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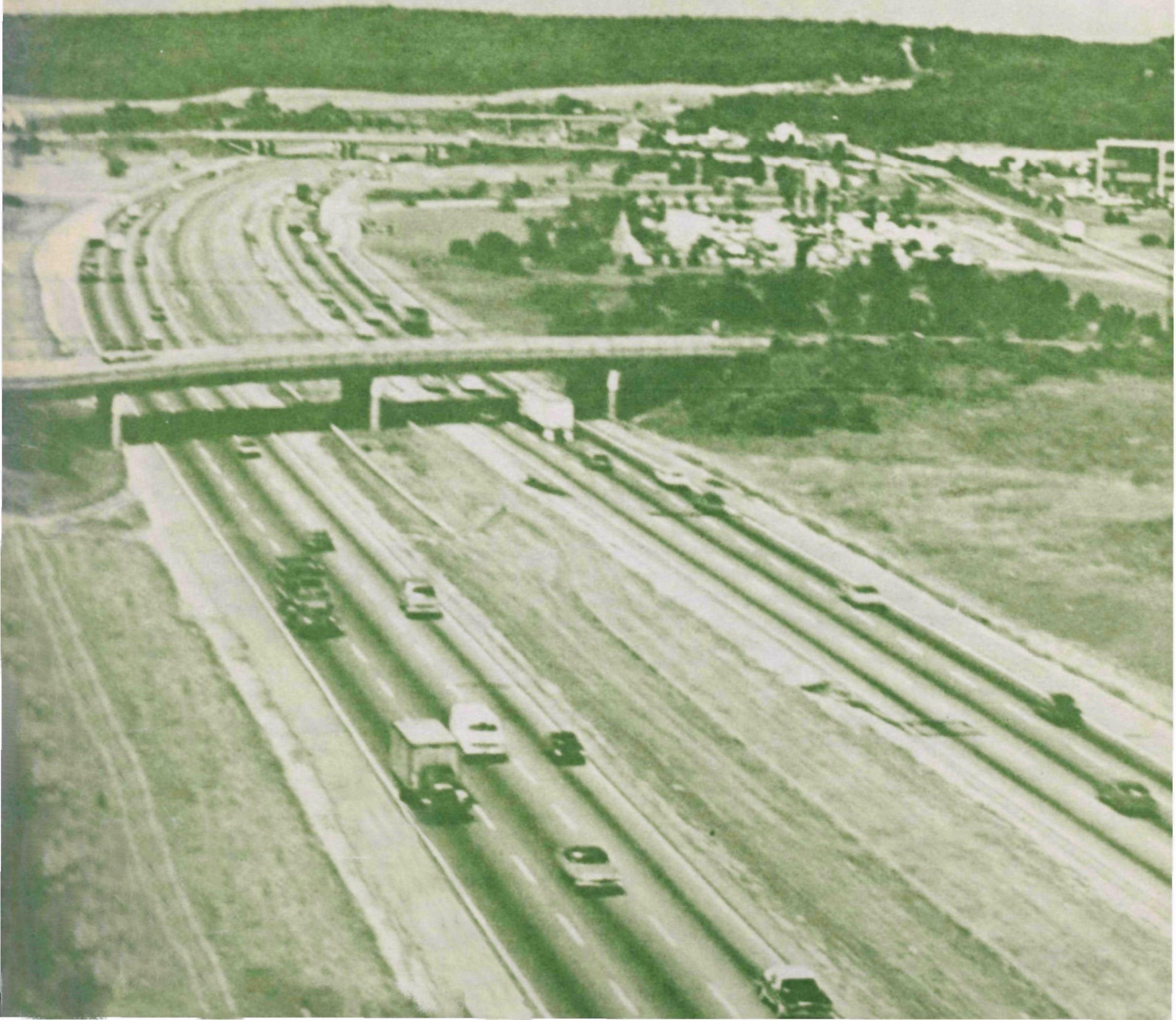
Research and Development

User's Guide for HIWAY — 2

A Highway Air Pollution Model



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USER'S GUIDE FOR HIWAY-2
A HIGHWAY AIR POLLUTION MODEL

by

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AUTHOR'S AFFILIATION

The author, William B. Petersen, is on assignment with the U.S. Environmental Protection Agency from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

PREFACE

HIWAY-2 is intended as an update to the HIWAY model. The changes necessary to update HIWAY were significant enough that a simple change in the version number seemed inappropriate. The name of the mdoel was changed to HIWAY-2 (version 80080) to reflect the major changes in the model. These changes also warranted a rewriting of the user's guide.

The User's Guide for HIWAY-2 was written so that the model can be easily executed without a thorough understanding of the mathematical formulation. Although the User's Guide is complete in itself, the user may wish to avoid the step of going from the printed page to a computer source program by obtaining the source code on magnetic tape from the National Technical Information Service, Springfield, VA 22151.

While attempts are made to thoroughly check out computer programs with a wide variety of data, errors occur occasionally. In case this model needs to be corrected, revised, or updated revisions will be distributed in the same manner as this report. If your copy was obtained by purchase or special order, you may obtain revisions as they are issued by completing the mailing form on the last page of this report.

Comments and suggestions regarding this document should be directed to Chief, Environmental Operations Branch, Meteorology and Assessment Division, Mail Drop 80, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

ABSTRACT

A computer model, called HIWAY-2, is described that can be used to estimate the concentrations of nonreactive pollutants from highway traffic. This steady-state Gaussian model can be applied to determine air pollution concentrations at receptor locations downwind of "at-grade" and "cut section" highways located in relatively uncomplicated terrain. For an at-grade highway, each lane of traffic is modeled as though it were a finite, uniformly emitting line source of pollution. For the cut section, the top of the cut is considered an area source. The area source is simulated by using ten line sources of equal source strength. The total source strength equals the total emissions from the lanes in the cut.

The air pollution concentration representative of hourly averaging times at a downwind receptor location is found by a numerical integration along the length of each lane and a summing of the contributions from each lane. With the exception of receptors directly on the highway or within the cut, the model is applicable for any wind direction, highway orientation, and receptor location. The model was developed for situations where horizontal wind flow occurs. The model cannot consider complex terrain or large obstructions to the flow such as buildings or large trees.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

EPA -- U.S. Environmental Protection Agency

g -- grams

GM -- General Motors

hr -- hours

km -- kilometers

LIE -- Long Island Expressway

m -- meters

mi -- miles

PG -- Pasquill-Gifford

sec -- seconds

UNAMAP -- User's Network for Applied Modeling of Air Pollution

veh -- vehicles

SYMBOLS

A -- end point of line source

B -- end point of line source

c -- term to determine θ_p, dependent upon stability, degrees

d -- factor to determine θ_p, dependent upon stability, degrees

n -- Number of reflections in Equation 9 ,dimensionless a — factor to determine σ_z (depends upon stability and distance range)

b — exponent to determine σ_z (depends upon stability and distance range), dimensionless

C — constant related to vehicle traffic

D — line source length, m

EF — emission factor, g veh^{-1} mi^{-1}

f — point source dispersion function, m^{-2}

H — effective source height, m

L — mixing height, m

ℓ — distance from point A to point R,S, m

q_ℓ — emission rate from line source, g m^{-1} sec^{-1}

U_C — cross-road wind component, m sec^{-1}

U — wind speed corrected for aerodynamic drag, m sec^{-1}

R — east coordinate, m

R_A — east coordinate of point A, m

R_B — east coordinate of point B, m

R_k — east coordinate of receptor k, m

S — north coordinate, m

S_A — north coordinate of point A, m

S_B — north coordinate of point B, m

S_k — north coordinate of receptor k, m

TV — traffic volume, veh hr^{-1}

u — wind speed, m sec^{-1}

x — downwind distance, meters or km

x_o — normalizing distance, km

y — crosswind distance, meters or km

z — receptor height above ground, m

β — direction, relative to north, of line from point A to point B, degrees

θ — wind direction, relative to north, degrees

θ_p — half angle of horizontal plume spreading, degrees

σ_y — standard deviation of the concentration distribution in the crosswind direction, m

σ_{y_o} — initial σ_y, m

σ_z — standard deviation of the concentration distribution in the vertical direction, m

σ_{z_o} — initial σ_z, m

σ_{z_a} — vertical dispersion due to the ambient environment, m

σ_{z_T} — total vertical dispersion, m

σ_{y_a} — crosswind dispersion due to the ambient environment,m

σ_{y_T} — total crosswind dispersion, m

χ — concentration, g m^{-3}

ϕ — wind angle relative to the roadway, degrees

ACKNOWLEDGMENTS

The User's Guide for HIWAY-2 contains verbatim much of the information recorded in the User's Guide to HIWAY. The author wishes to acknowledge John Zimmerman and Roger Thompson for their work. The author also expresses his appreciation to Dr. S.T. Rao and his staff at the New York State Department of Environmental Conservation without whose help this document could not have been written. Sincere appreciation also goes to Bruce Turner and George Schewe for their comments and review, and to Joan Emory for her assistance.

SECTION 1

INTRODUCTION

The National Environmental Policy Act of 1969 requires any federally funded highway construction project to be preceded by an impact statement analyzing the effect of the proposed roadway on air quality. This report describes a computer program, called HIWAY-2, that calculates air quality levels of nonreactive pollutants produced by highway automotive traffic at distances tens to hundreds of meters downwind of the highway in relatively uncomplicated terrain. HIWAY-2 provides the air quality specialist with a valuable tool for projecting the air quality impacts of future highway construction.

