urban freeway locations removed from "point" source trip generators such as stadiums or convention centers, the 50% reduction is appropriate. Even if trips are generated out of isolated sectors radiating away from the microscale location, Equation 6-9 is still valid because of symmetry.

For composite emission computations, the 50% reduction can easily be accomplished by using cold and hot-start vehicle fractions of half the amount they are assumed to be.

A useful by-product of Equation 6-16 is its application to transient emissions from parking lots. A significant portion of air quality impacts from these types of facilities is attributable of excess cold-start emissions. By deter- mining an average egress time for vehicles leaving a parking lot, the fraction of the transient cycle assignable to the lot can be computed (FTP-75 cold and hot-start cycles are 505 seconds long). Equation 6-16 can then be used to determine the fraction of excess transient emissions assignable to the lot. The resultant quantity is distributed uniformly over the parking lot links. The distance rate emission factor needed by CALINE4 can be computed as follows,

$$EFL = \frac{1}{LL_T} * \left[(E_{tr} * f_e) + (EF_{hot} * SPD * t_e) \right] , \qquad (6\text{-}20)$$

where LL_T = Average distance traveled within the parking lot,

SPD = Average speed in the lot (say 5 mph),

EF_{hot} = Hot-stabilized emission rate at SPD,

t_e = Average egress time.

Care should be taken to use consistent units in Equation 6-20. For use in CALINE4, EFL must be in units of grams per vehicle mile (gm/veh-mi).

7. SENSITIVITY ANALYSIS

A sensitivity analysis for CALINE4 is included in this report for the following reasons:

1. It provides a formalized means for checking the behavior of the model under a variety of conditions.

2. It allows the user to gauge the sensitivity of the model to each input parameter, thereby identifying the degree of accuracy to which parameters need to be estimated.

3. It provides benchmark values against which users may check results from their copies of the model.

Since most of the CALINE4 input parameters act independently, interactions between two or more variables are of little importance. Perturbation of one variable at a time is sufficient for characterizing the overall sensitivity of the model. In cases where a significant interaction exists, a qualitative discussion of the interaction is given in the text.

The main series of sensitivity runs consists of CO concentration-wind angle (PHI) graphs. Each of these runs involves the perturbation of a discrete input variable from a standard value. The runs are made for a single highway link, and are replicated for three distances from the highway centerline: 15, 30 and 60 meters. The standard values for the input variables are given in Table 3.

TABLE 3

Standard Input Values for the CALINE4 Sensitivity Analysis

I. Site Variables

Temperature:	T =	25°	(C)
Wind Speed:	U =	1.0	(m/s)
Wind Direction:	BRG =	variable	(deg)
Directional Variability:	SIGTH =	10	(deg)
Atmospheric Stability:	CLAS =	6	(F)
Mixing Height:	MIXH =	1000	(m)
Surface Roughness:	Z0 =	50	(cm)
Settling Velocity:	VS =	0	
Deposition Velocity:	VD =	0	
Ambient:	AMB =	0	
Altitude:	ALT =	0	

II. Link Variables

Traffic Volume:	VPH =	5000	(veh/hr)
Emission Factor:	EF =	20	(gms/veh-mi)
Height:	H =	0	
Width:	W =	30	(m)
Link Coordinates:	X1 =	0	
	Y1 =	5000	(m)
	X2 =	0	
	Y2 =	-5000	(m)

III. Receptor Locations

	XR =	15,30,60	(m)
	YR =	0	
	ZR =	0	

The CALINE4 results are shown as tic marks on the sensitivity graphs. No attempt was made to smooth the curves running through these computed values. Insignificant anomalies in the model results can be observed in some of the graphs. These anomalies are due to the discrete nature of the element formulation. To smooth them out would require finer element and sub-element resolution, resulting in increased computational time.

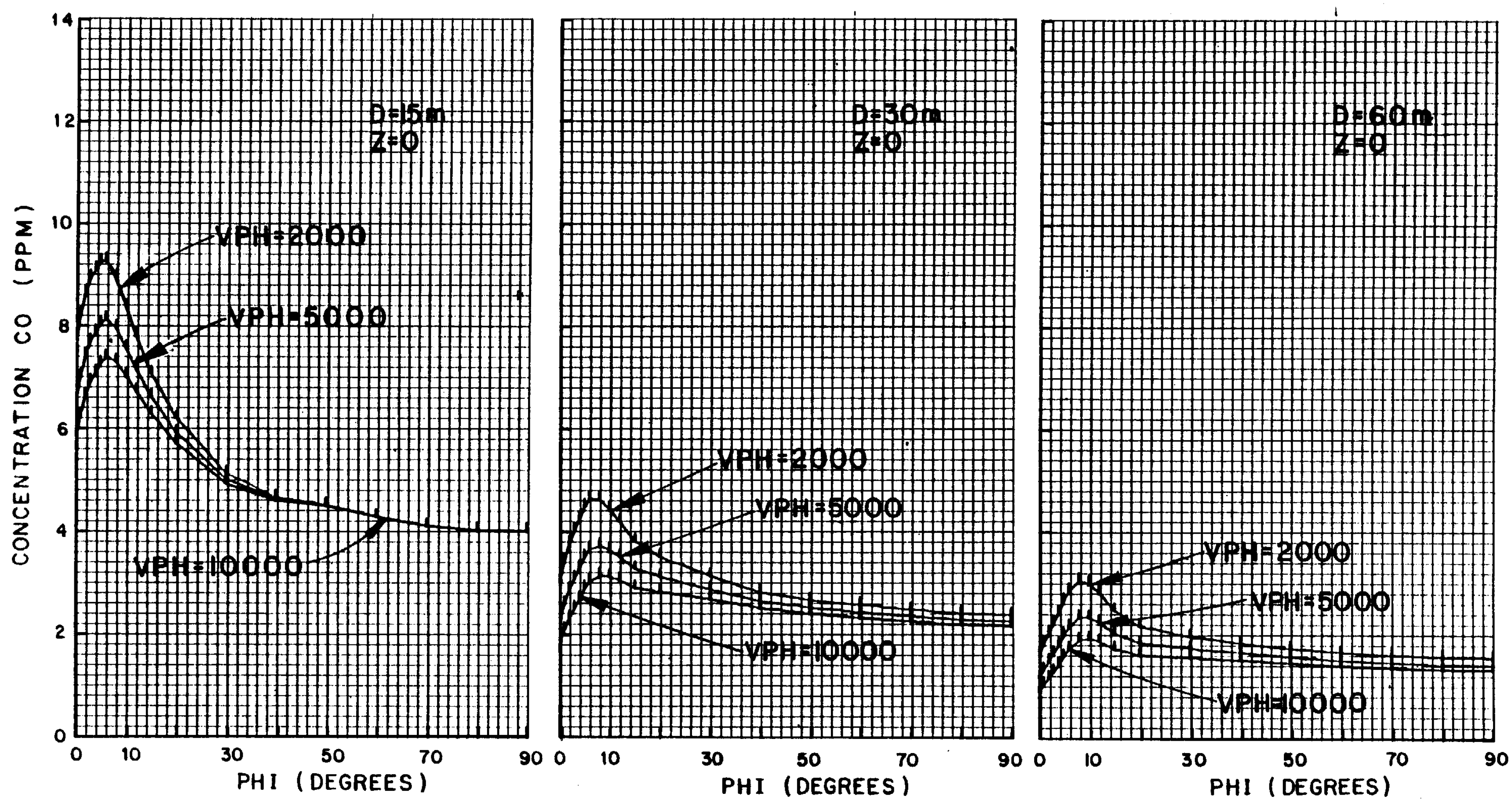
7.1 Emission Factor

CALINE4 link emission factors for relatively inert pollutants such as CO are directly proportional to the predicted concentrations. A twofold increase in an emission factor will result in a doubling of the predicted concentration. Because of this simple relationship, no sensitivity analysis was performed for the emission factor variable.

7.2 Traffic Volume (Figure 21)

In the CALINE3 model, both emission factor and traffic volume were directly proportional to concentration. In CALINE4, however, the vehicle-induced heat flux component of the vertical dispersion algorithm alters the one-to-one correspondence between traffic volume and concentration. The sensitivity graphs shown in Figure 21 are normalized to permit a direct comparison between traffic volumes. This is done by varying the emission factor so that the traffic volume-emission factor product remains constant.

CALINE4 clearly shows lower concentrations for higher traffic volumes at the constant overall source strength maintained in the analysis. Similar graphs for CALINE3



CALINE4 SENSITIVITY ANALYSIS— VARIABLE: TRAFFIC VOLUME (VPH)
(NOTE: RESULTS NORMALIZED FOR CONSTANT SOURCE STRENGTH)

FIGURE 21

would show no difference between the traffic volumes. The difference in the CALINE4 results is attributable to the augmented rate of vertical dispersion used by the model to account for the additional thermal turbulence created by more vehicles. The effect is most pronounced for parallel winds. The distance over which the augmented rate is used (DMIX) is considerably longer for parallel winds than for crosswinds.

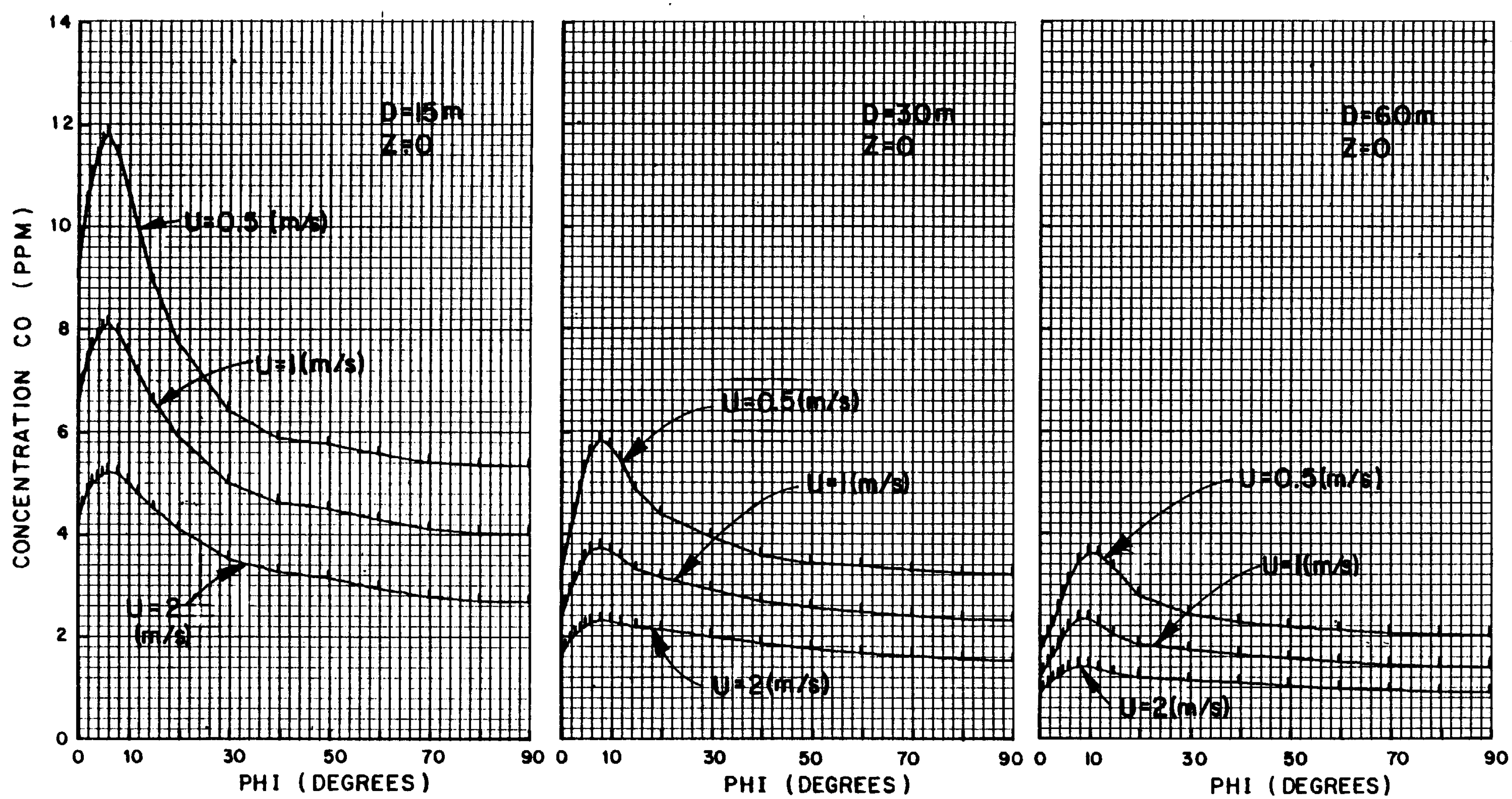
Under crosswind conditions at the edge of the mixing zone (D=15 meters) the traffic volume effect is absent. The mixing zone model, which is independent of the heat flux adjustment, determines the vertical dispersion parameter at this point. It is assumed that mechanical turbulence is usually the dominant dispersion mechanism within the mixing zone. However, under parallel wind conditions, mixing zone concentrations receive a significant number of contributions from distant elements. These contributions are heavily influenced by the heat flux adjustment, and therefore lead to a significant drop in normalized mixing zone concentrations at higher traffic volumes.

7.3 Wind Speed (Figure 22)

CALINE4 model results are sensitive to wind speed in several important ways. Wind speed determines the extent to which pollutants are initially diluted with ambient air at the point of release. This effect is treated as an inverse relationship between wind speed and concentration in the Gaussian formula. Wind speed also plays an important role in the dispersion parameter computations. It determines the mixing zone residence time used for computing the initial vertical dispersion parameter, and is involved in the heat flux modification to the vertical dispersion curve. It is also used in horizontal dispersion parameter computations for calculating the dispersion time for each element-receptor combination.

The net effect of wind speed on model results is shown in Figure 22. A series of sensitivity curves are plotted for 0.5, 1 and 2 m/s. In all cases, lower wind speeds yield higher concentrations. This demonstrates that the inverse relationship between wind speed and concentration (dilution effect) is still dominant in CALINE4. However, the sensitivity curves also reveal the influence of wind speed on dispersion parameter computations. At lower wind speeds, both initial vertical dispersion and vehicle-induced thermal effects lead to higher estimates of the vertical dispersion parameter and, hence, lower concentration estimates. These effects lessen in importance as the roadway-receptor distance increases. Ratios between high to low wind speed concentrations taken from Figure 22 confirm this by decreasing slightly with increased distance from the roadway. Lower wind speeds also have the effect of reducing the horizontal dispersion parameter given a constant value for $\sigma\theta$. This leads to higher concentration estimates. Since the horizontal dispersion parameter is most important under parallel wind conditions, the relative difference between low and high wind speed concentrations should be greater for parallel wind cases. This is clearly shown in Figure 22.

Maximum concentrations occur under near-parallel wind conditions for all wind speeds. These maximums become less pronounced at higher wind speeds and greater distances. The roadway-wind angles at peak concentration appear to be



CALINE4 SENSITIVITY ANALYSIS — VARIABLE: WIND SPEED (U)

FIGURE 22

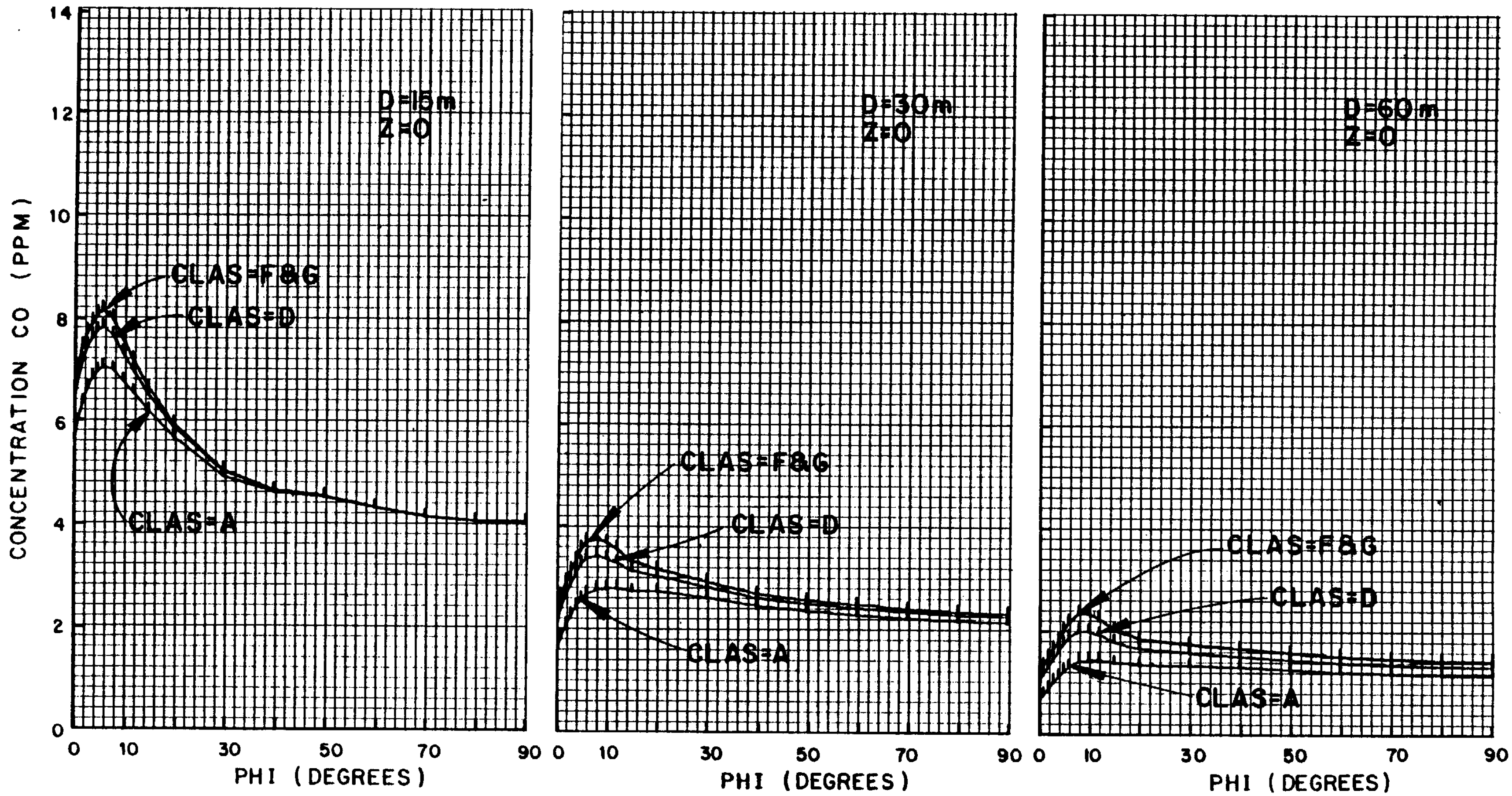
relatively independent of wind speed, and to shift slightly away from parallel at greater receptor distances.

7.4 Stability Class (Figure 23)

The CALINE4 sensitivity curves for stability class are dramatically different from the CALINE3 curves. Sensitivity to stability class is much reduced in CALINE4. There are two reasons for this change. First, vehicle- induced mechanical and thermal turbulence reduce the importance of ambient stability near the roadway. Second, stability class no longer plays a direct role in determining the horizontal dispersion parameter. Instead, $\sigma\theta$ is assigned directly by the user.

The role of stability class can actually be much more important than is indicated in Figure 23. If traffic volume is low, vehicle-induced turbulence becomes less significant so that ambient stability again becomes the dominant factor in determining vertical dispersion outside of the mixing zone. Also, stability class is often used to estimate $\sigma\theta$ when measured values are not available. In such instances, $\sigma\theta$ becomes a surrogate for stability class so that the combined effects of both variables must be examined to estimate overall model sensitivity to atmospheric stability.

As can be seen in Figure 23, CALINE4 model results are independent of stability class under oblique to crosswind conditions at the edge of the roadway. Wind speed and mixing zone width control the vertical dispersion parameter at this location via the mixing zone model (Equation 5-12). Under parallel wind conditions, contributions from more distant elements cause a spread in model results over the



CALINE4 SENSITIVITY ANALYSIS — VARIABLE: STABILITY CLASS (CLAS)

FIGURE 23

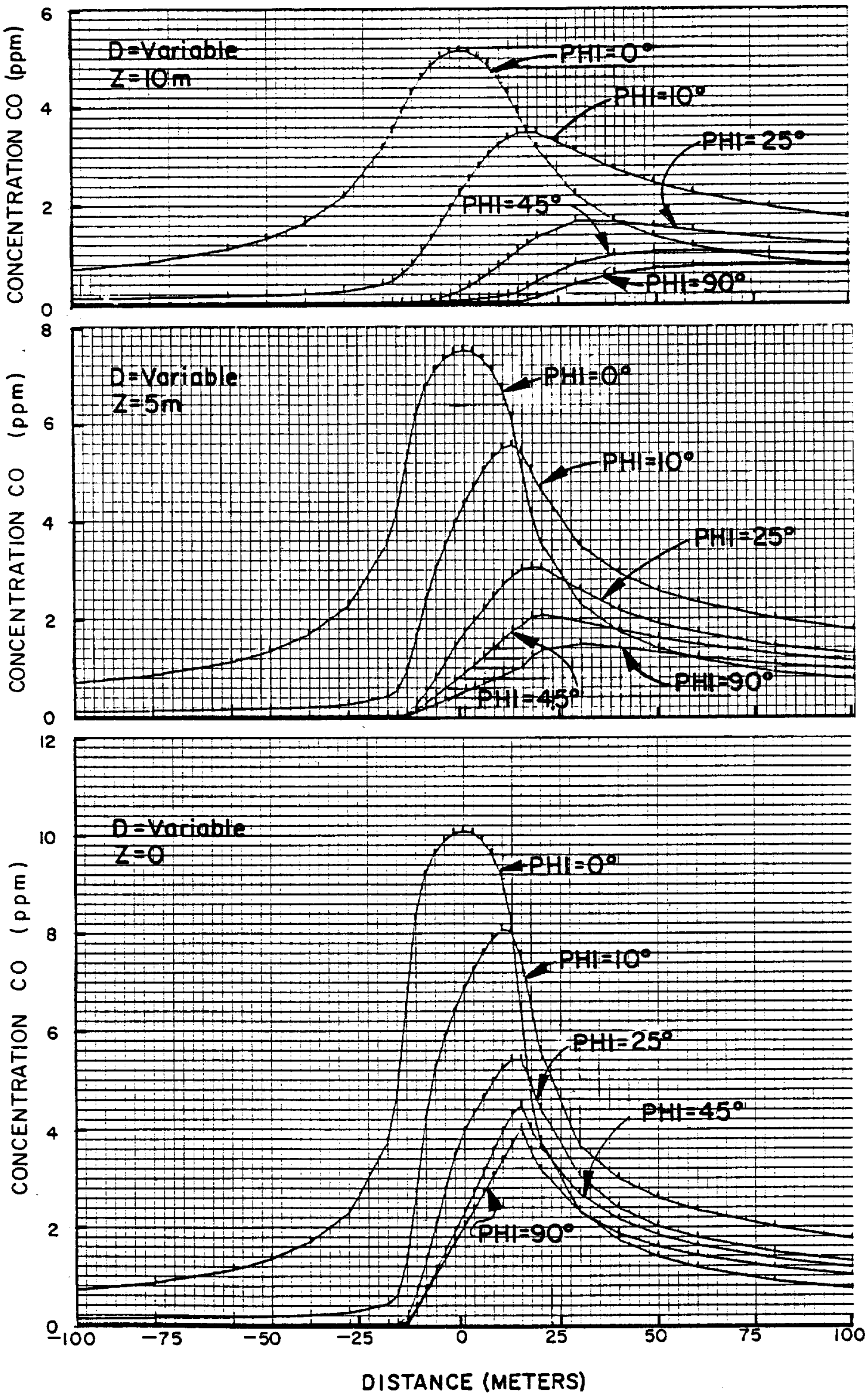
range of stability classes (A=very unstable, G=extremely stable). As distance from the mixing zone increases, some sensitivity to stability class is exhibited by the model under crosswind conditions. For a given receptor distance5 the wind angle of maximum concentration exhibits little or no sensitivity to stability class.

7.5 Wind Angle (Figure 24)

CALINE4 sensitivity to the roadway-wind angle is illustrated for three receptor heights in Figure 24. Results are given for both upwind and downwind locations out to a distance of 100 m from the roadway centerline. For downwind locations outside of the mixing zone, PHI=10˚ yields the highest concentrations. A smooth build-up of concentrations across the mixing zone is readily apparent in the PHI=90˚, Z=O case. Receptors located just upwind of the mixing zone appear to be extremely sensitive to small changes in PHI under near-parallel wind conditions.

Predicted concentrations near and within the mixing zone are sensitive to receptor height. However, for distant receptors there is little noticeable difference as a function of receptor height. This implies a fairly uniform distribution of the pollutants within the first 10 meters of the surface layer for distant receptors.

Peak concentrations for pure parallel winds occur along the centerline of the roadway. The previous graphs showing peak concentrations occurring usually in the 3˚ to 4˚ range were for receptors at the edge of the roadway (D = 15 meters). The crossover point for wind angle curves of 0˚ and 10˚ occurs further from the roadway for greater receptor heights. Therefore, one would expect the critical



CALINE4 . SENSITIVITY ANALYSIS— VARIABLE: WIND ANGLE (PHI)

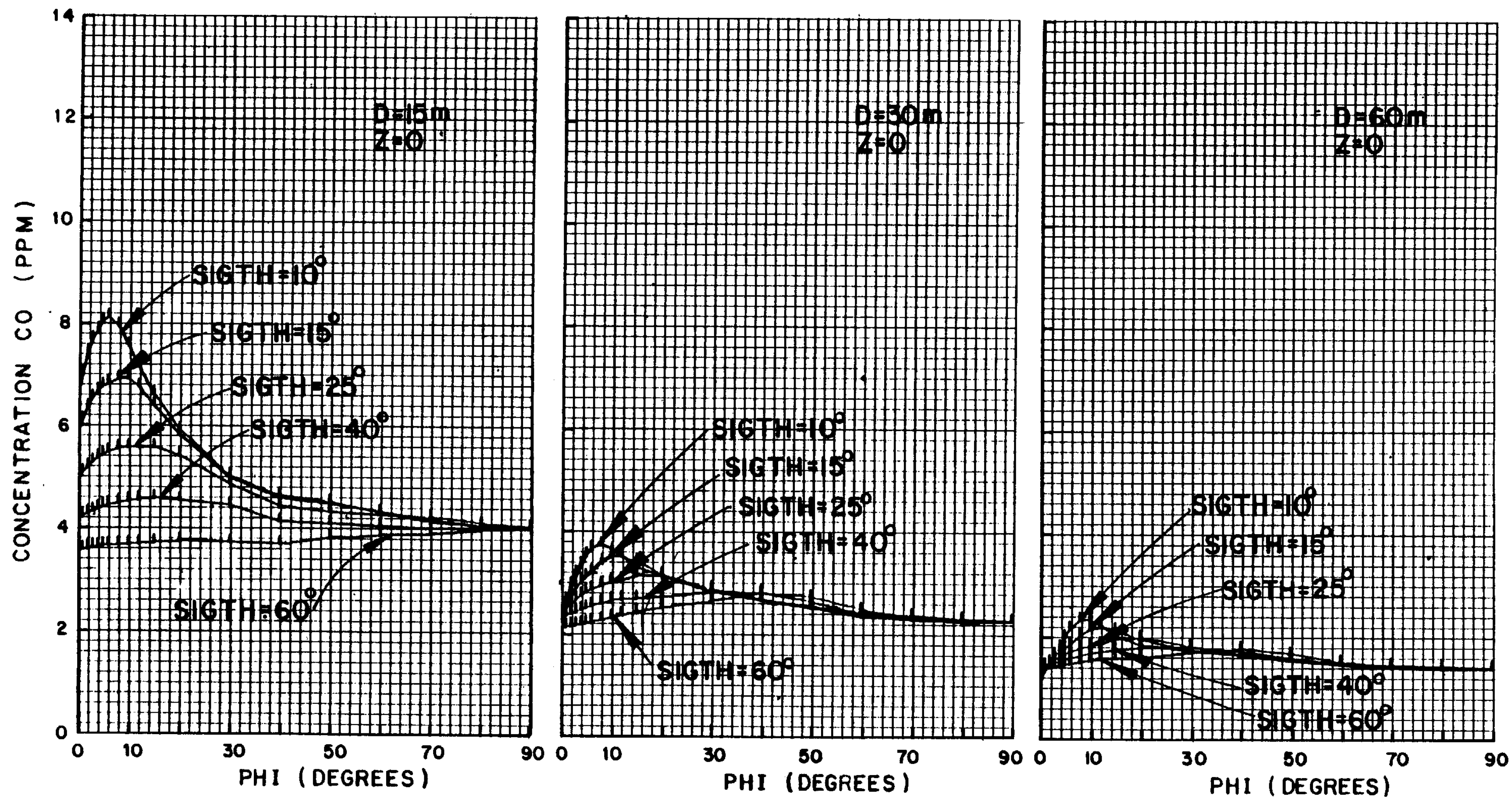
Figure 24

wind angle of maximum predicted concentration to shift inward toward the pure parallel wind condition for increased receptor heights. This is due to the lowering of contributions from the closest elements as the receptor height is increased. These close elements, with still tightly directed plumes, are the ones that cause peak concentrations to occur at wind angles of 3˚ to 4˚ (under standard run conditions) for ground level receptors at the roadway edge.

7.6 Directional Variability (Figure 25)

Variability of wind direction is explicitly defined in CALINE4 as the standard deviation of the wind direction, $\sigma\theta$. This is denoted in the model as SIGTH. In CALINE3, directional variability was implicit in the horizontal dispersion curves, and varied according to stability class and averaging time. Averaging time is no longer required as an input for CALINE4, and stability class is no longer directly involved in the horizontal dispersion parameter determination. Instead, both these effects are incorporated into the SIGTH variable.

Figure 25 illustrates the model's sensitivity to SIGTH. For parallel winds, concentrations increase with decreasing SIGTH. This is caused by the greater impact of distant elements under conditions when horizontal dispersion is slight. This effect weakens as receptor distance in- creases. Under crosswind conditions, the value of SIGTH is of little or no importance to the model since concentrations from a semi-infinite link are independent of horizontal dispersion as PHI approaches 90˚. However, a situation involving a short link and a distant receptor would exhibit some sensitivity to SIGTH under crosswind conditions.



CALINE4 SENSITIVITY ANALYSIS — VARIABLE: WIND DIRECTIONAL VARIABILITY (SIGTH)

FIGURE 25

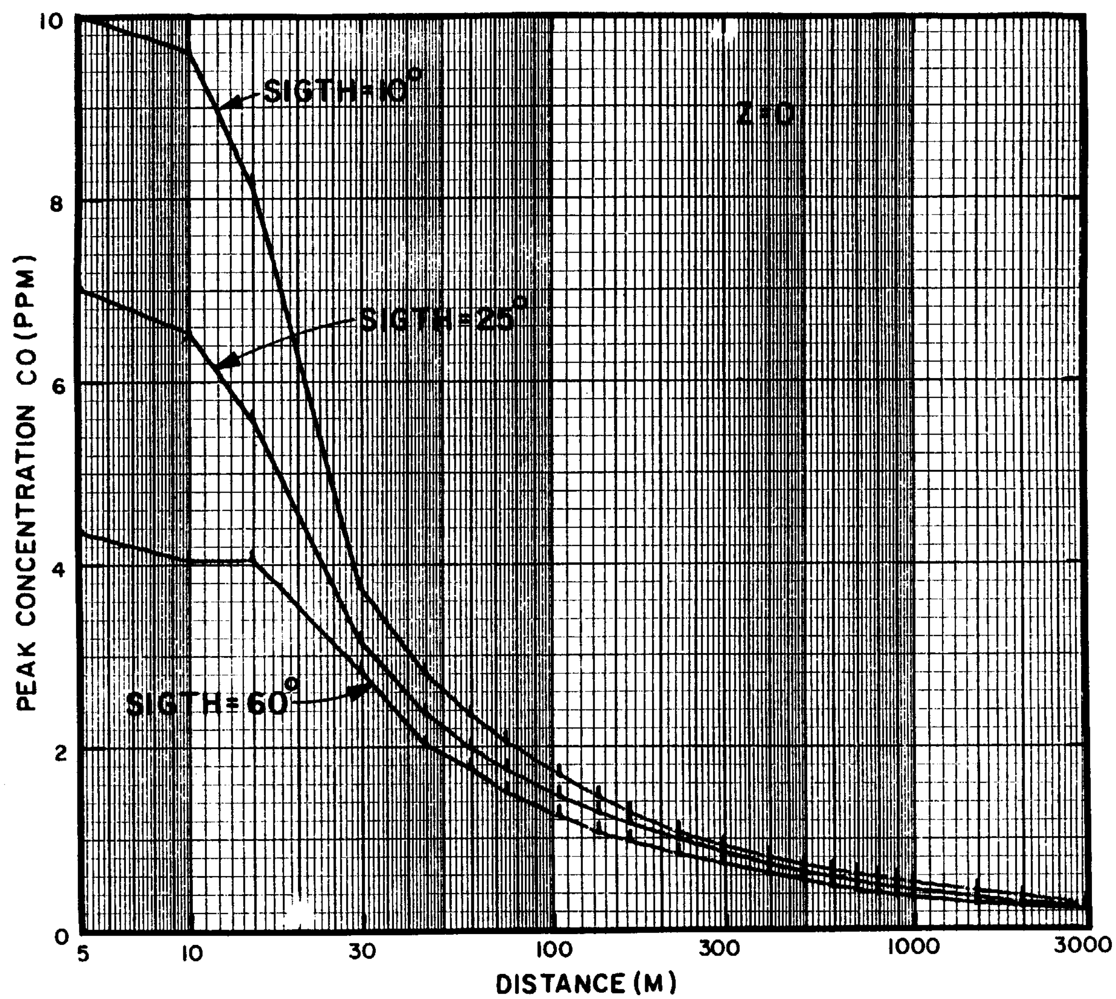
As the values for SIGTH shown in Figure 25 increase, the importance of the wind angle diminishes. For values of SIGTH greater than 40°, downwind concentrations are virtually independent of PHI. This effect is most noticeable at the edge of the roadway. For high values of SIGTH, the contributions from distant elements drop off rapidly. When the only significant contributions are from the nearest one or two elements, model results tend to approach crosswind conditions regardless of the wind angle.

There is a significant shift in the wind angle of maximum concentration away from parallel as SIGTH increases. This is apparent at all three distances studied. The explanation again rests with the diminishing importance of distant elements as SIGTH gets larger. As closer elements become more important, higher concentrations result when these elements are directly upwind of the receptor. This shifts the wind angle away from the parallel condition.

7.7 Receptor Distance (Figures 26 and 27)

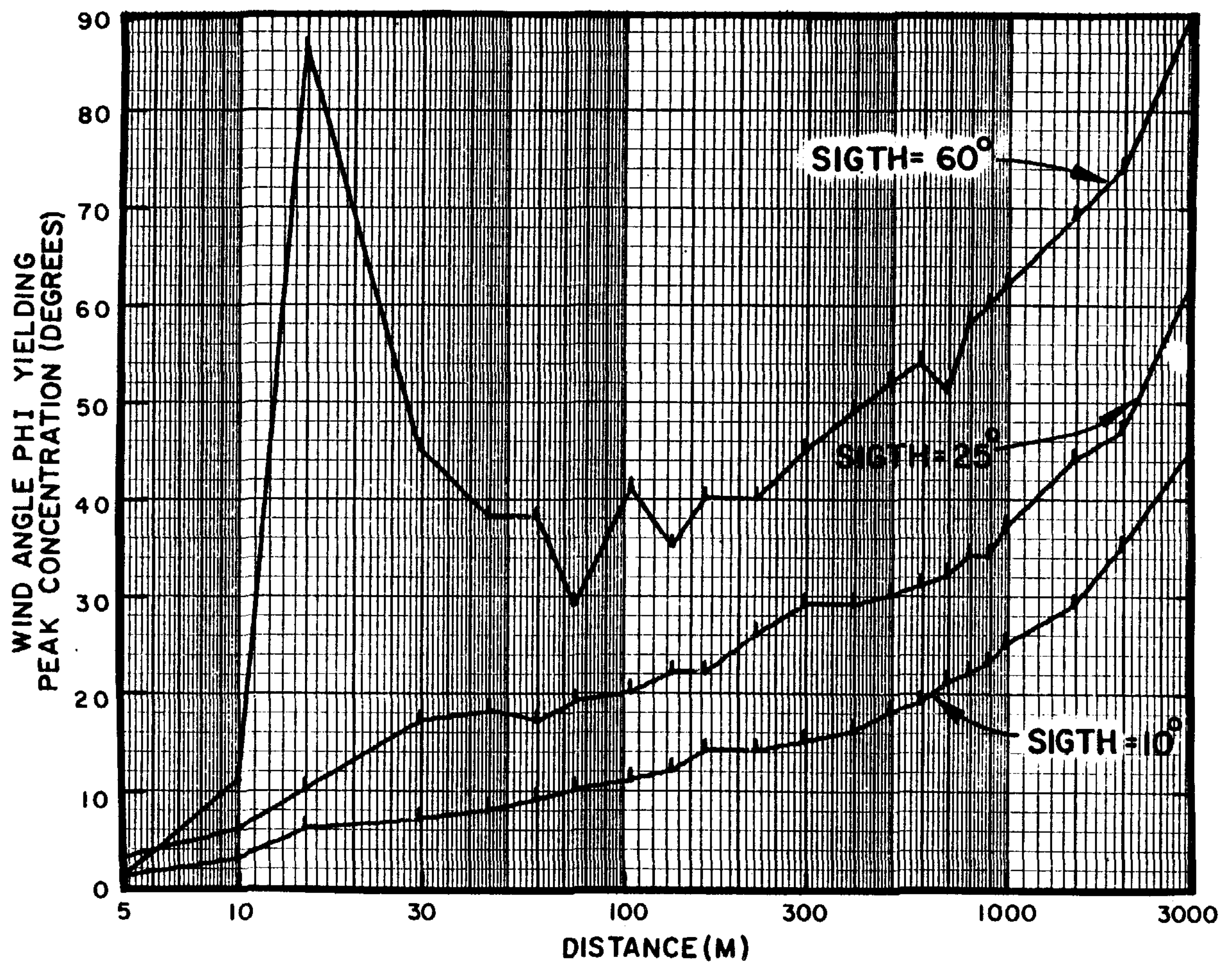
As the distance from a ground level source increases, ground level concentrations naturally decrease. The rate of this decrease as predicted by CALINE4 is shown in Figure 26 for peak concentrations at three levels of SIGTH. The corresponding values for PHI are shown in Figure 27.