In making estimates of pollution concentrations for an "at-grade" highway, highway emissions are considered to be equivalent to a series of finite line sources. Each lane of traffic is modeled as though it were a straight, continuous, finite line source with a uniform emission rate. Air pollution concentrations downwind from a line source are found by a numerical integration along the line source of a simple Gaussian point-source plume. Although most applications of this model will be for ground-level sources and receptors, and for receptors close to the source where mixing height will have almost no effect, the more general case of nonzero source and receptor heights and inclusion of the effects of mixing height can be considered by the model.

The HIWAY-2 model is similar to the line-source equations (5.19 and 5.20) in the Workbook of Atmospheric Dispersion Estimates (Turner, 1970) but can also consider finite line sources at any angle to the wind.

An estimate may also be made of air pollution concentrations downwind of a "cut section" for which the top of the cut section is considered to be equivalent to an area source. This area source is simulated by using a series of ten equal line sources such that the total source strength is equal to the total pollution emissions of the highway.

No pollution emissions module is included in this version of the model. A value of the line-source strength, q_{ℓ}($g\ m^{-1}\ sec^{-1}$), for each lane of traffic must be obtained from a separate computation. Line-source strength is generally a function of traffic rate, average vehicle speed, and traffic mix (fraction of heavy-duty vehicles, fraction of late models with emission control devices, etc.). Data input for the HIWAY-2 program can be accomplished in two ways: (1) through batch mode, with data cards that follow the program deck (see Section 4 for format), and (2) through continuous mode, i.e., interactively on a time-share computer terminal. The term interactive refers to the information exchange between the user and the computer program in asking and answering questions.

SECTION 2

DESCRIPTION OF MODEL

AT-GRADE HIGHWAY

A view of an idealized four-lane at-grade highway is shown in Figure 1. Traffic emissions from each lane are simulated in the computer model by a straight line source of finite length. As shown in Figure 1 for a four-lane highway, the location of the highway is specified by the coordinates at the centerline (from edge to edge) of the highway (points 1 and 2). The ordering of the lanes is from left to right when one looks from point 1 to point 2. One lane or any even number of lanes from 2 to 24 can be used in the model.

The width of the highway and its center strip must also be entered as input data. With this information, the computer program HIWAY-2 will assign a finite uniform line source to each lane of traffic. These line sources are placed at the center of each traffic lane.

A uniform emission rate, q_ℓ, must be specified for each line source. This line-source emission rate can be found if the emission factor, EF (g veh^{-1} mi^{-1}), and the traffic volume, TV (veh hr^{-1}), are known:

$$q_\ell \; (g\ sec^{-1}\ m^{-1}) = \frac{EF\ (g\ veh^{-1}\ mi^{-1})\ TV\ (veh\ hr^{-1})}{1609.3(m\ mi^{-1})\ 3600\ (sec\ hr^{-1})} \qquad (1)$$

$$= 1.726 \times 10^{-7}\ (EF)\ (TV)$$

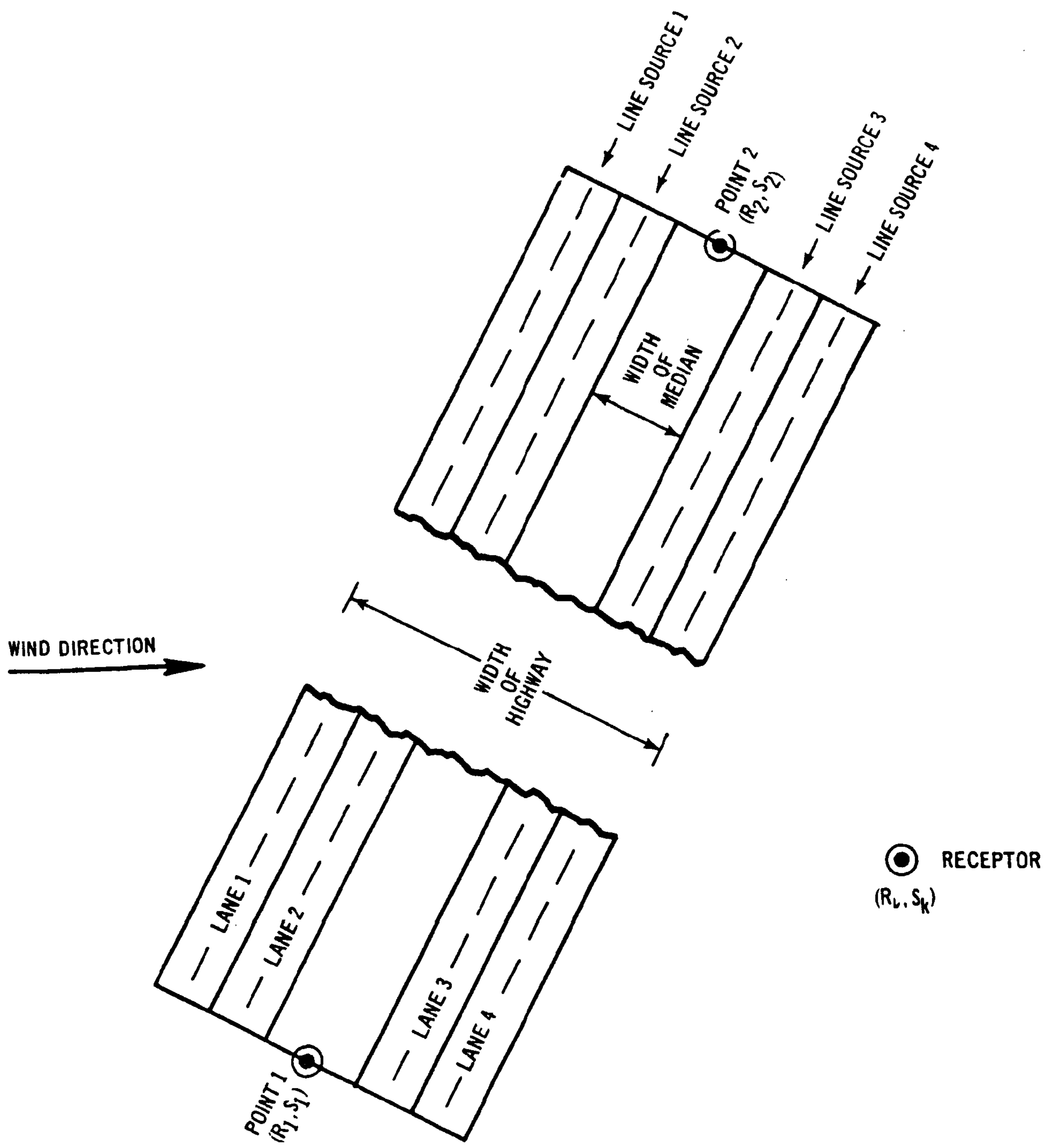

Figure 1. Overhead view of the geometry of at-grade highway as seen by the computer model. The endpoints of the highway are specified by the centerline coordinates, (R_1,S_1) and (R_2,S_2), while the receptor coordinates are given as (R_k,S_k). Line sources (four) are indicated by the dashed lines at the center of each lane of traffic.

A value of the emission factor for vehicles can be obtained from the most current issue of mobile source emission factors (EPA, 1974 and 1978).

CALCULATIONS

The calculation of concentration is made by a numerical integration of the Gaussian plume point-source equation over a finite length. The coordinates (meters) of the end points of a line source of length D (meters), representing a single lane extending from point A to point B (see Figure 2), are R_A, S_A and R_B, S_B. The direction of the line source from A to B from the north is β (degrees). The coordinates, R,S, of any point along the line at an arbitrary distance, ℓ (meters), from point A are given by:

$$R = R_A + \ell \sin \beta \qquad \text{(Eq.2)}$$

$$S = S_A + \ell \cos \beta \qquad \text{(Eq.3)}$$

Given a receptor at R_k, S_k, the downwind distance, x (meters), and the crosswind distance, y (meters), of the receptor from the point R,S for any wind direction, θ (degrees), is given by:

$$x = (S - S_k) \cos \theta + (R - R_k) \sin \theta \qquad \text{(Eq.4)}$$

$$y = (S - S_k) \sin \theta - (R - R_k) \cos \theta \qquad \text{(Eq.5)}$$

Since R and S are functions of ℓ, x and y are also functions of ℓ. The concentration, χ (gm^{-3}), from the line source is then given by:

$$\chi = \frac{q_\ell}{u} \int_0^D f \, d_\ell \qquad \text{(Eq.6)}$$

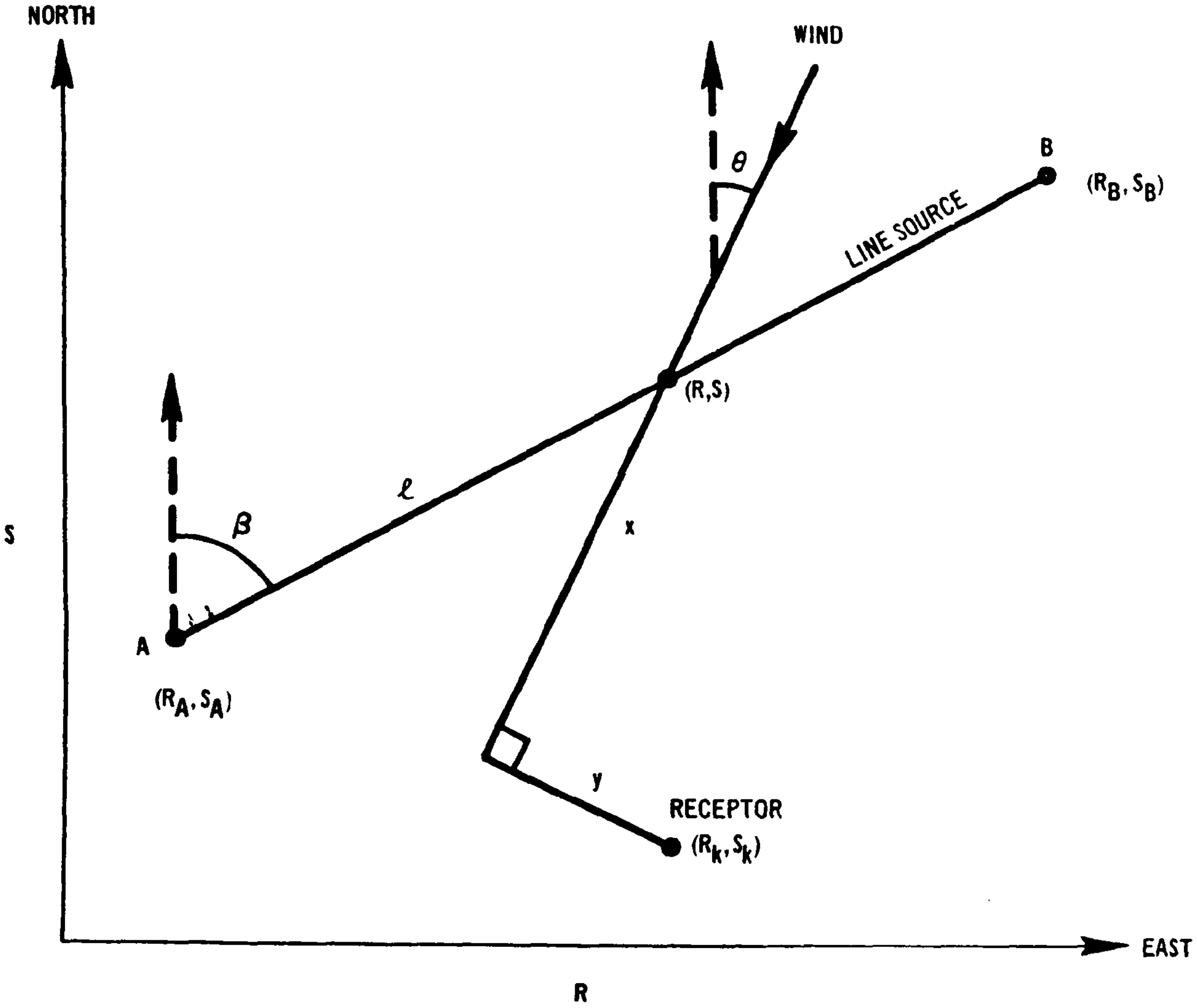

Figure 2. Line source and receptor relationships.

where: u = wind speed, m sec^{-1}

D = line source length, m

f = point source dispersion function (Equations 7 to 9), m^{-2}

For application of this model to a highway segment in relatively open terrain, an estimate of the wind speed, u, at approximately 2 meters height above ground is suitable.

For stable conditions, or if the mixing height is > 5000 meters:

$$f = \frac{1}{2\pi\sigma_y\sigma_z} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \quad \text{(Eq. 7)}$$

where: σ_y = standard deviation of the concentration distribution in the crosswind direction, m

σ_z = standard deviation of the concentration distribution in the vertical direction, m

z = receptor height above ground, m

H = effective source height, m

In unstable or neutral conditions, if σ_z is greater than 1.6 times the mixing height, L (meters), the distribution below the mixing height is uniform with height regardless of source or receptor height, provided both are less than the mixing height:

$$f = \frac{1}{\sqrt{2\pi}\sigma_y L} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \quad \text{(Eq. 8)}$$

In all other unstable or neutral conditions:

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

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

$$+ \exp -\frac{1}{2}\left(\frac{z+H-2NL}{\sigma_z}\right)^2 + \exp -\frac{1}{2}\left(\frac{z-H+2NL}{\sigma_z}\right)^2$$

$$\left.\left. + \exp -\frac{1}{2}\left(\frac{z+H+2NL}{\sigma_z}\right)^2\right]\right\} \quad \text{(Eq.9)}$$

The infinite series in Equation 9 converges rapidly, and more than four or five sums of the four terms are seldom required. In each of the three equations above, σ_y and σ_z are evaluated for the given stability class and downwind distance. If z, H, or both are zero, the resulting simpler forms of Equations 7, 8, and 9 are used by the computer program.

The value of the integral in Equation 6 is approximated by use of the Richardson extrapolation of the trapezoidal rule. The general idea of Richardson extrapolation is that a weighted average of two different estimates of the same value is a more accurate value than either of the initial estimates if the weights are chosen according to a known relation between the errors in the individual estimates.

In the algorithm HWYLNE, estimates are first made using the number of intervals equal to 3, 6,..., $3*(2)^9$. Calculations are successively repeated until the concentration estimates converge to within 2 percent of the previous estimate. If convergence is not reached by the time the number of intervals reaches 1536 (which is $3*(2)^9$), the estimated integral value is saved. A new sequence of estimations for intervals equal to 4, 8,..., $4*(2)^9$ is performed. Any new integral estimate for interval values of 4, 8,..., 2048 which is $4*(2)^9$) having a relative error from the saved integral estimate less than 2 percent signals convergence. If convergence is not obtained after 2048 intervals the program writes out a message indicating the relative error, the receptor number, and the line source number. The program then uses the minimum of the saved integral estimate and the current integral estimate as the integrated results.

The above evaluation of the integral is repeated for each lane of traffic; the resulting concentrations are summed to represent the total concentration from the highway segment.

CUT SECTION

Estimates of air pollution concentrations at locations downwind of a depressed highway (cut section) can be determined by considering the top of the cut section to be an area source of pollution (Figure 3). In the model, this area source is approximated by using ten line sources located at the top of the cut section. The total emission rate for the highway is first found by adding together the emission rates for each individual lane of traffic. Then this emission rate is distributed equally over each of the ten line sources used to simulate the area source at the top of the cut section. The procedure used to determine pollutant concentrations downwind of the cut section is then entirely similar to the procedure used to determine the concentrations for an at-grate highway. It should be emphasized that these estimates of air pollution concentrations should be made for receptors downwind of the cut section and not for locations inside the cut section itself.

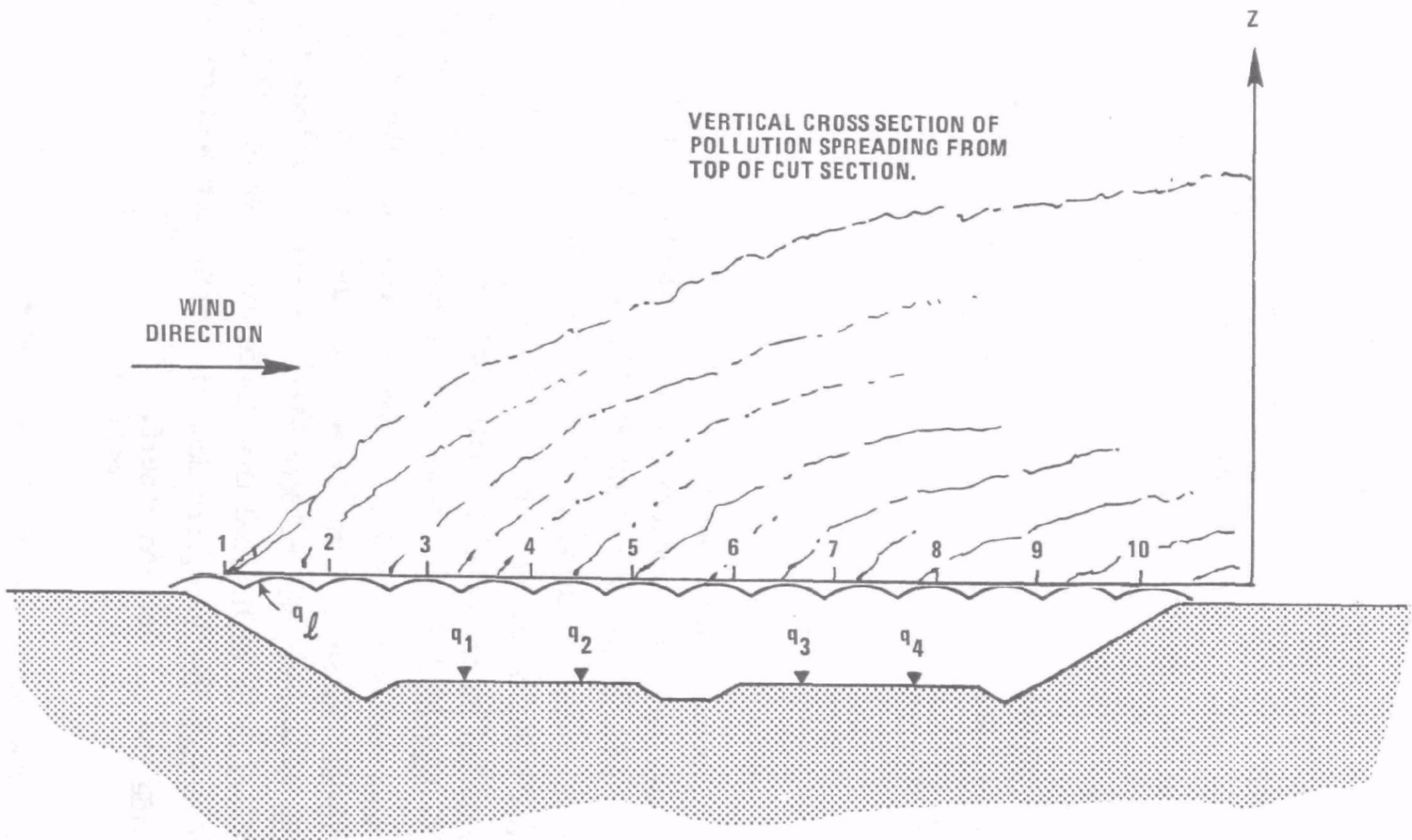

Figure 3. Method of simulating dispersion from a cut section. In this illustration, there are four lanes of traffic in a cut section with pollution emission rates q_1, q_2, q_3, and q_4. These emission rates are summed up and distributed equally over ten line sources placed at the top of the cut section, i.e., $q_\ell = (q_1 + q_2 + q_3 + q_4)/(10)$.