The rate of decrease in peak concentration is smooth and fairly constant for all three cases at distances of 30 m and greater. The peak concentrations for the three cases differ only slightly at these distances. The importance of SIGTH increases dramatically for distances under 30 m, however, with higher peak concentrations for low values of SIGTH



CALINE4 SENSITIVITY ANALYSIS—PEAK CONCENTRATION

FIGURE 26



CALINE4 SENSITIVITY ANALYSIS — PEAK WIND ANGLE

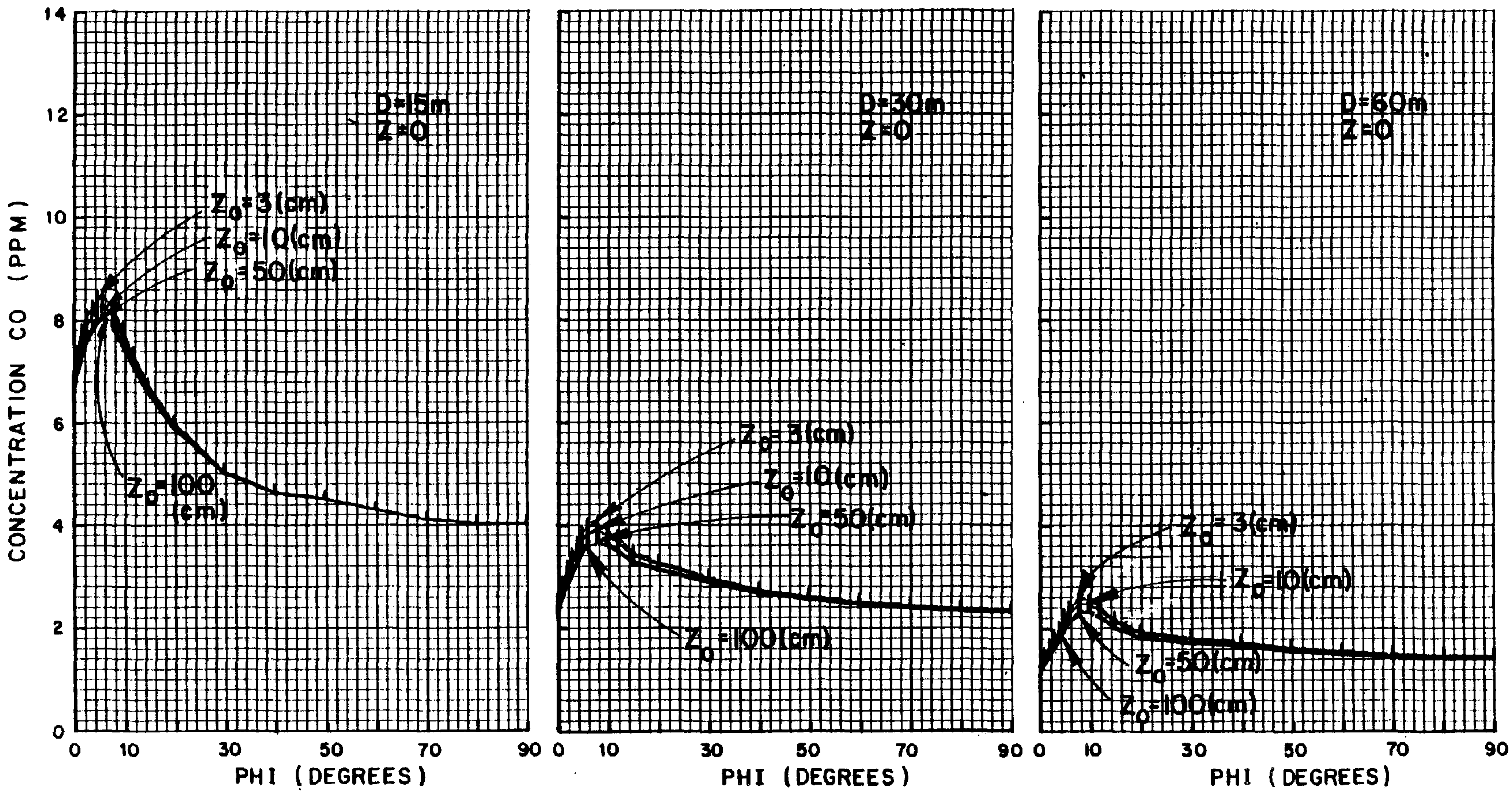
FIGURE 27

As has already been seen, the value of PHI for peak concentrations at receptors in and near the mixing zone approaches 0° (parallel wind). As distance increases, the peak wind angle shifts toward more oblique values. This shift is strongest for the case representing a high amount of directional variability (SIGTH = 60°). This same case also exhibits a large amount of instability for peak wind angles at distances of 10 to 100 meters. Such transient behavior is not a sign of overall instability in the model, but is merely the result of the flat model response to wind angle for high values of SIGTH. In terms of peak concentration, the model response is completely stable for all three cases.

7.8 Surface Roughness (Figure 28)

Mechanical turbulence is generated by air movement over surface roughness elements. An increase in surface roughness will increase the amount of mechanical turbulence generated. This can enhance both the vertical and horizontal dispersion of pollutants released near ground level. The aerodynamic roughness length, ZO, is used in meteorological work as a common measure of surface roughness.

As can be seen in Figure 28, CALINE4 is relatively insensitive to ZO. For crosswind conditions, predicted concentrations near the roadway are dominated by the mixing zone model. This model is independent of surface roughness. At greater receptor distances than shown in Figure 28, a slight sensitivity to ZO under crosswind conditions would begin to emerge. For near-parallel winds, a slight difference in model results can be seen in Figure 28. This follows the expected trend of lower concentrations for higher values for ZO. However, the heat flux algorithm has a significantly greater influence on model output (Figure 21).



CALINE4 SENSITIVITY ANALYSIS — VARIABLE: ROUGHNESS (ZO)

FIGURE 28

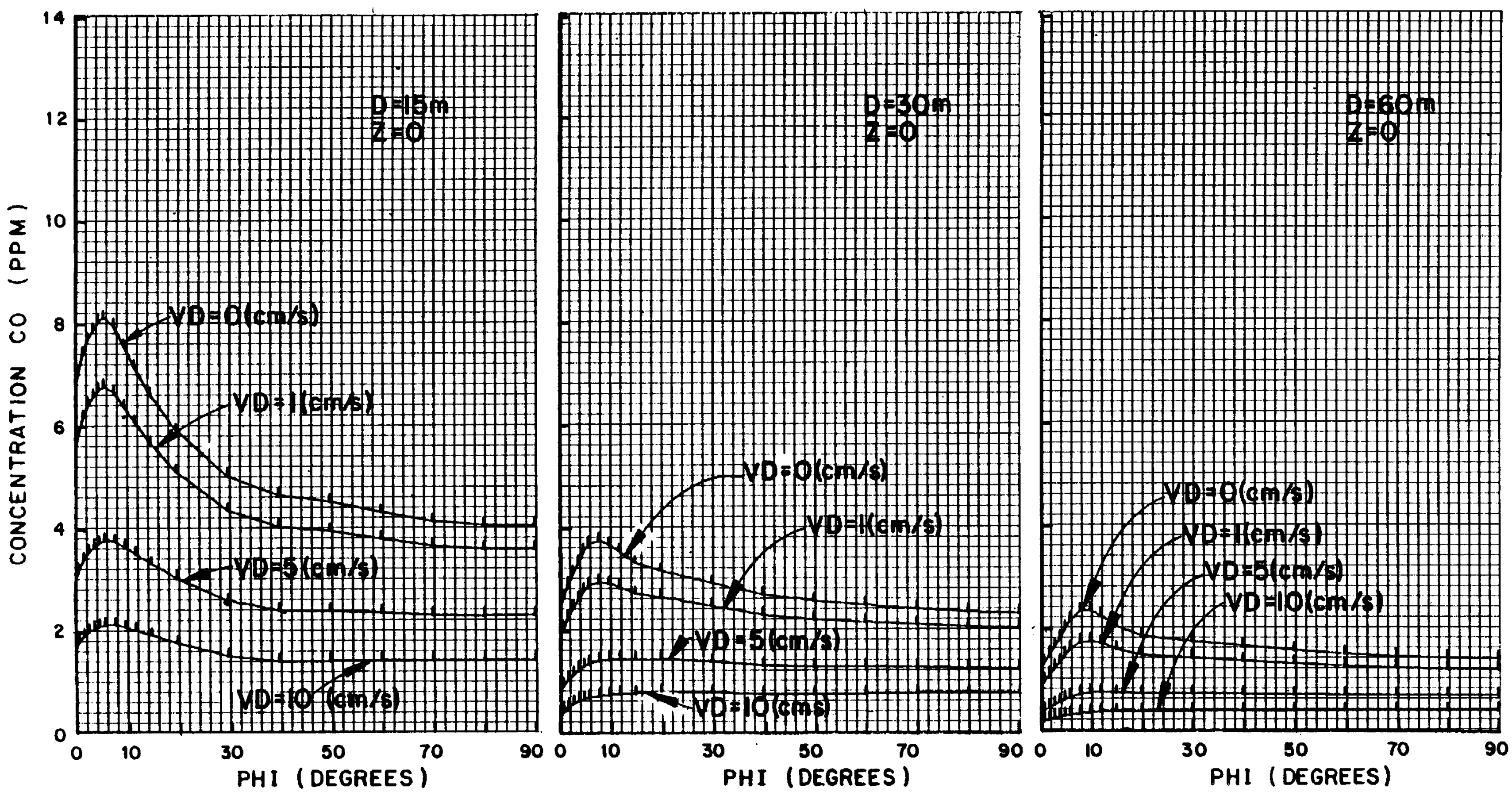
7.9 Deposition Velocity (Figure 29)

A significant deposition velocity tends to lessen the impact of distant elements on receptor concentrations (the longer the time of travel, the more material deposited). Because of this, increasing deposition velocities tend to flatten the near-parallel concentration peaks (Figure 29). At the D=60 meter receptor, maximum concentrations actually occur during crosswind conditions when the deposition velocity is high. Figure 29 also shows that higher deposition velocities reduce crosswind concentrations. This effect is fairly consistent as receptor distance increases.

7.10 Settling Velocity (Figure 30)

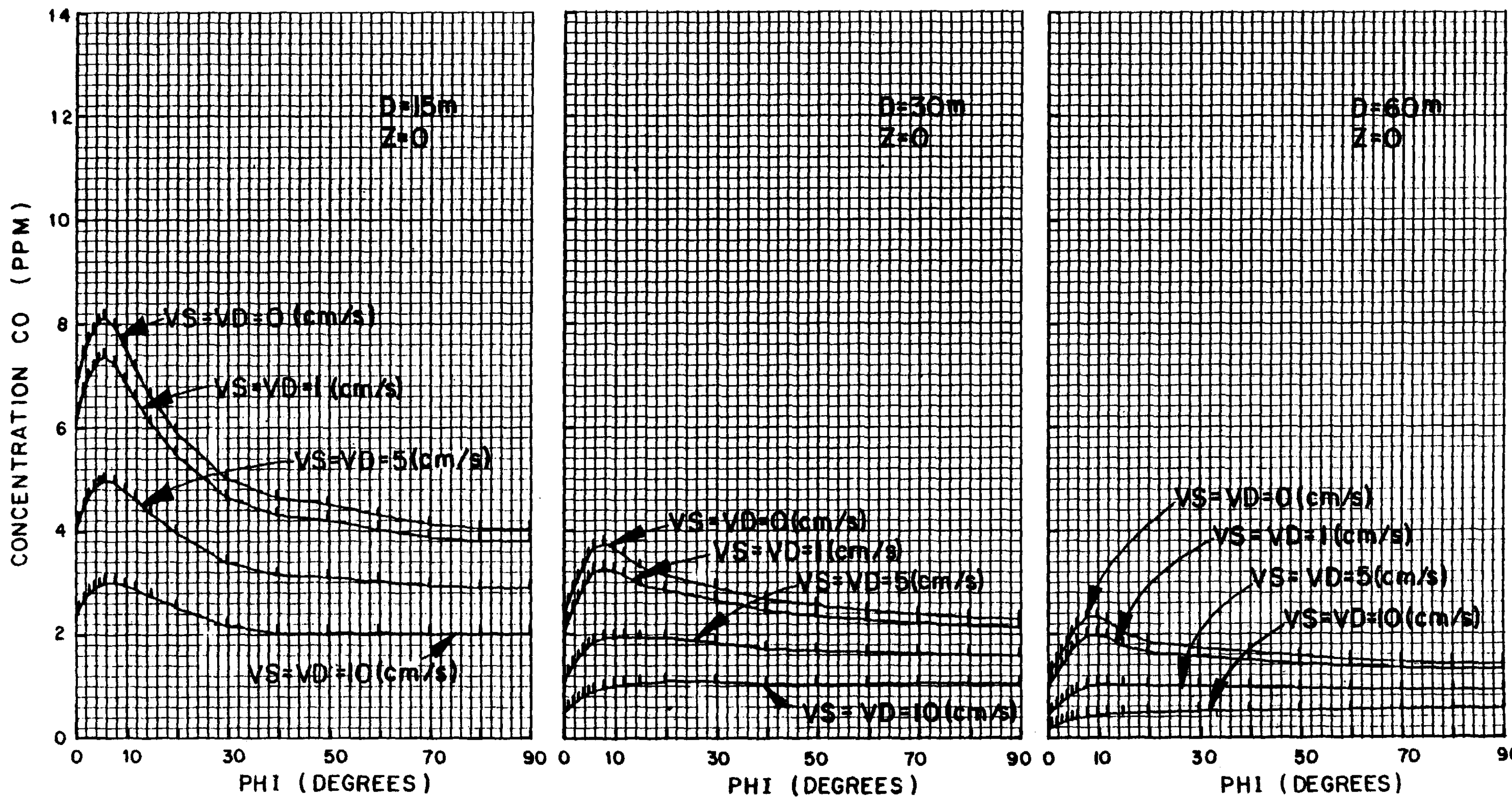
While deposition velocity controls the amount of material leaving the air to be deposited on the ground, settling velocity actually inhibits the rate of vertical dispersion, thereby decreasing the importance of distant elements. The same type of model response observed for deposition velocity is expected for settling velocity because of this similar effect on distant elements. However, somewhat higher concentrations are observed for the settling velocity sensitivity curves shown in Figure 30. The inhibition of vertical pollutant dispersion will actually increase concentrations from elements located close enough to the receptor so that their contributions have not settled out. This leads to the higher concentrations observed in Figure 30.

Note that the deposition velocity is assumed to be equal to the settling velocity in Figure 30. Presumably, the settling velocity of a particle will be identical whether in a



CALINE4 SENSITIVITY ANALYSIS — VARIABLE: DEPOSITION VELOCITY (VD)

FIGURE 29



CALINE4 SENSITIVITY ANALYSIS – VARIABLE: DEPOSITION & SETTLING VELOCITY (VD, VS)

FIGURE 30

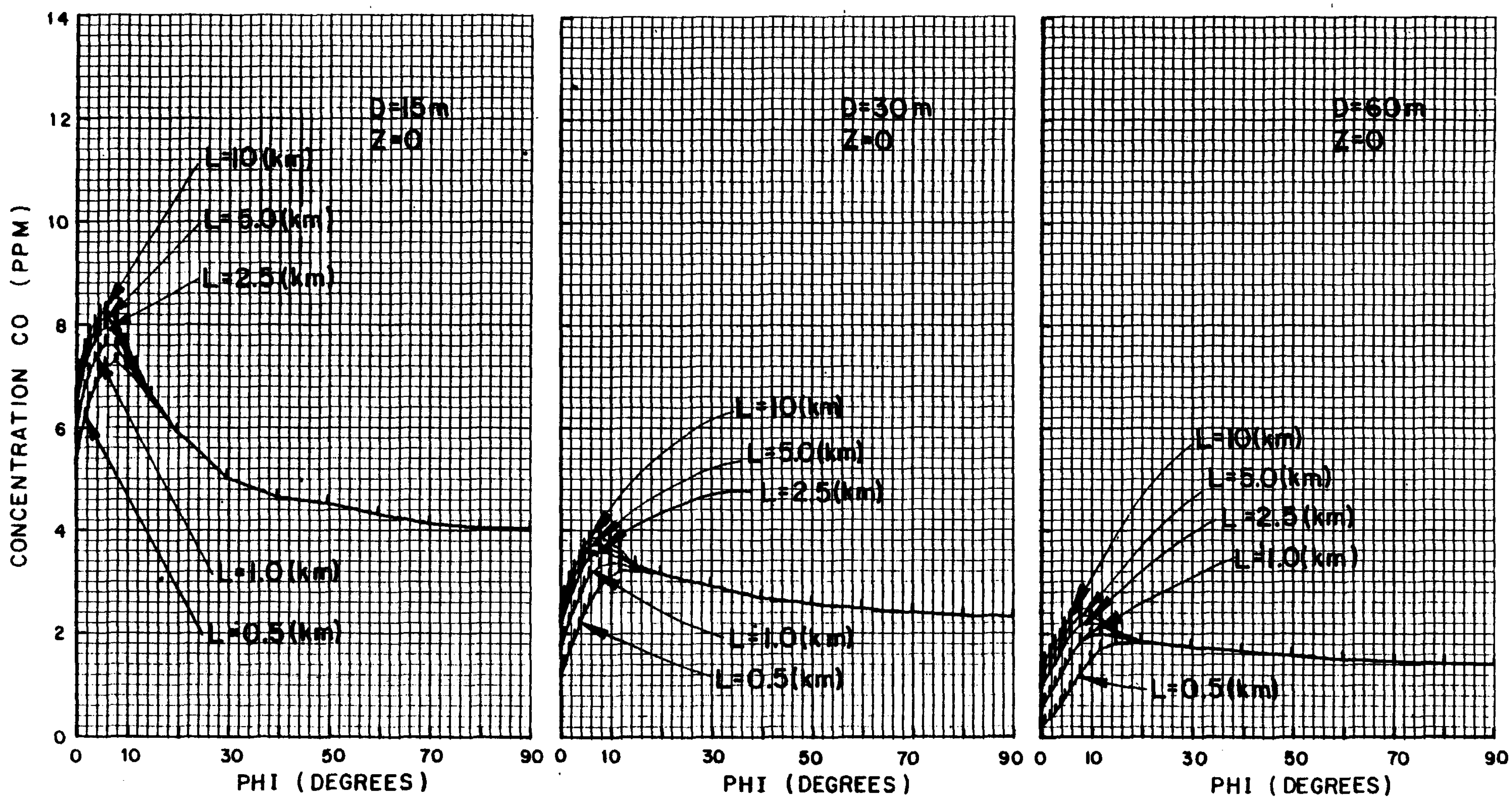
turbulent regime or the laminar sublayer. If one were to assign a specific settling velocity and set the deposition velocity equal to zero, extremely high ground concentrations would result. This would not be a realistic use of the model.

7.11 Highway Length (Figure 31)

Sensitivity graphs for five highway lengths ranging from 0.5 to 10 kilometers are shown in Figure 31. The lengths given in the figure are measures of the upwind, not the total, link length. For example, the standard run is denoted by L = 5 kilometers, though the total length of the standard link is 10 kilometers. The highest value of L given in Figure 31, 10 kilometers, is also the upper limit for L allowed by the model.

The pronounced peak concentrations for near-parallel winds which are characteristic of CALINE4 are the result of the transport of pollutants from distant elements. By reducing the highway length, a substantial reduction in these concentrations occurs because distant elements no longer contribute. Reduction of the highway length has virtually no effect on oblique and crosswind predictions. Location of the wind angle of maximum concentration is somewhat sensitive to highway length, especially at greater receptor distances.

The model sensitivity to highway length shown in Figure 31 is based on a 10° value for SIGTH. As directional variability increases, model sensitivity to highway length can be expected to decrease.



CALINE4 SENSITIVITY ANALYSIS—VARIABLE: HIGHWAY LENGTH (L)
FIGURE 31

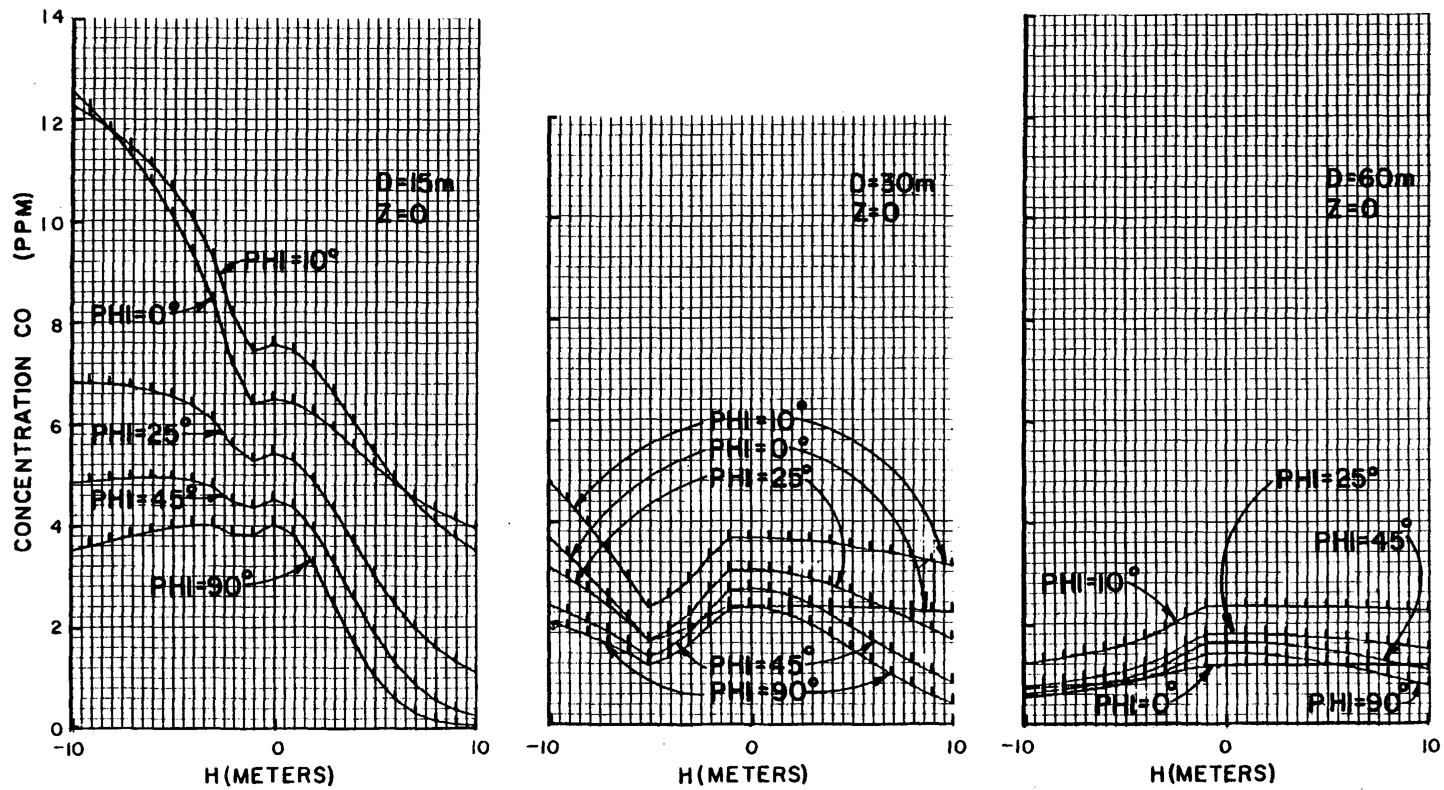
7.12 Source Height (Figure 32)

The model response to changes in source height is quite complex, though based on simple underlying assumptions. If the highway is elevated as a bridge above a receptor, predicted concentrations generally decrease. This decrease is much more significant for crosswind conditions than for parallel wind conditions. For crosswind conditions, significant contributions for receptor concentrations come from nearby elements so that the effect of source elevation is important. Under parallel wind conditions, this effect is less significant because of the larger distance over which pollutants must travel.

For depressed sections, CALINE4 predicts relatively high concentrations for receptors located within and near the highway. This area is defined as the highway width plus a distance equal to three times the depressed section depth. The algorithms used for predicting concentrations near depressed sections were empirically derived from data collected at a depressed section site along the Santa Monica Freeway in Los Angeles(3). The data showed particularly higher than normal concentrations within the depressed section and lower concentrations at receptors outside of the depressed section. As can be seen in Figure 32, this is exactly how CALINE4 responds to negative source height.

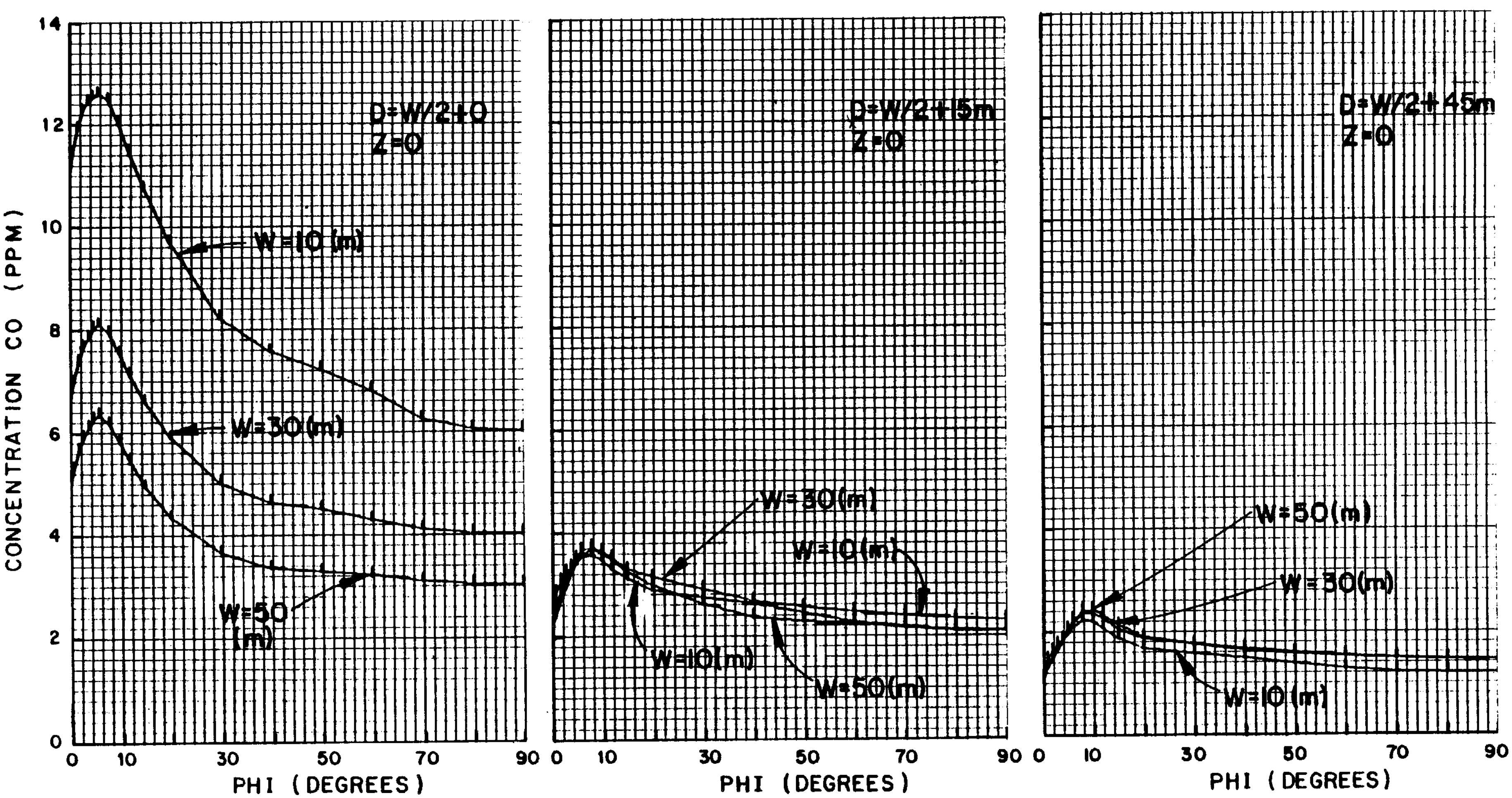
7.13 Highway Width (Figure 33)

By widening the highway, the residence time over the mixing zone and the initial horizontal distribution of the source are both increased. This enhances both vertical and horizontal dispersion near the point of release. Given a



CALINE4 SENSITIVITY ANALYSIS – VARIABLE: SOURCE HEIGHT (H)

FIGURE 32



CALINE4 SENSITIVITY ANALYSIS — VARIABLE: HIGHWAY WIDTH (W)

FIGURE 33

constant source strength, and a receptor distance referenced from the downwind edge of the roadway, the model consistently predicts lower concentrations for greater highway widths (Figure 33). This effect is most apparent for receptors near the roadway edge. If receptor distances for this analysis were not adjusted for the varying widths (i.e., D = W/2 + constant), the effects of enhanced dispersion over the mixing zone would be more than offset by the closer proximity of the mixing zone to the receptor.

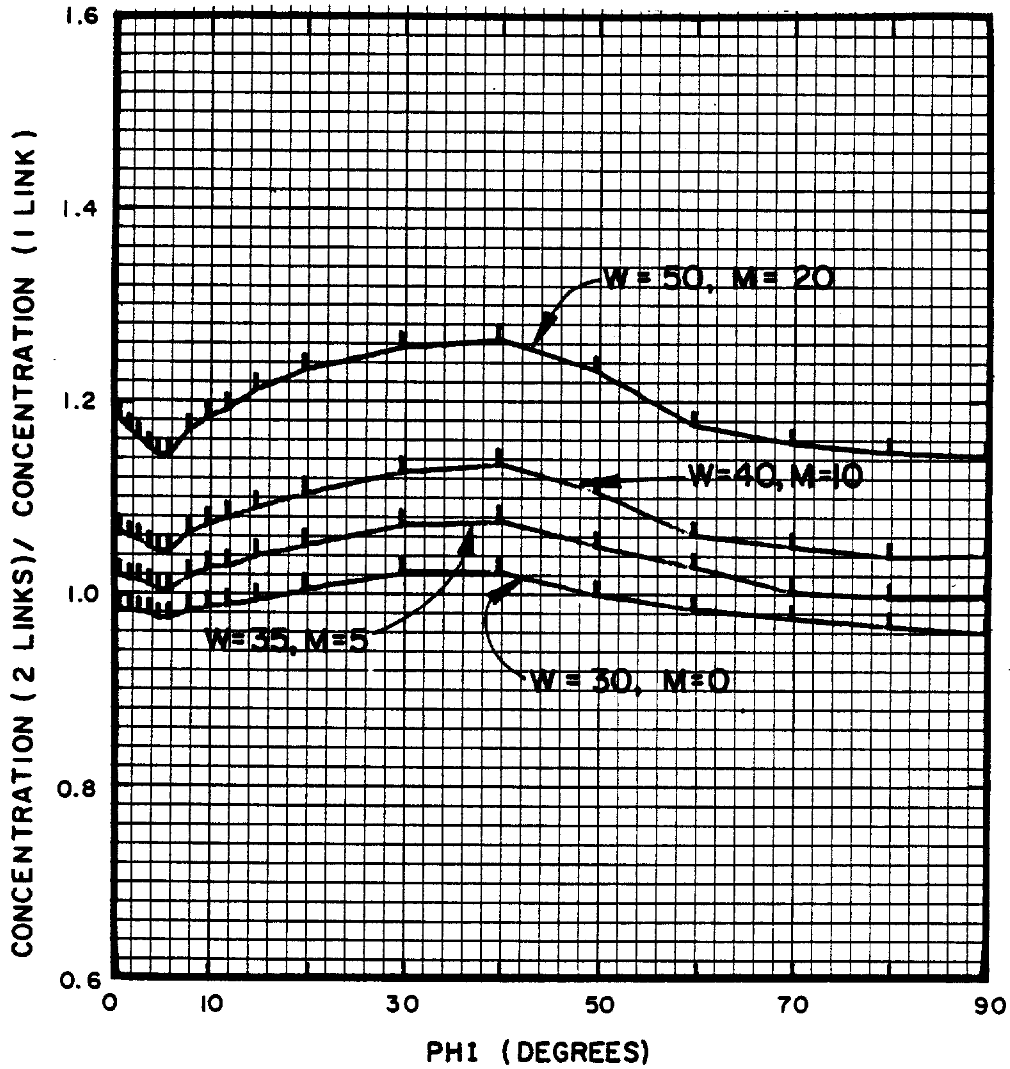
The sensitivity of the model to highway width is relatively independent of the wind angle. Also, the value of the wind angle for maximum concentration is relatively insensitive to highway width.

7.14 Median Width (Figure 34)

Because of the link capabilities of CALINE4, it is not necessary to incorporate medians as part of the mixing zone. A divided roadway may be modeled as either two separate links, or a single link with the median incorporated in the highway width specification (this assumes identical link specifications for both directions of flow). For cases where there is a significant median involved, the two link computation gives slightly higher predicted concentrations over the single link model (Figure 34). This holds true for most wind angles, but tends to be more pronounced for values of PHI between 10° to 60°.

7.15 Mixing Height (Figure 35)

Model sensitivity to mixing height is significant only for extremely low values occurring under parallel wind



CALINE4 SENSITIVITY ANALYSIS –
HIGHWAY WIDTH (W), MEDIAN WIDTH (M)

FIGURE 34

conditions (Figure 35). This is because the amount of vertical dispersion that can take place within the limits of the microscale region is small relative to normal mixing heights of 100 m or more. For unstable atmospheric conditions, model sensitivity to mixing height will increase somewhat. However, low level inversions are not compatible with unstable conditions.

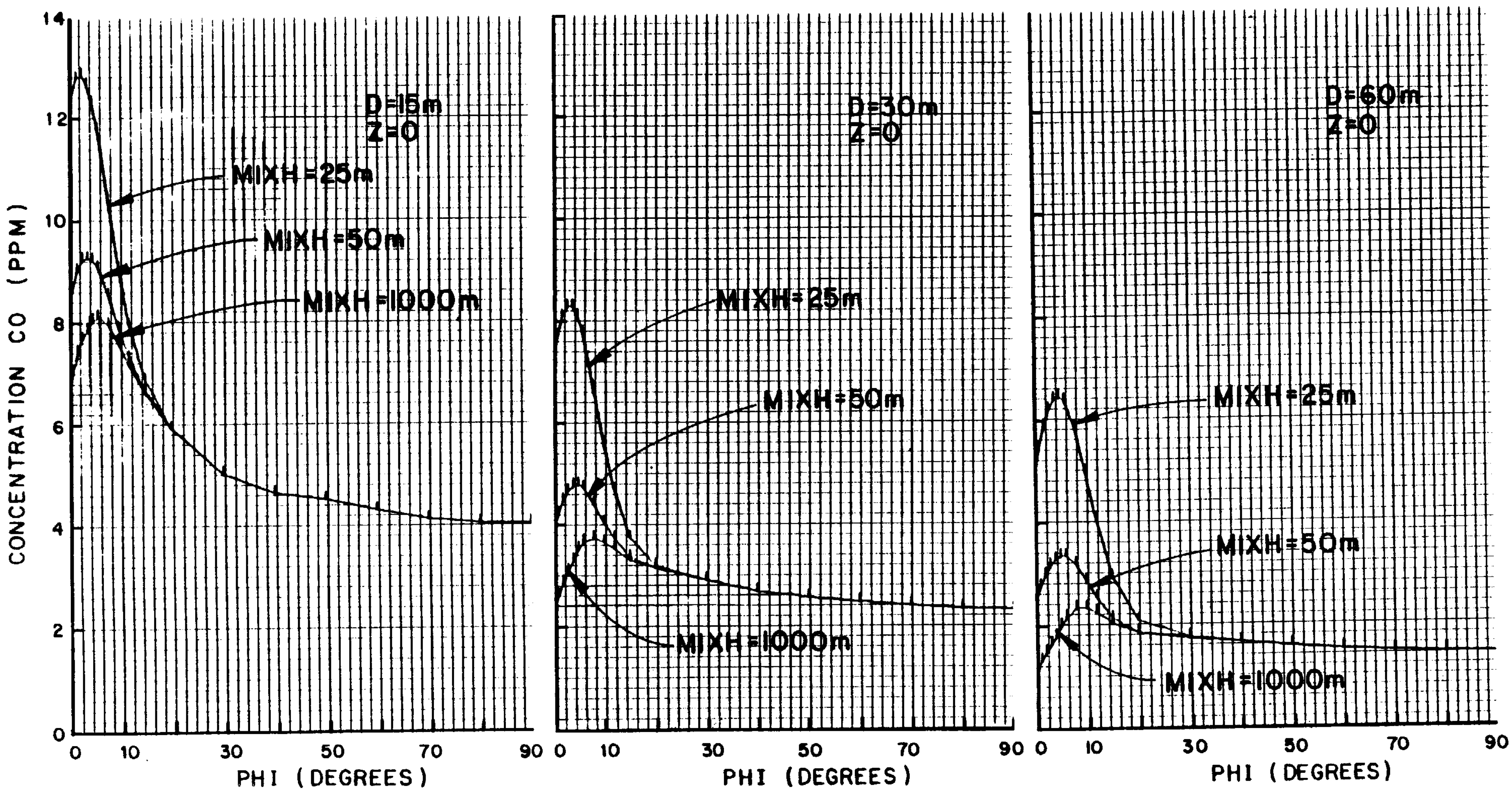
It should be remembered that the mixing height algorithm is primarily meant for study of special case nocturnal inversions, and may be bypassed by assigning a value of 1000 meters or greater to MIXH.

7.16 Bluff/Canyon Option (Figure 36)

CALINE4 results for four restricted mixing widths are given in Figure 36. The single (bluff) and double (canyon) restrictions are plotted separately. The bluff/canyon option is valid for parallel winds only, so that PHI = 0° for all cases. The vertical scale used in Figure 36 is expanded over the previous sensitivity graphs in order to accommodate the high canyon option results.

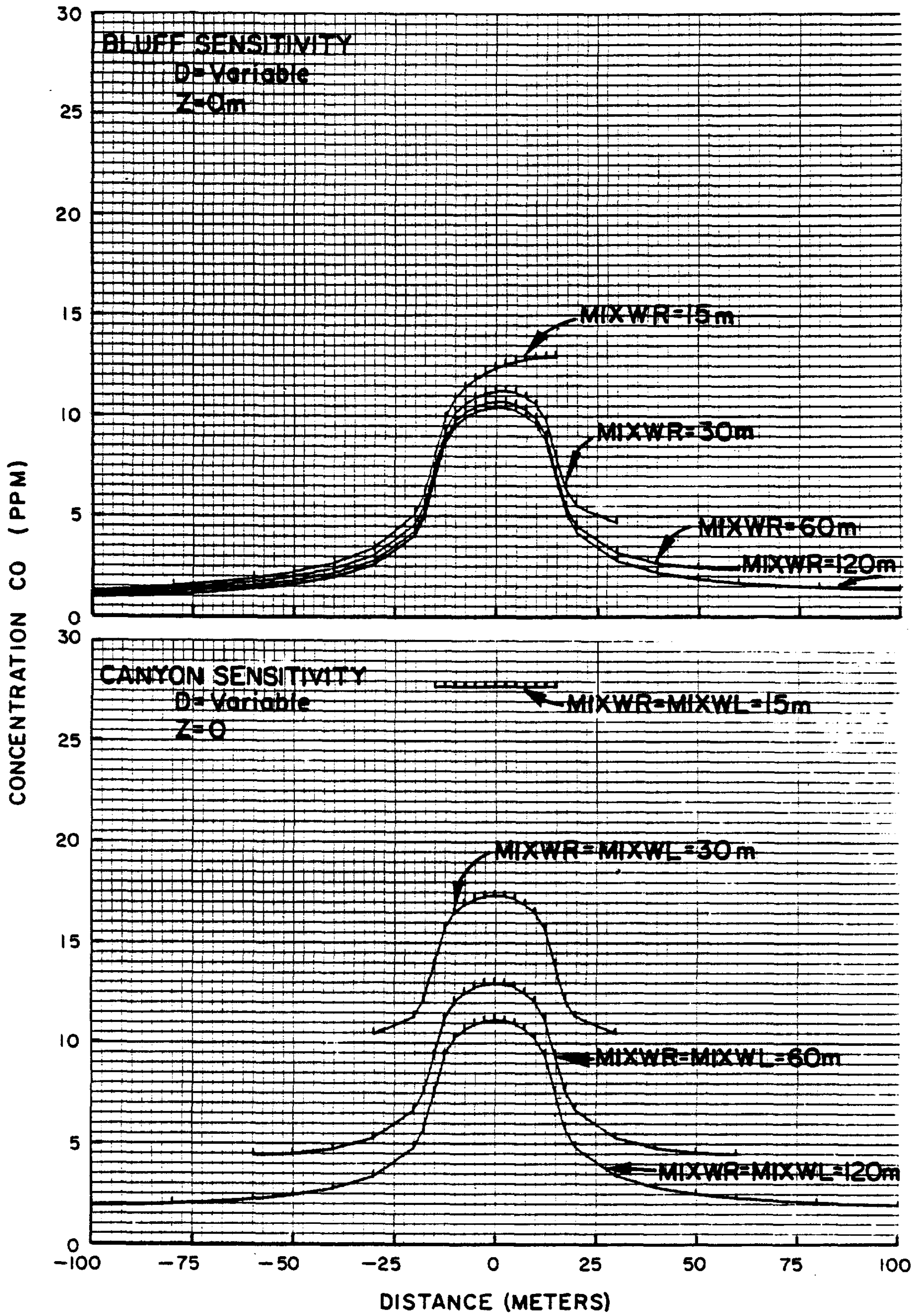
Figure 36 shows that the greatest sensitivity to a bluff restriction is on the side of the roadway where the restriction is placed. However, results on the far side of the roadway also exhibit a degree of sensitivity equal to some of the other input variables already discussed when allowance is made for the expanded vertical scale.