SECTION 3

DISPERSION AND DILUTION

Recent studies by Rao et al. (1979, 1980) and Eskridge et al. (1979a, 1979b) have demonstrated that the dispersion near the roadway is dominated by the turbulence generated by the moving traffic and that the ambient atmospheric stability plays little role in dispersing the pollutant in the immediate vicinity of the roadway. The dispersion parameters, σ_y and σ_z, indicate the amount the pollutant plume has spread (dispersed) after leaving its source. The values for these parameters near the roadway are documented in Appendix C.

The vertical dispersion parameter, σ_z, was evaluated from the tracer data collected during the General Motors (GM) Experiment (Cadle et al., 1976) and the Long Island Expressway (LIE) Experiment (Rao et al., 1978). Figure 4 is a plot of σ_z versus downwind distance. The (Pasquill-Gifford) (PG) curves are shown for reference. The data indicate that the dispersion downwind of the highway is typically between stability class A and C, even though the GM data represented a large number of cases when the atmosphere was stable. Also, considerable scatter in σ_z was found between stability classes. For these reasons, the dispersion in HIWAY-2, is specified to be a function of only three stability regimes. For PG stability classes A, B, and C, the unstable curve is used. For stability class D, the neutral curve is used; for stabilities E and F, the stable curve is used. The user specifies the PG stability class (A-F) and the appropriate dispersion curve is chosen by the model.

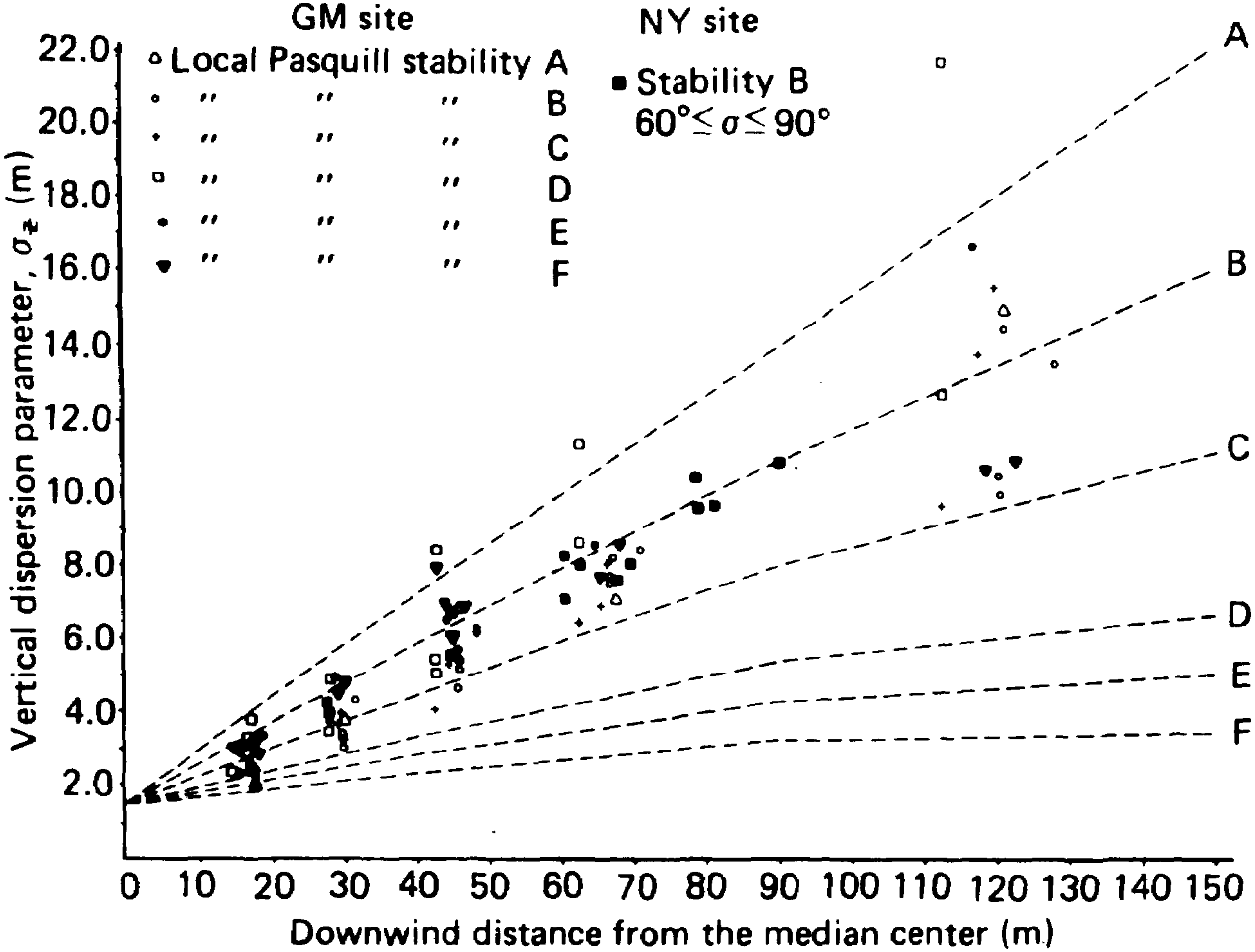

Figure 4. Vertical dispersion parameter as a function of downwind distance.

The total vertical dispersion paramter, σ_{z_T}, is composed of dispersion due to ambient turbulence plus the initial dispersion due to the turbulence generated by the vehicles, similar to that suggested by Pasquill (1976). σ_{z_T} is computed as:

$$\sigma_{z_T} = (\sigma_{z_a}^2 + \sigma_{z_o}^2)^{1/2} \qquad \text{(Eq.10)}$$

σ_{z_a} is of the form $a\ x^b$. Table 1 shows the values for a and b for the three stability regimes used in the model.

TABLE 1. VALUES OF a AND b USED TO COMPUTE σ_{z_a}

Stability Regime	a	b
Unstable	110.62	0.93198
Neutral	86.49	0.92332
Stable	61.14	0.91465

The total horizontal dispersion parameter, σ_{y_T}, is given by:

$$\sigma_{y_T} = (\sigma_{y_a}^2 + \sigma_{y_o}^2)^{1/2} \qquad \text{(Eq.11)}$$

σ_{y_a} is the horizontal dispersion due to ambient turbulence, and σ_{y_o} is the initial cross-wind dispersion due to the turbulence generated by the vehicles. σ_{y_a} is given by:

$$\sigma_{y_a} = 465.1(x) \tan \theta_p \qquad \text{(Eq.12)}$$

where: x = downwind distance from source to receptor, km

θ_p = half angle of horizontal plume spreading, degrees

The factor 465.1 is 1000 m km^{-1} divided by 2.15, the number of standard deviation of a Gaussian distribution from the centerline to the point where the distribution falls to 10 percent of the centerline value. The angle θ_p is given by:

$$\theta_p = c - d \ln (x/x_o) \qquad \text{(Eq.13)}$$

where c and d (degrees) are functions of stability and the normalizing distance, x_o, is 1 km. Values of the parameters c and d are given in Table 2.

TABLE 2. VALUES OF c AND d USED TO CALCULATE, θ_p

Stability Regimes	c	d
Unstable	18.333	1.8096
Neutral	14.333	1.7706
Stable	12.5	1.0857

Sufficiently far downwind the atmospheric dispersion process dominates the dispersion of the plume from the roadway. At 300 meters downwind the dispersion curves are merged into the PG curves; the unstable curve is merged into the PG class B curve, the neutral curve into the PG class D curve, and the stable curve into the PG class E curve. At 300 meters downwind the dispersion due to the roadway is computed by subtracting the square of the ambient dispersion parameter (a function of stability class) from the square of the total dispersion, ${\sigma_{z_T}}^2$ or ${\sigma_{y_T}}^2$. The initial dispersion due to the roadway at 300 meters is then used as the initial dispersion and the ambient dispersion is determined from the PG curves. σ_z and σ_y for distances beyond 300 meters are then computed in a similar manner to Equations 10 and 11.

INITIAL DISPERSION

Turbulence of the air produced by the motion of automobiles results in a rapid mixing of the pollutants near the highway. This mixing is modeled by assuming that an initial spreading of the pollutant plume occurs over the highway. Zimmerman and Thompson (1975), using a limited data base, suggested that the initial vertical dispersion, σ_{z_o}, should be 1.5 meters. The value of 1.5 meters is a conservative estimate of the vertical standard deviation of the plume at the downwind edge of the at-grade highway and was considered as a tentative value by the authors.

In order to improve the estimate of the initial vertical dispersion, σ_{z_o} was calculated as a function of wind speed from the GM data for the nearest roadside receptor. (See Appendix C). The initial vertical dispersion parameter is specified as:

$$\sigma_{z_o} = 3.57 - 0.53\, U_c \qquad \text{(Eq. 14)}$$

The cross-road wind component is indicated by U_c. HIWAY-2 is programmed such that U_c is computed and used in Equation 14 to estimate σ_{z_o}. However, the smallest allowable value of σ_{z_o} is 1.5 meters.

For at-grade highways, the initial horizontal dispersion, σ_{y_o}, has an arbitrary value of twice the initial vertical dispersion. When σ_{z_o} equals 1.5 meters, σ_{y_o} equals 3.0 meters, the same as in HIWAY. However, as σ_{z_o} increases due to small cross-road winds, σ_y increases proportionally. The value given to σ_{y_o} has little effect on the computation of air pollution concentration when the wind direction has a component perpendicular to the highway. The use of an initial σ_y accounts for a reasonable amount of cross-road spreading caused by vehicle-generated turbulence when the wind direction is parallel or nearly parallel to the highway.

Very few measurements have been published on air quality downwind of a cut section. Nevertheless, the available data indicate that the cut section configuration tends to increase the dispersion of the air pollution orginating from the cut section. This effect occurs particularly when wind speeds are light, for then the release of heat from combustion, the long travel time of the pollutant to the receptor, and mechanical turbulence produced by the cut section highway aid the dispersion. Thus, for the cut section case, based upon very limited data, the initial σ's for wind speeds less than 1 m sec^{-1} were set at 10 meters for σ_y and 5 meters for σ_z. It was assumed that for wind speeds greater than 3 m sec^{-1} the cut section did not enhance the initial dispersion. Therefore, 3 meters for σ_y and 1.5 meters for σ_z were used. For speeds between 1 and 3 m sec^{-1}, the initial sigmas are linearly interpolated. These initial σ's are assumed for each of the ten lanes used to represent the cut. The initial values of σ_y and σ_z (meters) are found from:

$$\left.\begin{aligned} \sigma_{yo} &= 3 \\ \sigma_{zo} &= 1.5 \end{aligned}\right\} \text{ for } u > 3 \text{ m sec}^{-1} \qquad \text{(Eq. 15)}$$

$$\left.\begin{aligned} \sigma_{yo} &= 10 - 7\left(\frac{u-1}{2}\right) \\ \sigma_{zo} &= 5 - 3.5\left(\frac{u-1}{2}\right) \end{aligned}\right\} \text{ for } 1 < u < 3 \text{ m sec}^{-1} \qquad \text{(Eq. 16)}$$

and

$$\left.\begin{aligned} \sigma_{yo} &= 10 \\ \sigma_{zo} &= 5 \end{aligned}\right\} \text{ for } u < 1 \text{ m sec}^{-1} \qquad \text{(Eq. 17)}$$

AERODYNAMIC DRAG

HIWAY-2 has incorporated in it an aerodynamic drag factor that accounts for the initial dilution of the pollutant on the roadway, and allows the model to make reasonable concentration estimates during low wind speed conditions. Analysis of the GM data revealed that the aerodynamic drag factor must be a function of the wind-road orientation angle, because the amount of acceleration in the lower layers is most significant under parallel wind-road orientation (Appendix C). Hence, an aerodynamic drag factor that is a function of wind-road angle was developed and incorporated into the HIWAY-2 model. The relation developed is:

$$U_C = C\, u^{0.164} \cos^2 \phi \qquad \text{(Eq. 18)}$$

u is the ambient wind speed (m sec^{-1}), ϕ is the wind-road angle, and C is a constant related to the traffic speed. It is observed that C equals 1.85 for moderate to high traffic speed conditions. However, for low traffic speeds data are not available at this time to evaluate the value of C. This relation takes full effect for parallel wind ($\phi = 0$) situations but has no effect for perpendicular wind cases. If the ambient wind speed is less than the wind speed computed according to the above relation, then only the corrected wind speed will be applied. If the ambient wind speed is greater than the corrected wind speed, no changes to the wind speed are made, thus, allowing correction for only low wind speed situations (ambient wind speeds less than 2 m sec^{-1}).

SECTION 4

COMPUTER ASPECTS AND INPUT DATA PREPARATION

COMPUTER MODEL

The FORTRAN computer program consists of a main program and four subroutines. Figure 5 depicts the general flow of the model. The main program handles input and sets up a separate line source for each lane of traffic. Subroutine HWYLNE does the integration and provides printouts of results. This subroutine calls HWYRCX, which evaluates Equations 7, 8, or 9, or simplifications of these equations if H or z is zero. Evaluation of σ_y and σ_z are done by subroutines HWYSIG and DBTSIG, which are called from HWYRCX. The program is capable of processing multiple hours of meteorology for multiple sources, (see Appendix A).

An east-north coordinate system (see figure 2) is used in the computer model. The width of the highway and of its center strip, the coordinates of the centerline of the highway, and the coordinates of the receptor(s) are input parameters. However, in Equations 4 and 5, x and y refer to a coordinate system aligned along the wind vector (x, the downwind direction, and y, the crosswind direction). That system is distinct from the coordinate system used for locating sources and receptors in the model.

In the basic equations given earlier (Equations 2 to 5), units of the coordinate system have been specified as meters for dimensional balance. However, for practicality units of the computer coordinate system, are in kilometers. The user may use any convenient highway map unit if he enters an appropriate scaling factor to convert those units to kilometers. For example, if units of meters are desired for highway coordinates, the scale factor should be entered as 0.001. This section contains a list of the input variables, including a brief description of each of the units by which the input parameters must be expressed. An example of input data, as well as the output of a run made with the example input data, is given in Appendix A.

CARD INPUT SEQUENCE

The sequence of input data cards is shown in Figure 6. The format of data on the input cards for the batch mode of operation is given in Table 3. The coordinates of the roadway are in the center of the highway (from edge to edge). The ordering of the lanes is from left to right when looking from point 1 to point 2 (Figure 1).

INTERACTIVE OPERATION

The self-explanatory listing produced by the model on a remote computer terminal is shown in Appendix A to illustrate the operation of the model in an interactive mode. The computer communicates to the user in upper case letters, while the user replies in lower case letters.

Operation of the model in an interactive mode is similar to batch mode operation. However, in the interactive mode the data for each line source must be entered seperately. Thus, the impact of multiple line sources on air quality is more easily assessed using the batch mode. The model is capable of assessing the air quality impact for multiple sets of meteorological data in both the batch and interactive modes.

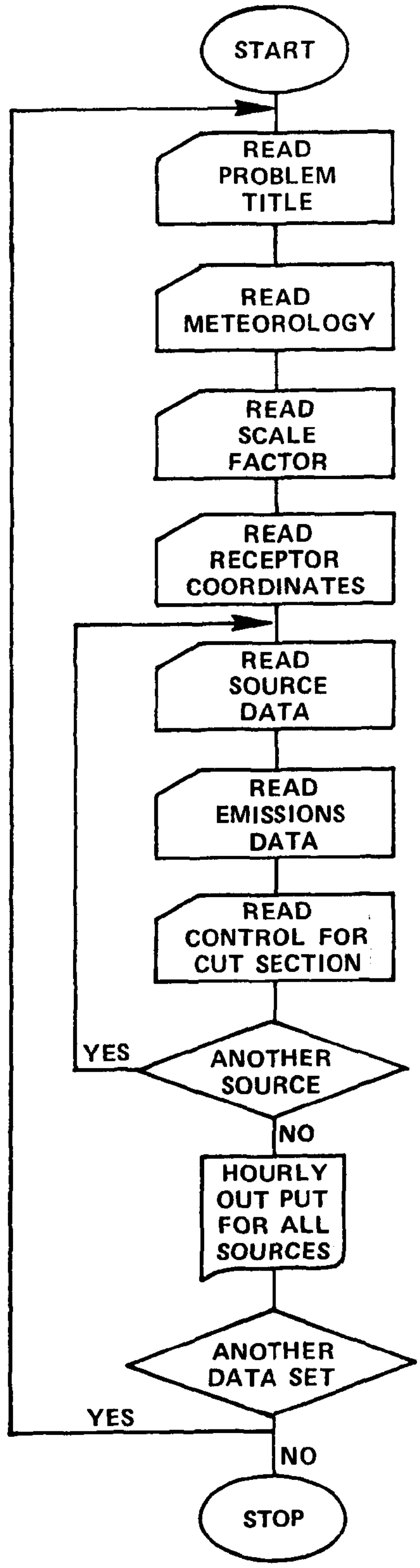

Figure 5. General flow diagram for HIWAY-2.