Model results are naturally more sensitive to the canyon restriction than the bluff restriction. Horizontal dispersion is restricted on both sides of the roadway in the case



CALINE 4 SENSITIVITY ANALYSIS — VARIABLE: MIXING HEIGHT (MIXH)

FIGURE 35



CALINE4 SENSITIVITY ANALYSIS—VARIABLE:
MIXING WIDTH (MIXWR, MIXWL)

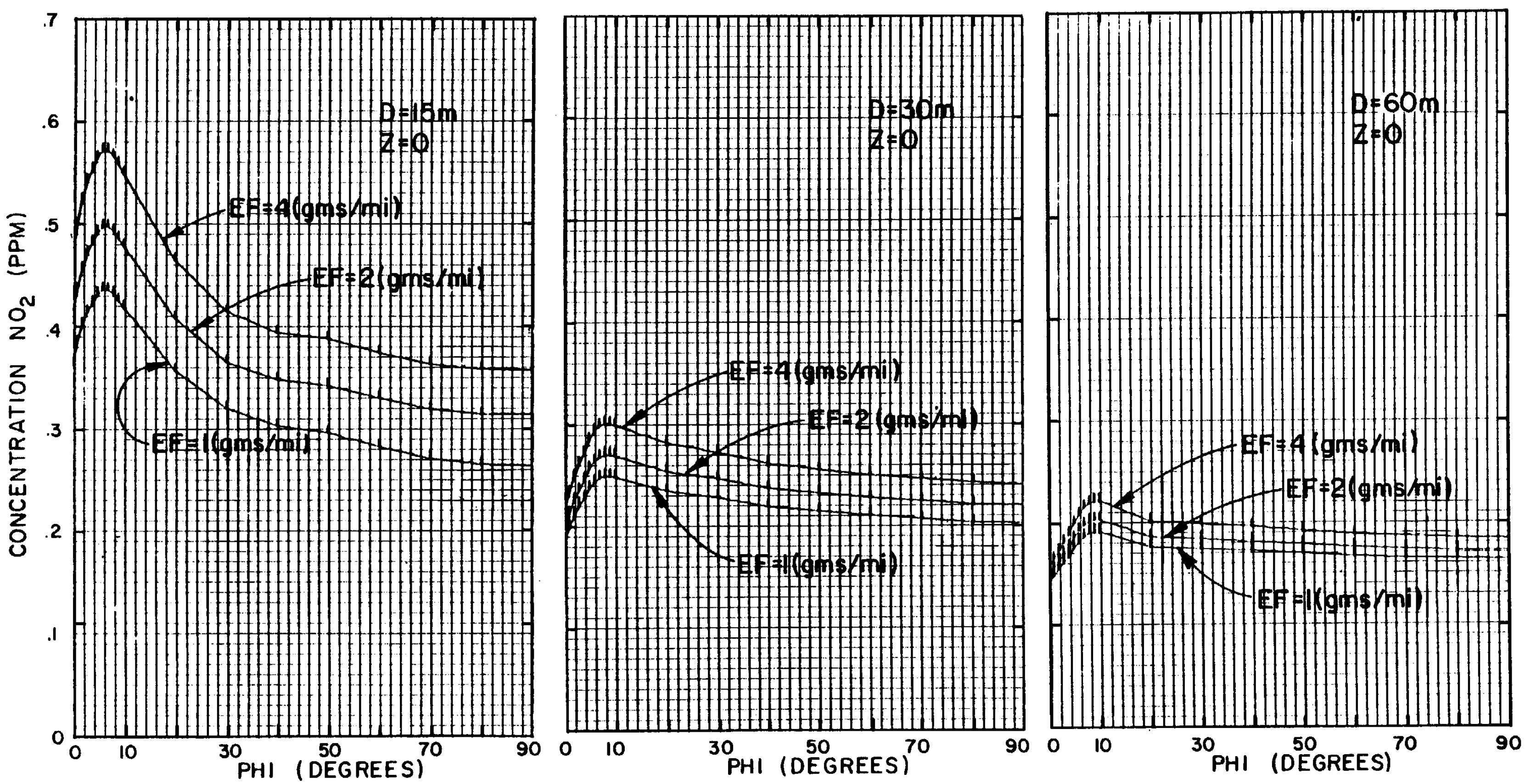
FIGURE 36

of a canyon. This leads to elevated mixing zone concentrations when the canyon is narrow. Figure 36 clearly shows CALINE4's response in such cases. The sensitivity to canyon width would be even greater if not for the adjustment made by the model to the vertical dispersion curves for the influence of thermal emissions from the vehicles.

7.17 NO2 Option (Figures 37, 38 and 39)

The CALINE4 NO2 option requires specification of several additional variables not mentioned in Table 3. Ambient levels of NO, NO2 and O3 must be specified. These were assigned standard values of 0.02, 0.10 and 0.20 ppm, respectively, for the sensitivity analysis. Also, a photodissociation rate (KR) and a NOx emission factor are needed. Values of 4×10^{-3} s^{-1} for KR and 1.0 gm/veh-mi for the NOx emission factor were used in the standard sensitivity run.

When the NO2 option is used, resultant concentrations are no longer directly proportional to the link emission factor. Figure 37 illustrates this point by showing the diminishing effect over distance of a fourfold increase in emissions. The forward and reverse reaction rates used by the model for NO/NO2 conversion are functions of the initial concentrations of the pollutants in the mixing zone. As NOx concentrations within the mixing zone increase because of higher emission factors, the reaction rates change. These changes are proportional to the changes in the initial concentrations, including both ambient and vehicular components. The reaction rates are also sensitive to the availability of O3 for completing

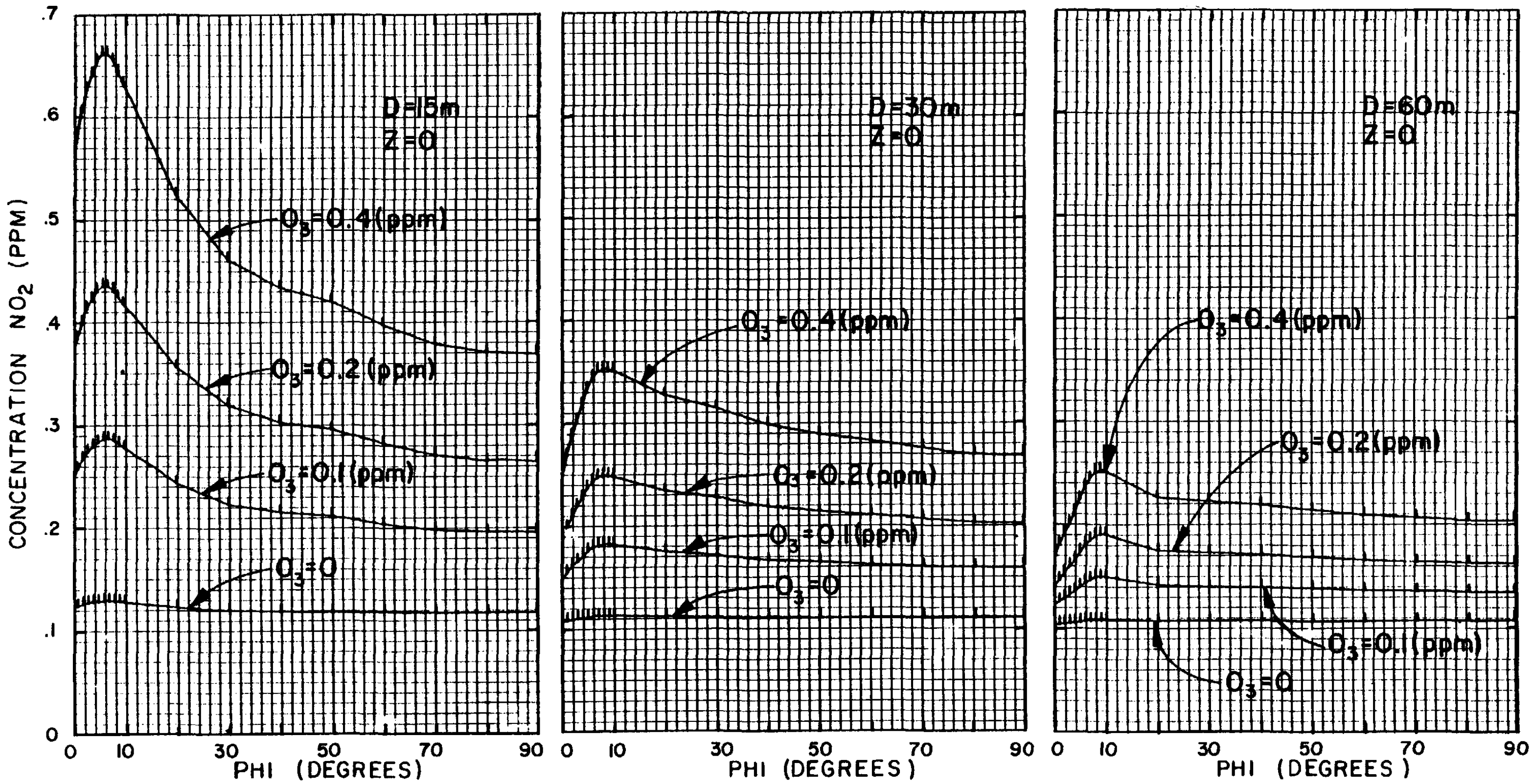


CALINE4 SENSITIVITY ANALYSIS— VARIABLE: NO_x EMISSION FACTOR (EF)

FIGURE 37

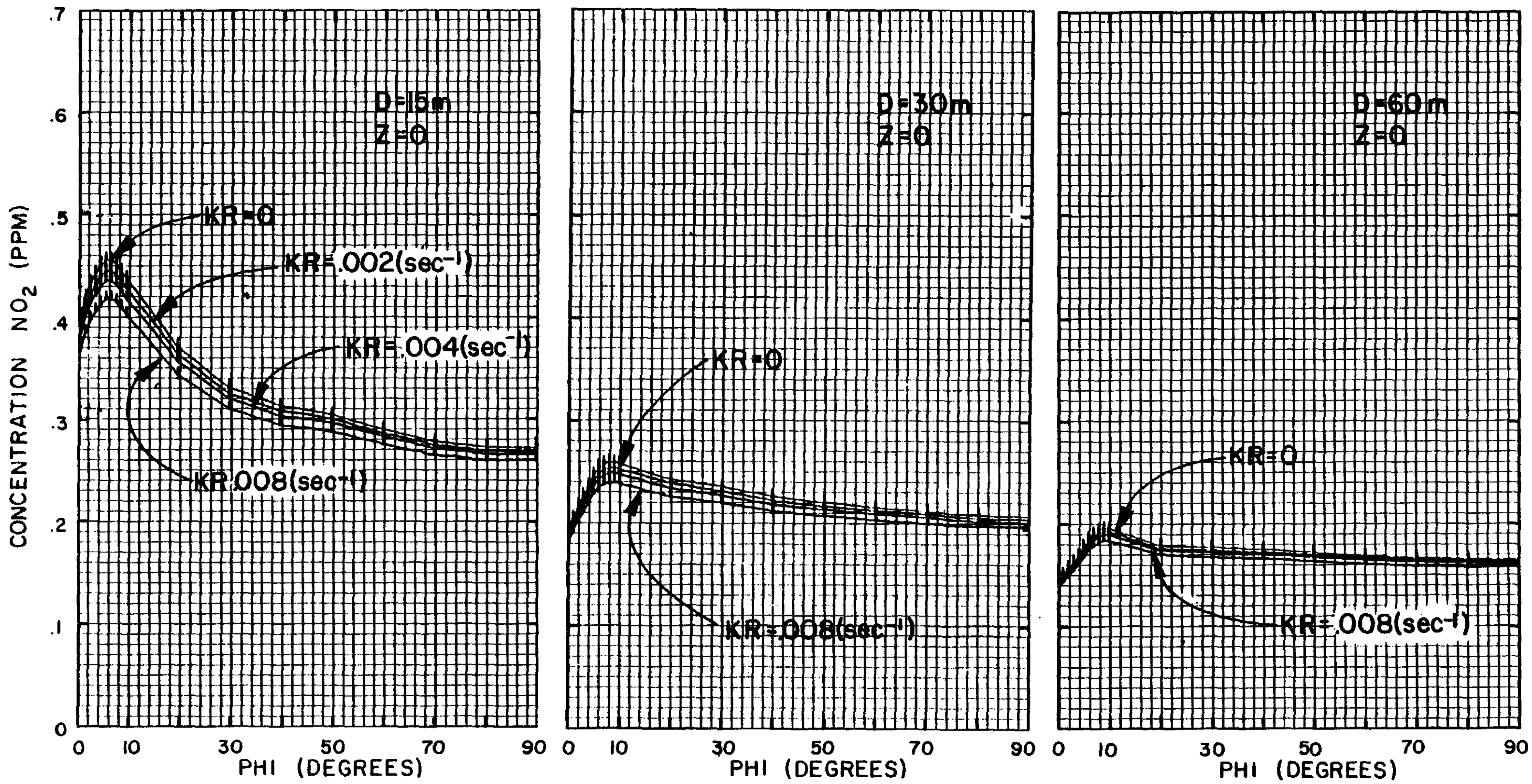
the forward reaction (NO to NO2). The complex interaction of these effects preclude a simple one-to-one relationship between concentration and emissions strength.

Figures 38 and 39 demonstrate model sensitivity to O3 and KR, respectively. For the standard case, it is clear that the model is much more sensitive to the ambient O3 concentration than to the photodissociation rate. This behavior is consistent with the relative strengths of the forward and reverse reactions under normal conditions. Given high O3 concentrations, the forward reaction dominates. In cases where ambient O3 is low, however, the photodissociation rate will assume greater importance.



CALINE4 SENSITIVITY ANALYSIS — VARIABLE: AMBIENT OZONE (O_3)

FIGURE 38



CALINE4 SENSITIVITY ANALYSIS — VARIABLE: PHOTODISSOCIATION RATE (KR)

FIGURE 39

8. MODEL VERIFICATION

The CALINE4 model was verified using data from several independent field studies. These studies represented a variety of possible model applications including the intersection link and NO2 options. Where applicable, CALINE3 results were also compiled and compared to CALINE4.

Several of the studies were based on tracer gas releases. This type of data provided the best direct verification of CALINE4 because it eliminated the need to estimate a composite emission factor.

8.1 Methodology

A statistical method developed through the National Cooperative Highway Research Program was used as a primary tool for verifying CALINE4(39). The method involves the computation of an overall figure of merit (FOM) based on six component statistics. These statistics are defined as follows:

- S1 - The ratio of the largest 5% of the measured concentrations to the largest 5% of the predicted concentrations,
- S2 - The difference between the predicted and measured proportion of exceedances of a concentration threshold or air quality standard,
- S3 - Pearson's correlation coefficient for the paired measured and predicted concentrations,

S4 - The temporal component of Pearson's correlation coefficient,

S5 - The spatial component of Pearson's correlation coefficient,

S6 - The root-mean-square of the difference between the paired measured and predicted concentrations.

Statistic S1 is a measure of the model's ability to predict high concentrations. Statistic S2 measures how well the model can predict the frequency of exceedance of an air quality standard or threshold. Statistics S3, S4 and Ss measure the degree to which the model's response to changing conditions follows the real-world response. Statistic S4 is concerned with changes over time (e.g., wind speed, stability) while statistic Ss is associated with changes over space (e.g., source-receptor distance, topography). Statistic S3 represents a combination of both these factors. Statistic S6 provides a measure of the overall error that exists between the measured and predicted concentrations. This error term represents the combined effect of inherent model errors (or misassumptions), input variable errors and measurement errors.

The six component statistics are transformed into individual figures of merit (Fi) on a common scale from 0 to 10. They are then weighted and summed as follows:

$$FOM = \left[(F_1+F_2)/2+(F_3+F_4+F_5)/3+F_6\right]/3 \quad . \qquad (8\text{-}1)$$

Equation 8-1 determines the overall figure of merit for the model.

No standard value for FOM has been established to differentiate between "good" and "bad" model performance. Instead, the FOM is used as a relative measure of model performance. In this report, it is used to compare the performance of CALINE4 to CALINE3, and the performance of the NO2 and intersection options to standard applications of the model.

In addition to the FOM method, two graphical verification methods are employed. The first is a simple scatterplot of predicted (P) versus measured (M) concentrations. The second involves the following

$$E_r = 100*(P-M)/(P+M). \qquad (8\text{-}2)$$

relative error term,

Results for this term are plotted against the critical input variables of wind angle and wind speed for the two tracer release data bases.

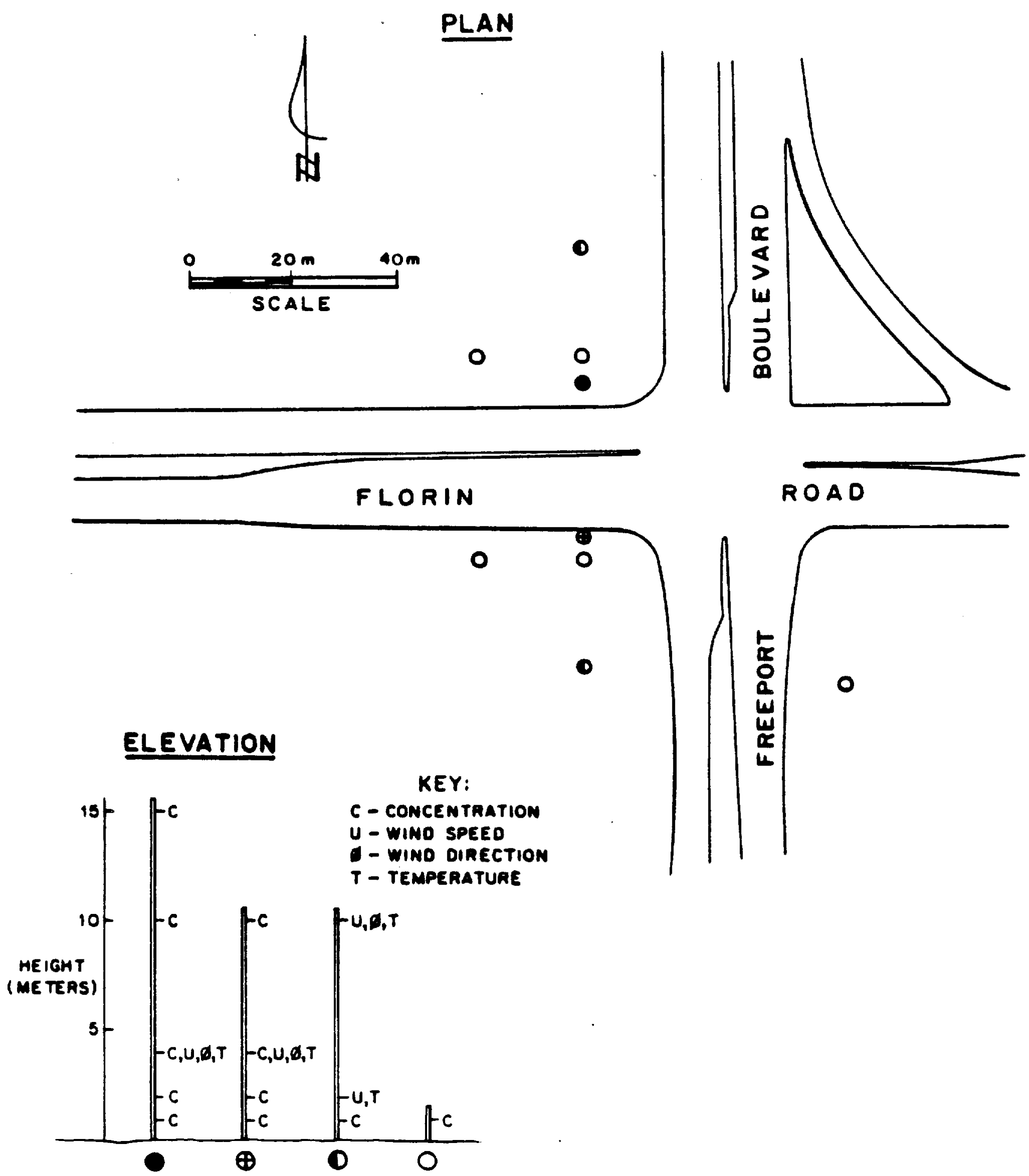
8.2 Description of Field Studies

8.2.1 Caltrans Intersection Study

During the first three months of 1980, Caltrans conducted an extensive aerometric survey at the intersection of Florin Road and Freeport Boulevard in Sacramento. One of the purposes of this study was to furnish a data base for verifying the CALINE4 intersection link option. The intersection site consisted of bare or grass covered ground on all four quadrants for a distance of at least 50 meters back from the traveled ways. The surrounding terrain was level and occupied by scattered single story residential developments. The intersection was oriented with Freeport Boulevard running due north-south and Florin Road due east- west. A small community shopping center was located well back from the intersection in the northwest quadrant. The site offered a reasonably high traffic flow without the interfering background sources of gas stations and parking lots normally associated with busy intersections. Also, the openness of the site eliminated the possibility of channeled flow typical of street canyon sites.

Fifteen probe locations were chosen --- eight in the north- west quadrant and the remainder in the southwest quadrant (Figure 40). Also, a sequential bag sampler was placed in the southeast quadrant. The two towers innermost to Florin Road contained vertical probe arrays with four probes on the southern tower at 1, 2, 4 and 10 meter heights, and five on the northern tower at 1, 2, 4, 10 and 15 meter heights. Three additional ground level probes ($z = 1.0$ meter) were located on each side of Florin Road. The outermost meteorological towers had cup anemometers and temperature probes mounted at 2 and 10 meter heights to provide wind shear and temperature profile estimates. Wind direction was measured with wind vanes mounted at the 10 meter level. Traffic counts were made using pneumatic counters for inflow and outflow on each leg of the intersection.

A Caltrans air quality research van with on-board mini- computer was used to monitor and record the various air quality and meteorological parameters. Sampling for CO was accomplished using two separate systems: Nondispersive infrared (NDIR) and gas chromatography with flame ionization detection. Three NDIR analyzers were used, each



CALTRANS SACRAMENTO (SACTO)
INTERSECTION TEST SITE

FIGURE 40

dedicated to five probe lines. The on-board minicomputer performed switching at one minute intervals so that each line was sampled one minute out of every five by an NDIR analyzer at line velocities of 10 feet/second. The NDIR results were used as the basis for the verification analysis. The gas chromatography samples were taken as bag samples over the first 15 minutes of each hour, providing an integrated concentration measurement. The gas chromatography analysis was run only for the nine probes in the vertical arrays next to Florin Road. These results were used in preliminary mass balance studies. Sums and sums of squares of 0.1 second wind speed and direction readings were stored by the minicomputer and written out on magnetic tape every 10 seconds. Temperature readings were recorded once every 60 seconds. Further information on the operation of the research van and its data acquisition system has been reported by others(40,41).

8.2.2 Caltrans Highway 99 Tracer Experiment

An extensive series of tracer release experiments were conducted by Caltrans during the winter of 1981-82 along a 2.5 mile section of U.S. Highway 99 in Sacramento. The highway follows a straight northwest (N 40°13' W) alignment along this section. The nearby terrain consists of open fields and parks to the north, and scattered residential developments to the south. The highway has two lanes in each direction separated by a 14 meter median. It carries over 35,000 vehicles daily with a peak hourly traffic count of 3,450.

Sulfur hexafluoride, SF_6, was used as the tracer gas. It is a highly inert gas, detectable at extremely low concentrations. Its presence in ambient air samples is negligible.

The SF_6 was released from eight specially equipped 1970 Matador sedans. Each sedan had an on/off flow control switch mounted on the dashboard and a strip chart recorder to monitor the flow status. The gas was contained in a cylinder housed in the trunk of the sedan, and was metered out by a preset Condyne precision needle valve. It was carried by copper tubing through the trunk floor and to the tailpipe where it was heated by looping the tubing around the tailpipe several times. The SF_6 was then released into the exhaust stream.

The tracer gas flow rates were checked before and after each test with a bubblemeter. These flow rates were corrected to standard temperature and pressure. The nominal flow rate was 0.5 liter/minute. The measured rates typically varied no more than 5% from this nominal value over the course of a test.

The tests were three hours in duration, with samples being taken only during the last two hours. The one hour delay was made to avoid sampling during the transient build-up phase of the release.

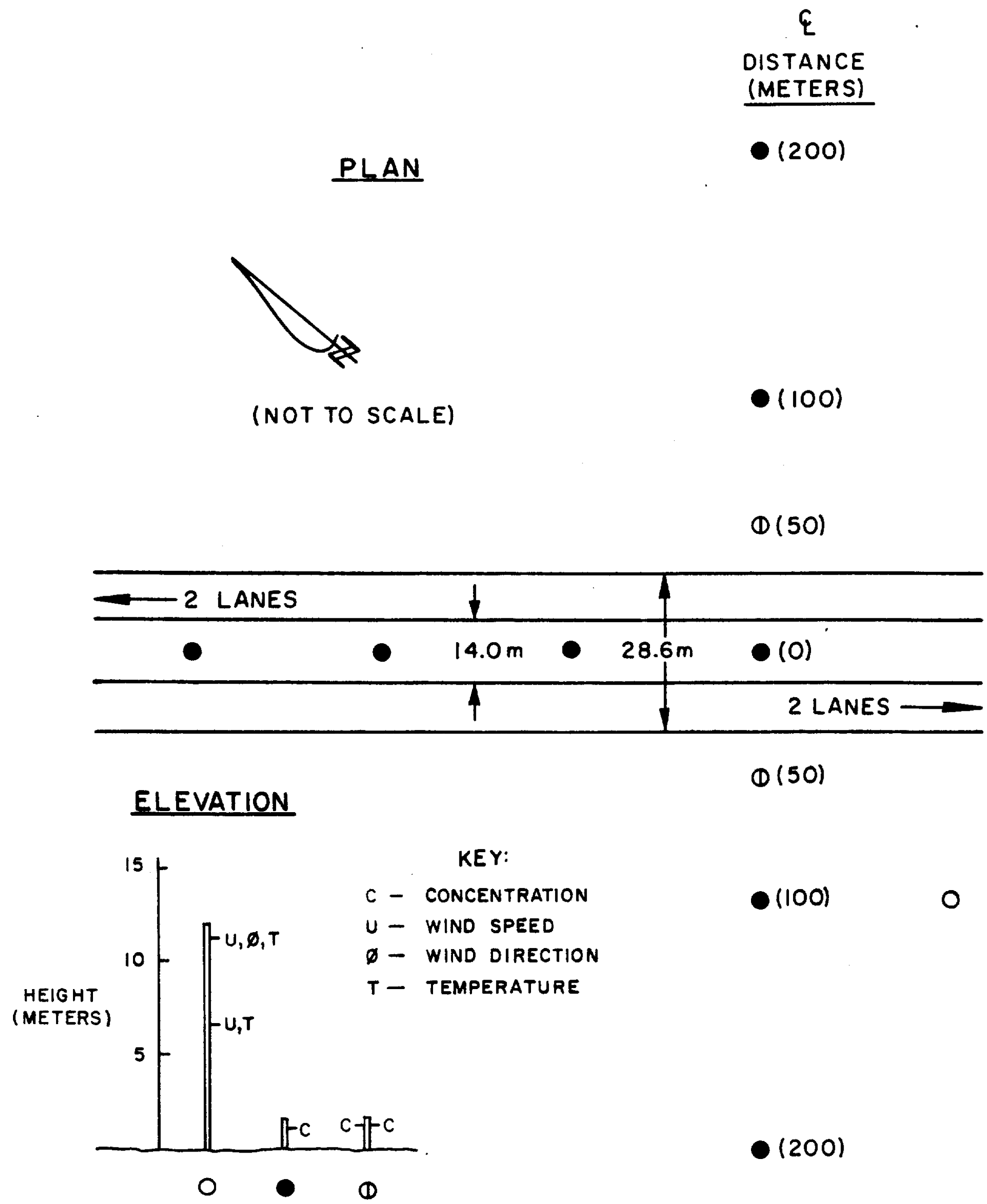
The tracer vehicles were driven on a seven-mile loop starting at a staging area near the Mack Road Interchange, proceeding northwest to the 47th Avenue Interchange and then returning to the staging area. The vehicles released SF_6 along the 2.5 mile test section on both the depart and return legs of the loop. Each vehicle was allowed 12 minutes to complete the loop. The distribution of the vehicles was controlled at the staging area by spacing departures 1.5 minutes apart. This meant that, on average, a 2.5 mile release was being started every 45 seconds.

The eight tracer vehicles were divided into two groups. Half the vehicles were driven in the slow lane, the other half in the fast lane. Drivers were instructed to reach a safe cruising speed compatible with traffic conditions in their lane, and to try to maintain that speed through the test section.

The primary sampling site was located 0.65 mile from the south end of the test section. Nine bag samplers were situated at this point at distances of 0, 50, 100 and 200 meters from the highway centerline on both sides of the highway (Figure 41). Replicate samplers were maintained a both 50 meter sampling locations. The remaining three samplers used in the study were situated along the media at 0.5 mile increments northwest of the primary sampling site.

All samples were taken at a height of 1.0 meter. The samples were collected in tedlar bags by EMI Model AQS III samplers equipped with positive displacement pulse pumps. The samples represented 30 minute integrated concentrations. They were analyzed on a Perkin-Elmer Sigma 2 gas chromatograph with electron capture detector. This instrument was calibrated using a Dasibi Model 1005CA flow dilution system and a National Bureau of Standards traceable cylinder of 5 ppm SF6.

A 12 meter high meteorological tower was located near the south end of the test section in a open, plowed field. It was equipped with a horizontal wind vane, two low-threshold cup anemometers (0.3 m/s), and a set of self-aspirated temperature sensors. The instrument heights are shown in Figure 41.



CALTRANS HIGHWAY 99 TRACER EXPERI MENT
FIGURE 41

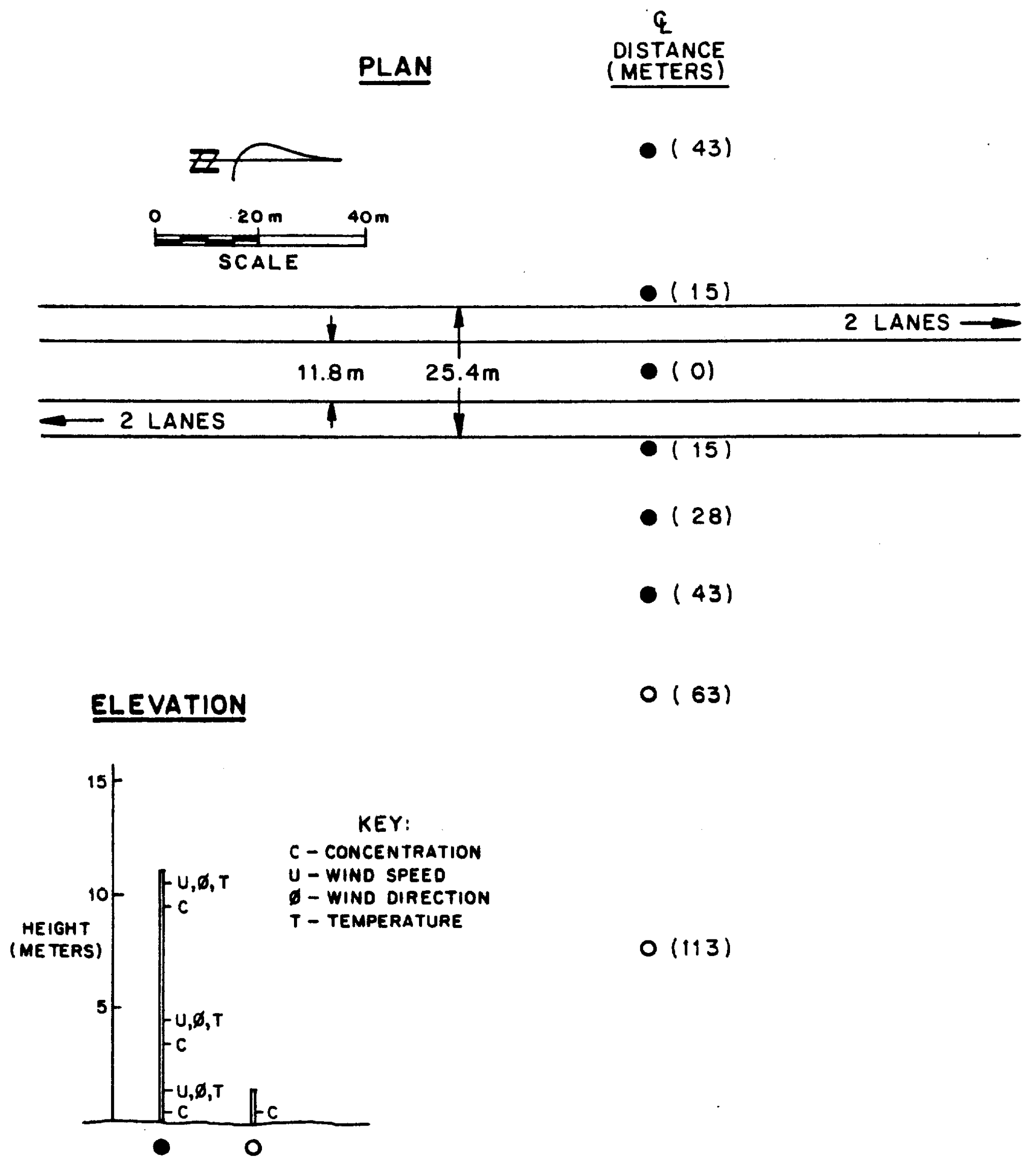
A total of 14 tracer release tests were made. All but three of these were morning tests with samples taken from 6:30 to 8:30 a.m. PST in most cases. Two of the three afternoon runs took place from 4:00 to 6:00 p.m. The remaining afternoon run was made from 5:00 to 7:00 p.m. No more than one test was made per day. Traffic counts and classifications were made concurrently with the aerometric measurements for many of the test runs.

A complete summary of the results of the Highway 99 Tracer Experiment is given in Appendix C of this report. The vehicle speeds listed in the summary were determined from the tracer vehicle strip charts. The Pasquill Stability Classes were computed via Golder's Method(42). Asterisks indicate missing data.

8.2.3 General Motors Sulfate Dispersion Experiment

The General Motors (GM) Sulfate Experiment was conducted at the GM Milford, Michigan, proving grounds straightaway track during the month of October, 1975(4). The track is 5 kilometers long and is surrounded by lightly wooded, rolling hills. Three hundred and fifty-two cars, including 8 vehicles emitting SF6 tracer gas, were driven at constant speeds of 80 km/hr around the track. This simulated a traffic flow of 5,462 vehicles per hour along a four lane freeway with a median width of approximately 12 meters.

Monitoring probes were stationed at 2 upwind locations and 5 downwind locations out to a distance of 113 meters from the track centerline (Figure 42). In addition, a monitoring location was situated in the track median. The westerly, median and closest 3 easterly locations were



GENERAL MOTORS (GM) SULFATE EXPERIMENT TEST SITE

FIGURE 42

equipped with tower mounted sampling probes at heights of 0.5, 3.5 and 9.5 meters above the ground. The two additional more distant downwind probes were positioned at a height of 0.5 meter. Wind speed and direction measurements were made at each probe location using Gill UVW anemometers. Temperature profiles were recorded at the two outermost towers, 43 meters from the track centerline

Data from over 60 half hour test runs was compiled. Most of these were conducted during early morning hours to take advantage of the stable atmospheric conditions prevalent then. The cars were grouped into 32 single lane packs of 11 cars each and distributed over the track so that two packs from each direction passed the sampling area simultaneously at approximately 30 second intervals.

The experimental procedure in the GM study was carefully controlled, resulting in one of the most reliable highway air quality data bases ever compiled. The only shortcoming in the experiment was the lack of variability in the traffic parameters of speed, volume and occupancy.

8.2.4 Illinois EPA Freeway/Intersection Study

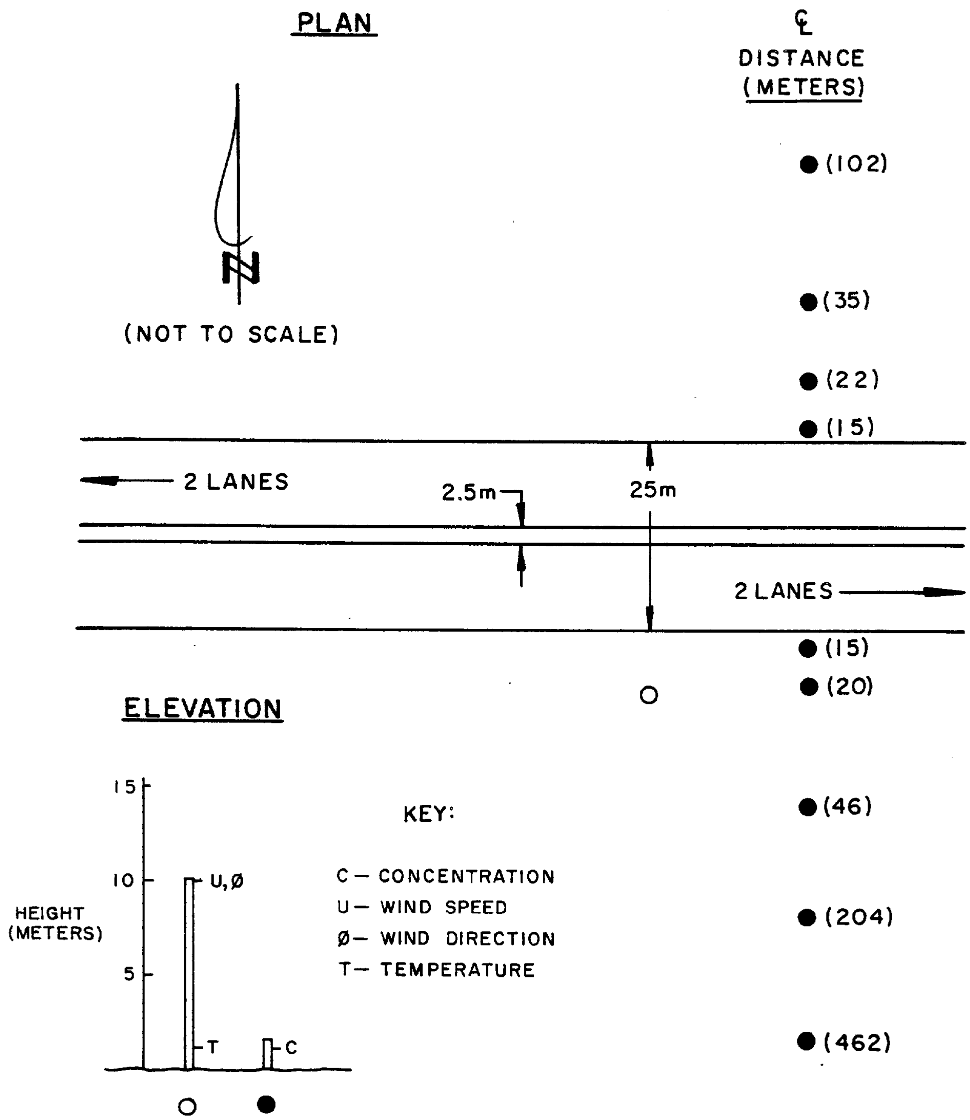
This study was performed for the Illinois Environmental Protection Agency by Noll Associates and Enviro-Measure, Inc. during 1978(43). The study involved the measurement of CO concentrations and related traffic and meteorological parameters near two urban sites located just outside of Chicago. A series of SF6 tracer release experiments were performed in conjunction with the overall monitoring program.

The first site monitored was the Eisenhower Expressway, I-90, between Des Plaines and First Avenues. This segment of I-90 is a heavily traveled six-lane freeway with average daily traffic in excess of 100,000 vehicles. It is an at-grade, straight section about 0.75 kilometers in length, and is surrounded by level terrain. The test section traverses a cemetery with grass and scattered trees, but the overall setting is urban residential.

Air samples were collected from June 20 through August 29, 1978 using automatic bag samplers at eight locations near the test section. Distances ranged from 3 to 192 meters from the roadway edge (Figure 43). A ninth sampler was placed 450 meters from the roadway to measure background concentrations. All samples were collected over a one hour period at a height of 1.0 meter.

Continuous traffic counts and periodic heavy-duty vehicle counts were made during the course of the study. A meteorological tower was established 10 meters from the roadway edge. This provided wind speed, wind direction and temperature data. Cloud cover and ceiling height information taken from nearby O'Hare International Airport was also included in the data base.

The second site was located at the intersection of two six-lane arterials, North and First Avenues in Melrose Park, Illinois. This site, studied from October 3 through November 16, 1978, was typical of a high volume, urban intersection. The surrounding terrain was level and open, consisting of a mix of one-story buildings, parking lots and forest preserve. The nearby parking lots were empty during the course of the study. The intersection was



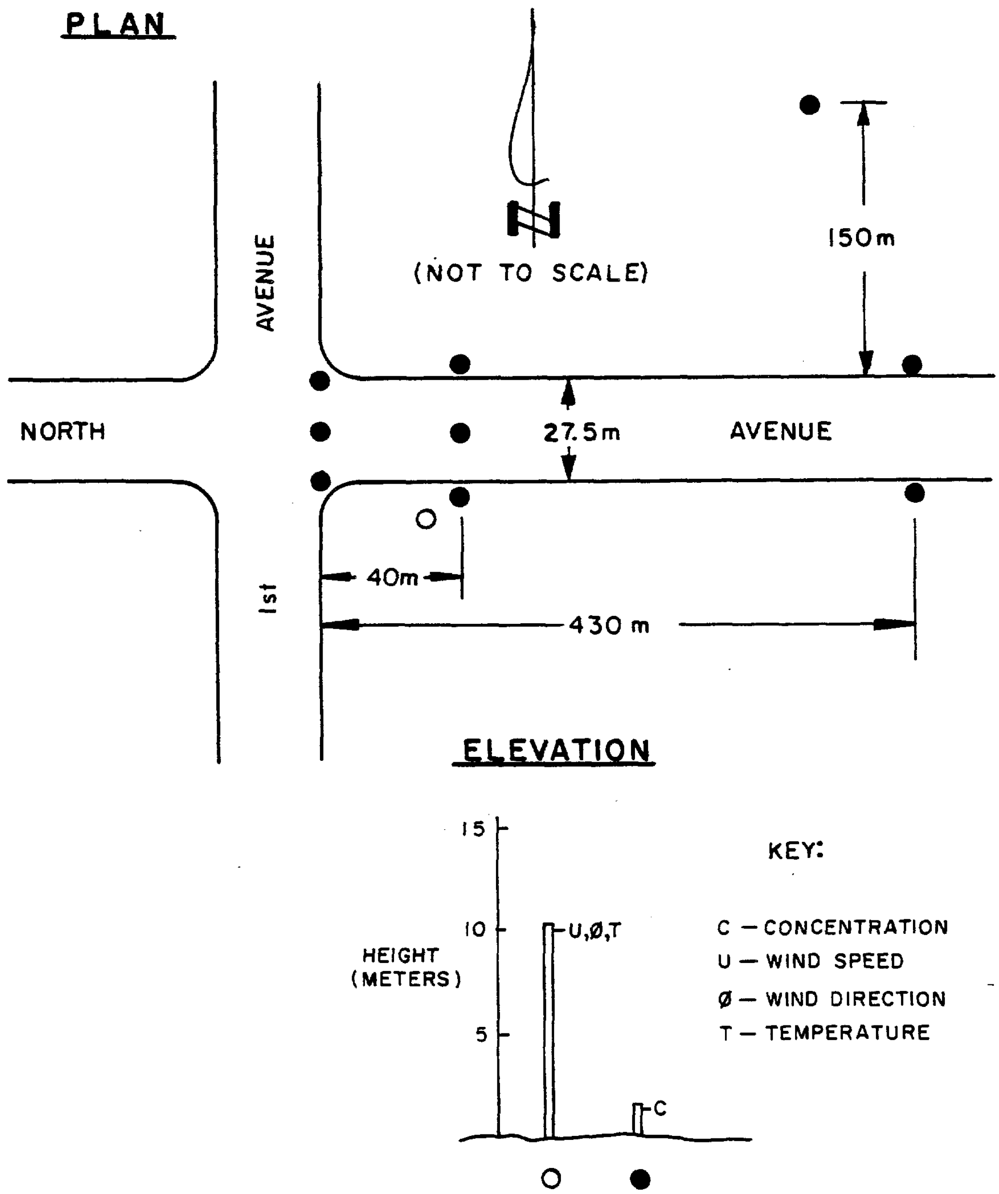
ILLINOIS EPA FREEWAY STUDY
FIGURE 43

controlled by a demand actuated signal. Approach and depart volumes were well balanced. Information on vehicle speed profiles, red light time, vehicle stop time and average queue length were collected during the study.

Eight bag sampling locations were established near the intersection (Figure 44). These were intended to cover three zones: the vehicle queue zone, the acceleration/ deceleration zone and the mid-block cruise zone. In addition, a ninth background monitoring site was maintained at a distance of 100-150 meters from the roadway. As with the previous study, all samples represented hourly averages at a height of 1.0 meter.

Approach traffic volumes were monitored on all legs via pneumatic hose counters. Depart volume was monitored on only the eastern leg of the intersection. Meteorological data was collected from a tower located in the southeast quadrant of the intersection 10 meters from the roadway edge. Cloud cover and ceiling height information was again obtained from O'Hare International Airport.

In both studies-, samples were analyzed for CO concentrations using a Mine Safety Appliance Model 202 LIRA non-dispersive infrared analyzer. Concentrations of SF6 were determined via gas chromatography and electron capture device. However, the SF6 results were not used for the CALINE4 verification analysis. Since SF6 was released from only a single vehicle, it is questionable whether the results adequately represented a continuous line source.



ILLINOIS EPA INTERSECTION STUDY

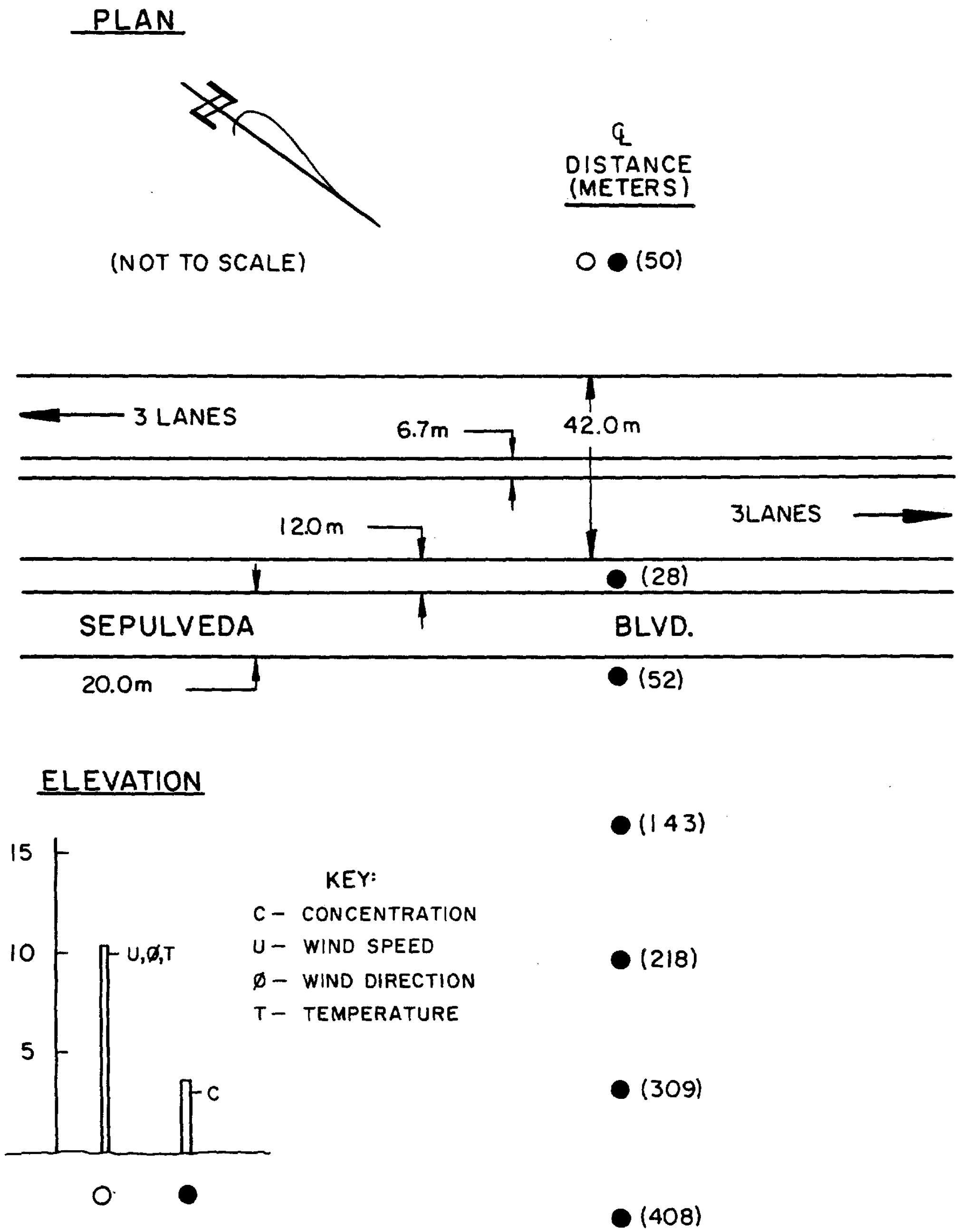
FIGURE 44

8.2.5 U.S. EPA NO_2/O_3 Sampler Siting Study

In August, 1978 a study was conducted by the U.S. Environmental Protection Agency along a section of the San Diego Freeway in Los Angeles(44). The objective of the study was to quantify the effect of mobile source NO_x issions on ambient O_3 concentrations immediately downwind of a heavily traveled freeway. To accomplish this, continuous monitoring of NO, NO_2, and O_3 was conducted at one upwind and six downwind locations.

The study site was located 0.8 kilometer north of Wilshire Boulevard in relatively flat terrain. The immediate vicinity is open, grass covered cemetery grounds. The surrounding land-use is primarily urban residential and commercial development. The freeway carries approximately 200,000 vehicles per day. The downwind monitoring sites were located from 8 to 400 meters downwind of the roadway (Figure 45). All samples were taken at a height of 3 meters, and averaged over a 1-hour time period.

Prevailing winds from the ocean generally crossed the free- way at near perpendicular angles. A 10 meter meteorological tower measured wind speed and direction immediately upwind of the freeway. Hourly traffic volumes were measured for the freeway using magnetic loop detectors. Cloud cover and ceiling height data were obtained from the Los Angeles International Airport.



U.S. EPA NO_2/O_3 SAMPLER SITING STUDY

FIGURE 45

8.3 Verification Results

8.3.1 Freeway Sites

A direct comparison between CALINE3 and CALINE4 was made using the FOM method and data from three of the freeway studies. A summary of the individual and overall figures of merit is given in Table 4. The results were based on measured and predicted concentrations at downwind locations only. In the case of the Illinois EPA study, separate statistics were computed for the north and south sample locations because of the lack of symmetry in the site lay- out. The number of sample locations and time periods used in the analysis are also given in Table 4. The threshold values used for computing F2 were 1.0 ppb SF6 for the two tracer studies, and 10 ppm CO for the Illinois EPA study.

The results for both individual and overall figures of merit clearly indicate the improved performance of CALINE4 over CALINE3 for the General Motors and Caltrans tracer studies. The results for the Illinois EPA study are not as conclusive, however. While CALINE4 shows slight improvements in temporal correlation and residual error, it does not perform as well in predicting the highest 5% of the measured concentrations. Yet, for the tracer studies, prediction of the hiqhest measured concentrations is the area in which CALINE4 shows the most dramatic improvement over CALINE3.

A possible explanation for the discrepancy in model performance on high measured concentrations involves the method whereby emission factors were determined for the

TABLE 4

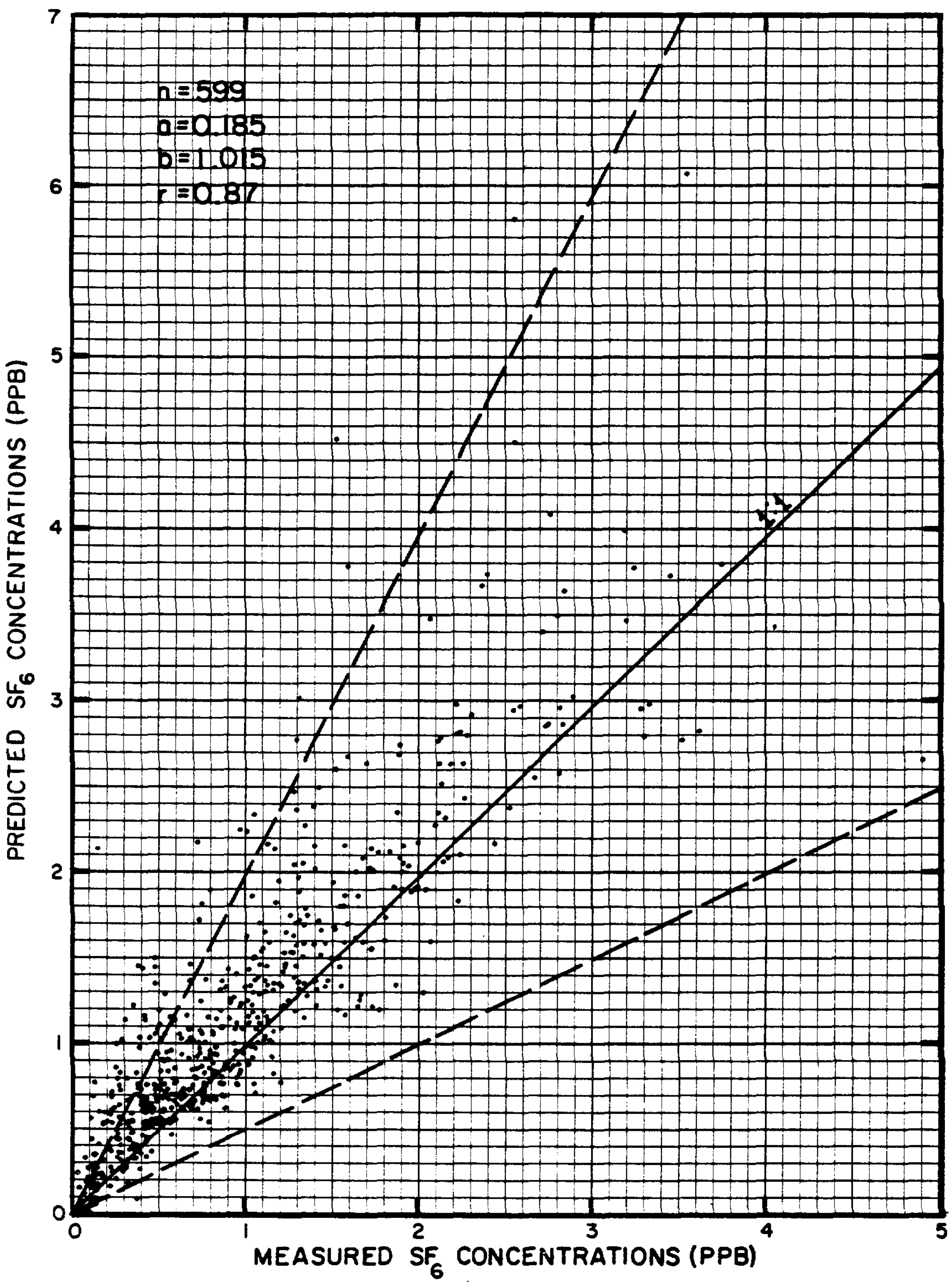
Comparison of CALINE3 (C3) and CALINE4 (C4)
Figures of Merit (FOM) for Freeway Sites

Study	No. Locations	No. Periods	Model	F_1	F_2	F_3	F_4	F_5	F_6	FOM
General Motors	11	62	C3	6.5	10.0	7.8	7.1	9.7	2.0	6.2
			C4	8.5	10.0	8.3	7.2	9.7	2.8	6.8
Caltrans	3	56	C3	5.7	9.9	5.6	3.5	10.0	2.5	5.6
			C4	8.6	10.0	5.9	4.2	10.0	3.2	6.4
Illinois EPA (North)	4	249	C3	9.7	10.0	7.3	4.3	9.9	3.6	6.9
			C4	8.8	10.0	7.5	4.6	9.9	3.7	6.8
Illinois EPA (South)	4	49	C3	9.9	10.0	7.2	2.4	9.9	3.4	6.6
			C4	8.6	10.0	8.0	3.1	9.9	3.6	6.6

studies. For both of the tracer studies, emission factors were determined by direct measurement of SF6 flow rates immediately before and after each test run. For the Illinois EPA study, however, emission factors were computed by the MOBILE1 emission factor model(45). This method is subject to inaccuracies in assumed input values (such as percent cold-start vehicles) as well as overall model inaccuracies. Therefore, the higher values of F1 obtained for CALINE3 using the Illinois EPA data base were possibly the result of bias attributable to the emission factor calculations. An examination of the actual values of the statistic, S1, showed that CALINE4 was overpredicting the high concentrations to a slightly greater degree than CALINE3. The uncertainty of the modeled emission factors makes it difficult to attach any significance to this, especially when results from two independent tracer studies indicate improved model performance in this area for CALINE4.

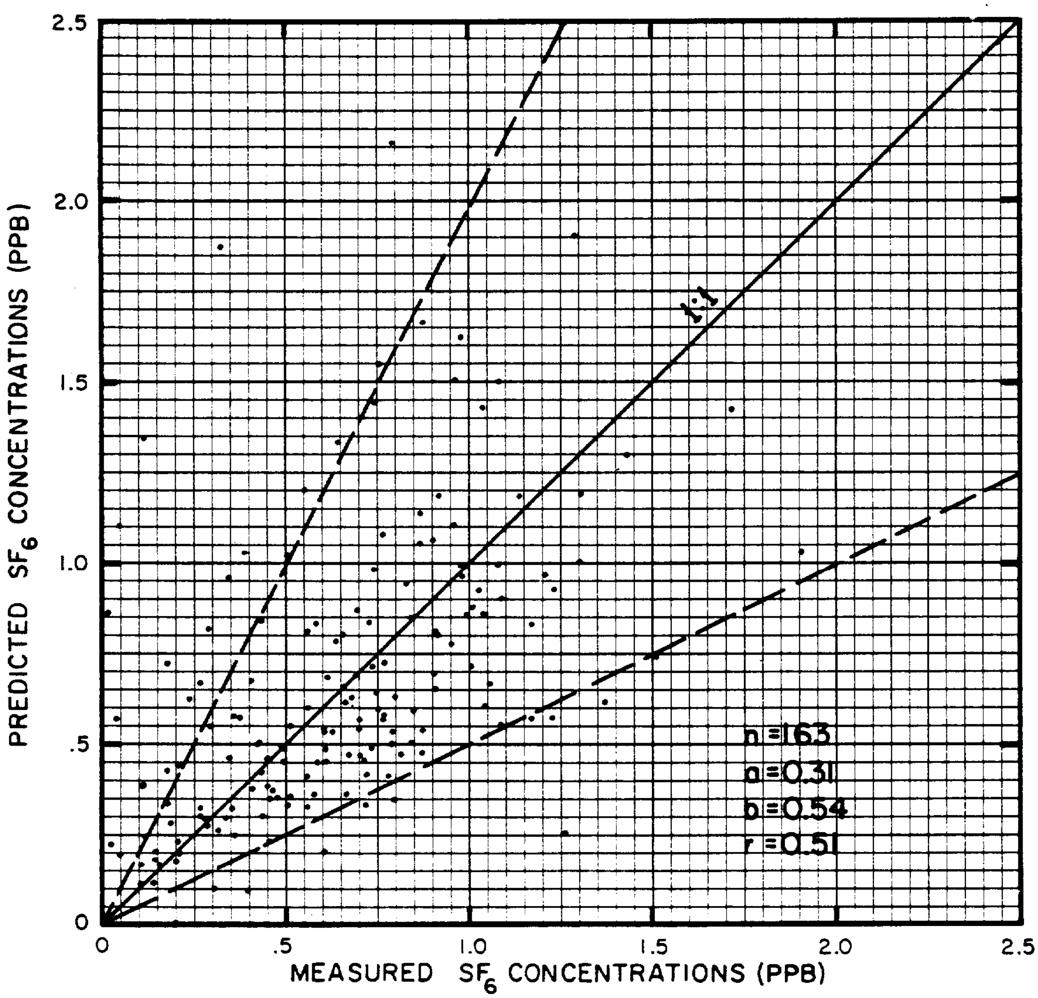
A series of scatterplots showing CALINE4 predictions versus measured concentrations for downwind locations at the three sites studied are given in Figures 46 through 49. A line of perfect agreement and factor-of-two envelope are also plotted on the graphs. The predictions for those points falling inside the envelope are within plus or minus a factor of two of the measured concentrations, a commonly held minimum criterion for judging adequate model performance. The number of points (n), intercept (a), slope (b) and correlation coefficient (r) for a linear, least-square regression analysis are also given in the figures.

At least 75% of the paired data points fall within the factor-of-two envelope for each of the three freeway



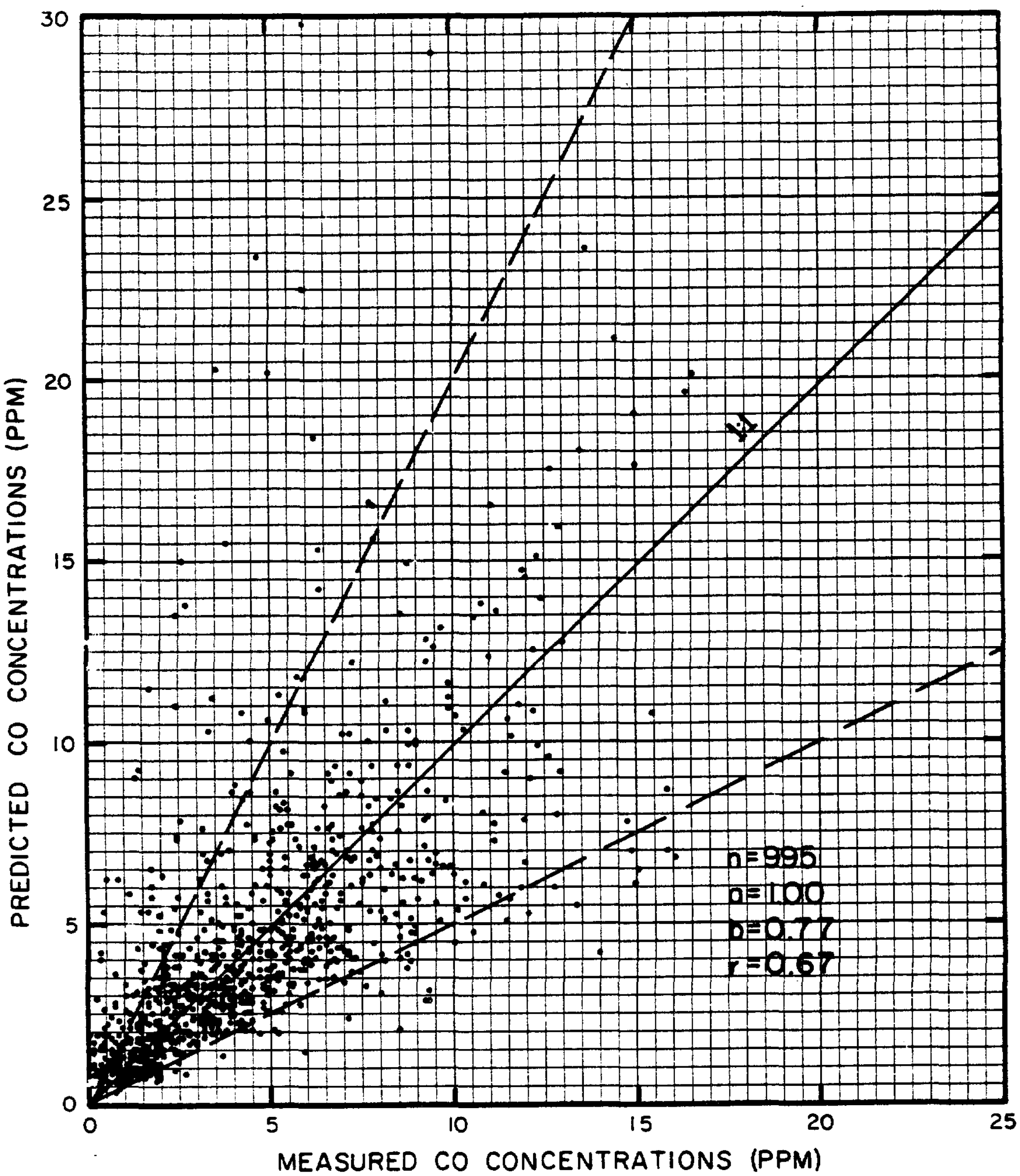
CALINE4 SCATTERPLOT FOR GENERAL MOTORS DATA

FIGURE 46



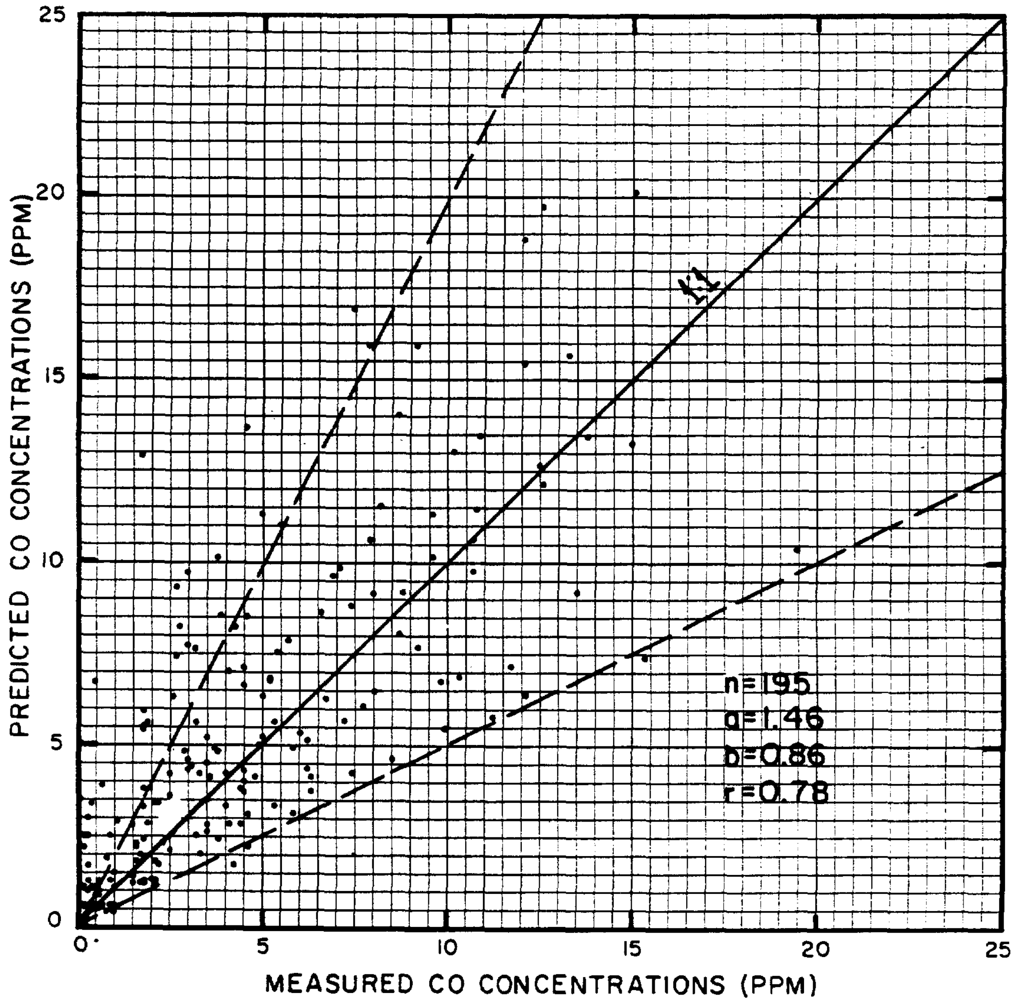
CALINE4 SCATTERPLOT FOR CALTRANS HIGHWAY 99 TRACER STUDY

FIGURE 47



CALINE4 SCATTERPLOT FOR ILLINOIS EPA FREEWAY STUDY (NORTH RECEPTORS)

FIGURE 48



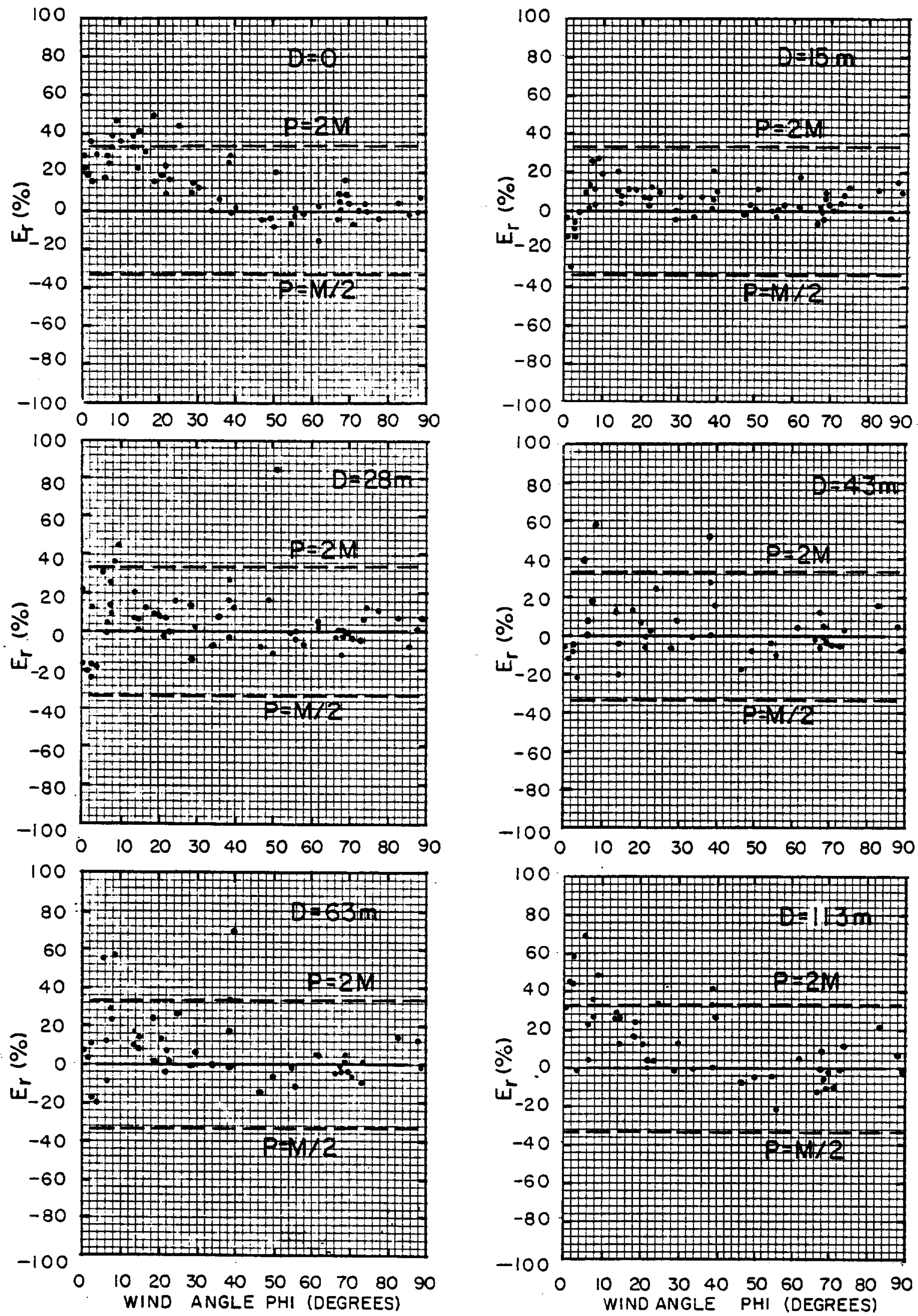
CALINE4 SCATTERPLOT FOR ILLINOIS EPA
FREEWAY STUDY (SOUTH RECEPTORS)

FIGURE 49

studies. Of the points falling outside the envelope, a greater number represent overpredictions by the model than underpredictions. For the General Motors and Caltrans studies, 12% and 15%, respectively, fell above the envelope (overpredictions) while only 1% and 77S fell below (underpredictions).

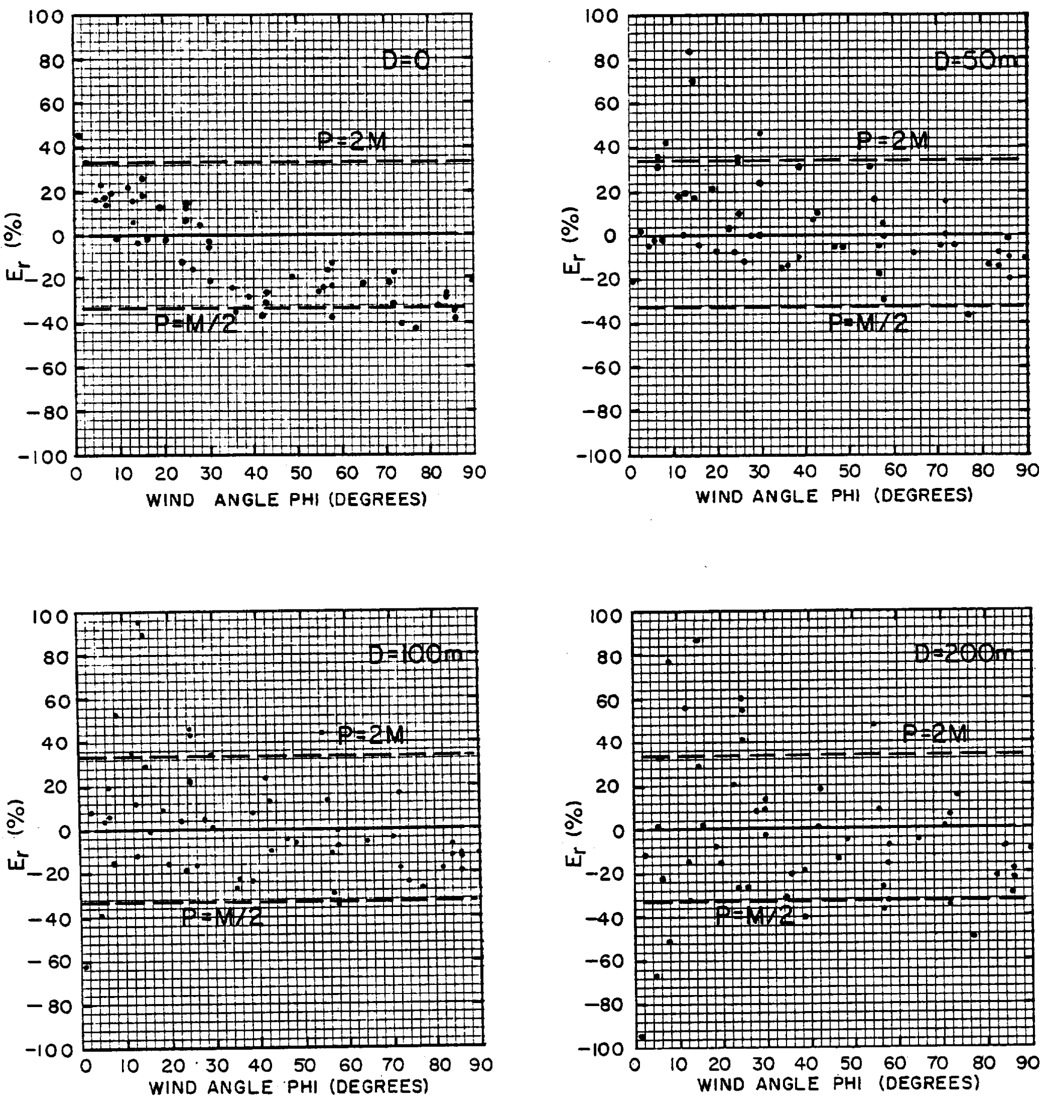
The types of patterns exhibited in the scatterplots are typical when comparing Gaussian model results to measured data. Measured data sets invariably contain some results averaged over time periods during which significant shifts in mean wind direction occur. These directional shifts tend to lower peak concentrations at downwind receptors by spreading emissions over a greater area. The Gaussian model assumes that the assigned mean wind direction continues for the full time period, and that any variability in the direction is normally distributed about the mean. Overpredictions will occur when the calculated mean wind direction actually represents a point somewhere between two or more mean wind directions experienced during the time period.

Wind directional shifts are most critical for line source models when the mean wind direction is parallel to the road. Also directional shifts are most likely to occur when wind speeds are low. Figures 50 and 51 show the relative error of CALINE4 as a function of roadway-wind angle for the General Motors and Caltrans tracer studies. A factor-of-two envelope is indicated by the P=2M and P=M/2 dashed lines. The plots show that relative error increases as the distance from the roadway increases and as the angle between the wind and the roadway decreases. There is a definite tendency for overpredictions to occur more frequently during near-parallel wind conditions.



RELATIVE ERROR, E_r, VERSUS WIND ANGLE FOR GROUND LEVEL RECEPTORS (Z=0.5m)—GENERAL MOTORS DATA

FIGURE 50



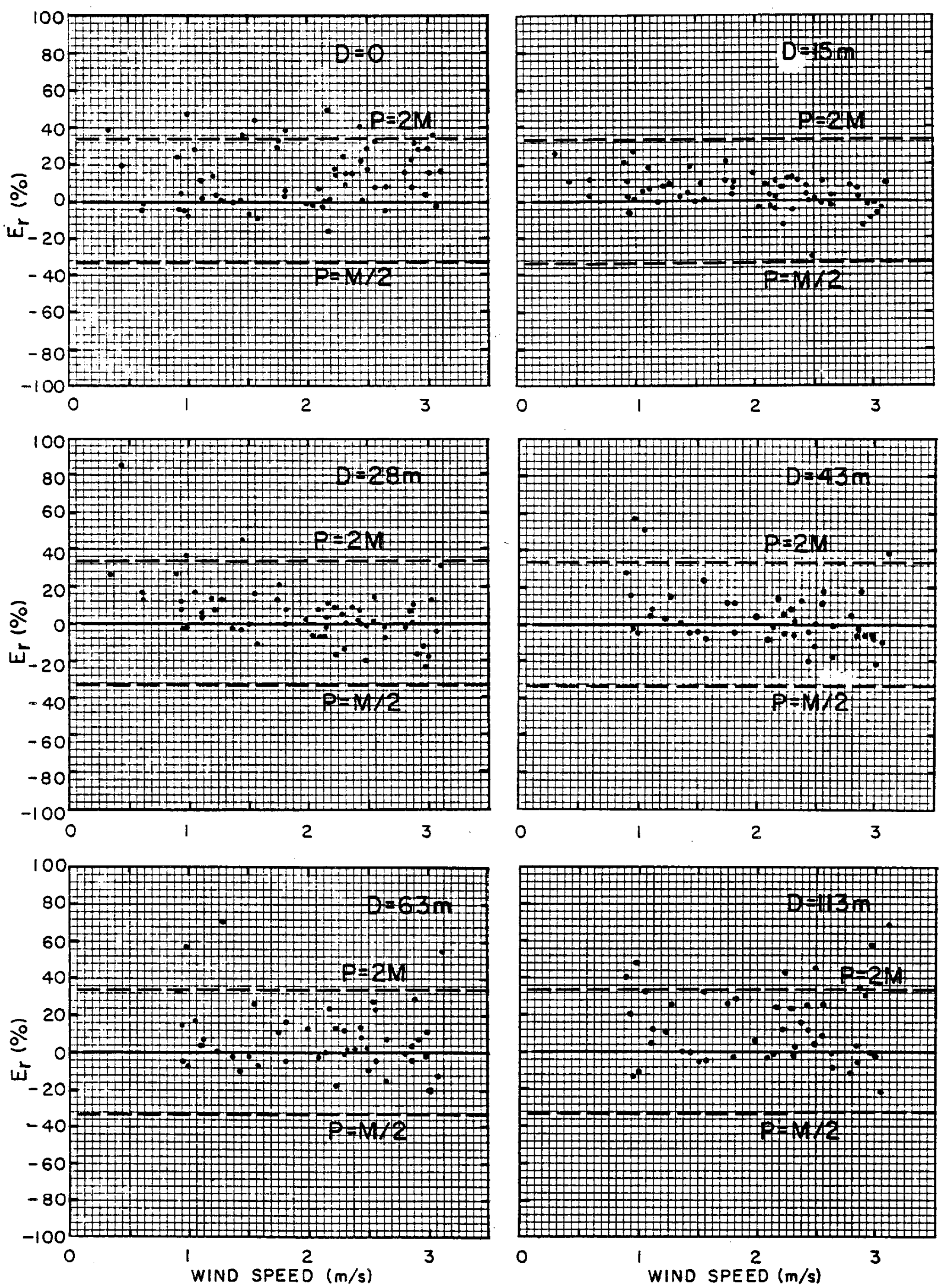
RELATIVE ERROR, E_r, VERSUS WIND ANGLE FOR GROUND LEVEL RECEPTORS (Z=0.5m)—CALTRANS HIGHWAY 99 TRACER STUDY

FIGURE 51

The increase of relative error with distance may be attributed, in part, to difficulties in measuring lower concentrations precisely. Also, a number of the overpredictions for parallel winds may be due to directional wind shifts.