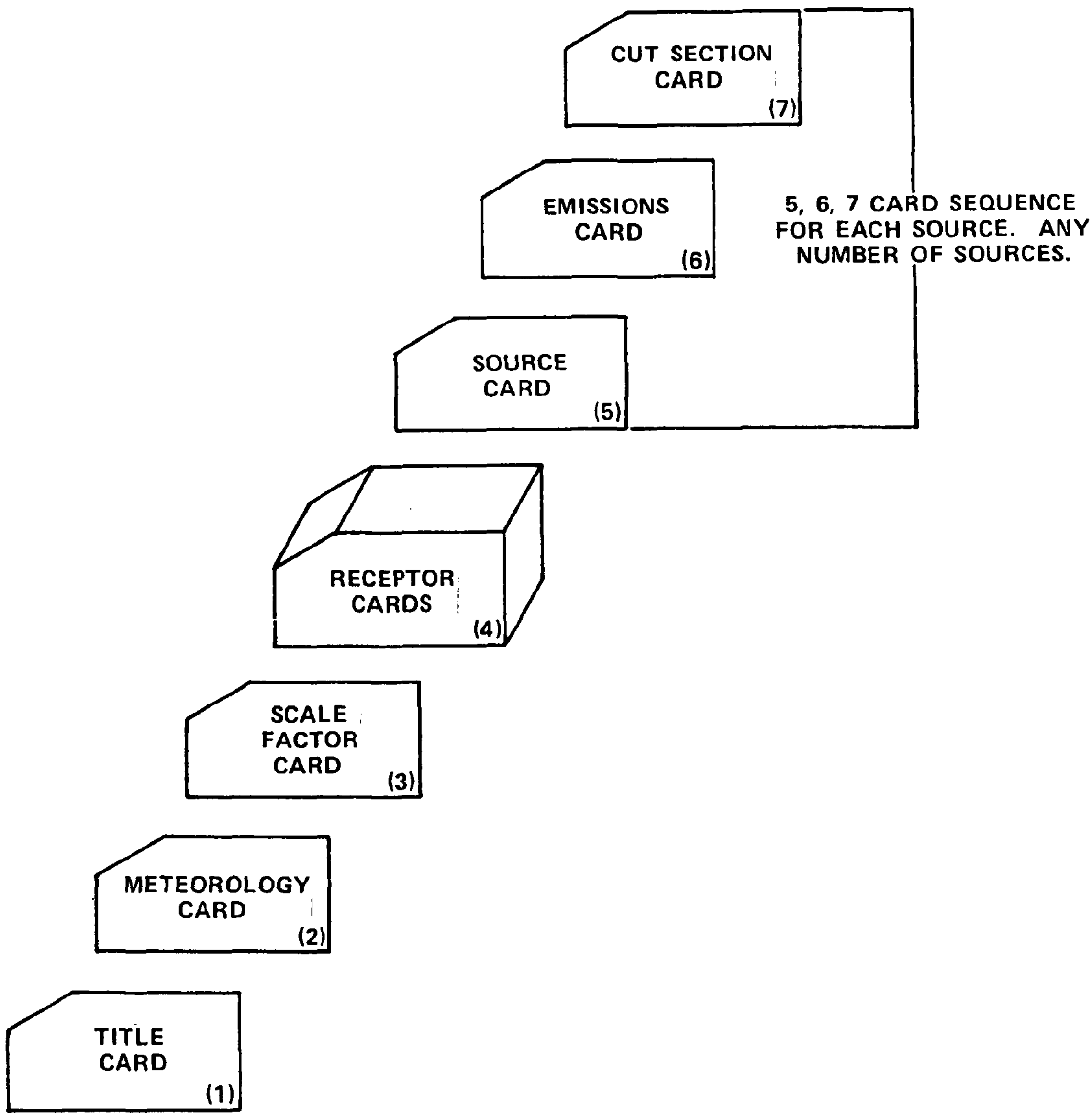

Figure 6. Input data deck for the batch mode of operation for HIWAY-2. Card type numbers are in parenthesis.

TABLE 3. INPUT DATA CARDS

Name	Columns	Format	Form	Variable	Units
Card type 1 (1 card)					
Head	1-80	20A4	AAAA	Alphanumeric data for heading	-
Card type 2 (1 card)					
THETA	1-10	F10.0	XXX.	Wind direction	Degrees
u	11-20	F10.0	XX.X	Wind speed	$m\ sec^{-1}$
HL	21-30	F10.0	XXXX.	Height of mixing layer	Meters
XKST	31-40	F10.0	X.	Pasquill stability class	-
Card type 3 (1 card)					
GS[a]	1-10	F10.0	X.	Scale factor	-
Card type 4 (up to 50 cards)					
XXRR[b]	1-10	F10.0	XXXX.XXX	East coordinate of receptor	Map units
XXSR	11-20	F10.0	XXXX.XXX	North coordinate of receptor	Map units
Z	21-30	F10.0	XX.	Height (above ground) of receptor	Meters
Card type 5 (any number of cards					
REP1[c]	1-0	F10.0	XXXX.XXX	East coordinate, point 1	Map units
SEP1	11-20	F10.0	XXXX.XXX	North coordinate point 1	Map units
REP2	21-30	F10.0	XXXX.XXX	East coordinate, point 2	Map units
SEP2	31-40	F10.0	XXXX.XXX	North coordinate, point 2	Map units
H	41-50	F10.0	XX.X	Height of line source	Meters
WIDTH	51-60	F10.0	XX.	Total width of highway	Meters
CNTR	61-70	F10.0	XX.	Width of center strip	Meters
XNL	71-80	F10.0	X.	Number of traffic lanes	-
Card type 6 (up to 3 cards)					
QLS	1-80	F10.0	.XXXXXXX	Emission rate for each lane	$g\ sec^{-1}m^{-1}$
Card type 7 (1 card, can be blank for at grade)					
CUT	1-10	F10.0	X.	1, if cut; 0, if at grade	-
WIDTC	11-20	F10.0	XX.	Width of top of cut section	Meters

[a]The scale factor converts map units to kilometers:
If map units in kilometers, scale factor = 1.0
If map units in meters, scale factor = 0.001
If map units in feet, scale factor = 0.000305
If map units in miles, scale factor = 1.61

[b]To begin again with another set of data, a value 9999. is punched for XXRR (card type 4) following the last receptor card. A value of -9999. for XXRR will cause the program to terminate after data set.

[c]Any number of sources can be input. Card types 5-7 must be used for each source. 1F REP1=9999. end of source data, card types 6 and 7 should not follow.

A complete listing of the computer code is given in Appendix B with verification of HIWAY-2 demonstrated in Appendix C. The HIWAY-2 model has been placed on the EPA User's Network for Applied Modeling of Air Pollution (UNAMAP) computer system. For information on this system contact: Chief, Data Management, Meteorology Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

REFERENCES

Cadel, S.H., D. P. Chock, J. M. Heuse and P. R. Monson 1976. Results of the General Motors Sulfate Dispersion Experiments, General Motors Research Publication, GMR-2107.

Eskridge, R.E., and J.C.R. Hunt 1979a. Highway Modeling: Part I - Prediction of Velocity and Turbulence Fields in the Wake of Vehicles. J. Appl. Meteor. 36: 387.

Eskridge, R.E., F.S. Binkowski, J.C.R. Hunt, T.L. Clark and K.E. Demerjian 1979b. Highway Modeling Part II - Advection and Diffusion of SF_6 Tracer Gas. J. Appl. Meteor. 36: 401.

Pasquill, F. 1976. Atmospheric Dispersion Parameters in Gaussian Plume Modeling Part II. Possible Requirements for Changes in the Turner Workbook Values. EPA-600/4-76-030b, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. 43 pp.

Rao, S.T., M. Chen, M. Keenan, G. Sistla, R. Peddada, G. Wotzak, and N. Kolak 1978. Dispersion of Pollutants Near Highways - Experimental Design and Data Acquisition Procedures. EPA-600/4-78-037, U.S. Environmental Protection Agency, Reseach Triangle Park, North Carolina. 56 pp.

Rao, S.T., M. Kennan, F. Sistla, and P. Sampson 1979. Dispersion of Pollutants Near Highways, Data Analysis and Model Evaluation. EPA-600/4-79-011, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. 158 pp.

Rao, S.T. Final Report of Grant 806017-01. Atmospheric Turbulence and Pollutant Dispersion Near Highways. 1980. (Unpublished)

U.S. Environmental Protection Agency 1974. Automobile Exhaust Emission Modal Analysis Model. EPA-460/3-74-005, U.S. Environmental Protection Agency, Ann Arbor, Michigan.

U.S. Environmental Protection Agency 1978. Mobile Source Emission Factors. EPA-400/9-78-005, U.S. Environmental Protection Agency, Washington, D.C.

Turner, D.B. 1970 Workbook of Atmospheric Dispersion Estimates. AP-26, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. 84 pp.

Zimmerman, J.R., and R.S. Thompson 1975 User's Guide for HIWAY, A Highway Air Pollution Model, EPA-650/4-74-008, U.S. Environmental Protection Agency Research Triangle Park, North Carolina 59 pp.

APPENDIX A

EXAMPLE PROBLEM

INTRODUCTION

In order to clarify the procedure for using both the batch and interactive (continuous) versions of the HIWAY-2 model, the following test problem is solved using both versions.

Given: Length of highway - 5 km.
Orientation - east-west.
Number of lanes - four.
Road width (edge to edge) - 46 meters.
Median width - 30 meters.
Emission rate in each lane from south to north
0.0112, 0.0103, 0.0106, and 0.0156 g sec^{-1} m^{-1}.
Wind direction - 42 degrees.
Wind speed - 3.7 m sec^{-1}.
Stability class - 3.

Find: The expected concentration at receptors along a line perpendicular to the center of the highway segment at distances 1, 5, 10, 30, and 50 meters from the downwind edge of the roadway (1) if the road is an at-grade section, and (2) if the road is a cut section with the top of the cut being 50 meters in width.

SOLUTION USING THE INTERACTIVE VERSION

Assuming that you have already logged on the computer, etc.,you are then given the choice of receiving a description of the model. Following that, enter the input parameters as the model calls for them. Most of them are self-explanatory; however, a few comments are in order:

1. When entering the mixing height, never use the value 0.
2. If you do not want the effect of a limit to vertical mixing in your calculation, use a large enough mixing height so that there is no chance of its influencing your results, such as 5000 meters.
3. The coordinates for the ends of the roadway segment are assumed to be in the center of the road (from edge to edge).
4. The ordering of emission rates is for lanes in order from left to right when looking from point 1 to point 2.