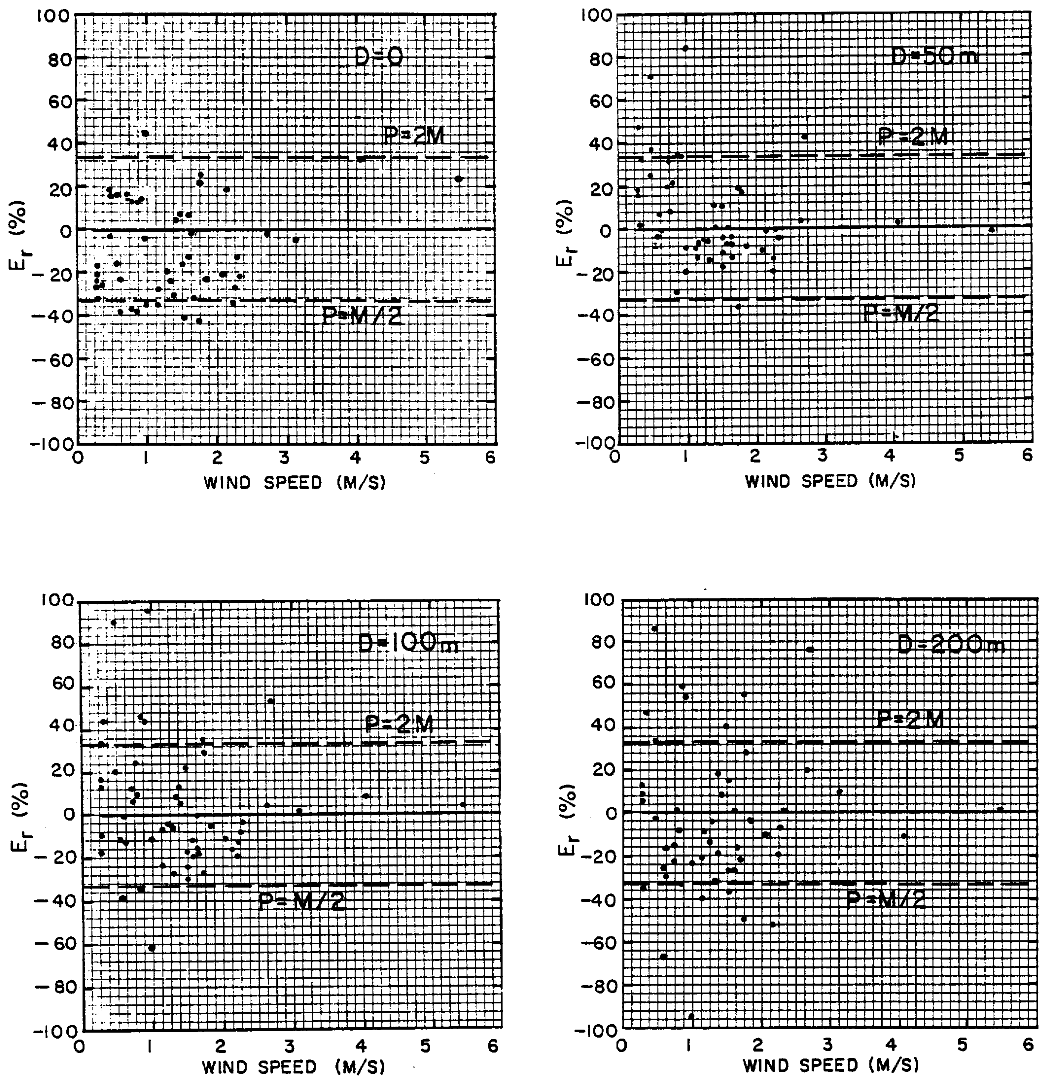
The most pronounced bias with respect to roadway-wind angle occurs at the median sampling location. The relative errors show a clear trend toward overprediction for near- parallel winds. Significant underpredictions are seen in the Caltrans study for crosswind conditions. The reasons for this behavior are not well understood. The assumption of a constant initial vertical dispersion parameter over the mixing zone may not be realistic. The shearing effect between opposing flows of traffic may be a significant factor that is not accounted for by CALINE4. In any case, the CALINE4 model predictions for locations within the mixing zone must be suspect for bias. If desired, corrections can be made to model results using the relative error plots for median locations given in Figures 50 and 51.

Relative errors plotted against wind speed for the two tracer studies are shown in Figures 52 and 53. For both studies there seems to be a tendency toward overprediction at locations near the roadway when winds are light. The wind speed at which this bias starts is about 2 m/s for the General Motors data, and 1 m/s for the Caltrans data. These overpredictions are probably due to the unlikelihood of achieving steady-state conditions (assumed by the Gaussian model) during near calm winds. Calm winds often prevail for a short time between diurnal shifts in the mean wind flow. If conditions are right, however, a light wind can persist in speed and direction. In such cases, the conservative overpredictions of the model provide a safeguard against underpredicting air quality impacts.



RELATIVE ERROR, E_r VERSUS WIND SPEED FOR GROUND LEVEL RECEPTORS (Z=0.5m)— GENERAL MOTORS DATA

FIGURE 52



RELATIVE ERROR, E_r VERSUS WIND SPEED FOR GROUND LEVEL RECEPTORS (Z=1.0m)—CALTRANS HIGHWAY 99 TRACER STUDY

FIGURE 53

8.3.2 Intersection Sites

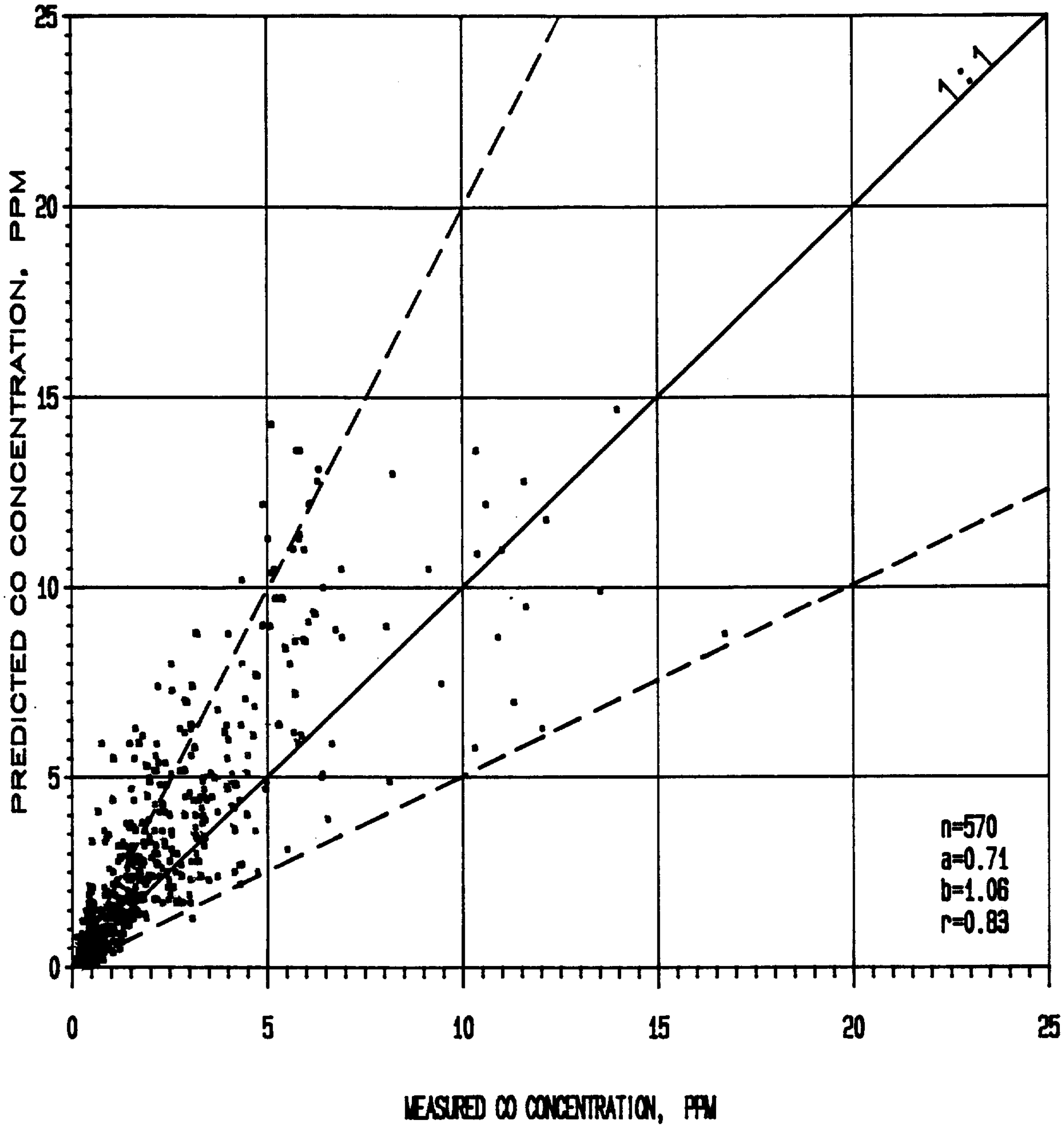
The determination of accurate emission factors and traffic parameters for the two intersection sites included in this verification analysis posed serious problems. The distributions of cold-start vehicles and vehicle types tend to vary more from hour-to-hour on surface streets than on highways. Therefore, emission factors are more difficult to estimate. Acceleration rates, vehicle delay, turn movements and other needed traffic parameters were not fully documented in either study. These parameters had to be estimated from float car surveys and representative traffic counts. Because of these difficulties, only a fraction of the intersection data was used in the verification analysis. For each data base, approximately 30 randomly selected hours were combined with the 10 highest hours to form a verification data set. National average values were assumed for percent cold and hot-starts and vehicle mix. The critical inputs of approach volume per cycle and delay per cycle were related to total traffic volume through field observations in the case of the Florin/Freeport study, and reported results in the case of the Illinois study.

The results of all this educated guess work turned out surprisingly well. Using air quality thresholds of 9 ppm for Florin/Freeport and 20 ppm for the Illinois EPA study, the individual and overall figures of merit were as follows:

	Florin/ Freeport	Illinois EPA
F1	8.1	6.9
F2	10.0	9.9
F3	8.8	8.5
F4	8.8	7.6
F5	9.4	9.3
F6	2.4	2.8
FOM	6.8	6.6

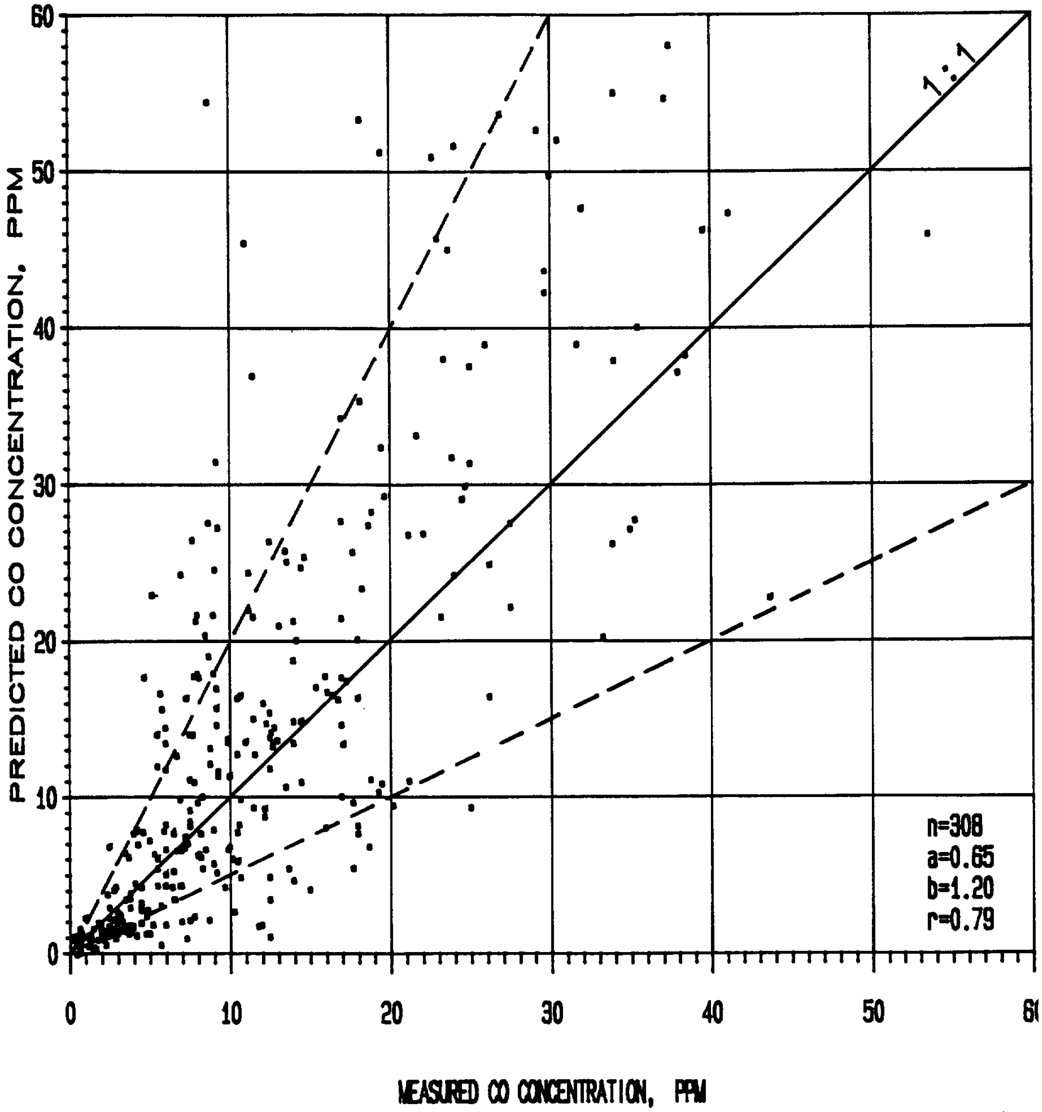
The overall model performance for intersection sites closely matches the performance for the freeway sites listed in Table 4. However, the temporal correlation between predicted and measured concentrations is consistently better, while the spatial correlation is worse. The improved temporal correlation is explained by the higher wind speeds that were experienced during the intersection sampling periods ($U \geq 0.7$ m/s), and the elimination of parallel winds as a critical condition due to the localized nature of intersection emissions. Spatial correlation deteriorated slightly because receptor-to-source distance was less well-defined at the intersection sites.

Scatterplots of predicted versus measured CO concentrations for the two intersection studies are shown in Figures 54 and 55. The Florin/Freeport scatterplot shows a significant number of overpredictions with 24% of the results falling outside of the factor-of-two envelope (23% over-predictions and 1% underpredictions). The Illinois EPA results are more evenly scattered, with 27% falling outside of the envelope (14% overpredictions and 13% underpredictions). For both studies, the peak unpaired measured and predicted values differed by less than 13%.



CALINE4 SCATTERPLOT FOR CALTRANS INTERSECTION STUDY

FIGURE 54



CALINE4 SCATTERPLOT FOR ILLINOIS EPA
INTERSECTION STUDY

FIGURE 55

The predominance of overpredictions recorded for the Florin-Freeport site was in part due to the use of the 2 meter wind speed measurement. The Gaussian model assumes a constant vertical wind profile, an assumption which is at odds with reality. Therefore, it is very important that the wind speed used in the model approximate the average wind speed over the depth of the surface layer for which the predictions are being made. For highway applications with relatively long, parallel wind transport distances, wind speeds measured at a height of 10 meters are reason- able. For intersection applications with localized emission sources and nearby receptors, the bulk of the dispersive process takes place in the first several meters of the surface layer. Wind speeds measured at approximately 5 meters are more appropriate for such applications. Two meters was apparently too low.

8.3.3 NO2 Option

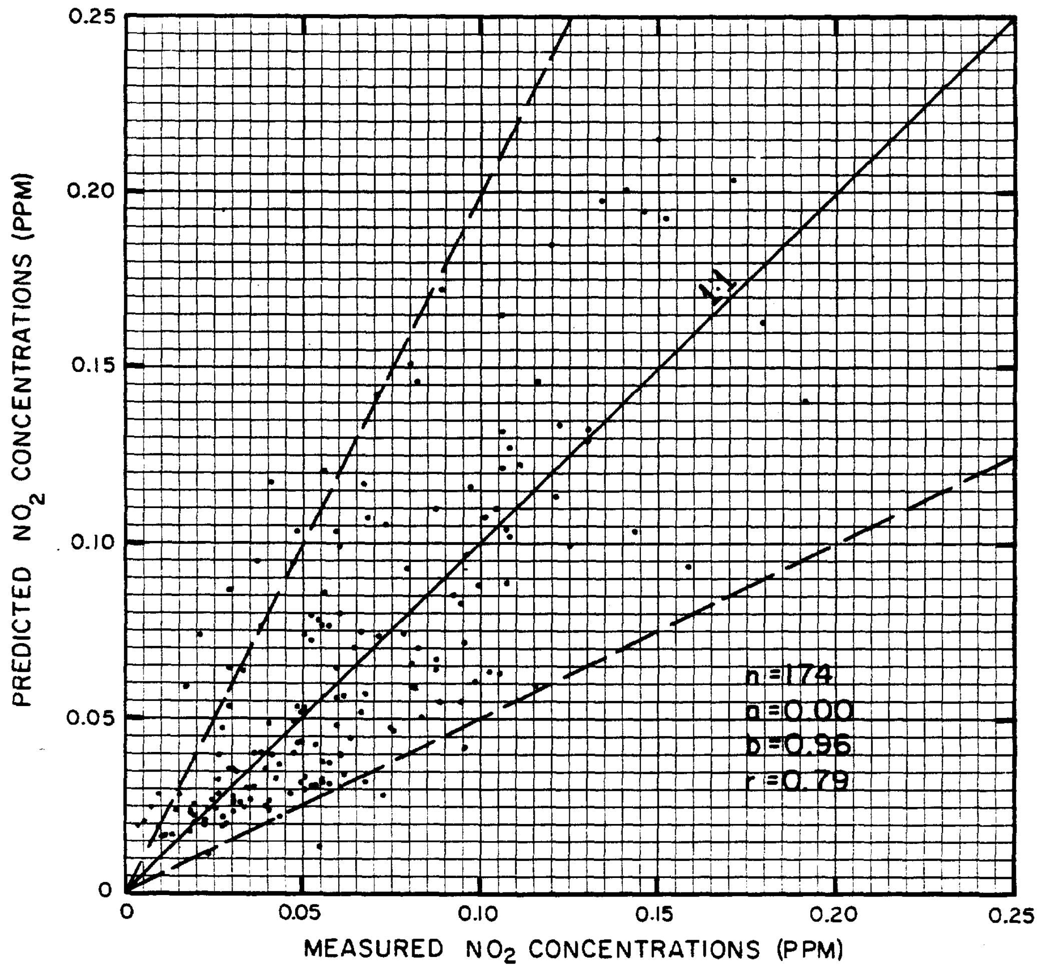
The verification analysis for the CALINE4 NO2 option was performed using the EPA NO2/O3 Sampler Siting Study data base. Thirty time periods were chosen from the data base to represent a variety of traffic and meteorological conditions. Photolysis rate constants were determined using a method which incorporated the effects of cloud cover(46). Traffic estimates were obtained for Sepulveda Boulevard so that contributions from this link could be added to the San Diego Freeway results. Emission factors for NO2 were determined using California's EMFAC6 model, and assuming 21% cold-starts on the freeway and 45% on Sepulveda 8Oulevard.

The resulting individual and overall figures of merit for the six downwind locations were as follows:

F1 = 8.4
F2 = 9.9
F3 = 7.7
F4 = 7.9
F5 = 6.9
F6 = 5.7
FOM = 7.5

This model performance is actually better than the results shown in Table 4 for the relatively inert species, SF6 and CO. However, the improvement is due to the nature of the site, not the use of the NO2 option. Prevailing winds at the San Diego Freeway site are perpendicular to the highway alignment and steady in speed and direction. Of the thirty time periods studied, the roadway-wind angle was never less than 60 degrees, and the average wind speed never dropped below 1.4 m/s. These are the types of conditions under which the model performs at its best.

A scatterplot of the predicted and measured NO2 concentrations is shown in Figure 56. A total of 12% of the points fall outside of the factor-of-two envelope (9% over- predictions and 3% underpredictions). From the standpoint of this minimum criterion, the CALINE4 NO2 option performs adequately, at least for crosswind conditions. Because of the time scale assumption used in the Discrete Parcel Method, and the assumption of uniform mixing with upwind ambient O3, application of the NO2 option is not recommended for near-parallel winds applications unless measured results are available for verifying or calibrating the model.



CALINE4 SCATTERPLOT FOR U.S. EPA NO_2/O_3 SAMPLER SITING STUDY

FIGURE 56

9. USER INSTRUCTIONS

9.1 General Comments[‡]

CALINE4 is written to conform to the American National Standard Programming Language FORTRAN 77, as described in the American National Standards Institute (ANSI)X3.9-1978 standard. The core requirement to compile and run the program is approximately 167K. Data is input to the program via a single file created by the user. This file contains both formatted and unformatted records. At present, there is no interactive version of the program available.

The input file is organized on two levels: The "JOB" level and the "RUN" level. Each job is represented by a single input file. The job may contain one or more runs, each resulting in an array of concentrations predicted by the model. Job-related variables are listed first in the input file. These variables represent physical characteristics of the site or pollutant that are not likely to change over time. Examples include settling velocity, molecular weight and link/receptor coordinates. Run-related variables are transient in nature, and therefore are likely to change over the course of multi-hour averaging times. Variables related to meteorology or traffic fall into this category.

CALINE4 can process up to a maximum of 20 links and 20 receptors per job. These limits can be expanded by the user through redimensioning of the appropriate arrays in the model and modification of the output. However, this will also increase the core requirement.

[‡] CALINE4 was used on a mainframe computer at the time this report was written. An IBM PC executable version was released in 1994. An executable file can be downloaded from http://www.dot.ca.gov/hq/env/air/. Any interactive user interface available is separate from the CALINE4 program itself and communicates with the model through the file structure described here. – M.J. Brady, 11/2010

CALINE4 contains several useful program options. Link type can be selected from among six specialized categories including parking lot and intersection types. Mixing height and canyon or bluff restrictions can be specified by the user. Several types of pollutants can be dealt with by the model. A worst-case wind angle search is available to the user. These options are invoked by either coded entries or non-zero variable specifications within the input file.

The model offers several possible output formats. In the standard format, the output contains a full summary of all pertinent input values, descriptive titles for the job, run, links and receptors (supplied by the user), and predicted concentrations for each receptor/link combination. A multi-run format is also available. It contains a summary of the pertinent input values, though in condensed form. Concentrations for individual runs and contributions by link are not identified in the multi-run format. Instead, a concentration averaged over the multiple runs is listed for each receptor. Variations in output format can also depend on the program options invoked. Output for the Nø2 option lists the additional variables needed to run that option. Wind directions derived from the worst-case search option are listed with the model results and noted by the words "WORST CASE". Runs involving intersection links detail the traffic parameters needed to run the intersection link option.

9.2 Input

9.2.1 Coordinate System

CALINE4 uses a combination of the X-Y Cartesian coordinate system and the standard compass system to establish receptor locations, link geometry and wind direction. The standard, 360ø compass is overlaid onto the X-Y coordinate plane such that north corresponds to the +Y direction and east corresponds to the +X direction. Wind angles (BRG) are measured as the azimuth bearing of the direction from which the wind is coming (i.e., BRG = 270° for a wind from the west). Coordinates, link height, link width, mixing width (canyon/bluff) and stopline distance may be assigned in any consistent length units. The user must input a scale factor (SCAL) to convert the chosen units to meters (SCAL=1. if coordinates, etc. are input in meters).

The X-Y grid and compass systems are combined into a single system and may be used with north representing true north, magnetic north or an assumed north. Once north has been chosen, all angles and X-Y pairs must be consistently assigned. Negative coordinates are permitted.

The model assumes that air flow will adjust to gradual changes in topography. Therefore, receptor and link heights are referenced to the ground level in their immediate vicinity, not to a fixed elevation datum. The Z component of the coordinate system differs from the X and Y components in this respect. The horizontal X-Y components form a fixed rectangular grid system. The Z component is not fixed. Instead, it follows the surface topography. Consequently, two receptors at different absolute elevations can have the same Z coordinate if they are both at equal heights above their respective ground levels.

9.2.2 Input File Format

A complete summary of the input variables used by CALINE4 is given in Table 5. The table shows the organization of the input file by record number, distinguishes between formatted and unformatted records, and denotes conditional inputs. Data type, units and a brief description of each variable are also given.

Several features of the input file format deserve special attention. The user may assign unique link and/or receptor titles, or opt to let the program assign default titles. The default option assigns letter titles to the links and numeric titles to the receptors in sequential fashion starting with "A" and "1", respectively. A zero entry for the code variables LC or RC will invoke the default option. If at least one title is needed, the default option cannot be used.

Modeling situations often require the inputting of a series of contiguous links. This can result in duplicative data entries when consecutive link endpoint coordinates are coincident. To eliminate this problem, a continuation code was added to the CALINE4 input format. This code is set equal to 1 when the first endpoint of the following link is coincident with the second endpoint of the current link. The program will then look for only one set of link coordinates (XL2, YL2) when the next record is read.

The input file contains a series of codes to signify to the program what changes in run-related variables have occurred from the previous run. The variables are divided into four categories for this purpose: traffic volume, emission

TABLE 5

Summary of Input File Format Used
By CALINE4

Record Number	Variable Name	Type	Units	Description
1	JOB	Alphameric	-	Job title (40 characters or less)
2	PTYP	Integer	-	Pollutant Type: 1 = CO 2 = NO_2 3 = Inert Gas (such as SF_6) 4 = Particulate
	NAME	Alphameric	-	Pollutant name (30 characters or less)
3*	ZO	Real	cm	Aerodynamic roughness coefficient
	MOWT	Real	-	Molecular weight
	VS	Real	cm/s	Settling velocity
	VD	Real	cm/s	Deposition velocity
	NR	Integer	-	Number of receptors
	NL	Integer	-	Number of links
	SCAL	Real	m/?	Scale Factor - converts roadway geometry input variables to meters
	LC	Integer	-	Link Title Option - equals 0 for default titles
	RC	Integer	-	Receptor Title Option - equals 0 for default titles
	ALT	Real	?	Altitude above sea level
(4) RC=0	RCP	Alphameric	-	Receptor name (8 characters or less)
5*	XR	Real	?	X receptor coordinate
	YR	Real	?	Y receptor coordinate
	ZR	Real	?	Z receptor coordinate

Record Number	Variable Name	Type	Units	Description
(6) LC≠0	LNK	Alphameric	-	Link name (12 characters or less)
7*	TYP	Integer	-	Link Type: 1 = At-Grade 2 = Depressed 3 = Fill 4 = Bridge 5 = Parking Lot 6 = Intersection
	(XL1,YL1) CC ≠ 1	Real	?	Coordinates of link endpoint 1
	XL2,YL2	Real	?	Coordinates of link endpoint 2
	HL	Real	?	Roadway height
	WL	Real	?	Mixing zone width
	MIXWR	Real	?	Mixing width (right)
	MIXWL	Real	?	Mixing width (left)
	CC	Integer	-	Continuation Code - equals 1 if endpoint 1 of next link coincident with endpoint 2 of current link
(8*) TYP=6	STPL	Real	?	Distance from link endpoint 1 to stopline
	DCLT	Real	s	Deceleration time
	ACCT	Real	s	Acceleration time
	SPD	Real	mph	Cruise speed
9	RTYP	Integer	-	Run Type: 1 = Standard 2 = Multi-run 3 = Worst-case wind angle 4 = Multi-run/worst-case hybrid 9 = Multi-run (last run)
	VPHCOD	Integer	-	Traffic Volume Code - equals 0 if traffic volume on all links unchanged from previous run

Record Number	Variable Name	Type	Units	Description
	EFLCOD	Integer	-	Emission Factor Code - equal 0 if emission factors for all links unchanged from previous run
	INTCOD	Integer	-	Intersection Parameter Code - equals 0 if intersection parameters unchanged from previous run
	METCOD	Integer	-	Meteorology Code - equal 0 if meteorology unchanged from previous run
	RUN	Alphameric	-	Run Title (12 characters or less)
(10*) VPHCOD≠0	VPHL	Real	vph	Hourly traffic volumes by link (approach for TYP=6)
(11*) EFLCOD≠0	EFL	Real	gm/v-mi	Composite emission factors by link (@ 16 mph for TYP=6)
(12*) INTCOD≠0	NCYC	Integer	-	Average number of vehicles handled per cycle per lane
	NDLA	Integer	-	Average number of vehicles delayed per cycle per lane
	VPHO	Real	vph	Hourly depart traffic volume
	EFI	Real	gm/v-min	Composite idle emission factor
	IDT1	Real	s	Vehicle idle time at stopline
	IDT2	Real	s	Vehicle idle time at end of queue (0 for non-platooned arrival)
13*	BRG	Real	deg	Wind direction bearing
	U	Real	m/s	Wind speed
	CLAS	Integer	A=1 to G=7	Atmospheric stability class
	MIXH	Real	m	mixing height
	SIGTH	Real	deg	Wind direction standard deviation

Record Number	Variable Name	Type	Units	Description
	(AMB) PTYP≠2	Real	ppm	Ambient concentration
	TEMP	Real	°C	Temperature
	(O3) PTYP=2	Real	ppm	Ambient O_3 concentration
	(NOA) PTYP=2	Real	ppm	Ambient NO concentration
	(NO2A) PTYP=2	Real	ppm	Ambient NO_2 concentration
	(KR) PTYP=2	Real	s^{-1}	NO_2 photolysis rate constant

* Denotes unformatted record. Include decimal point for reals and leave at least one space between data entries.

( )Denotes conditional input. Record or variable required only if condition listed below parentheses is satisfied.

? Denotes units of length that will equal meters when multiplied by SCAL.

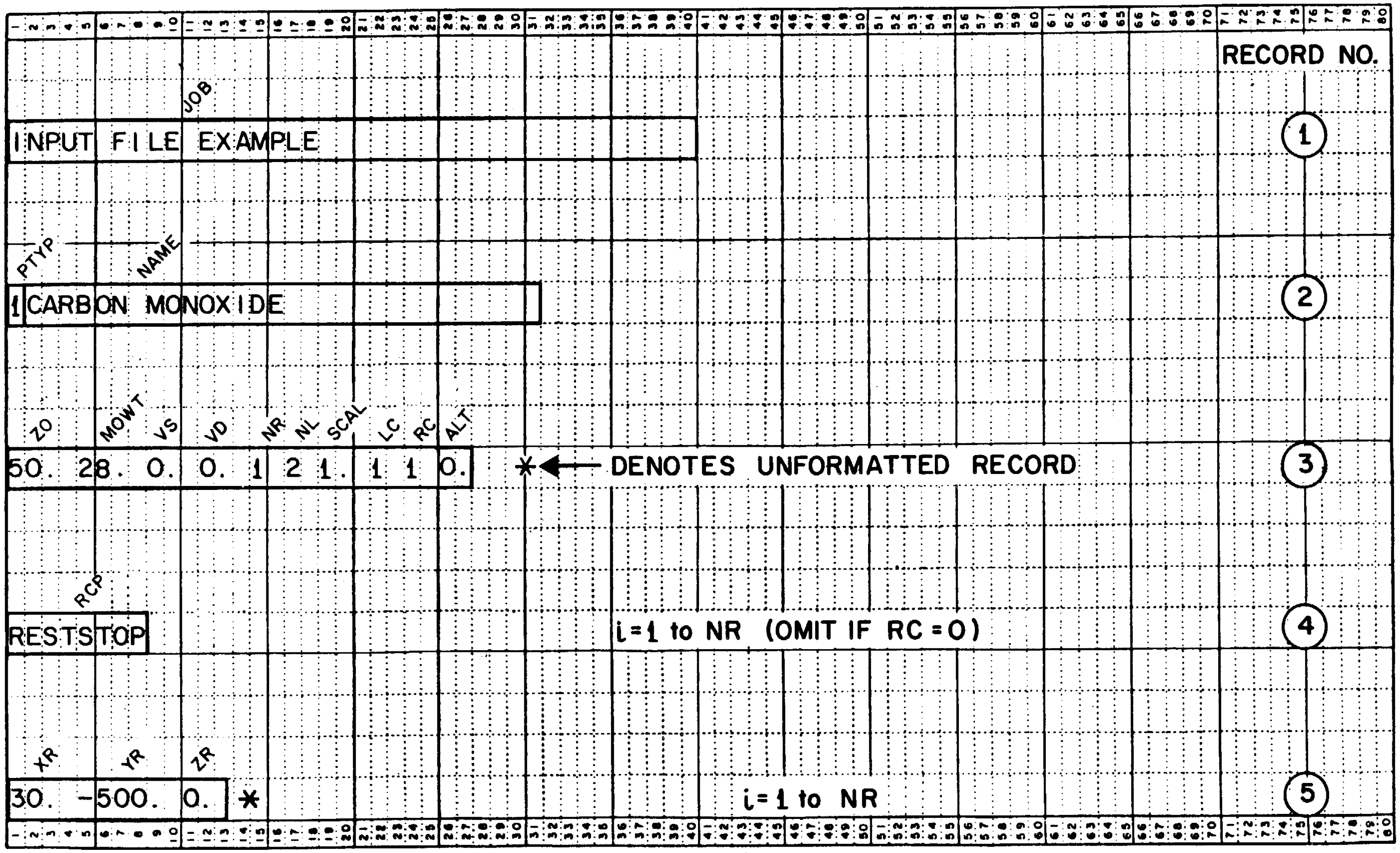
factors, intersection parameters and meteorology. When there are no changes for a particular category of vari- ables, the appropriate code is assigned a value of zero by the user. The program will then assume that the values assigned in the previous run are still valid and will not execute read statements for these variables.

The additional inputs required for the NO_2 option are located with the meteorological variables on record 13. The input file must contain entries for these variables when PTYP=2. The user should also remember to omit an entry for AMB when the NO_2 option is used.

An example of a CALINE4 input file is shown in Figure 57. The figure shows what records need to be repeated and distinguishes between formatted and unformatted records. Unformatted records require at least one space between data entries and decimal points for real variables. To add additional runs to the file, the user repeats the format starting at record 9.

9.2.3 Input Variables

Table 6 is intended to help the user assign proper and realistic values to the many input variables used by the model.



DAS-CS 90-062

INPUT FILE FORMAT
FIGURE 57

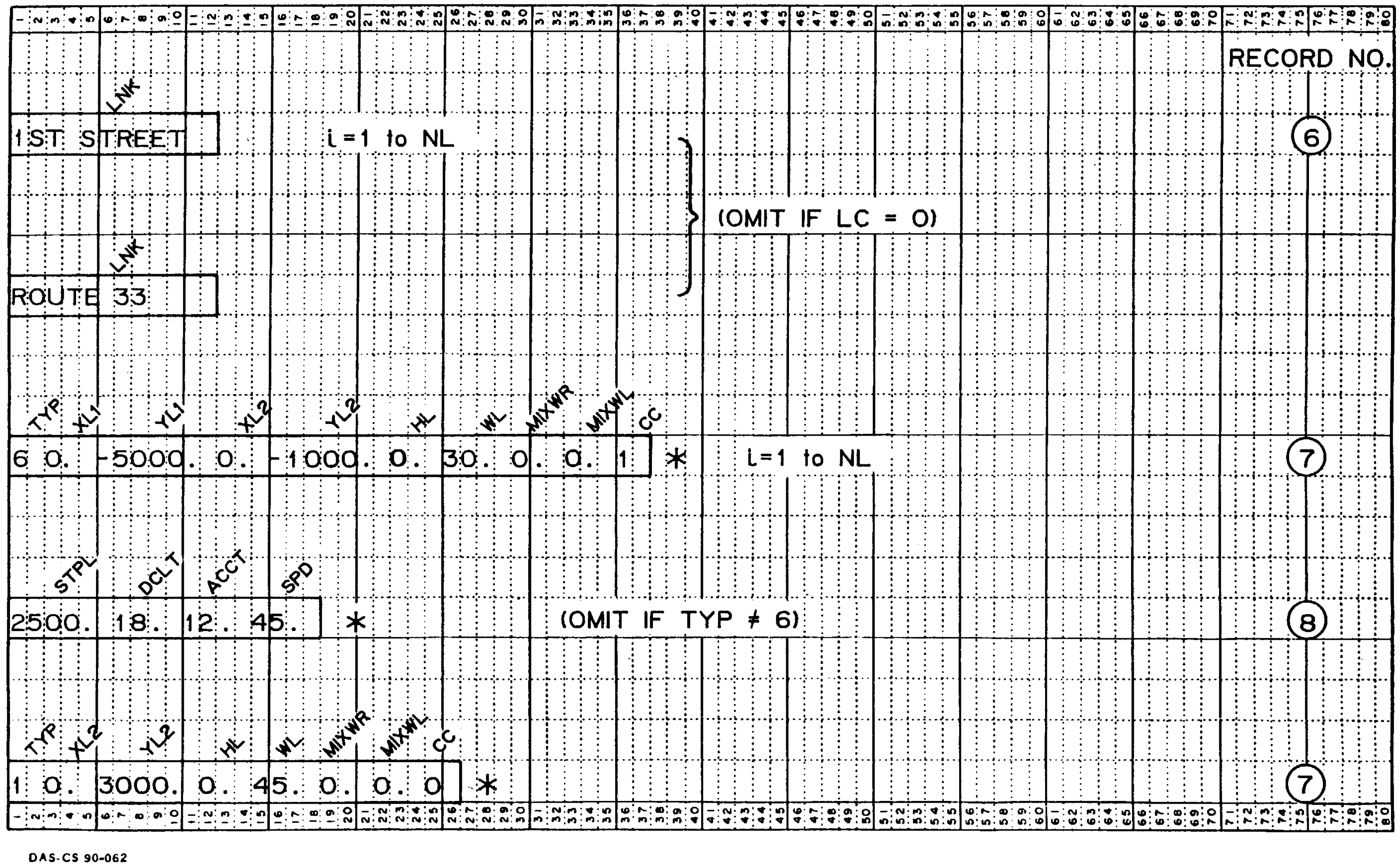
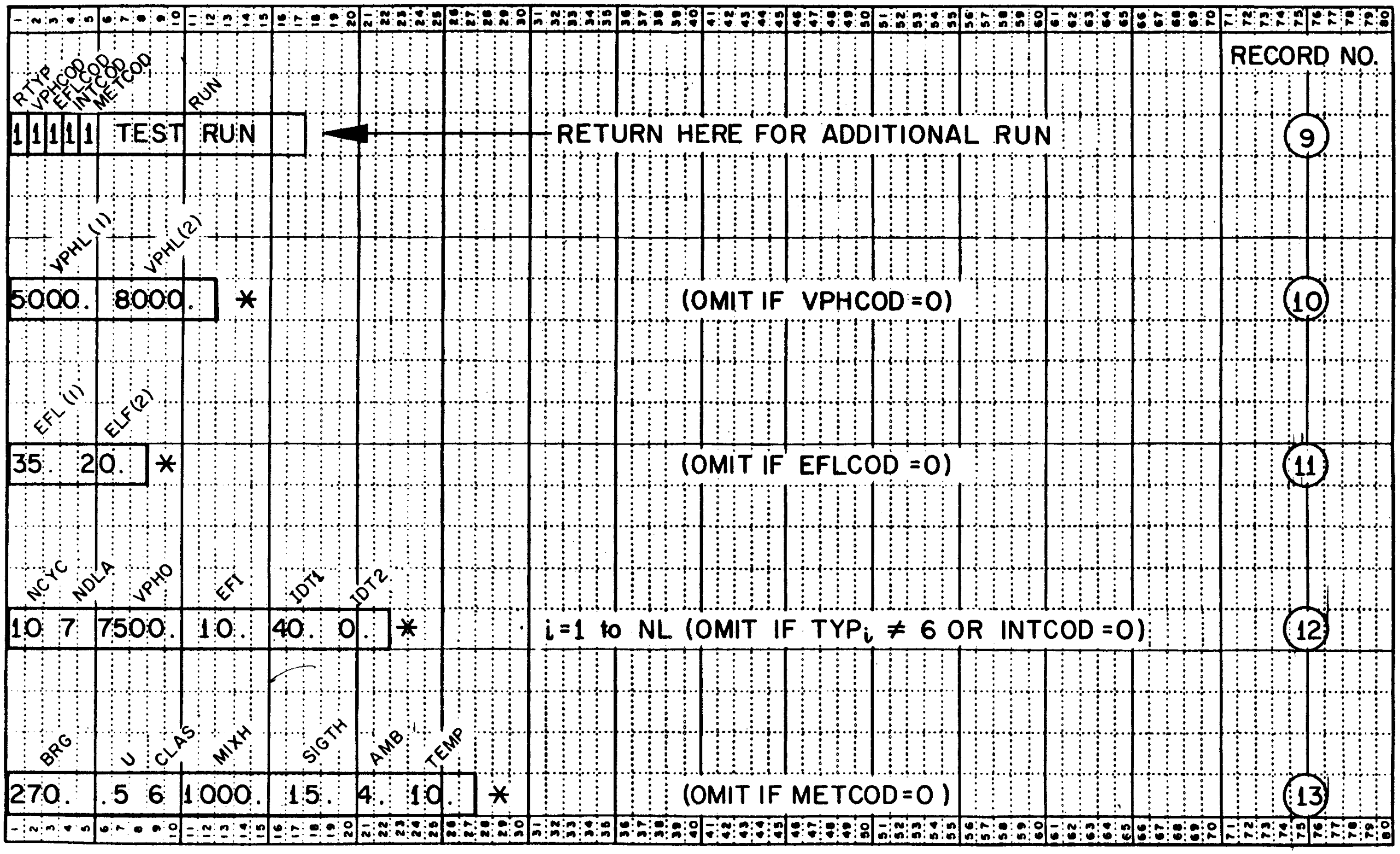


FIGURE 57 (CON'T)



DAS-CS 90-062

FIGURE 57 (CON'T)

TABLE 6

Limits and References for Various CALINE4 Input Variables

Variable	Suggested or Mandatory Limits	Comments	References
Surface Roughness (ZO)	$3 \leq ZO \leq 400$cm	15% of average canopy height.	(47,48)
Settling Velocity (VS)	$VS \geq 0$	$VS=2.98x10^5 D_{ar}^2$, D_{ar}=Aerodynamic resistance diameter (cm)	(49)
Deposition Velocity (VD)	$VD \geq 0$		(21,50,51)
Intersection Traffic Parameters (Various)		Traffic assumed to flow from link endpoint 1 to link endpoint 2.	(52,53)
Wind Speed (U)	$U \geq 0.5$m/s	Measure at 5 to 10 m or assume worst-case. For localized sources & nearby receptors, wind speeds measured at lower elevations (5 m) desirable. For more diffuse sources & distant receptors, 10 m height more appropriate.	(54)
Stability Class (CLAS)	$1 \leq CLAS \leq 7$	Figure 11, Golder, Turner, or assume worst-case.	(15,42,54,55,56)
Directional Variability (SIGTH)	$5° \leq SIGTH \leq 60°$	Measure at 4 to 10 m or assume worst-case.	(54,57,58,59)
Mixing Height (MIXH)	$MIXH \geq 5$m (Note: $MIXH \geq 1000$m Deactivates this algorithm)	$MIXH = \frac{0.185*U*k}{\ell n(Z/ZO)*f}$ U = Wind speed (m/s) Z = Height U measured at (m) ZO = Surface roughness (m) k = von Karman constant (0.35) f = Coriolis parameter $= 1.45 \times 10^{-4} \cos\theta$ (radian/sec) $\theta = 90°$ - site latitude	(60)

TABLE 6 (con't.)

Variable	Suggested or Mandatory Limits	Comments	References
Temperature (TEMP)		January mean minimum plus time period adjustment.	(54)
Photolysis Rate (KR)	$KR \geq 0$		(46,61)
Wind Direction (BRG)	$0° \leq BRG \leq 360°$	Wind azimuth bearing measured relative to positive Y-axis.	
Mixing Zone Width (W)	$WL \geq 10$ m	Minimum of 1 lane plus 3 m per side (Exception: Parking Lot Link)	
Link Length (LL)	$WL \leq LL \leq 10$ km	Link length needs to be greater than or equal to the mixing zone width for proper element resolution and less than 10 km to stay within the range of validity for the vertical dispersion algorithm.	
Source Height (H)	$-10 \leq HL \leq 10$ m	Limits of verified model performance.	
Receptor Height (Z)	$ZR \geq 0$	For depressed sections $Z \geq H$ (where H is negative) is permitted for receptors within the section.	
Mixing Width (MIXWR, MIXWL)	$MIXWR \geq WL/2$, $MIXWL \geq WL/2$	An assigned value of zero is is interpreted as no horizontal obstruction. Right (R) and left (L) determination made facing link endpoint 2.	

9.3 Input/Output Examples

The following five examples are intended to demonstrate many of the features available in CALINE4. For each example, one or more job files are given. This information is followed by the resulting output. A discussion of each example follows.

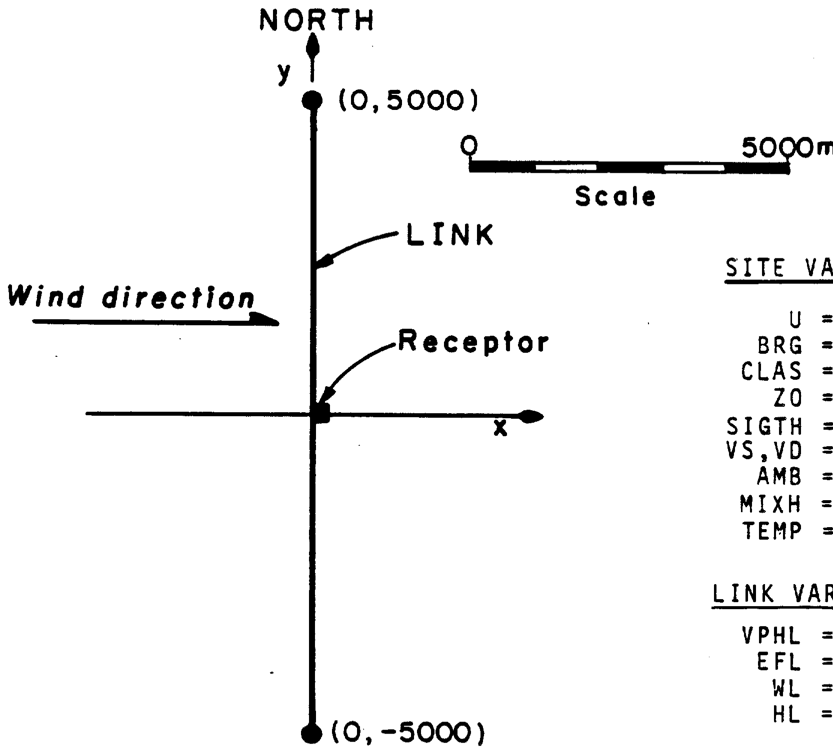
9.3.1 Example 1: Single Link

Any application of CALINE4 must involve at least a single link and a single receptor. A single link/receptor example is shown in Figure 58. The user should note the assumed north orientation of the Y-axis, and how this relates to of the the assigned wind direction (BRG).

Exhibit 1 consists of an input file for a standard CALINE4 run using the Example 1 data. The resulting output is given as Exhibit 2. Assigned receptor and link titles are used in this example (note that RC=1 and LC=1). Since there are no intersection links, INTCOD is assigned a value of zero. All length units describing the example geometry are in meters, so that SCAL=1. The assigned mixing height of 1000 meters bypasses the mixing height computations, thereby shortening execution time.

The output contains all pertinent input values in a format separating "site" and "link" variables. The consistent set of units used by CALINE4 is noted. Input values given in feet or meters for the roadway-receptor geometry will be labeled accordingly in the output. Units used other than feet or meters will appear in the output as meters. The predicted concentration and receptor coordinates are listed

EXAMPLE 1: SINGLE LINK



SITE VARIABLES

U = 1 m/s
BRG = 270°
CLAS = 6 (F)
Z0 = 10 cm
SIGTH = 15°
VS,VD = 0 cm/s
AMB = 3.0 ppm
MIXH = 1000 m
TEMP = 10° c

LINK VARIABLES

VPHL = 7500
EFL = 30 g/mi
WL = 30 m
HL = 0 m

RECEPTOR COORDINATES

	X	Y	Z
1.	30	0	1.8

NOTE: Coordinates of Link Endpoints on Diagram (m)

FIGURE 58

EXHIB1T 1

```
EXAMPLE ONE: AT-GRADE SECTION
lCO
10. 28. 0. 0. 1 1 1. 1 1 0
RESTSTOP
30. 0. 1.8
HIGHWAY 22
1 0. -5000. 0.  5000. 0. 30. O. 0. 0
11101STANDARD RUN
7500.
30.0
  270. 1.0 6 1000.  15. 3. 10.
```

EXHIBIT 2

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
JUNE 1989 VERSION
PAGE 1

JOB: EXAMPLE ONE: AT-GRADE SECTION
RUN: STANDARD RUN
POLLUTANT: CO

I. SITE VARIABLES

```
      U=   1.0 M/S            Z0=  10. CM          ALT=      0. (M)
    BRG= 270.0 DEGREES        VD=  0.0 CM/S
   CLAS=     6 (F)            VS=  0.0 CM/S
   MIXH= 1000. M             AMB=  3.0 PPM
  SIGTH=   15. DEGREES      TEMP= 10.0 DEGREE (C)
```

II. LINK VARIABLES

```
      LINK       *  LINK COORDINATES (M)   *
   DESCRIPTION   *  X1    Y1     X2    Y2  * TYPE  VPH  EF      H     W
                 *                         *            (G/MI)  (M)   (M)
-----------------*-------------------------*------------------------------
A. HIGHWAY 22    *   0 -5000     0  5000   *  AG   7500  30.0   0.0  30.0
```

III. RECEPTOR LOCATIONS AND MODEL RESULTS

```
             *                           * PRED
             *    COORDINATES (M)        * CONC
  RECEPTOR   *   X        Y      Z       * (PPM)
-------------*---------------------------*------
1. RESTSTOP  *   30       0     1.8      *  7.5
```

in a block at the end of the output. The concentration is a sum of both the ambient and modeled components.

In Exhibits 3 and 4 the canyon option is activated by assigning values of 50 and 100 meters, respectively, to MIXWR and MIXWL. The right (R) and left (L) designations are always defined facing link endpoint 2 (XL2, YL2). A separate job file is needed because these are job-related variables (i.e., variables entered before record 9). The wind direction assigned by the user must be parallel to the canyon link (0˚ or 180˚ in this example). Otherwise, an error statement will be generated by the model.

One clear-cut result of invoking the canyon option is a significant increase in the receptor concentration!

9.3.2 Example 2: Rural Curved Alignment

Example 2 demonstrates the ability of CALINE4 to model a curved alignment and multiple receptors (Figure 59). The job file shown in Exhibit 5 contains information for two runs: A worst-case wind angle search (RTYP=3) and a multi- run (RTYP=2). Exhibits 6 and 7 are the respective outputs for these two runs.

The default labeling option was used for this example (i.e., LC,RC=0). This option is particularly convenient when there are numerous links and receptors along one route. Because the links are contiguous, coordinates for only a single endpoint are needed for each link (except the first). This is accomplished by assigning a value of one to the continuation code (CC).

EXHIBIT 3

```
EXAMPLE ONE: AT-GRADE SECTION
1CO
10. 28. 0. 0. 1 1 1.0 1 1 0
RESTSTOP
30. 0. 1.8
HIGHWAY 22
1 0. -5000. 0.  5000. 0. 30.50. 100. 0
11101CANYON RUN
7500.
30.0
0. 1.0 6 1000. 15. 3. 10
```

EXHIBIT 4

```
        CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
                 JUNE 1989 VERSION
                 PAGE   1

            JOB: EXAMPLE ONE: AT-GRADE SECTION
            RUN: CANYON RUN
      POLLUTANT: CO

 I.  SITE VARIABLES

      U=   1.0 M/S              Z0=  10. CM             ALT=      0. (M)
    BRG= 360.0 DEGREES          VD=  0.0 CM/S
   CLAS=     6 (F)              VS=  0.0 CM/S
   MIXH= 1000. M               AMB=  3.0 PPM
  SIGTH=   15. DEGREES        TEMP= 10.0 DEGREE (C)

 II.  LINK VARIABLES

      LINK      *  LINK COORDINATES (M)  *                  EF     H     W
   DESCRIPTION  *  X1     Y1     X2    Y2  * TYPE  VPH  (G/MI)  (M)   (M)
 ---------------*------------------------*-----------------------------
 A. HIGHWAY 22  *    0 -5000      0  5000 *  AG   7500  30.0    0.0  30.0

      *   MIXW
      *  L     R
 LINK * (M)  (M)
 -----*----------
  A.  * 100.  50.

 III.  RECEPTOR LOCATIONS AND MODEL RESULTS

             *                         * PRED
             *    COORDINATES (M)      * CONC
   RECEPTOR  *    X        Y       Z   * (PPM)
 ------------*-------------------------*------
 1. RESTSTOP *    30       0     1.8   * 11.3
```

EXAMPLE 2: RURAL CURVED ALIGNMENT

NOTE: Coordinates of Link Endpoints on Diagram (m)

RECEPTOR COORDINATES

	X	Y	Z
1.	400	1700	1.8
2.	100	1500	1.8
3.	200	1300	1.8
4.	100	350	1.8

SITE VARIABLES

U = 1.0 m/s
BRG = WORST
CLAS = 6 (F)
Z0 = 50 cm
SIGTH = 17.5°
VS,VD = 0 cm/s
AMB = 3.0 ppm
MIXH = 1000 m
TEMP = 15° C

LINK VARIABLES

TYPE = 1 (AG)
VPH L = 8500
EF L = 30 g/mi
H L = 0 m
W L = 28 m

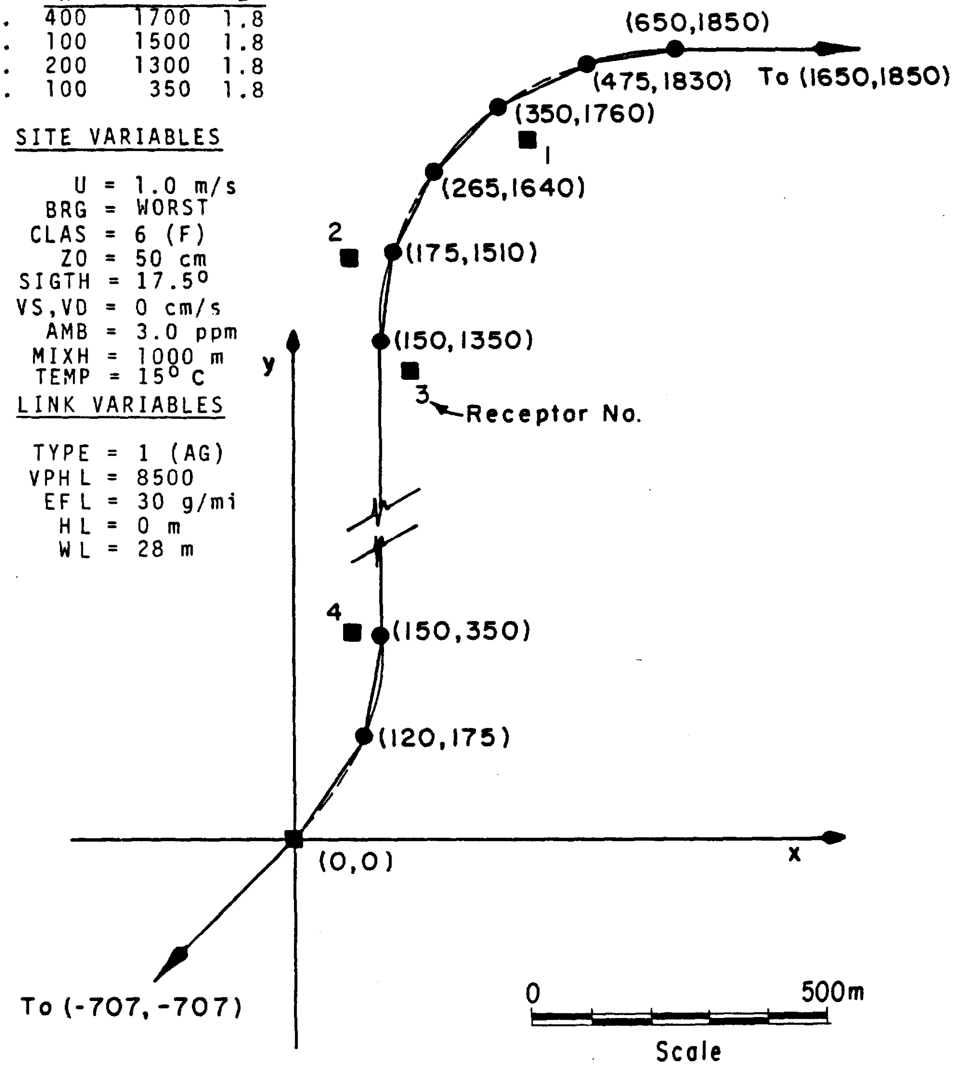


FIGURE 59

EXHIBIT 5

```
EXAMPLE TWO RURAL CURVED ALIGNMENT
1CO
50. 28.  0. 0. 4 10 1. 0 0 0
400. 1700. 1.8
100. 1500. 1.8
200. 1300. 1.8
100.  350. 1.8
1  -707. -707.  0.  0.  0.  28.  0.  0.  1
1   120.  175.  0. 28.  0.   0.  1
1   150.  350.  0. 28.  0.   0.  1
1   150. 1350.  0. 28.  0.   0.  1
1   175. 1510.  0. 28.  0.   0.  1
1   265. 1640.  0. 28.  0.   0.  1
1   350. 1760.  0. 28.  0.   0.  1
1   475. 1830.  0. 28.  0.   0.  1
1   650. 1830.  0. 28.  0.   0.  1
1  1650. 1850.  0. 28.  0.   0.  1
31101WORST CASE
   8500. 8500. 8500. 8500. 8500.
   8500. 8500. 8500. 8500. 8500.
   30.0  30.0  30.0  30.0  30.0
   30.0  30.0  30.0  30.0  30.0
   0.   1.0   6   1000. 17.5   3.0  15.0
20001HOUR 1
  50.   0.5   7   1000. 17.5   3.0   5.0
20001HOUR 2
  45.   0.5   6   1000. 25.0   3.0   5.0
20001HOUR 3
  45.   1.0   6   1000. 15.0   3.0  12.5
20001HOUR 4
  30.   1.5   5   1000. 15.0   3.0  12.5
20001HOUR 5
  30.   2.5   4   1000. 15.0   3.0  12.5
20001HOUR 6
  30.   2.5   4   1000. 30.0   3.0  20.0
20001HOUR 7
  90.   2.5   4   1000. 30.0   3.0  20.0
20001HOUR 8
  90.   2.5   4   1000. 10.0   3.0  20.0
            1000. 15.0  3.0   12.5
```

EXHIBIT 6

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
JUNE 1989 VERSION
PAGE 1

JOB: EXAMPLE TWO: RURAL CURVED ALIGNMENT
RUN: WORST CASE (WORST CASE ANGLE)
POLLUTANT: CO

I. SITE VARIABLES

U= 1.0 M/S	Z0= 50. CM	ALT= 0. (M)
BRG= WORST CASE	VD= 0.0 CM/S	
CLAS= 6 (F)	VS= 0.0 CM/S	
MIXH= 1000. M	AMB= 3.0 PPM	
SIGTH= 18. DEGREES	TEMP= 15.0 DEGREE (C)	

II. LINK VARIABLES

LINK DESCRIPTION	*	LINK COORDINATES (M) X1	Y1	X2	Y2	*	TYPE	VPH	EF (G/MI)	H (M)	W (M)
A. LINK A	*	-707	-707	0	0	*	AG	8500	30.0	0.0	28.0
B. LINK B	*	0	0	120	175	*	AG	8500	30.0	0.0	28.0
C. LINK C	*	120	175	150	350	*	AG	8500	30.0	0.0	28.0
D. LINK D	*	150	350	150	1350	*	AG	8500	30.0	0.0	28.0
E. LINK E	*	150	1350	175	1510	*	AG	8500	30.0	0.0	28.0
F. LINK F	*	175	1510	265	1640	*	AG	8500	30.0	0.0	28.0
G. LINK G	*	265	1640	350	1760	*	AG	8500	30.0	0.0	28.0
H. LINK H	*	350	1760	475	1830	*	AG	8500	30.0	0.0	28.0
I. LINK I	*	475	1830	650	1830	*	AG	8500	30.0	0.0	28.0
J. LINK J	*	650	1830	1650	1850	*	AG	8500	30.0	0.0	28.0

III. RECEPTOR LOCATIONS

RECEPTOR	*	COORDINATES (M) X	Y	Z
1. RECPT 1	*	400	1700	1.8
2. RECPT 2	*	100	1500	1.8
3. RECPT 3	*	200	1300	1.8
4. RECPT 4	*	100	350	1.8

EXHIBIT 6 (CONT.)

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
JUNE 1989 VERSION
PAGE 2

JOB: EXAMPLE TWO: RURAL CURVED ALIGNMENT
RUN: WORST CASE (WORST CASE ANGLE)
POLLUTANT: CO

IV. MODEL RESULTS (WORST CASE WIND ANGLE)

RECEPTOR	BRG (DEG)	PRED CONC (PPM)	CONC/LINK (PPM) A	B	C	D	E	F	G	H
1. RECPT 1	250.	6.1	0.0	0.0	0.0	0.0	0.0	1.1	2.0	0.0
2. RECPT 2	61.	8.2	0.0	0.0	0.0	0.0	0.1	3.2	0.4	0.1
3. RECPT 3	196.	8.1	0.6	0.1	0.1	4.3	0.0	0.0	0.0	0.0
4. RECPT 4	18.	8.1	0.0	0.0	0.0	4.4	0.0	0.1	0.1	0.1

RECEPTOR	CONC/LINK (PPM) I	J
1. RECPT 1	0.0	0.0
2. RECPT 2	0.4	0.9
3. RECPT 3	0.0	0.0
4. RECPT 4	0.2	0.3

EXHIBIT 7

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
JUNE 1989 VERSION
PAGE 3

JOB: EXAMPLE TWO: RURAL CURVED ALIGNMENT
RUN: (MULTI-RUN)
POLLUTANT: CO

I. SITE VARIABLES

VD= 0.0 CM/S   Z0= 50. CM   ALT= 0. (M)
VS= 0.0 CM/S

II. METEOROLOGICAL CONDITIONS

RUN	U (M/S)	BRG (DEG)	CLASS	AMB (PPM)	MIXH (M)	SIGTH (DEG)	TEMP (C)
1. HOUR 1	0.5	50.	7 (G)	3.0	1000.	25.00	5.0
2. HOUR 2	0.5	45.	6 (F)	3.0	1000.	25.00	5.0
3. HOUR 3	1.0	45.	6 (F)	3.0	1000.	15.00	12.5
4. HOUR 4	1.5	30.	5 (E)	3.0	1000.	15.00	12.5
5. HOUR 5	2.5	30.	4 (D)	3.0	1000.	15.00	12.5
6. HOUR 6	2.5	30.	4 (D)	3.0	1000.	30.00	20.0
7. HOUR 7	2.5	90.	4 (D)	3.0	1000.	30.00	20.0
8. HOUR 8	2.5	90.	4 (D)	3.0	1000.	10.00	20.0

III. LINK GEOMETRY

LINK DESCRIPTION	X1	Y1	X2	Y2	TYPE	H (M)	W (M)
A. LINK A	-707	-707	0	0	AG	0.0	28.0
B. LINK B	0	0	120	175	AG	0.0	28.0
C. LINK C	120	175	150	350	AG	0.0	28.0
D. LINK D	150	350	150	1350	AG	0.0	28.0
E. LINK E	150	1350	175	1510	AG	0.0	28.0
F. LINK F	175	1510	265	1640	AG	0.0	28.0
G. LINK G	265	1640	350	1760	AG	0.0	28.0
H. LINK H	350	1760	475	1830	AG	0.0	28.0
I. LINK I	475	1830	650	1830	AG	0.0	28.0
J. LINK J	650	1830	1650	1850	AG	0.0	28.0

(LINK COORDINATES (M): X1, Y1, X2, Y2)

EXHIBIT 7 (CONT.)

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
JUNE 1989 VERSION
PAGE 4

JOB: EXAMPLE TWO: RURAL CURVED ALIGNMENT
RUN: (MULTI-RUN)
POLLUTANT: CO

IV. EMISSIONS AND VEHICLE VOLUMES

RUN		LINK A	B	C	D	E	F	G	H	I	J
1	VPH	8500	8500	8500	8500	8500	8500	8500	8500	8500	8500
	EF	30.	30.	30.	30.	30.	30.	30.	30.	30.	30.
2	VPH	8500	8500	8500	8500	8500	8500	8500	8500	8500	8500
	EF	30.	30.	30.	30.	30.	30.	30.	30.	30.	30.
3	VPH	8500	8500	8500	8500	8500	8500	8500	8500	8500	8500
	EF	30.	30.	30.	30.	30.	30.	30.	30.	30.	30.
4	VPH	8500	8500	8500	8500	8500	8500	8500	8500	8500	8500
	EF	30.	30.	30.	30.	30.	30.	30.	30.	30.	30.
5	VPH	8500	8500	8500	8500	8500	8500	8500	8500	8500	8500
	EF	30.	30.	30.	30.	30.	30.	30.	30.	30.	30.
6	VPH	8500	8500	8500	8500	8500	8500	8500	8500	8500	8500
	EF	30.	30.	30.	30.	30.	30.	30.	30.	30.	30.
7	VPH	8500	8500	8500	8500	8500	8500	8500	8500	8500	8500
	EF	30.	30.	30.	30.	30.	30.	30.	30.	30.	30.
8	VPH	8500	8500	8500	8500	8500	8500	8500	8500	8500	8500
	EF	30.	30.	30.	30.	30.	30.	30.	30.	30.	30.

V. RECEPTOR LOCATIONS AND MULTI-RUN AVERAGE CONCENTRATIONS

RECEPTOR	COORDINATES (M) X	Y	Z	AVG (PPM)
1. RECPT 1	400	1700	1.8	4.7
2. RECPT 2	100	1500	1.8	5.3
3. RECPT 3	200	1300	1.8	3.7
4. RECPT 4	100	350	1.8	6.5

The results for the first run, summarized in Exhibit 6, indicate that the worst-case wind angle has been selected (BRG=WORST CASE). The actual worst-case wind angles are listed in the model results output block.

The multi-run requires information for each time period covered. The example given here is for an 8-hour average. Since only the meteorological variables are varying from hour-to-hour, information for traffic volumes and emission factors need not be repeated (i.e., VPHCOD=0 and EFLCOD=0). For the last hour of the multi-run, RTYP=9. Without this "flag" value, the model will expect to see an additional time period. An end-of-file error will result if no data is available to be read.

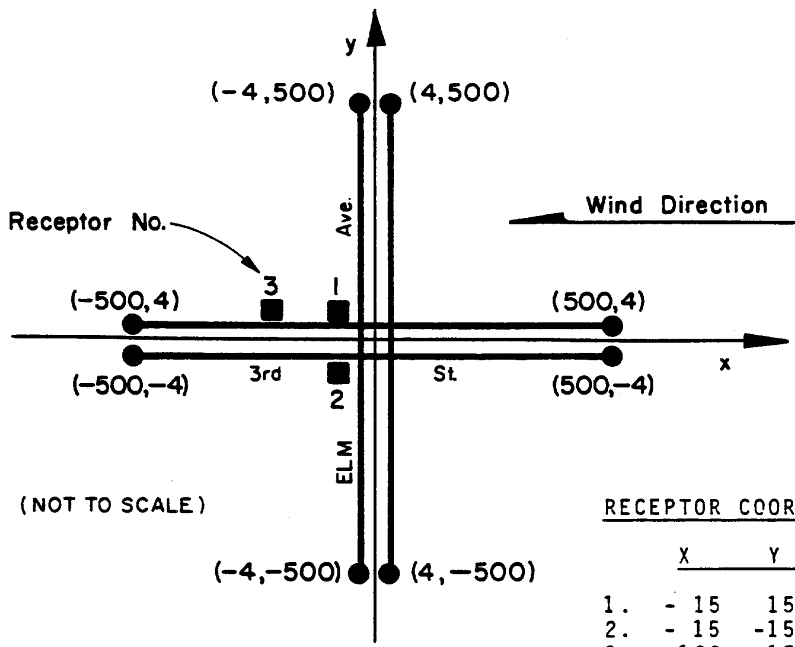
The multi-run output is listed on two pages (Exhibit 7). A table showing the meteorological conditions for each time period is listed in output Block II. Block IV gives the emission factors and vehicle volumes by the time period and link. The overall average concentrations for each receptor are listed along with the receptor coordinates in Block V.

The multi-run may be used with a variety of other options including worst-case wind angle, intersection link and the NOx option.

9.3.3 Example 3: Urban Intersection

An example of a typical urban intersection is given in Figure 60. For convenience, identical traffic parameters were used for all four links. The model is actually cap- able of handling a mix of traffic parameters. The input

EXAMPLE 3: URBAN INTERSECTION



RECEPTOR COORDINATES

	X	Y	Z
1.	- 15	15	1.8
2.	- 15	-15	5.0
3.	-100	15	1.8

LINK VARIABLES

LNK	VPHL (VPHI)	VPHO	EFL (g/mi)	EFI (g/min)	STPL (m)	HL (m)	WL (m)	NCYC	NDLA
3rd St. (WB)	2500	3000	45	7.5	490	0	14	25	15
3rd St. (EB)	1500	1250	45	7.5	490	0	14	15	10
Elm Ave. (NB)	1250	1250	35	5.0	490	0	14	12	8
Elm Ave. (SB)	1000	750	35	5.0	490	0	14	10	6

TRAFFIC PARAMETERS (ALL LINKS)

SPD = 30 mph
DCLT = 15 s
ACCT = 12 s
IDT1 = 45 s
IDT2 = 0 s

SITE VARIABLES

U	= 1 m/s	Z0	= 100 cm
BRG	= 90^{o}	SIGTH	= 25^{o}
CLAS	= 6 (F)	VS,VD	= 0 cm/s
MIXH	= 1000 m	TEMP	= 10^{o} C
		AMB	= 5.0 ppm

FIGURE 60

file and output for a standard run using the Example 3 data are labeled as Exhibits 8 and 9, respectively. Link titles are assigned for the example, but default titles are used for the receptors. In addition to the normal link inputs, intersection information (STPL, DCLT, ACCT and SPD) is listed for each intersection link as record 8 of the input file format. Also, intersection variables related to the run are specified for each link (record 12 format). The program automatically looks for this information for each intersection link because INTCOD=1.

The output (Exhibit 9) is identical to the previous standard run examples, with the exception that the contribution by link to the total predicted concentration is summarized in output Block IV. The model will do this for the standard run when there is more than one link and the worst-case wind angle option is not used. The additional link information required for the intersection option is listed in the output block II (link variables).

A second application of CALINE4 to Example 3 is given in Exhibits 10 and 11. In this instance, one of the streets (3rd Street) is designated as a street canyon by assigning values for MIXWR and MIXWL. The user must remember that the right (MIXWR) and the left (MIXWL) designations are determined facing link endpoint 2, and the traffic on intersection links is always assumed to proceed from link endpoint 1 to endpoint 2.

The input file contains specifications for a 34 meter wide canyon centered on 3rd Street. The wind angle is parallel to the 3rd Street links. Elm Avenue is modeled as two

EXHIBIT 8

```
EXAMPLE THREE URBAN INTERSECTION
lCO
100. 28. 0. 0. 3 4 1.1 0 0
-15.  15. 1.8
-15. -15. 5.0
-100. 15. 1.8
3RD ST.- WB
3RD ST.- EB
ELM AVE.- NB
ELM AVE.- SB
6  500.  4. -500. 4. 0.  14. 0. 0. 0.
490. 15. 12. 30.
6  -500. -4.   500.  -4. 0.  14.   0.    0.    0.
490. 15. 12. 30.
6   4.  -500.  4.   500.   0. 14. 0.    0.    0.
490. 15. 12. 30.
6   -4. 500. -4. -500.  0.  14.  0.  0.  0.
11111STANDARD RUN
2500. 1500. 1250. 1000.
45. 45. 35. 35.
25 15 3000. 7.5 45 0.
15 10 1250. 7.5 45. 0.
12  8 1250. 5.0 45. 0.
10  6  750. 5.0 45. 0.
90. 1.0 6 1000. 25.  5.0 10.0
```

EXHIBIT 9

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
JUNE 1989 VERSION
PAGE 1

JOB: EXAMPLE THREE: URBAN INTERSECTION
RUN: STANDARD RUN
POLLUTANT: CO

I. SITE VARIABLES

U= 1.0 M/S	Z0= 100. CM	ALT= 0. (M)
BRG= 90.0 DEGREES	VD= 0.0 CM/S	
CLAS= 6 (F)	VS= 0.0 CM/S	
MIXH= 1000. M	AMB= 5.0 PPM	
SIGTH= 25. DEGREES	TEMP= 10.0 DEGREE (C)	

II. LINK VARIABLES

LINK DESCRIPTION	*	LINK COORDINATES (M) X1	Y1	X2	Y2	*	TYPE	VPH	EF (G/MI)	H (M)	W (M)
A. 3RD ST.- WB	*	500	4	-500	4	*	IN	2500	45.0	0.0	14.0
B. 3RD ST.- EB	*	-500	-4	500	-4	*	IN	1500	45.0	0.0	14.0
C. ELM AVE.- NB	*	4	-500	4	500	*	IN	1250	35.0	0.0	14.0
D. ELM AVE.- SB	*	-4	500	-4	-500	*	IN	1000	35.0	0.0	14.0

LINK	*	MIXW L (M)	MIXW R (M)	STPL (M)	DCLT (SEC)	ACCT (SEC)	SPD (MPH)	NCYC	NDLA	VPHO	EFI (G/MIN)	IDT1 (SEC)	IDT2 (SEC)
A.	*	0.	0.	490	15.	12.	30.	25	15	3000	7.50	45.	0.
B.	*	0.	0.	490	15.	12.	30.	15	10	1250	7.50	45.	0.
C.	*	0.	0.	490	15.	12.	30.	12	8	1250	5.00	45.	0.
D.	*	0.	0.	490	15.	12.	30.	10	6	750	5.00	45.	0.

III. RECEPTOR LOCATIONS

RECEPTOR	*	COORDINATES (M) X	Y	Z
1. RECPT 1	*	-15	15	1.8
2. RECPT 2	*	-15	-15	5.0
3. RECPT 3	*	-100	15	1.8

EXHIBIT 9 (CONT.)

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
JUNE 1989 VERSION
PAGE 2

JOB: EXAMPLE THREE: URBAN INTERSECTION
RUN: STANDARD RUN
POLLUTANT: CO

IV. MODEL RESULTS (PRED. CONC. INCLUDES AMB.)

RECEPTOR	* PRED CONC (PPM) *	CONC/LINK (PPM) A	B	C	D
1. RECPT 1	21.3	7.7	0.8	1.9	5.9
2. RECPT 2	13.4	3.7	1.4	2.8	0.5
3. RECPT 3	13.7	3.8	3.0	0.9	1.0

<u>EXHIBIT 10</u>

```
EXAMPLE THREE: URBAN INTERSECTION
lCO
100. 28. 0. 0. 3 4 1. 1 0 0
-15. 15. 1.8
-15. -15. 5.0
-100. 15. 1.8
3RD ST.- WB
3RD ST.- EB
ELM AVE.- NB
ELM AVE.- SB
6   500. 4. -500. 4. 0. 14. 15. 19. 0
490. 15. 12. 30.
6  -500. -4. 500. -4. 0. 14. 15. 19. 0
490. 15. 12. 30.
6  4. -500. 4. 500. 0. 14. 0. 0. 0
490. 15. 12. 30.
6  -4. 500. ~4. -500. 00 14. 0. 0. 0
490. 15. 12. 30.
lllllST. CANYON
2500. 1500. 1250. 1000.
45. 45. 35. 35.
25 15  3000.  7.5  45.  0.
15 10  1250.  7.5  45.  0.
12  8  1250.  5.0  45.  0.
10  6   750.  5.0  45.  0.
90. 1.0  6  1000.  25.  5.0  10.0
```

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EXHIBIT 11

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
JUNE 1989 VERSION
PAGE 1

JOB: EXAMPLE THREE: URBAN INTERSECTION
RUN: ST. CANYON
POLLUTANT: CO

I. SITE VARIABLES

U= 1.0 M/S	Z0= 100. CM	ALT= 0. (M)
BRG= 90.0 DEGREES	VD= 0.0 CM/S	
CLAS= 6 (F)	VS= 0.0 CM/S	
MIXH= 1000. M	AMB= 5.0 PPM	
SIGTH= 25. DEGREES	TEMP= 10.0 DEGREE (C)	

II. LINK VARIABLES

LINK DESCRIPTION	*	X1	Y1	X2	Y2	*	TYPE	VPH	EF (G/MI)	H (M)	W (M)
	*	LINK COORDINATES (M)				*					
A. 3RD ST.- WB	*	500	4	-500	4	*	IN	2500	45.0	0.0	14.0
B. 3RD ST.- EB	*	-500	-4	500	-4	*	IN	1500	45.0	0.0	14.0
C. ELM AVE.- NB	*	4	-500	4	500	*	IN	1250	35.0	0.0	14.0
D. ELM AVE.- SB	*	-4	500	-4	-500	*	IN	1000	35.0	0.0	14.0

LINK	*	MIXW L (M)	MIXW R (M)	STPL (M)	DCLT (SEC)	ACCT (SEC)	SPD (MPH)	NCYC	NDLA	VPHO	EFI (G/MIN)	IDT1 (SEC)	IDT2 (SEC)
A.	*	19.	15.	490	15.	12.	30.	25	15	3000	7.50	45.	0.
B.	*	19.	15.	490	15.	12.	30.	15	10	1250	7.50	45.	0.
C.	*	0.	0.	490	15.	12.	30.	12	8	1250	5.00	45.	0.
D.	*	0.	0.	490	15.	12.	30.	10	6	750	5.00	45.	0.

III. RECEPTOR LOCATIONS

RECEPTOR	*	COORDINATES (M) X	Y	Z
1. RECPT 1	*	-15	15	1.8
2. RECPT 2	*	-15	-15	5.0
3. RECPT 3	*	-100	15	1.8

EXHIBIT 11 (CONT.)

```
CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
         JUNE 1989 VERSION
         PAGE   2

     JOB: EXAMPLE THREE: URBAN INTERSECTION
     RUN: ST. CANYON
POLLUTANT: CO

IV.  MODEL RESULTS (PRED. CONC. INCLUDES AMB.)

              * PRED  *       CONC/LINK
              * CONC  *         (PPM)
 RECEPTOR     * (PPM) *   A     B     C     D
--------------*-------*--------------------
1. RECPT   1  *  26.3 * 11.4   2.1   1.9   5.9
2. RECPT   2  *  21.7 * 10.9   2.5   2.8   0.5
3. RECPT   3  *  22.2 *  8.3   6.9   0.9   1.0
```

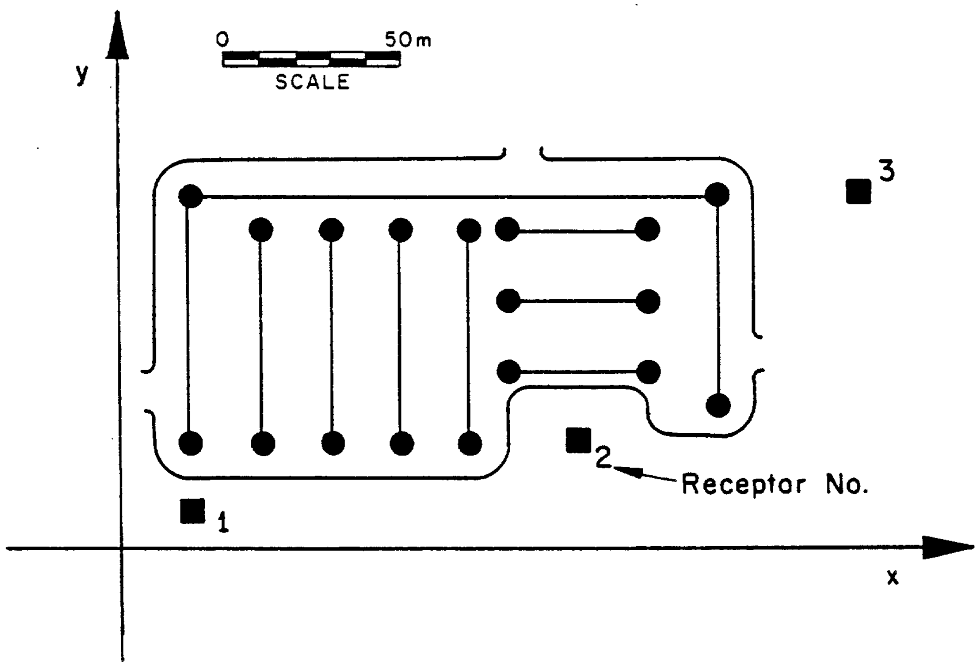
links under crosswind conditions without mixing width restrictions. While Elm Avenue may also be a street canyon, the model will only see that part of the avenue that is contributing to the 3rd Street parallel wind condition because of the crosswind orientation. This method, used when applying CALINE4 to street canyons, is only applicable to low wind speed conditions and channeled flow.