An example problem using the interactive version of HIWAY-2 is shown in Table A-1. The results for the at-grade section are given following the entry of receptor coordinates. For convenience, the center of the roadway has been placed 0.023 km north of the origin in this example, so that the edge of the road is on the axis and the y coordinate of the receptor is the distance from the edge of the road. The roadway and receptors could have been placed at any location.

The option to run the model for a new receptor location (LOC), change the road type (TYPE), or to end the program (END) is given after the results.

In the second part of the problem, the road type (cut), the width (50 meters), and the location of the road (to again place the edge of the road at a "y" coordinate value of zero) are changed. The results for the cut section are shown following the entry of data. Note that the concentrations are in micrograms per cubic meter (UGM/M**3). The part per million (PPM) column is a conversion from micrograms per cubic meter for the pollutant carbon monoxide. The part per million column would be incorrect for any other pollutant.

SOLUTION USING THE BATCH VERSION

The batch version requires at least seven input cards. Depending upon the number of receptor points, the number of sources, and number of problems to be run, more cards may be necessary. The format for each card is given in Table 3. Table A-2 lists the input for the example problem; Table A-3 lists the results. Note that for the cut section, the sixth and seventh fields (columns 51 to 70) in card type 5 were left blank. Also, note that for card type 4, XXRR can have a value of -9999. or 9999. A -9999. indicates the end of the problem after card types 5-7 are read in. A value of 9999. indicates a new problem follows after card types 5-7. Card types 5-7 are always read in sequence. Any number of sources can be input using the 5,6,7 card sequence to describe the source and emissions. If REP1 = 9999., then the last source has been read in and card types 6,7 are not read. The program will print out the concentration estimates from each line source and the total contribution from all the line sources.

TABLE A-1. EXAMPLE PROBLEM USING INTERACTIVE VERSION OF HIWAY-2.

```
DO YOU WANT A DESCRIPTION OF THE EPA "HIWAY-2" MODEL
BEFORE APPLYING IT?(YES OR NO)

>yes

1.THE EPA "HIWAY-2" MODEL COMPUTES INERT POLLUTANT CONCENTRATIONS IN THE
  VICINITY OF A ROADWAY ON A SHORT TERM BASIS (HOURLY AVERAGES) USING
  THE GAUSSIAN PLUME FORMULATION. IF MORE THAN ONE ROADWAY IS PRESENT,
  SUPERPOSITION APPLIES. THE MODEL CAN BE USED FOR AT GRADE AND CUT
  SECTIONS FOR RECEPTOR DISTANCES OF TENS TO HUNDREDS OF METERS DOWNWIND
  OF THE LINE SOURCE IN RELATIVELY UNCOMPLICATED TERRAIN.
2.THE COORDINATE SYSTEM IS ARRANGED SUCH THAT THE X-AXIS INCREASES FROM
  WEST TO EAST WHILE THE Y-AXIS INCREASES FROM SOUTH TO NORTH.THE UNITS
  RELATED TO HIGHWAY MEASUREMENTS ARE INDICATED BY A SCALE FACTOR OF
  USER UNITS TO KILOMETERS. THE MOST FREQUENTLY USED FACTORS ARE:
                      UNITS          SCALE FACTOR
                    KILOMETERS        1.0
                    METERS            0.001
                    FEET              0.000305
                    MILES             1.61
  SCALE FACTOR UNITS APPLY EXCEPT WHEN OTHER UNITS ARE SPECIFICALLY
  REQUESTED.
3.THE EMISSION DATA IS DEPENDENT ON VEHICLE SPEED,TYPES AND NUMBER OF
  VEHICLES,AND EMISSION CONTROL DEVICES. EMISSIONS (GM/SEC*M) ARE
  ENTERED IN ORDER FROM LEFT TO RIGHT WHEN LOOKING FROM ROAD END
  PT 1 TO END PT 2.
4.ROAD COORDINATES ARE THE ENDPOINTS OF THE HIGHWAY CENTER LINE.
  WIND DIRECTION IS DERIVED BY MEASURING CLOCKWISE(EAST) FROM
  DUE NORTH.(E.G.,WIND FROM NORTH IS 0 DEGREES;EASTERLY WIND IS 90.)
5.THE PROGRAM CONTAINS THE OPTION TO EVALUATE ANY NUMBER OF
  RECEPTOR LOCATIONS AND/OR TYPES OF ROADS.
6.YOU MUST SEPARATE MULTIPLE INPUTS WITH COMMAS.
7.FOR MOST APPLICATIONS,THE HEIGHTS OF THE RECEPTOR AND
  SOURCES ARE ASSUMED TO BE THE SAME.


DO YOU WANT A DESCRIPTION OF THIS VERSION OF "HIWAY-2"?(YES OR NO)

>no
ENTER PROBLEM TITLE OF 64 CHARACTERS OR LESS
> example of interactive version of HIWAY-2
ENTER SCALE FACTOR (KILOMETERS/USER UNIT).
>1.
ENTER LINE(ROAD) ENDPOINTS.(ORDERED PAIRS:X1,Y1,X2,Y2)
>
```

TABLE A-1. (continued)

```
 2.5,.023,-2.5,.023
ENTER EMISSION HEIGHT. (METERS)
>0.
ENTER WIND DIRECTION (DEG).  NORTH IS ZERO.
>42.
ENTER WIND SPEED (METERS/SEC).
>3.7
ENTER MIXING HEIGHT (METERS).
>1000.
ENTER PASQUILL-TURNER STABILITY CLASS (1-6).
>3
ENTER THE NUMBER OF LANES.
>4
ENTER LINE SOURCE STRENGTH VECTOR.(A VALUE FOR EACH LANE)
>.0112,.0103,.0106,.0156
IS THIS A CUT SECTION?  (YES OR NO)
>no
ENTER HIGHWAY WIDTH (METERS).
>46.
ENTER WIDTH OF CENTER STRIP (METERS).
>30.
ENTER NUMBER OF RECEPTOR LOCATIONS DESIRED.(MAXIMUM OF 25)
>5
ENTER RECEPTOR COORDINATE SETS.(X&Y IN SCALE FACTOR UNITS;Z IN METERS)
>0.,-.001,0.,0.,-.005,0.,0.,-.010,0.,
>0.,-.030,0.,0.,-.050,0.



HIWAY-2 VERSION: 80080

 example of interactive version of HIWAY-2
ENDPOINTS OF THE LINE SOURCE
    2.500,     .023  AND   -2.500,     .023
EMISSION HEIGHT IS     .000 METERS
EMISSION RATE (GRAMS/SECOND*METER) OF    4 LANE(S)
   .112-001     .103-001     .106-001     .156-001
WIDTH OF AT-GRADE HIGHWAY IS    46.000 METERS
WIDTH OF CENTER STRIP IS    30.000 METERS
WIND DIRECTION IS    42.  DEGREES
WIND SPEED IS    3.7 METERS/SEC
STABILITY CLASS IS    3
HEIGHT OF LIMITING LID IS  1000.0 METERS
THE SCALE FACTOR IS     1.0000 KM/USER UNIT.
```

TABLE A-1. (continued)

RECEPTOR LOCATION X	Y	HEIGHT Z (M)	CONCENTRATION UGM/M**3	PPM*
.0000	-.0010	.0000	3258.	2.834
.0000	-.0050	.0000	3137.	2.730
.0000	-.0100	.0000	2634.	2.292
.0000	-.0300	.0000	1546.	1.345
.0000	-.0500	.0000	1106.	.962

* PPM CONCENTRATIONS CORRECT FOR CARBON MONOXIDE ONLY.

```
YOU HAVE THE OPTION TO RUN THE MODEL FOR A NEW RECEPTOR LOCATION
(LOC),OR TO CHANGE THE ROADWAY TYPE,OR TO END THE PROGRAM.
ENTER LOC, OR TYPE, OR END.
>type
ENTER LINE(ROAD) ENDPOINTS.(ORDERED PAIRS:X1,Y1,X2,Y2)
>2.5,.025,-2.5,.025
ENTER EMISSION HEIGHT. (METERS)
>0.
ENTER WIND DIRECTION (DEG).  NORTH IS ZERO.
>42.
ENTER WIND SPEED (METERS/SEC).
>3.7
ENTER MIXING HEIGHT (METERS).
>1000.
ENTER PASQUILL-TURNER STABILITY CLASS (1-6).
>3
ENTER THE NUMBER OF LANES.
>4
ENTER LINE SOURCE STRENGTH VECTOR.(A VALUE FOR EACH LANE)
>.0112,.0103,.0106,.0156
IS THIS A CUT SECTION?  (YES OR NO)
>yes
ENTER WIDTH OF TOP OF CUT. (METERS)
>50.
ENTER NUMBER OF RECEPTOR LOCATIONS DESIRED.(MAXIMUM OF 25)
>5
ENTER RECEPTOR COORDINATE SETS.(X&Y IN SCALE FACTOR UNITS;Z IN METERS)
>0.,-.001,0.,0.,-.005,0.,
>0.,-.010,0.,0.,-.030,0.,
>0.,-.050,0.
```

TABLE A-1. (continued)

```
HIWAY-2 VERSION: 80080

 example of interactive version of HIWAY-2
ENDPOINTS OF THE LINE SOURCE
    2.500,      .025   AND   -2.500,      .025
EMISSION HEIGHT IS     .000 METERS
EMISSION RATE (GRAMS/SECOND*METER) OF    4 LANE(S)
   .112-001     .103-001     .106-001     .156-001
WIDTH OF TOP OF CUT SECTION IS    50.000 METERS
WIND DIRECTION IS     42.  DEGREES
WIND SPEED IS     3.7 METERS/SEC
STABILITY CLASS IS     3
HEIGHT OF LIMITING LID IS  1000.0 METERS
THE SCALE FACTOR IS      1.0000 KM/USER UNIT.
```

RECEPTOR LOCATION		HEIGHT	CONCENTRATION	
X	Y	Z (M)	UGM/M**3	PPM*
.0000	-.0010	.0000	3023.	2.630
.0000	-.0050	.0000	2740.	2.384
.0000	-.0100	.0000	2343.	2.039
.0000	-.0300	.0000	1465.	1.274
.0000	-.0500	.0000	1076.	.937

* PPM CONCENTRATIONS CORRECT FOR CARBON MONOXIDE ONLY.