The output (Exhibit 11) illustrates the significantly higher concentrations that can be expected in a street canyon configuration.

9.3.4 Example 4: Parking Lot

An example of a parking lot modeled as a series of short CALINE4 links is given in Figure 61. The link widths do not include the usual six meter augmentation because the vehicle wakes are not well developed in the parking lot. The emission factor is unusually high because of the large component of transient emissions (cold and hot-starts) released in the lot. For this example, the egress time was estimated at 120 seconds. This means that approximately 56; of the transient emissions will occur in the lot (Equation 6-16, f_r = 120/505 seconds). The lot contains 350 parking stalls and is assumed to be filled to capacity at the start of the one-hour time period being considered. The lot is expected to empty completely during the hour, with 40% of the starts assumed to be cold and 60% hot. Given excess transient emissions of 150 gms/veh-start (cold) and 15 gms/veh-start (hot), a composite excess transient emission factor is computed as follows:

EXAMPLE 4: PARKING LOT



LINK VARIABLES
(ALL LINKS)

TYP = 5 (PK)
VPHL = 73
EFL = 530 (g/mi)
HL = 0 m
WL = 4 m

(See Output for
Link Coordinates)

SITE VARIABLES

U = 0.5 m/s
BRG = WORST
CLAS = 5 (E)
Z0 = 50 cm
SIGTH = 35°
VS,VD = 0 cm/s
AMB = 3.0 ppm
MIXH = 100 m
TEMP = 7.5° C

RECEPTOR COORDINATES

	X	Y	Z
1.	20	10	1.5
2.	130	30	1.5
3.	210	100	1.5

FIGURE 61

E_{tr} = (150 gms/veh)(0.4)+(15 gms/veh)(0.6)
= 69 gms/veh-start.

Equation 6-20 is then used to compute the link emission factor. Running emissions at 5 mph of 35 gms/veh-mi are assumed. The average distance traveled at 5 mph over 120 seconds (minus 60 seconds for warm-up, back-up and exit queue) is 134 meters (0.083 mile). The resulting emission factor is approximately 530 gms/veh-mi. Transient emissions account for 87% of this figure!

The input file (Exhibit 12) is set-up for RTYP=3 (worst- case wind angle search). Note that the parking lot link type is specified (TYP=5). The continuation code is used for several of the contiguous links. Also, 100 meters is assigned for the mixing height. This will automatically engage the mixing height algorithm.

The output (Exhibit 13) is similar to previous worst-case wind angle runs. Note that the traffic volume and emission factor are identical for all links. This is attributable to the method used to compute the emission factor. The emission factor represents the lump sum emissions per vehicle distributed over the average distance traveled by vehicles leaving the parking lot. The traffic volume per link is determined by multiplying the ratio of the average distance traveled to the total link length (134m/640m in this example) by the total number of vehicles leaving the parking lot per hour (350 in this example). The resulting volume of 73 vph is used on each of the links. When multi- plied in the model by 530 gms/veh-mi, this traffic volume will yield a uniform distribution of the emissions over all the links.

EXHIBIT 12

```
EXAMPLE FOUR: PARKING LOT
1CO
50. 28. 0. 0. 3 10 1. 0 0 0 0
20. 10. 1.5
130. 30. 1.5
210 100 1.5
5   20.  30.  20. 100.  0.  4.  0.  0.  1
5  170. 100.   0.   4.  0.  0.  1
5  170.  40.   0.   4.  0.  0.  0
5   40.  30.  40.  90.  0.  4.  0.  0.  0
5   60.  30.  60.  90.  0.  4.  0.  0.  0
5   80.  30.  80.  90.  0.  4.  0.  0.  0
5  100.  30. 100.  90.  0.  4.  0.  0.  0
5  110.  90. 150.  90.  0.  4.  0.  0.  0
5  110.  70. 150.  70.  0.  4.  0.  0.  0
5  110.  50. 150.  50.  0.  4.  0.  0.  0
31101WORST BRG
  73.  73.  73.  73.  73.
  73.  73.  73.  73.  73.
 530. 530. 530. 530. 530.
 530. 530. 530. 530. 530.
 0.  0.5  5  100.  35.0  3.0  7.5
```

EXHIBIT 13

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
JUNE 1989 VERSION
PAGE 1

JOB: EXAMPLE FOUR: PARKING LOT
RUN: WORST BRG (WORST CASE ANGLE)
POLLUTANT: CO

I. SITE VARIABLES

U= 0.5 M/S
BRG= WORST CASE
CLAS= 5 (E)
MIXH= 100. M
SIGTH= 35. DEGREES

ZO= 50. CM
VD= 0.0 CM/S
VS= 0.0 CM/S
AMB= 3.0 PPM
TEMP= 7.5 DEGREE (C)

ALT= 0. (M)

II. LINK VARIABLES

LINK DESCRIPTION	LINK COORDINATES (M) X1	Y1	X2	Y2	TYPE	VPH	EF (G/MI)	H (M)	W (M)
A. LINK A	20	30	20	100	PK	73	530.0	0.0	4.0
B. LINK B	20	100	170	100	PK	73	530.0	0.0	4.0
C. LINK C	170	100	170	40	PK	73	530.0	0.0	4.0
D. LINK D	40	30	40	90	PK	73	530.0	0.0	4.0
E. LINK E	60	30	60	90	PK	73	530.0	0.0	4.0
F. LINK F	80	30	80	90	PK	73	530.0	0.0	4.0
G. LINK G	100	30	100	90	PK	73	530.0	0.0	4.0
H. LINK H	110	90	150	90	PK	73	530.0	0.0	4.0
I. LINK I	110	70	150	70	PK	73	530.0	0.0	4.0
J. LINK J	110	50	150	50	PK	73	530.0	0.0	4.0

III. RECEPTOR LOCATIONS

RECEPTOR	COORDINATES (M) X	Y	Z
1. RECPT 1	20	10	1.5
2. RECPT 2	130	30	1.5
3. RECPT 3	210	100	1.5

EXHIBIT 13 (CONT.)

```
CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
         JUNE 1989 VERSION
         PAGE   2

     JOB: EXAMPLE FOUR: PARKING LOT
     RUN: WORST BRG         (WORST CASE ANGLE)
POLLUTANT: CO
```

IV. MODEL RESULTS (WORST CASE WIND ANGLE)

RECEPTOR	BRG (DEG)	PRED CONC (PPM)	CONC/LINK (PPM) A	B	C	D	E	F	G	H
1. RECPT 1	39.	8.3	0.6	0.8	0.1	1.4	1.0	0.6	0.4	0.2
2. RECPT 2	317.	8.8	0.2	0.9	0.0	0.2	0.4	0.8	1.5	0.1
3. RECPT 3	256.	7.9	0.2	1.3	0.9	0.2	0.3	0.3	0.4	0.5

RECEPTOR	CONC/LINK (PPM) I	J
1. RECPT 1	0.2	0.1
2. RECPT 2	0.3	1.3
3. RECPT 3	0.5	0.3

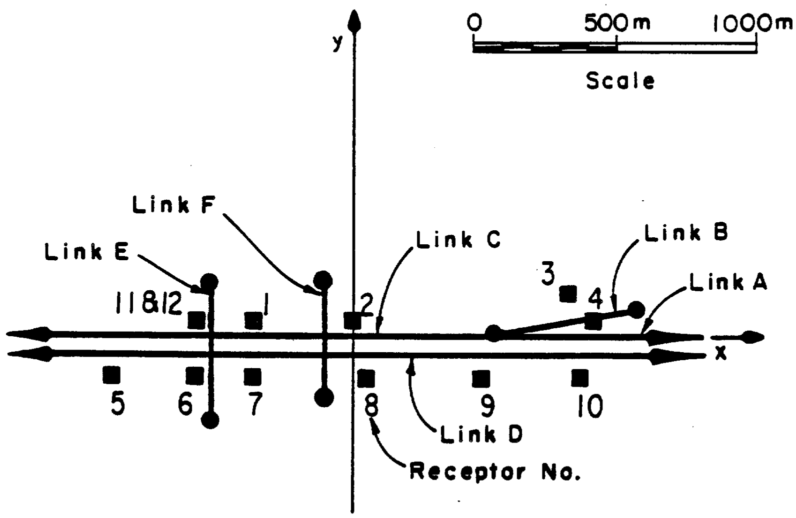
9.3.5 Example 5: Urban Freeway

Example 5 consists of a depressed urban freeway with multiple links and receptors (Figure 62). The on-ramp link (link B) is assigned a significantly higher emission factor than the other links. The higher emission rate accounts for the vehicle accelerations on link B. The method described in Section 6.2 can be used to generate this type of modal emission factor. For on-ramp applications with accelerations from "at rest" condition to freeway speeds, the ramp and merge segments should normally be modeled as two links: One representing the "at rest" modal emissions model (Equation 6-2) and the other representing the "moving" model (Equation 6-3). In the case of this example, the ramp has a negative grade. An adjustment to the acceleration-speed product can be made to account for the less strenuous downhill acceleration (Section 6.2). The value used in the example was not arrived at rigorously, however, but was simply chosen to point out the difference between ramp emissions and emissions from other types of links.

The input file for Example 5 is given in Exhibit 14. A worst-case wind angle run type is indicated. The depressed section link type (TYPE=2) is assigned for four of the six links. The output is shown in Exhibit 15.

A second job file was created for Example 5 for prediction of NO_2 concentrations (Exhibit 16). Note the changed values for PTYP and MOWT (2 and 46, respectively). Again,

EXAMPLE 5 URBAN FREEWAY



LINK VARIABLES

	X_1 (m)	Y_1 (m)	X_2 (m)	Y_2 (m)	TYP	VPHL	EFL (g/mi)	HL (m)	WL (m)
LINK A	500	0	3000	0	2(DP)	9700	30	-8	23
" B	500	0	1000	100	2(DP)	1200	150	-4	13
" C	-3000	0	500	0	2(DP)	10900	30	-8	23
" D	-3000	-75	3000	-75	2(DP)	9300	30	-8	23
" E	-500	200	-500	-300	1(AG)	4000	50	0	27
" F	-100	200	-100	-200	1(AG)	5000	50	0	27

SITE VARIABLES

U = 1 m/s
BRG = WORST
CLAS = 6 (F)
Z0 = 100 cm
SIGTH = 25°
VS,VD = 0 cm/s
AMB = 5.0 ppm
MIXH = 1000 m
TEMP = 15° C

RECEPTOR COORDINATES

(See Output)

FIGURE 62

EXHIBIT 14

```
EXAMPLE FIVE: URBAN FREEWAY (CO)
1CO
 100.    28.  0.  0.  12  6  1. 0  0  0
-350.    30.  1.8
   0.    30.  1.8
 750.   100.  1.8
 850.    30.  1.8
-850.  -100.  1.8
-550.  -100.  1.8
-350.  -100.  1.8
  50.  -100.  1.8
 450.  -100.  1.8
 800.  -100.  1.8
-550.    25.  1.8
-550.    25.  6.1
2   500.   0. 3000.    0. -8. 23. 0. 0. 0
2   500.   0. 1000.  100. -4. 13. 0. 0. 0
2 -3000.   0.  500.    0. -8. 23. 0. 0. 0
2 -3000. -75. 3000.  -75. -8. 23. 0. 0. 0
1  -500. 200. -500. -300.  0. 27. 0. 0. 0
1  -100. 200. -100. -200.  0. 27. 0. 0. 0
31101WORST CO
9700. 1200. 10900. 9300. 4000.
  30.  150.    30.   30.   50.  50.
0.  1.0  6  1000.  25.0  5.0  15.0
```

EXHIBIT 15

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
JUNE 1989 VERSION
PAGE 1

JOB: EXAMPLE FIVE: URBAN FREEWAY (CO)
RUN: WORST CO (WORST CASE ANGLE)
POLLUTANT: CO

I. SITE VARIABLES

U= 1.0 M/S	Z0= 100. CM	ALT= 0. (M)
BRG= WORST CASE	VD= 0.0 CM/S	
CLAS= 6 (F)	VS= 0.0 CM/S	
MIXH= 1000. M	AMB= 5.0 PPM	
SIGTH= 25. DEGREES	TEMP= 15.0 DEGREE (C)	

II. LINK VARIABLES

LINK DESCRIPTION	LINK COORDINATES (M) X1	Y1	X2	Y2	TYPE	VPH	EF (G/MI)	H (M)	W (M)
A. LINK A	500	0	3000	0	DP	9700	30.0	-8.0	23.0
B. LINK B	500	0	1000	100	DP	1200	150.0	-4.0	13.0
C. LINK C	-3000	0	500	0	DP	10900	30.0	-8.0	23.0
D. LINK D	-3000	-75	3000	-75	DP	9300	30.0	-8.0	23.0
E. LINK E	-500	200	-500	-300	AG	4000	50.0	0.0	27.0
F. LINK F	-100	200	-100	-200	AG	5000	50.0	0.0	27.0

III. RECEPTOR LOCATIONS

RECEPTOR	COORDINATES (M) X	Y	Z
1. RECPT 1	-350	30	1.8
2. RECPT 2	0	30	1.8
3. RECPT 3	750	100	1.8
4. RECPT 4	850	30	1.8
5. RECPT 5	-850	-100	1.8
6. RECPT 6	-550	-100	1.8
7. RECPT 7	-350	-100	1.8
8. RECPT 8	50	-100	1.8
9. RECPT 9	450	-100	1.8
10. RECPT 10	800	-100	1.8
11. RECPT 11	-550	25	1.8
12. RECPT 12	-550	25	6.1

EXHIBIT 15 (CONT.)

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
JUNE 1989 VERSION
PAGE 2

JOB: EXAMPLE FIVE: URBAN FREEWAY (CO)
RUN: WORST CO (WORST CASE ANGLE)
POLLUTANT: CO

IV. MODEL RESULTS (WORST CASE WIND ANGLE)

RECEPTOR	BRG (DEG)	PRED CONC (PPM)	CONC/LINK (PPM) A	B	C	D	E	F
1. RECPT 1	107.	15.1	0.6	0.2	6.3	1.8	0.0	1.3
2. RECPT 2	252.	16.7	0.0	0.0	6.9	1.8	0.8	2.3
3. RECPT 3	247.	10.5	0.8	1.6	1.2	1.4	0.2	0.3
4. RECPT 4	262.	15.2	4.1	1.7	2.2	1.5	0.3	0.4
5. RECPT 5	74.	17.9	0.3	0.2	1.8	9.2	0.9	0.5
6. RECPT 6	73.	20.3	0.4	0.2	1.7	9.2	2.9	1.0
7. RECPT 7	73.	17.8	0.4	0.3	1.6	9.1	0.0	1.4
8. RECPT 8	287.	18.7	0.0	0.0	2.1	9.1	0.7	1.8
9. RECPT 9	286.	17.4	0.0	0.0	2.1	9.2	0.3	0.8
10. RECPT 10	287.	17.5	0.7	0.6	1.4	9.2	0.2	0.4
11. RECPT 11	106.	21.3	0.7	0.1	9.9	1.8	2.9	0.8
12. RECPT 12	105.	20.2	0.8	0.2	9.5	1.8	2.2	0.8

<u>EXHIBIT 16</u>

```
EXAMPLE FIVE: URBAN FREEWAY (N02)
2N02
100.  46.  0.   0.  12  6 1.  0  0  0
-350.     30.  1.8
   0.     30.  1.8
 750.    100.  1.8
 850.     30.  1.8
-850.   -100.  1.8
-550.   -100.  1.8
-350.   -100.  1.8
  50.   -100.  1.8
 450.   -100.  1.8
 800.   -100.  1.8
-550.     25.  1.8
-550.     25.  6.1
2    500.    0.  3000.    0.  -8.  23.  0.  0.  0
2    500.    0.  1000.  100.  -4.  13.  0.  0.  0
2  -3000.    0.   500.    0.  -8.  23.  0.  0.  0
2  -3000.  -75.  3000.  -75.  -8.  23.  0.  0.  0
1   -500.  200.  -500. -300.   0.  27.  0.  0.  0
1   -100.  200.  -100. -200.   0.  27.  0.  0.  0
31101WORST N02
9700.  1200.  10900.  9300.  4000.  5000
1.0  1.0  1.0  1.0  1.0  1.0
0. 1.0  6  1000.  25.0  15.0  0.2  0.02  0.1  0.004
```

the worst-case wind angle run type was called for. The output is given in Exhibit 17. Little, if any, change occurred in the worst-case wind angles. Since the winds nearly parallel the primary links, caution should be used in interpreting the results (Section 8.3.3). Aside from the addition of the NO_x/O_3 ambient levels and the photolysis rate, the output is similar to previous examples.

EXHIBIT 17

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
JUNE 1989 VERSION
PAGE 1

JOB: EXAMPLE FIVE: URBAN FREEWAY (NO2)
RUN: WORST NO2 (WORST CASE ANGLE)
POLLUTANT: NO2

I. SITE VARIABLES

U= 1.0 M/S
BRG= WORST CASE
CLAS= 6 (F)
MIXH= 1000. M
SIGTH= 25. DEGREES

Z0= 100. CM
VD= 0.0 CM/S
VS= 0.0 CM/S
TEMP= 15.0 DEGREE (C)

ALT= 0. (M)

NOX VARIABLES

NO2= 0.10 PPM NO= 0.02 PPM O3= 0.20 PPM KR= 0.004 1/SEC

II. LINK VARIABLES

LINK DESCRIPTION	X1	Y1	X2	Y2	TYPE	VPH	EF (G/MI)	H (M)	W (M)
A. LINK A	500	0	3000	0	DP	9700	1.00	-8.0	23.0
B. LINK B	500	0	1000	100	DP	1200	1.00	-4.0	13.0
C. LINK C	-3000	0	500	0	DP	10900	1.00	-8.0	23.0
D. LINK D	-3000	-75	3000	-75	DP	9300	1.00	-8.0	23.0
E. LINK E	-500	200	-500	-300	AG	4000	1.00	0.0	27.0
F. LINK F	-100	200	-100	-200	AG	5000	1.00	0.0	27.0

III. RECEPTOR LOCATIONS

RECEPTOR	X	Y	Z
1. RECPT 1	-350	30	1.8
2. RECPT 2	0	30	1.8
3. RECPT 3	750	100	1.8
4. RECPT 4	850	30	1.8
5. RECPT 5	-850	-100	1.8
6. RECPT 6	-550	-100	1.8
7. RECPT 7	-350	-100	1.8
8. RECPT 8	50	-100	1.8
9. RECPT 9	450	-100	1.8
10. RECPT 10	800	-100	1.8
11. RECPT 11	-550	25	1.8
12. RECPT 12	-550	25	6.1

EXHIBIT 17 (CONT.)

CALINE4: CALIFORNIA LINE SOURCE DISPERSION MODEL
JUNE 1989 VERSION
PAGE 2

JOB: EXAMPLE FIVE: URBAN FREEWAY (NO2)
RUN: WORST NO2 (WORST CASE ANGLE)
POLLUTANT: NO2

IV. MODEL RESULTS (WORST CASE WIND ANGLE)

RECEPTOR	BRG (DEG)	PRED CONC (PPM)	CONC/LINK (PPM) A	B	C	D	E	F
1. RECPT 1	252.	0.26	0.00	0.00	0.10	0.03	0.02	0.00
2. RECPT 2	252.	0.28	0.00	0.00	0.10	0.03	0.01	0.03
3. RECPT 3	250.	0.17	0.01	0.01	0.02	0.02	0.00	0.01
4. RECPT 4	261.	0.25	0.07	0.01	0.03	0.03	0.00	0.01
5. RECPT 5	74.	0.31	0.00	0.00	0.03	0.15	0.02	0.01
6. RECPT 6	73.	0.34	0.01	0.00	0.03	0.15	0.04	0.01
7. RECPT 7	73.	0.31	0.01	0.00	0.02	0.15	0.00	0.02
8. RECPT 8	287.	0.32	0.00	0.00	0.03	0.15	0.01	0.03
9. RECPT 9	286.	0.30	0.00	0.00	0.03	0.15	0.01	0.01
10. RECPT 10	286.	0.30	0.01	0.00	0.02	0.15	0.00	0.01
11. RECPT 11	106.	0.35	0.01	0.00	0.15	0.03	0.04	0.01
12. RECPT 12	106.	0.33	0.01	0.00	0.14	0.03	0.03	0.01

REFERENCES

1. Beaton, J. L., et al, Mathematical Approach to Estimating Highway Impact on Air Quality, Federal Highway Administration, FHWA-RD-72-36, April 1972.

2. Ward, C. E., et al, CALINE2 - An Improved Microscale Model for the Diffusion of Air Pollutants from a Line Source, California Department of Transportation (Caltrans), CA-DOT-TL-7218-1-76-23, November 1976.

3. Bemis, G. R., et al, Air Pollution and Roadway Location, Design, and Operation - Project Overview, Caltrans, FHWA-CA-TL-7080-77-25, September 1977.

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

5. Dabberdt, W. F., Studies of Air Quality On and Near Highways, Interim Report, Contract DOT-FH-11 8125, Federal Highway Administration, 1975.

6. Benson, P.E., and Squires, B. T., Validation of the CALINE2 Model Using Other Data Bases, Caltrans, FHWA-CA-TL79-09, May 1979.

7. Noll, K. E., et al, A Comparison of Three Highway Line Source Dispersion Models, Atmospheric Environment, V. 12, pp 1323-1329, 1978.

8. Benson, P. E., CALINE3 - A Versatile Dispersion Model for Predicting Air Pollutant Levels Near Highways and Arterial Streets, Caltrans, FHWA/CA/TL-79/23, November 1979.

9. Benson, P. E., Background and Development of the CALINE3 Line Source Dispersion Model, Caltrans, FHWA/CA/TL-80/31, November 1980.

10. Abramowitz, M., Handbook of Mathematical Functions. National Bureau of Standards, 1968.

11. Chock, D. P., General Motors Sulfate Dispersion Experiment - An Overview of the Wind, Temperature and Concentration Fields, Atmospheric Environment, V. 11, pp 553-559, 1977.

12. Chock, D. P., General Motors Sulfate Dispersion Experiment - An Analysis of the Wind Field Near A Road, Boundary-Layer Meteorology, V. 18, pp 431-451, 1980.

13. Pasquill F., Atmospheric Diffusion. Wilev & Sons. 1974.

14. Benson, P. E., Modifications to the Gaussian Vertical Dispersion Parameter, z, Near Roadways, Atmospheric Environment, V. 16, pp 1399-1405, 1982.

15. Smith, F. B., A Scheme for Estimating the Vertical Dispersion of a Plume From a Source Near Ground Level, Air Pollution - Modeling No. 14 CCMS/NATO- 1972

16. Draxler, R. R., Determination of Atmospheric Diffusion Parameters, Atmospheric Environment, V. 10, No. 2, pp 99-105, 1976.

17. Gloyne, R. W., Some Characteristics of the Natural Wind and Their Modification by Natural and Artificial Obstructions, Proceedings 3rd International Congress of Biometeorology, Pergamon Press, 1964.

18 Turner, D B , Workbook of Atmospheric Dispersion Estimates, Environmental Protection Agency, 1970.

19. Ermak, D. L., An Analytical Model for Air Pollutant Transport and Deposition from a Point Source, Atmospheric Environment, V. 11, pp 231-237, 1977.

20. Little, P., and Wiffen, R. D., Emission and Deposition of Lead from Motor Exhausts, Atmospheric Environment, V. 12, pp 1331-1341, 1978.

21. McMahon, T. A., and Denison, P. J., Empirical Atmospheric Deposition Parameters - A Survey, Atmospheric Environment, V. 13, pp 571-585, 1979.

22. Messina, A. D., et al, Estimates of Air Pollution Near Simple Signalized Intersections, Texas Transportation Institute, FHWA/TX-81/541-1, June 1982.

23. Griffin, R. G., Air Quality Impact of Signaling Decisions, Colorado Department of Highways, CDOH-DTP-R- 80-12, October 1980.

24. Cole, H. S., and Summerhays, J. E., A Review of Techniques Available for Estimating Short-Term NO_2 Concentrations, APCA Journal, Y. 29, pp 812-817, 1979.

25. Donaldson, C. duP. and Hilst, G. Re, Effect of Inhomogeneous Mixing on Atmospheric Photochemical Reactions, Environmental Science and Technology, V. 6, pp 812-816, 1972.

26. Bilger, R. W., The Effect of Admixing Fresh Emissions on the Photostationary state Relationship in Photochemical Smog, Atmospheric Environment, V. 12, pp 1109-1118, 1978.

27. Kewley, D. J., Atmospheric Dispersion of a Chemically Reacting P1ume, Atmospheric Environment, V. 12, pp 1895-1900, 1978.

28. Keyes, D. L., et al, A Reexamination of the Ozone Limiting Approach to Estimating Short-Term NO_2 Concentrations, APCA Journal, V. 31, pp 671-673, 1981.

29. Angle, R. P., et al, Observed and Predicted Values of NO_2/NO_x in the Exhaust Plume From a Compressor Installation, APCA Journal, V. 29, pp 253-255, 1979.

30. B1 anks, J. P., et al . Investigation of NO2/NOx Ratios in Point Source Plumes, U.S. Environmental Protection Agency, EPA-600/7-80-036, February 1980.

31. Compilation of Air Pollutant Emission Factors: Highway Mobile Sources, U.S. Environmental Protection Agency, EPA 460/3-81-005, March 1981.

32. Coats, D. M., et al, Mobile Source Emission Factors, Caltrans, CA-TL-80/15, May 1980.

33. Kunselman, P., et al, Automobile Exhaust Emission Modal Analysis Model, U.S. Environmental Protection Agency, EPA-460/3-74-005, January 1974.

34. McAdams, H. T., Automobile Exhaust Emission Modal Analysis Model Extension and Refinement, U.S. Environmental Protection Agency EPA-460/3-74-024, October 1974.

35. Marzen, J. M., A Study of Emissions From Light Duty Vehicles in Six Cities, U S. Environmental Protection Agency, APTD-1497, March 1973.

36. Rutherford, J. A., Automobile Exhaust Emission Surveillance - Analysis of the FY 1975 Program, U.S. Environmental Protection Agency, EPA-460/3-77-022, December 1977.

37. Dickey, P., Lake Tahoe High Altitude Vehicle Surveillance Program, California Air Resources Board, Project T, December 1976.

38. Eccleston, B. H., and Hurn, R. W., Ambient Temperature and Vehicle Emissions, EPA-460/30-74-028, 1974.

39. Martinez, J. R., et al, Methodology for Evaluating Highway Air Pollution Dispersion Models, National Cooperative Highway Research Program, Report No. 245, December 1981.

40. Winter, W. A., and Farrockhrooz, M., Mini-Computer Software - Data Acquisition and Process Control System for Air Pollution Monitoring. Caltrans. CA-DOT-TL-7080-3-76-39, May 1976.

41. Peter, R. R., et al, Variables Affecting Air Quality Instrumentation Operation, Caltrans, FHWA-CA-TL-7080-77-15, June 1977.

42. Golder, D., Relations Among Stability Parameters in the Surface Layer, Boundary-Layer Meteorology, V. 3, pp 47-58, 1972.

43. Noll, K. E., and Claggett M., Carbon Monoxide Monitoring and Line Source Model Evaluation Study for an Urban Freeway and an Urban Intersection, Illinois Environmental Protection Agency, Final Report, November 1979.

44. Rodes, C. E., and Holland, D. M., NO_2/O_3 Sampler Siting Study, U.S. Environmental Protection Agency, Contract No. 68-02-2292, August 1979.

45. Mobile Source Emission Factors, U.S. Environmental Protection Agency, EPA-400/9-78-006, March 1978.

46. Jones, F. L., et al, A Simple Method for Estimating the Influence of Cloud Cover on the NO_2 Photolysis Rate Constant, APCA Journal, V. 31, pp 42-45, 1981.

47. Plate, F 1 Aerodynamic Characteristics of Atmospheric Boundary Layers, Atomic Energy Commission, 1Y71.

48. Myrup, L. O., and Ranzieri, A. J., A Consistent Scheme For Estimating Diffusivities to be Used in Air Quality Models, Caltrans, FHWA-CA-TL-7169-76-32, June 1976.

49. Mercer, T. T., Aerosol Technology in Hazard Evaluation, Academic Press, 1973.

50. Slinn, W. G. N., Predictions for Particle Deposition to Vegetative Canopies, Atmospheric Environment, V. 16, pp 1785-1794, 1982.

51. Judeikis, H. S., and Wren, A. G., Laboratory Measurements of NO and NO_2 Depositions Onto Soil and Cement Surfaces, Atmospheric Environment, V. 12, pp 2315-2319, 1978.

52. Kimber, R. M., and Hollis, E. M., Traffic Queues and Delays at Road Junctions, British Transport and Road Research Laboratory, Report No. 909, 1979.

53. Pedersen, N. J., and Samdahl, D. R., Highway Traffic Data for Urbanized Area Project Planning and Design, National Cooperative Highway Research Program, Report No. 255, December 1982.

54. Nokes, W. W. and Benson, P. E., Development of Worst Case Meteorology Criteria, Caltrans, FHWA/CA/TL-85/14, November 1985.

55. Turner, D. B., A Diffusion Model for an Urban Area, Journal of Applied Meteorology, V. 3, pp 83-91, 1964.

56. Gifford, F. A., Turbulent Diffusion-Typing Schemes: A Review, Nuclear Safety, V. 17, pp 68-86, 1976.

57. Markee, E. H., On the Relationships of Range to Standard Deviation of Wind Fluctuation. Monthly Weather Review, pp 83-87, February 1963.

58. Verrall, K. A., and Williams, R. L., A Method for Estimating the Standard Deviation of Wind Directions, Journal of Applied Meteorology, V. 21, pp 1922-1925. 1982.

59. Hanna, S. R., Lateral Turbulence Intensity and Plume Meandering During Stable Conditions, Journal of C1imate and Applied Meteorology, V. 22, pp 1424-1430, 1983.

60. Benkley, C. W., and Schulman, L. L., Estimating Hourly Mixing Depths From Historical Meteorological Data, Journal of Applied Meteorology, V. 18, pp 772-780, 1979.

61. Zofonte, L., Nitrogen Dioxide Photolysis in the Los Angeles Atmosphere, Environmental Science and Technology, V. 11, pp 483-487, 1977.

APPENDIX A

DEVELOPMENT OF A CUMULATIVE EMISSIONS PROFILE

I. Method

The intersection link option provides a method for distributing modal emissions at and near an intersection in a physically realistic way. Cumulative emission profiles for acceleration, deceleration, cruise and idle modes form the basis for distributing the emissions. These profiles are constructed for each intersection link, and represent the cumulative emissions per cycle per lane for the dominant movement. The positional distribution of vehicles entering and leaving the traffic queue is fully accounted for by the model. To obtain the average lineal emission rate over an element, the total cumulative amount of emissions for the four modes is computed for each end of the element. The difference between these amounts is divided by the element length and multiplied by the cycles per unit time to yield a composite modal emission factor for the element.

II. Assumptions

A. Uniform vehicle arrival rate.

B. Constant acceleration and deceleration rates.

C. Equivalent acceleration rates for all departing vehicles on given link regardless of arrival link.

D. Constant time rate of emissions over duration of specific mode.

E. Deceleration time rate of emissions equals 1.5 times the idle rate.

F. An "at rest" vehicle spacing of 7 meters.

G. All delayed vehicles come to a full stop.

III. Input Variables

In addition to EFL (@ 16 mph), the following variables must be quantified for each intersection link:

1. VPHI - Arrival volume in vehicles per hour.

2. VPHO - Departure volume in vehicles per hour.

3. NCYC - Average number of vehicles entering the intersection per cycle per lane for dominant movement .

4. NDLA - Average number of vehicles delayed per cycle per lane for the dominant movement.

5. STPL - Distance from XL1, YL1 to stopline.

6. ACCT - Acceleration time.

7. DCLT - Deceleration time.

8. IDT1, IDT2 - Idle times at front (1) and end (2) of queue.

9. SPD - Cruise speed .

10. EFI - Idle emission rate.

IV. Computed Variables

The following variables are computed for each link from the input values:

1. Acceleration Rate
   ACCR = SPD/ACCT

2. Deceleration Rate
   DCLR = SPD/DCLT

3. Acceleration Length
   $LACC = (ACCR*ACCT^2)/2$

4. Deceleration Length
   $LDCL = (DCLR*DCLT^2)/2$

5. Acceleration - Speed Product
   AS = ACCR*SPD/2

6. FTP-75 (BAG2) Time Rate Emission Factor
   BAG2 = EFL*(16 mph)

7. Acceleration Emission Factor
   $EFA = BAG2*0.76*e^{0.0454*AS}$

8. Cruise Emission Factor
   $EFC = BAG2*(0.494+0.000227*SPD^2)$

9. Deceleration Emission Factor
   EFD = 1. 5*EFI

10. Queue Length

$LQU = NDLA*VSP$,

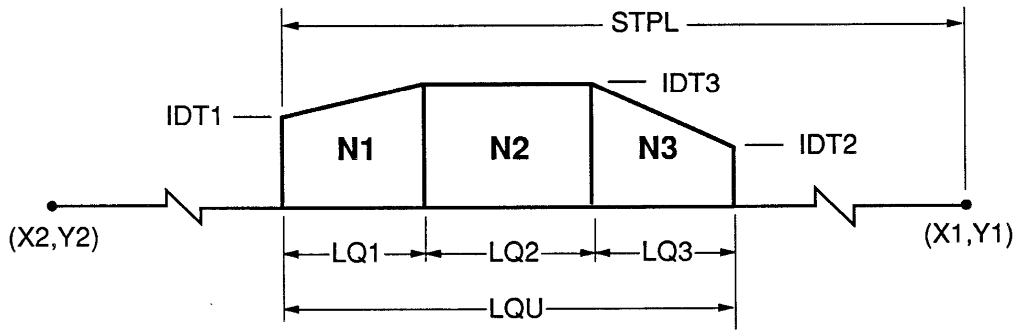
where VSP is the "at rest" vehicle spacing.

NOTE: A consistent set of units is assumed by the model. These are given in the User Instructions (Section 9).

V . Cumulative Emission Profile (CEP)

The CEP is developed by determining the time in mode for each vehicle during an average cycle/lane event as a function of distance from XL1, YL1 (called ZD), multiplying this time by the modal emission time rate ($\dot{e}$), and summing the results. The elementary equations of motion are used to relate time to ZD. The assumed "at rest" vehicle spacing is used to specify the positional distribution of the vehicles in the queue. The total cumulative emissions per cycle per lane at ZD is denoted as $ECUM_k(ZD)$, where the subscript signifies the mode (1 = accel., 2 = decel., 3 = cruise, 4 = idle). The formulas used by CALINE4 to determine $ECUM_k(ZD)$ are described in detail on the following pages.

Consider the following generalized model of a stationary queue of vehicles:



where the "IDT" variables are idletimes/cycle in seconds, the "LQ" variables are queue lengths in meters, and the "N" variable are numbers of vehicles.

CALINE4 assigns values to these generalized variables on the basis of three possible conditions:

1. NDLA≤NCYC
2. NDLA>NCYC, and NCYC≥(NDLA - NCYC)
3. NDLA>NCYC, and NCYC<(NDLA - NCYC).

Values are assigned as follows:

	C O N D I T I O N		
Variable	1	2	3
N1	0	NDLA - NCYC	NCYC
N2	0	0	NDLA - 2*NCYC
N3	NDLA	NCYC	NCYC
LQ1	0	N1*VSP	N1*VSP
LQ2	0	0	N2*VSP
LQ3	N3*VSP	N3*VSP	N3*VSP
IDT3[1]	IDT1	IDT1 + 2*N1	IDT1 + 2*N1

[1] Assumes 2 second headway between vehicles crossing the stopline. Start-up and clearance lost times are assumed to be incorporated in the input value for IDT1.

A. Acceleration Profile

1. Time/Distance Relation

$d = \frac{1}{2}at^2 \quad \rightarrow \quad t = \sqrt{2d/a}$

$ECUM_1(d) = \dot{e}t = \dot{e}\sqrt{2d/a}$

2. CEP

a. For ZD $\leq$ STPL - LQ3:

$ECUM_1(ZD) = 0$.

b. For ZD > STPL - LQ3 and ZD < STPL + LACC - VSP:

$$ECUM_1(ZD) = EFA\sqrt{2/ACCR} \sum_{i=n}^{m} (ZD'-(i-1)*VSP)^{\frac{1}{2}}$$

$$+ EFA*(n-1)*ACCT ,$$

where

$$ZD' = ZD - (STPL-LQ3),$$

$$n = MAX\left\{INT\left(\frac{ZD'-LACC}{VSP}+1\right)+1,\ 1\right\}$$

and

$$m = MIN\left\{INT\left(\frac{ZD'}{VSP}\right)+1,\ N3\right\} .$$

c. For ZD $\geq$ STPL + LACC - VSP:

$ECUM_1(ZD) = EFA*N3*ACCT$.

B. Deceleration Profile

1. Time/Distance Relation

$$d = v_0 t + \frac{1}{2}at^2 \quad \rightarrow \quad t = \frac{-v_0 + \sqrt{v_0^2 - 2ad}}{-a}$$

$$ECUM_2(d) = \dot{e}t = \dot{e}\,\frac{(-v_0 + \sqrt{v_0^2 - 2ad}\,)}{-a} .$$

2. CEP

a. For $ZD \leq STPL - (LQU + LDCL)$:

$ECUM_2(ZD) = 0.$

b. For $ZD > STPL - (LQU + LDCL)$

and

$ZD < STPL - (LQ1 + LQ2) - VSP$:

$$ECUM_2(ZD) = EFD* \sum_{i=n}^{m} \left[\frac{SPD-(SPD^2-2DCLR*(ZD'-(i-1)*VSP))^{\frac{1}{2}}}{DCLR} \right]$$

$$+ EFD*(n-1)*DCLT,$$

where

$$ZD' = ZD - \left[STPL-(LQU+LDCL) \right],$$

$$n = MAX \left[INT\left(\frac{ZD'-LDCL}{VSP} + 1 \right) + 1, \ 1 \right]$$

and

$$m = MIN \left[INT\left(\frac{ZD'}{VSP} \right) + 1, \ N3 \right].$$

c. For $ZD \geq STPL - (LQ1 + LQ2) - VSP$

$ECUM_2(ZD) = EFD*N3*DCLT$

C. Cruise Profile

1. Time/Distance Relation

$$d = vt \quad \rightarrow \quad t = \frac{d}{v}$$

$$ECUM_3(d) = \dot{e}t = \dot{e}\,\frac{d}{v}$$

2. CEP

Let

$$Z1 = STPL - (LQU+LDCL)$$

$$Z2 = STPL + LACC.$$

2. (continued)

Then,

$$ECUM_3(ZD) = \frac{EFC}{SPD} * \sum_{i=1}^{N3} \Big[ZD$$

$$-D_1\left[ZD-(Z1+(i-1)*VSP)\right]$$

$$+D_2\left[ZD-(Z2-i*VSP)\right]\Big]$$

$$+\frac{EFC}{SPD} *ZD*(NCYC-N3),$$

where,

$D_1=0$ if $ZD \le Z1+(i-1)*VSP$
(else $D_1=1$).

and

$D_2=0$ if $ZD \le Z2-i*VSP$
(else $D_2=1$).

D. Idle Profile

1. Time/Distance Relation

Idle time depends on position in queue. Linear interpolation used to determine this (i.e., uniform arrival rate).

Then,

$$ECUM_4(d)=e\dot{t}$$

2. CEP

a. For $ZD \le STPL-LQU$:

$ECUM_4(ZD)=0$.

b. For ZD>(STPL-LQU) and $ZD\leq(STPL-LQ1-LQ2)$

$ECUM_4(ZD)$ = EFI*ZQL*N3 * ((ZQL/2)*(IDT3-IDT2) + IDT2)

where ZQL = (ZD - (STPL-LQU))/LQ3

c. For ZD>(STPL-LQ1-LQ2) and $ZD\leq(STPL-LQ1)$

$ECUM_4(ZD)$ = EFI * ((ZQL*N2*IDT3) + (N3*(IDT3+IDT2)/2))

where ZQL = (ZD - (STPL-LQ1-LQ2))/LQ2

d. For ZD>(STPL-LQ1) and $ZD\leq STPL$

$ECUM_4(ZD)$ = EFI * (ZQL*N1 * ((1-(ZQL/2))*(IDT3-IDT1)+IDT1)
+ N2*IDT3 + N3*(IDT3+IDT2)/2)

where ZQL = (ZD-(STPL-LQ1))/LQ1

e. For ZD>STPL

$ECUM_4(ZD)$ = EFI*(N1*(IDT1+IDT3)/2 + N2*IDT3
+ N3*(IDT3+IDT2)/2)

VI. Element Emission Rates

Intersection link elements will always originate at the stopline (i.e., ZD1=STPL for first "upwind" element) and will be no longer than the mixing zone width (i.e., $ZD1-ZD2\leq W$).

The element lineal source strength, Q1, is determined as follows:

$$Q1 = \frac{VPH(ECLD)}{NCYC} * \left(\frac{\left| \sum_{k=1}^{4} ECUM_k(ZD1) - \sum_{k=1}^{4} ECUM_k(ZD2) \right|}{|ZD1-ZD2|} \right)$$

where,

$$VPH(ECLD) = \begin{cases} VPHI & ECLD\leq STPL \\ VPHO & ECLD>STPL \end{cases} .$$

APPENDIX B

Derivation of the Discrete Parcel Method

Consider the following forward and reverse reactions for producing NO_2:

$$NO + O_3 \overset{k_f}{\rightarrow} NO_2 + O_2 \qquad (B-1)$$

$$NO + O \overset{k_r}{\leftarrow} NO_2 + h_\nu, \qquad (B-2)$$

where k_f and k_r are first-order reaction rates. Let x be the amount of O_3 reacted in time t. Given the initial concentrations,

$$a = [O_3]_i$$
$$b = [NO]_i$$
$$c = [NO_2]_i,$$

the resulting concentrations after time t will be

$$[O_3]_t = a-x$$
$$[NO]_t = b-x$$
$$[NO_2]_t = c+x.$$

The reaction rates for O_3 can now be described as follows:

$$\left(\frac{dx}{dt}\right)_f = k_f(a-x)(b-x)$$

$$\left(\frac{dx}{dt}\right)_r = k_r(c+x).$$

The net reaction rate is given by

$$\frac{dx}{dt} = \left(\frac{dx}{dt}\right)_f - \left(\frac{dx}{dt}\right)_r$$

$$= A + Bx + Cx^2, \qquad \text{(B-3)}$$

where

$A = k_f ab - k_r c,$
$B = -(k_f a + k_f b + k_r),$ and
$C = k_f.$

Separating the variables in Equation B-3, integrating and noting the boundary condition x=0 when t=0 leads to,

$$t = p^{-1} \ln \left(\frac{x(B+p)+2A}{x(B-p)+2A}\right), \qquad \text{(B-4)}$$

where

$$p = (B^2-4AC)^{1/2}.$$

The integration is made under the assumption that $B^2-4AC \geq 0$, or

$$[k_f(a+b)+k_r]^2-4k_f(k_f ab-k_r c) \geq 0. \qquad \text{(B-5)}$$

Expanding and regrouping Equation B-5 gives,

$$k_f^2(a^2-2ab+b^2)+2k_f k_r(a+b+2c)+k_r^2 \geq 0.$$

Since $a,b,c,k_f,k_r \geq 0$ by definition, the validity of the assumption rests on

$$k_f^2(a^2-2ab+b^2) \geq 0,$$

which can be rewritten as

$$k_f^2(a-b)^2 \geq 0. \qquad \text{(B-6)}$$

Equation B-6 must be true since $k_f \geq 0$. Therefore, the assumption is applicable under all physically meaningful conditions.

Solving Equation B-4 for x yields,

$$x = \frac{2A(e^{tp}-1)}{B(1-e^{tp})+p(1+e^{tp})}. \qquad \text{(B-7)}$$

In the simple reaction sequence considered, each O_3 molecule which reacts produces a NO_2 molecule. Therefore, Equation B-7 is used without modification to compute discrete parcel NO_2 concentrations.

For large values of t, the equilibrium solution to Equation B-3,

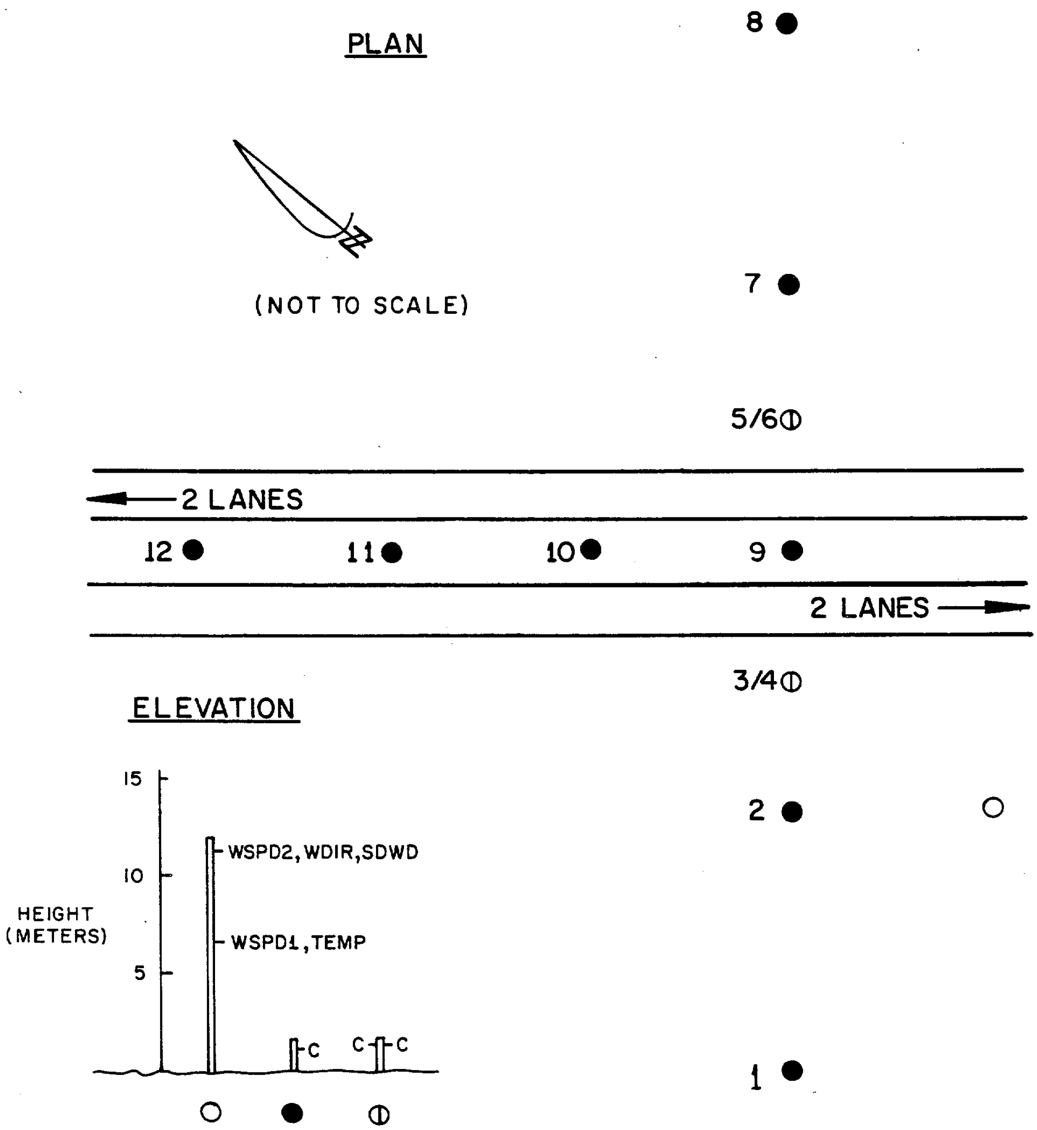
$$x = \frac{-(B+p)}{2C}, \qquad \text{(B-8)}$$

is used to avoid exponential overflow problems.

APPENDIX C

Summary of Highway 99 Tracer Experiment

The following pages summarize the results of the Caltrans Highway 99 Tracer Study. site location codes corresponding to those used in the data summary are given in Figure 63. The mean and standard deviation of the wind direction are denoted as WDIR and SDWD, respectively. SF_6 emission factors are given in mi11iliters per kilometer-second. This represents the total release by all eight tracer vehicles. Traffic counts were made for the on-ramps at both ends of the 2.5 kilometer test link to provide an estimate of the number of vehicles in hot-stabilized operation. This appears in the summary as a percent of the total flow in each direction.



SITE LOCATION CODES FOR THE CALTRANS HIGHWAY 99
TRACER EXPERIMENT

FIGURE 63

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT
DATA SUMMARY

RUN DATE: 12/23/81-WEDNESDAY

	PARAMETER (UNITS)	*	0630-0700	0700-0730	0730-0800	0800-0830
M	WSPD1 (M/S)	*	0.50	0.78	0.49	0.35
	WSPD2 (M/S)	*	0.67	1.04	0.79	0.66
E	WDIR (DEG)	*	147	182	125	195
	SDWD (DEG)	*	28.3	17.6	22.6	19.9
T	TEMP (C)	*	4.9	4.9	5.0	5.3
	STAB CLASS	*	D	E	G	G
	NBVOL (VPH)	*	****	****	****	****
	SBVOL (VPH)	*	778	848	926	912
T	NBSPD (MPH)	*	54.9	57.6	58.8	59.0
R	SBSPD (MPH)	*	60.5	56.0	57.5	58.9
A	LDA	*	****/65.3	****/68.6	****/70.8	****/67.1
F	% LDT	*	****/21.6	****/16.5	****/17.3	****/16.7
F	VEH TYP MDT	*	****/ 1.3	****/ 1.2	****/ 1.3	****/ 0.7
I	(NB/SB) HDG	*	****/ 4.1	****/ 4.0	****/ 5.2	****/ 7.2
C	HDD	*	****/ 7.7	****/ 9.4	****/ 5.4	****/ 8.1
	MC	*	****/ 0.0	****/ 0.2	****/ 0.0	****/ 0.2
	RAMP NB	*	****	****	****	****
	(%TOT) SB	*	27.8	22.9	41.3	22.8
E	NB(ML/KM-S)	*	3.52	3.36	3.59	3.64
F	SB "	*	3.32	3.59	3.71	3.72
	LOC 1 (PPT)	*	216	54	44	42
S	2 "	*	355	42	56	28
F	3/4 "	*	458	61	332	36
6	5/6 "	*	559	917	454	752
	7 "	*	382	412	392	396
C	8 "	*	122	454	287	295
O	9 "	*	2662	2477	2521	2398
N	10 "	*	3384	2664	3181	2559
C	11 "	*	2909	2304	3132	2376
	12 "	*	2516	2633	2683	2466
C	LOC 9 (PPM)	*	2.8	2.8	4.2	3.8
O	3/4 "	*	0.9	1.5	2.2	2.2
	5/6 "	*	1.2	2.4	1.7	2.7

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT
DATA SUMMARY

RUN DATE: 1/8/82-FRIDAY

	PARAMETER (UNITS)	0630-0700	0700-0730	0730-0800	0800-0830
M	WSPD1 (M/S)	0.49	0.30	0.74	0.58
	WSPD2 (M/S)	0.90	0.74	1.19	0.86
E	WDIR (DEG)	110	68	327	17
	SDWD (DEG)	39.7	50.1	16.9	34.4
T	TEMP (C)	1.3	1.1	1.5	2.5
	STAB CLASS	D	F	F	F
	NBVOL (VPH)	1756	2206	2722	2032
	SBVOL (VPH)	610	742	990	1050
T	NBSPD (MPH)	58.8	57.5	56.2	58.9
R	SBSPD (MPH)	60.5	61.4	58.3	59.2
A	LDA	69.6/63.3	75.1/72.8	76.8/71.5	75.5/71.4
F	% LDT	24.5/20.3	18.6/14.0	17.9/16.0	16.7/15.8
F	VEH TYP MDT	0.8/ 2.0	0.7/ 1.6	0.7/ 1.0	1.2/ 2.5
I	(NB/SB) HDG	2.2/ 4.3	1.2/ 4.0	1.0/ 3.4	2.2/ 2.5
C	HDD	2.7/10.2	3.9/ 7.3	3.2/ 7.9	4.2/ 7.8
	MC	0.2/ 0.0	0.5/ 0.3	0.3/ 0.2	0.2/ 0.0
	RAMP NB	46.7	42.4	39.5	42.7
	(%TOT) SB	8.9	9.7	9.1	8.4
E	NB(ML/KM-S)	3.62	3.56	3.87	3.77
F	SB "	3.33	3.41	3.63	3.91
	LOC 1 (PPT)	774	735	796	850
S	2 "	****	772	838	961
F	3/4 "	988	967	890	1334
6	5/6 "	49	74	501	143
	7 "	12	12	****	77
C	8 "	3	3	31	24
O	9 "	2466	1980	3358	1944
N	10 "	3275	2321	3446	2431
C	11 "	3414	2486	3242	2518
	12 "	2428	2483	2917	2712
C	LOC 9 (PPM)	3.9	4.6	7.6	8.1
O	3/4 "	2.8	3.9	6.3	7.3
	5/6 "	1.7	2.0	5.3	8.1

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT
DATA SUMMARY

RUN DATE: 1/13/82-WEDNESDAY

	PARAMETER (UNITS)	*	1600-1630	1630-1700	1700-1730	1730-1800
		*	R E S U L T S			
M	WSPD1 (M/S)	*	2.32	1.84	2.28	3.14
	WSPD2 (M/S)	*	2.38	1.98	2.47	3.41
E	WDIR (DEG)	*	211	205	198	170
	SDWD (DEG)	*	11.2	11.1	9.4	8.5
T	TEMP (C)	*	6.2	6.0	5.2	4.6
	STAB CLASS	*	D	D	E	E
	NBVOL (VPH)	*	1396	1314	1238	1078
	SBVOL (VPH)	*	1918	2398	2492	1890
T	NBSPD (MPH)	*	59.8	59.2	58.5	59.0
R	SBSPD (MPH)	*	59.9	59.1	56.9	57.1
A	LDA	*	77.8/75.5	76.3/77.4	83.5/80.9	85.2/81.0
F	% LDT	*	12.3/17.7	11.4/18.3	8.6/15.2	6.1/14.4
F	VEH TYP MDT	*	2.1/ 1.0	2.9/ 0.6	1.0/ 0.9	2.2/ 1.1
I	(NB/SB) HDG	*	1.6/ 1.0	1.1/ 0.4	1.0/ 0.3	0.4/ 0.6
C	HDD	*	5.9/ 4.0	7.2/ 2.8	5.8/ 2.6	6.1/ 2.5
	MC	*	0.3/ 0.7	1.2/ 0.5	0.2/ 0.1	0.0/ 0.4
	RAMP NB	*	42.0	41.4	38.1	41.9
	(%TOT) SB	*	11.3	8.9	11.2	11.0
E	NB(ML/KM-S)	*	3.14	3.23	3.08	3.45
F	SB "	*	3.24	3.07	3.45	3.22
	LOC 1 (PPT)	*	9	3	1	0
S	2 "	*	6	7	5	5
F	3/4 "	*	8	5	2	3
6	5/6 "	*	497	634	501	492
	7 "	*	292	359	343	284
C	8 "	*	160	216	207	150
O	9 "	*	784	954	737	841
N	10 "	*	1244	1588	1379	1327
C	11 "	*	801	960	715	879
	12 "	*	934	1339	1110	1163
C	LOC 9 (PPM)	*	1.5	2.3	1.9	1.8
O	3/4 "	*	0.8	1.1	0.9	1.0
	5/6 "	*	1.3	1.8	1.7	1.6

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT
DATA SUMMARY

RUN DATE: 1/29/82-FRIDAY

	PARAMETER (UNITS)	*	0700-0730	0730-0800	0800-0830	0830-0900
M	WSPD1 (M/S)	*	5.47	4.07	2.72	2.66
	WSPD2 (M/S)	*	6.02	4.44	3.25	4.16
E	WDIR (DEG)	*	326	323	311	297
	SDWD (DEG)	*	7.2	6.5	9.2	9.6
T	TEMP (C)	*	5.2	5.6	5.9	6.0
	STAB CLASS	*	D	D	C	C
	NBVOL (VPH)	*	2328	2596	2104	1538
	SBVOL (VPH)	*	718	990	1092	968
T	NBSPD (MPH)	*	55.6	54.7	59.0	59.4
R	SBSPD (MPH)	*	60.6	59.1	60.8	59.9
A	LDA	*	83.1/75.5	86.3/69.3	85.7/72.2	82.2/68.4
F	% LDT	*	10.1/16.2	7.9/17.8	5.7/14.5	7.8/18.0
F	VEH TYP MDT	*	0.8/ 1.7	0.2/ 2.4	1.2/ 1.3	1.3/ 1.7
I	(NB/SB) HDG	*	1.2/ 2.5	1.5/ 3.2	1.7/ 5.9	1.4/ 3.9
C	HDD	*	4.3/ 4.2	3.7/ 7.3	5.5/ 6.0	7.2/ 8.1
	MC	*	0.5/ 0.0	0.5/ 0.0	0.1/ 0.2	0.1/ 0.0
	RAMP NB	*	47.0	39.3	40.9	39.5
	(%TOT) SB	*	8.9	8.3	8.1	10.5
E	NB(ML/KM-S)	*	3.91	3.97	3.65	3.61
F	SB "	*	3.53	3.65	3.56	3.40
	LOC 1 (PPT)	*	109	146	47	7
S	2 "	*	212	274	127	22
F	3/4 "	*	439	566	334	40
6	5/6 "	*	3	3	273	520
	7 "	*	3	4	118	273
C	8 "	*	6	4	30	112
O	9 "	*	885	1153	1984	****
N	10 "	*	992	1182	2234	2149
C	11 "	*	960	1443	2011	2014
	12 "	*	955	1283	1816	1804
C	LOC 9 (PPM)	*	2.1	2.5	3.2	****
O	3/4 "	*	1.3	1.8	1.6	1.0
	5/6 "	*	0.6	0.9	1.5	1.6

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT
DATA SUMMARY

RUN DATE: 2/02/82-TUESDAY

	PARAMETER (UNITS)	*	R E S U L T S 0630-0700	0700-0730	0730-0800	0800-0830
M	WSPD1 (M/S)	*	0.85	1.52	1.25	1.37
	WSPD2 (M/S)	*	1.19	1.80	1.60	1.70
E	WDIR (DEG)	*	82	83	93	101
	SDWD (DEG)	*	51.7	10.0	14.0	14.1
T	TEMP (C)	*	4.3	3.7	4.8	5.8
	STAB CLASS	*	G	G	D	D
	NBVOL (VPH)	*	1766	2180	2518	2056
	SBVOL (VPH)	*	668	932	1248	1224
T	NBSPD (MPH)	*	57.3	59.0	56.8	59.9
R	SBSPD (MPH)	*	58.8	60.7	60.4	59.8
A	LDA	*	80.6/66.5	85.0/74.0	85.9/75.5	85.3/73.2
F	% LDT	*	12.5/19.8	8.8/16.3	7.5/13.9	8.1/15.7
F	VEH TYP MDT	*	0.2/ 1.2	0.4/ 0.9	0.5/ 1.3	0.3/ 2.5
I	(NB/SB) HDG	*	0.8/ 5.1	0.9/ 3.4	1.9/ 2.7	1.8/ 2.5
C	HDD	*	5.1/ 7.2	4.0/ 5.4	3.9/ 6.3	4.3/ 6.0
	MC	*	0.8/ 0.3	0.8/ 0.0	0.3/ 0.3	0.3/ 0.2
	RAMP NB	*	47.0	45.9	41.1	40.1
	(%TOT) SB	*	****	****	****	****
E	NB(ML/KM-S)	*	3.70	3.29	3.98	3.76
F	SB "	*	3.52	3.45	3.63	3.72
	LOC 1 (PPT)	*	1096	723	592	442
S	2 "	*	1522	880	667	429
F	3/4 "	*	1915	1015	1036	439
6	5/6 "	*	769	118	122	177
	7 "	*	****	****	36	68
C	8 "	*	757	99	35	30
O	9 "	*	2930	****	****	****
N	10 "	*	3294	1822	2648	2837
C	11 "	*	2877	2130	2688	2658
	12 "	*	2952	2183	2481	2412
C	LOC 9 (PPM)	*	3.4	****	****	****
O	3/4 "	*	2.5	3.2	2.8	2.4
	5/6 "	*	1.3	1.9	2.1	2.0

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT
DATA SUMMARY

RUN DATE: 2/03/82-WEDNESDAY

	PARAMETER (UNITS)	*	R E S U L T S 1600-1630	1630-1700	1700-1730	1730-1800
M	WSPD1 (M/S)	*	1.74	1.77	0.98	0.98
	WSPD2 (M/S)	*	1.97	2.03	1.19	1.27
E	WDIR (DEG)	*	152	155	141	126
	SDWD (DEG)	*	13.9	10.3	7.9	17.5
T	TEMP (C)	*	13.1	12.9	12.4	12.0
	STAB CLASS	*	C	D	D	G
	NBVOL (VPH)	*	1550	1292	1232	1124
	SBVOL (VPH)	*	2078	2528	2720	2040
T	NBSPD (MPH)	*	61.3	60.5	61.4	59.8
R	SBSPD (MPH)	*	59.7	57.6	58.0	59.0
A	LDA	*	78.7/76.9	78.9/78.2	84.4/79.8	84.3/81.7
F	% LDT	*	11.7/16.6	11.8/16.2	6.7/17.1	7.8/13.6
F	VEH TYP MDT	*	2.1/ 1.3	2.8/ 0.7	1.3/ 0.3	1.1/ 0.4
I	(NB/SB) HDG	*	0.8/ 0.8	1.9/ 0.3	2.4/ 0.5	1.8/ 0.6
C	HDD	*	5.8/ 4.0	4.3/ 3.6	4.5/ 1.5	4.8/ 3.3
	MC	*	0.9/ 0.4	0.3/ 0.9	0.6/ 0.8	0.2/ 0.4
	RAMP NB	*	38.3	41.0	43.3	41.8
	(%TOT) SB	*	11.9	10.6	10.6	12.7
E	NB(ML/KM-S)	*	3.60	2.94	2.98	3.53
F	SB "	*	3.68	3.45	2.91	3.64
	LOC 1 (PPT)	*	7	2	2	0
S	2 "	*	1	3	1	23
F	3/4 "	*	3	4	2	123
6	5/6 "	*	564	589	740	352
	7 "	*	213	300	402	287
C	8 "	*	55	185	204	149
O	9 "	*	1400	967	1591	3047
N	10 "	*	1840	1762	2053	2961
C	11 "	*	1497	1300	1756	2454
	12 "	*	1465	1325	1623	2310
C	LOC 9 (PPM)	*	1.8	2.0	2.6	3.2
O	3/4 "	*	0.8	1.0	1.2	1.8
	5/6 "	*	1.3	1.6	2.0	1.9

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT
DATA SUMMARY

RUN DATE: 2/8/82-MONDAY

	PARAMETER (UNITS)	*	R E S U L T S 1700-1730	1730-1800	1800-1830	1830-1900
M	WSPD1 (M/S)	*	2.24	2.07	2.22	1.67
	WSPD2 (M/S)	*	2.44	2.42	2.58	1.92
E	WDIR (DEG)	*	224	230	226	222
	SDWD (DEG)	*	9.6	6.9	8.5	9.5
T	TEMP (C)	*	12.2	10.7	9.9	9.3
	STAB CLASS	*	G	G	G	G
	NBVOL (VPH)	*	1190	1106	1084	884
	SBVOL (VPH)	*	2694	1994	1448	1152
T	NBSPD (MPH)	*	58.9	58.3	56.9	56.8
R	SBSPD (MPH)	*	57.1	60.0	58.6	56.7
A	LDA	*	82.7/80.0	79.4/79.0	82.5/78.3	84.2/78.0
F	% LDT	*	6.6/16.3	8.3/16.0	9.0/16.3	7.0/20.0
F	VEH TYP MDT	*	1.0/ 0.5	1.3/ 1.4	0.9/ 0.3	0.9/ 0.8
I	(NB/SB) HDG	*	1.5/ 0.4	1.8/ 0.8	1.3/ 0.8	0.7/ 0.6
C	HDD	*	7.9/ 2.3	8.1/ 2.1	5.9/ 4.0	7.2/ 0.6
	MC	*	0.3/ 0.4	1.1/ 0.6	0.4/ 0.3	0.0/ 0.0
	RAMP NB	*	42.9	42.3	46.7	42.8
	(%TOT) SB	*	11.2	11.1	13.7	13.0
E	NB(ML/KM-S)	*	3.55	3.60	3.57	3.61
F	SB "	*	3.78	3.62	3.42	3.69
	LOC 1 (PPT)	*	4	3	1	0
S	2 "	*	1	2	0	1
F	3/4 "	*	2	1	3	4
6	5/6 "	*	706	707	798	913
	7 "	*	461	470	518	678
C	8 "	*	355	322	367	511
O	9 "	*	1000	919	1117	1349
N	10 "	*	2083	1794	1879	2592
C	11 "	*	878	883	835	898
	12 "	*	1279	1471	1339	1688
C	LOC 9 (PPM)	*	1.6	1.7	1.4	1.4
O	3/4 "	*	0.5	0.7	0.7	0.8
	5/6 "	*	1.2	1.3	1.3	1.3

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT
DATA SUMMARY

RUN DATE: 2/11/82-THURSDAY

	PARAMETER (UNITS)	*	R E S U L T S			
		*	0630-0700	0700-0730	0730-0800	0800-0830
M	WSPD1 (M/S)	*	1.52	1.59	1.64	1.59
	WSPD2 (M/S)	*	1.96	1.88	2.09	1.96
E	WDIR (DEG)	*	114	116	124	127
	SDWD (DEG)	*	6.9	5.5	7.8	12.6
T	TEMP (C)	*	2.2	2.7	3.2	4.7
	STAB CLASS	*	G	D	C	C
	NBVOL (VPH)	*	1860	2520	2740	2240
	SBVOL (VPH)	*	788	960	1310	1338
T	NBSPD (MPH)	*	58.0	58.8	58.0	58.5
R	SBSPD (MPH)	*	60.1	59.9	60.3	59.7
A	LDA	*	70.5/****	78.1/69.2	****/****	****/71.2
F	% LDT	*	24.3/****	17.0/17.0	****/****	****/14.0
F	VEH TYP MDT	*	0.7/****	0.3/ 1.6	****/****	****/ 3.1
I	(NB/SB) HDG	*	1.4/****	0.5/ 2.7	****/****	****/ 2.3
C	HDD	*	3.2/****	3.5/ 8.8	****/****	****/ 9.3
	MC	*	0.0/****	0.6/ 0.5	****/****	****/ 0.0
	RAMP NB	*	46.2	42.5	38.6	48.1
	(%TOT) SB	*	7.1	7.1	7.8	7.0
E	NB(ML/KM-S)	*	3.72	3.36	3.87	3.53
F	SB "	*	3.51	3.55	3.53	3.41
	LOC 1 (PPT)	*	822	726	455	459
S	2 "	*	916	856	666	615
F	3/4 "	*	1218	1020	1090	850
6	5/6 "	*	9	7	18	16
	7 "	*	48	39	32	37
C	8 "	*	10	6	10	8
O	9 "	*	1923	1779	1894	1882
N	10 "	*	2098	2107	2248	2048
C	11 "	*	1923	****	****	****
	12 "	*	2418	2088	1913	2329
C	LOC 9 (PPM)	*	2.7	3.6	3.5	3.5
O	3/4 "	*	2.3	2.5	3.0	2.2
	5/6 "	*	0.8	1.3	1.5	1.2

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT
DATA SUMMARY

RUN DATE: 2/18/82-THURSDAY

	PARAMETER (UNITS)	*	R E S U L T S 0630-0700	0700-0730	0730-0800	0800-0830
M	WSPD1 (M/S)	*	1.42	1.49	0.87	0.92
	WSPD2 (M/S)	*	1.78	1.90	1.18	1.04
E	WDIR (DEG)	*	348	345	345	345
	SDWD (DEG)	*	29.4	13.3	20.4	20.9
T	TEMP (C)	*	8.0	7.9	8.6	9.2
	STAB CLASS	*	G	D	C	C
	NBVOL (VPH)	*	1880	2400	2740	2160
	SBVOL (VPH)	*	706	912	1282	1222
T	NBSPD (MPH)	*	56.3	57.7	56.1	58.1
R	SBSPD (MPH)	*	60.0	60.2	60.2	59.0
A	LDA	*	****/64.7	73.2/****	****/73.3	73.3/****
F	% LDT	*	****/20.6	21.8/****	****/18.1	20.2/****
F	VEH TYP MDT	*	****/ 2.2	1.2/****	****/ 1.1	1.0/****
I	(NB/SB) HDG	*	****/ 4.4	0.9/****	****/ 1.9	1.4/****
C	HDD	*	****/ 7.4	2.2/****	****/ 5.6	4.0/****
	MC	*	****/ 0.7	0.7/****	****/ 0.0	0.0/****
	RAMP NB	*	43.9	42.2	38.0	40.3
	(%TOT) SB	*	7.1	7.7	7.3	6.4
E	NB(ML/KM-S)	*	3.66	3.37	4.03	3.38
F	SB "	*	3.40	3.30	3.37	3.67
	LOC 1 (PPT)	*	433	183	184	115
S	2 "	*	620	365	351	243
F	3/4 "	*	987	702	650	512
6	5/6 "	*	17	47	39	34
	7 "	*	22	18	16	15
C	8 "	*	26	24	28	24
O	9 "	*	1489	1216	1629	1439
N	10 "	*	1635	1478	1652	1357
C	11 "	*	1453	1564	1727	1660
	12 "	*	1479	1413	1776	1655
C	LOC 9 (PPM)	*	2.4	2.3	3.5	3.1
O	3/4 "	*	1.9	1.7	2.4	1.9
	5/6 "	*	1.1	1.1	1.5	1.4

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT
DATA SUMMARY

RUN DATE: 2/24/82-WEDNESDAY

	PARAMETER (UNITS)	0600-0630	0630-0700	0700-0730	0730-0800
M	WSPD1 (M/S)	0.72	0.80	1.65	2.15
	WSPD2 (M/S)	1.07	0.98	1.87	2.51
E	WDIR (DEG)	127	121	120	132
	SDWD (DEG)	16.8	18.8	7.3	9.1
T	TEMP (C)	2.2	2.0	2.9	3.7
	STAB CLASS	G	D	C	C
	NBVOL (VPH)	1160	1860	2460	2980
	SBVOL (VPH)	502	848	970	1374
T	NBSPD (MPH)	60.0	58.6	57.8	58.1
R	SBSPD (MPH)	59.6	59.7	60.0	59.8
A	LDA	****/55.5	63.5/****	69.9/****	****/69.8
F	% LDT	****/26.7	30.1/****	22.5/****	****/19.8
F	VEH TYP MDT	****/ 1.4	0.7/****	0.6/****	****/ 0.3
I	(NB/SB) HDG	****/ 4.8	0.4/****	1.5/****	****/ 4.7
C	HDD	****/11.0	4.7/****	4.5/****	****/ 5.0
	MC	****/ 0.7	0.7/****	0.9/****	****/ 0.3
	RAMP NB	45.3	44.3	42.5	39.5
	(%TOT) SB	11.2	8.7	6.0	8.9
E	NB(ML/KM-S)	3.60	3.61	3.20	3.66
F	SB "	3.78	3.63	3.33	3.64
	LOC 1 (PPT)	774	754	564	311
S	2 "	928	876	772	483
F	3/4 "	1300	973	1003	744
6	5/6 "	44	34	47	46
	7 "	33	21	20	20
C	8 "	9	3	1	6
O	9 "	2561	1990	1463	1544
N	10 "	2624	2343	1927	1926
C	11 "	2765	2340	1721	1652
	12 "	3262	2464	2073	1913
C	LOC 9 (PPM)	2.4	3.3	3.8	3.3
O	3/4 "	1.7	1.9	2.6	2.2
	5/6 "	1.1	1.3	1.7	1.1

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT
DATA SUMMARY

RUN DATE: 2/25/82-THURSDAY

	PARAMETER (UNITS)	*	R E	S U	L T	S
		*	0600-0630	0630-0700	0700-0730	0730-0800
M	WSPD1 (M/S)	*	1.16	1.32	1.14	0.62
	WSPD2 (M/S)	*	1.64	1.78	1.42	0.97
E	WDIR (DEG)	*	104	105	101	82
	SDWD (DEG)	*	9.7	7.5	8.8	29.2
T	TEMP (C)	*	5.4	5.6	5.8	6.6
	STAB CLASS	*	F	F	D	C
	NBVOL (VPH)	*	1100	1900	2440	2880
	SBVOL (VPH)	*	500	706	886	1352
T	NBSPD (MPH)	*	59.0	59.2	58.8	57.1
R	SBSPD (MPH)	*	59.4	60.3	61.9	61.2
A	LDA	*	66.7/****	****/65.0	71.9/****	****/71.0
F	% LDT	*	23.0/****	****/23.6	21.9/****	****/17.8
F	VEH TYP MDT	*	0.0/****	****/ 1.4	0.6/****	****/ 0.0
I	(NB/SB) HDG	*	4.9/****	****/ 2.9	0.9/****	****/ 4.1
C	HDD	*	4.9/****	****/ 7.1	4.0/****	****/ 6.7
	MC	*	0.5/****	****/ 0.0	0.8/****	****/ 0.4
	RAMP NB	*	46.9	47.1	43.4	40.8
	(%TOT) SB	*	8.0	8.2	9.3	9.0
E	NB(ML/KM-S)	*	3.41	3.61	3.42	3.99
F	SB "	*	3.61	3.55	3.31	3.48
	LOC 1 (PPT)	*	709	786	802	616
S	2 "	*	1066	1052	882	696
F	3/4 "	*	1312	1242	1048	970
6	5/6 "	*	11	7	33	40
	7 "	*	13	10	16	21
C	8 "	*	24	13	24	26
O	9 "	*	2352	1822	1798	2095
N	10 "	*	2395	2175	1893	2165
C	11 "	*	2152	1962	1926	1962
	12 "	*	2407	1992	1738	1718
C	LOC 9 (PPM)	*	2.1	2.9	3.8	4.2
O	3/4 "	*	1.4	2.1	2.5	2.8
	5/6 "	*	0.9	0.8	1.5	1.9

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT
DATA SUMMARY

RUN DATE: 3/4/82-THURSDAY

	PARAMETER (UNITS)	*	0600-0630	0630-0700	0700-0730	0730-0800
M	WSPD1 (M/S)	*	1.00	1.16	1.29	1.38
	WSPD2 (M/S)	*	1.32	1.50	1.61	1.64
E	WDIR (DEG)	*	46	56	91	97
	SDWD (DEG)	*	12.1	16.6	9.5	13.8
T	TEMP (C)	*	5.1	5.4	7.3	7.2
	STAB CLASS	*	G	D	C	C
	NBVOL (VPH)	*	1140	1880	2580	2780
	SBVOL (VPH)	*	512	826	1008	1286
T	NBSPD (MPH)	*	59.6	60.3	58.5	56.8
R	SBSPD (MPH)	*	60.7	60.7	58.8	60.7
A	LDA	*	****/59.0	66.2/****	****/71.0	74.4/****
F	% LDT	*	****/23.0	25.5/****	****/15.4	18.8/****
F	VEH TYP MDT	*	****/ 1.0	0.0/****	****/ 0.0	0.2/****
I	(NB/SB) HDG	*	****/ 5.0	1.5/****	****/ 4.1	2.6/****
C	HDD	*	****/11.0	6.3/****	****/ 9.1	3.2/****
	MC	*	****/ 1.0	0.4/****	****/ 0.4	0.8/****
	RAMP NB	*	55.8	48.7	43.6	37.3
	(%TOT) SB	*	9.4	9.0	10.1	9.2
E	NB(ML/KM-S)	*	3.50	3.54	3.32	3.81
F	SB "	*	3.47	3.43	3.56	3.39
	LOC 1 (PPT)	*	720	455	414	192
S	2 "	*	806	609	609	352
F	3/4 "	*	1099	924	916	643
6	5/6 "	*	5	4	7	5
	7 "	*	13	5	7	6
C	8 "	*	14	12	10	11
O	9 "	*	1775	1423	1264	1721
N	10 "	*	1454	1682	1612	1729
C	11 "	*	1688	1795	1795	1944
	12 "	*	1880	1704	1584	1616
C	LOC 9 (PPM)	*	1.9	2.9	3.1	3.4
O	3/4 "	*	1.5	2.2	2.5	2.4
	5/6 "	*	0.8	1.3	1.5	1.3

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT .
DATA SUMMARY

RUN DATE: 3/23/82-TUESDAY

	PARAMETER (UNITS)	*	R E S U L T S 0600-0630	0630-0700	0700-0730	0730-0800
M	WSPD1 (M/S)	*	0.10	0.11	0.26	0.63
	WSPD2 (M/S)	*	0.35	0.27	0.46	1.01
E	WDIR (DEG)	*	110	196	248	46
	SDWD (DEG)	*	34.0	77.4	54.9	57.3
T	TEMP (C)	*	6.0	6.9	8.0	9.6
	STAB CLASS	*	C	C	B	B
	NBVOL (VPH)	*	1280	1860	2500	2860
	SBVOL (VPH)	*	542	818	1006	1284
T	NBSPD (MPH)	*	59.9	58.5	59.0	59.9
R	SBSPD (MPH)	*	61.3	61.4	61.4	61.3
A	LDA	*	65.5/****	****/64.5	72.3/****	****/68.9
F	% LDT	*	23.5/****	****/18.7	22.0/****	****/22.9
F	VEH TYP MDT	*	0.4/****	****/ 0.0	0.0/****	****/ 0.0
I	(NB/SB) HDG	*	1.7/****	****/ 6.0	0.5/****	****/ 1.7
C	HDD	*	7.1/****	****/10.2	4.6/****	****/ 6.1
	MC	*	1.7/****	****/ 0.6	0.5/****	****/ 0.3
	RAMP NB	*	44.1	46.1	42.3	38.7
	(%TOT) SB	*	****	****	****	****
E	NB(ML/KM-S)	*	3.45	3.47	3.06	3.74
F	SB "	*	3.55	3.09	3.24	3.46
	LOC 1 (PPT)	*	748	563	247	670
S	2 "	*	764	586	327	760
F	3/4 "	*	800	633	379	992
6	5/6 "	*	541	1093	1149	474
	7 "	*	212	878	1181	411
C	8 "	*	12	661	1180	308
O	9 "	*	3938	3037	2534	2451
N	10 "	*	4714	3522	2725	2478
C	11 "	*	4134	3823	3065	2459
	12 "	*	4109	3220	2700	2581
C	LOC 9 (PPM)	*	2.4	3.7	4.1	4.2
O	3/4 "	*	1.0	1.9	2.1	2.6
	5/6 "	*	1.0	2.0	2.6	2.0

CALTRANS 1981/82 TRACER DISPERSION EXPERIMENT
DATA SUMMARY

RUN DATE: 3/24/82-WEDNESDAY

	PARAMETER (UNITS)	*	0600-0630	0630-0700	0700-0730	0730-0800
M	WSPD1 (M/S)	*	0.13	0.58	1.73	1.52
	WSPD2 (M/S)	*	0.21	1.06	2.00	1.71
E	WDIR (DEG)	*	97	135	217	246
	SDWD (DEG)	*	43.2	20.5	23.2	13.3
T	TEMP (C)	*	6.9	7.5	8.0	8.4
	STAB CLASS	*	C	C	B	B
	NBVOL (VPH)	*	1280	1980	2580	2920
	SBVOL (VPH)	*	652	846	1058	1352
T	NBSPD (MPH)	*	59.8	58.9	57.7	58.6
R	SBSPD (MPH)	*	58.7	61.2	59.6	60.6
A	LDA	*	61.7/****	****/63.8	****/****	74.5/71.5
F	% LDT	*	25.9/****	****/20.7	****/****	18.2/22.3
F	VEH TYP MDT	*	1.2/****	****/ 0.0	****/****	0.0/ 0.0
I	(NB/SB) HDG	*	2.5/****	****/ 4.3	****/****	2.4/ 1.5
C	HDD	*	7.8/****	****/ 9.6	****/****	4.0/ 4.6
	MC	*	0.8/****	****/ 1.6	****/****	1.0/ 0.0
	RAMP NB	*	42.8	45.8	43.9	36.8
	(%TOT) SB	*	8.6	7.3	11.3	7.8
E	NB(ML/KM-S)	*	3.46	3.64	3.43	3.77
F	SB "	*	3.48	3.14	3.46	3.54
	LOC 1 (PPT)	*	1341	1269	227	377
S	2 "	*	1728	1380	343	187
F	3/4 "	*	1715	1442	340	113
6	5/6 "	*	281	595	1371	798
	7 "	*	177	58	565	582
C	8 "	*	578	146	609	150
O	9 "	*	2957	3139	1631	1784
N	10 "	*	3634	4027	1990	1959
C	11 "	*	4262	4063	2589	2213
	12 "	*	3385	4059	3000	2709
C	LOC 9 (PPM)	*	2.7	4.3	2.8	2.4
O	3/4 "	*	1.5	2.1	1.9	0.8
	5/6 "	*	1.3	1.9	2.0	1.6