ENTER LOC, OR TYPE, OR END.
>end

```
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
--------------------------------------------------------------------------------
 EXAMPLE OF BATCH VERSION OF HIWAY-2
       42.       3.7     1000.        3.
        1.
        0.     -.001        0.
        0.     -.005        0.
        0.     -.010        0.
        0.     -.030        0.
        0.     -.050        0.
    -9999.
       2.5     0.023      -2.5     0.023       0.0      46.0      30.0        4.
     .0112     .0103     .0106     .0156
        0.
       2.5     0.025      -2.5     0.025       0.0                            4.
     .0112     .0103     .0106     .0156
         1       50.
     9999.
--------------------------------------------------------------------------------
12345678901234567890123456789012345678901234567890123456789012345678901234567890
         1         2         3         4         5         6         7         8
```

TABLE A-2. CARD INPUT FOR EXAMPLE PROBLEM

TABLE A-3. EXAMPLE PROBLEM USING BATCH VERSION OF HIWAY-2.

```
EXAMPLE OF BATCH VERSION OF HIWAY-2


  HIWAY-2 VERSION: 80080
WIND DIRECTION IS     42.  DEGREES
WIND SPEED IS     3.7 METERS/SEC
STABILITY CLASS IS     3
HEIGHT OF LIMITING LID IS  1000.0 METERS
THE SCALE OF THE COORDINATE AXES IS     1.0000 KM/USER UNIT.


ENDPOINTS OF LINE SOURCE  1
   2.500,      .023 AND   -2.500,      .023
EMISSION HEIGHT IS     .000 METERS
EMISSION RATE (GRAMS/SECOND*METER) OF    4 LANE(S)
   .112-001     .103-001     .106-001     .156-001
WIDTH OF AT-GRADE HIGHWAY IS       46.0 M
WIDTH OF CENTER STRIP IS       30.0 M


  RECEPTOR LOCATION        HEIGHT     CONCENTRATION
     X          Y           Z(M)     UGM/METER**3      PPM *
   .0000      -.0010       .0000         3258.       2.834
   .0000      -.0050       .0000         3137.       2.730
   .0000      -.0100       .0000         2634.       2.292
   .0000      -.0300       .0000         1546.       1.345
   .0000      -.0500       .0000         1106.        .962

*  PPM CONCENTRATIONS CORRECT FOR CARBON MONOXIDE ONLY.



ENDPOINTS OF LINE SOURCE  2
   2.500,      .025 AND   -2.500,      .025
EMISSION HEIGHT IS     .000 METERS
EMISSION RATE (GRAMS/SECOND*METER) OF    4 LANE(S)
   .112-001     .103-001     .106-001     .156-001
WIDTH OF TOP OF CUT SECTION IS     50.000 M

  RECEPTOR LOCATION        HEIGHT     CONCENTRATION
     X          Y           Z(M)     UGM/METER**3      PPM *
   .0000      -.0010       .0000         3023.       2.630
   .0000      -.0050       .0000         2740.       2.384
   .0000      -.0100       .0000         2343.       2.039
   .0000      -.0300       .0000         1465.       1.274
   .0000      -.0500       .0000         1076.        .937

*  PPM CONCENTRATIONS CORRECT FOR CARBON MONOXIDE ONLY.
```

TABLE A-3. (continued)

TOTAL CONCENTRATION FROM ALL 2 LINE SOURCE(S)

RECEPTOR LOCATION X	Y	HEIGHT Z(M)	CONCENTRATION UGM/METER**3	PPM *
.0000	-.0010	.0000	6281.	5.464
.0000	-.0050	.0000	5878.	5.114
.0000	-.0100	.0000	4977.	4.330
.0000	-.0300	.0000	3011.	2.619
.0000	-.0500	.0000	2183.	1.899

* PPM CONCENTRATIONS CORRECT FOR CARBON MONOXIDE ONLY.

APPENDIX B
SOURCE CODE LISTING

```
C        HIWAY-2 - NEW VERSION - MARCH 1980
C        THIS PROGRAM CALCULATES THE CONCENTRATION FROM A LINE SOURCE
      COMMON /SOL/ QLN(25),HLN(25),RAQ(25),SAQ(25),RBQ(25),SBQ(25),CON(5
     10),CLSS(50),NLINE
      COMMON /REC/ RR(51),SR(51),ZR(51)
      COMMON /WEA/ THETA,U,KST,HL
      COMMON /PUT/ XXRR(51),XXSR(51),QLS(25),HEAD(20),IWRI
      COMMON /WS/ WSP,SYON,SZON
      DIMENSION Z(51), CONT(50), CLSST(50)
      IVERS=80080
      IRD=5
      IWRI=6
C         FORM OF INPUT TO HIWAY (BATCH)
C
C     VARIABLE
C      NAME
C          COLUMNS
C               FORMAT
C                    FORM     VARIABLE                          UNITS
C
C   CARD TYPE 1 (1 CARD) HEADER OR TITLE CARD
C      HEAD  1-80 20A4  AAAA        ALPHANUMERIC DATA FOR HEADING.
C
C   CARD TYPE 2 (1 CARD) METEOROLOGICAL CARD
C      THETA  1-10 F10.0 XXX.      WIND DIRECTION             (DEGREES)
C      U     11-20 F10.0 XX.X      WIND SPEED                  (METERS)
C      HL    21-30 F10.0 XXXX.     HEIGHT OF MIXING LAYER      (METERS)
C      XKST  31-40 F10.0 X.        PASQUILL STABILITY CLASS(DIMENSIONLESS)
C
C   CARD TYPE 3 (1 CARD) SCALE FACTOR (MAP UNITS TIMES SCALE FACTOR = KM)
C      GS     1-10 F10.0 X.XXXX    SCALE FACTOR
C   CARD TYPE 4 (UP TO 50 CARDS) RECEPTOR CARDS
C      XXRR   1-10 F10.0 XXXX.XXX EAST  COORD. OF RECEPTOR    (MAP UNITS)
C      XXSR  11-20 F10.0 XXXX.XXX NORTH COORD. OF RECEPTOR    (MAP UNITS)
C      Z     21-30 F10.0 X.XX      HEIGHT OF RECEPTOR (ABOVE GROUND) (METE
C
C         XXRR ON LAST RECEPTOR CARD SHOULD HAVE A VALUE OF -9999.
C         OR 9999.. IF XXRR = -9999. END OF PROBLEM . IF XXRR = 9999.
C         BEGIN A NEW PROBLEM AFTER CARD TYPES 5-7 ARE READ IN.
C
C   CARD TYPE 5 (1 CARD) SOURCE CARD
C      REP1   1-10 F10.0 XXXX.XXX EAST  COORD.,POINT 1        (MAP UNITS)
C      SEP1  11-20 F10.0 XXXX.XXX NORTH COORD.,POINT 1        (MAP UNITS)
C      REP2  21-30 F10.0 XXXX.XXX EAST  COORD.,POINT 2        (MAP UNITS)
C      SEP2  31-40 F10.0 XXXX.XXX NORTH COORD.,POINT 2        (MAP UNITS)
C      H     41-50 F10.0 XX.X      HEIGHT OF LINE SOURCE         (METERS)
C      WIDTH 51-60 F10.0 XX.       TOTAL WIDTH OF HIWAY          (METERS)
C      CNTR  61-70 F10.0 XX.       WIDTH OF CENTER STRIP (MEDIAN) (METERS)
C      XNL   71-80 F10.0 X.        NUMBER OF TRAFFIC LANES (DIMENSIONLESS)
C
```

```
C        CARD TYPES 5-7 ARE ALWAYS READ IN SEQUENCE. ANY NUMBER
C        OF SOURCES CAN BE INPUT USING THE 5,6,7 CARD SEQUENCE
C        TO DESCRIBE THE SOURCE AND EMISSIONS. IF REP1 = 9999.
C        LAST SOURCE. CARD TYPES 6,7 ARE NOT READ.
C
C  CARD TYPE 6 (UP TO 3 CARDS) EMISSIONS FOR EACH LANE.
C       LANES ORDERED LEFT TO RIGHT WHEN LOOKING FROM POINT 1 TO POINT 2
C     QLS     1-80 F10.0 .XXXXXXXXX EMISSION RATE FOR EACH LANE (G/SEC-M)
C
C  CARD TYPE 7 (1 CARD) AT-GRADE OR CUT? (CAN BE BLANK FOR AT-GRADE)
C     CUT     1-10 F10.0 X.         1, IF CUT; 0, IF AT-GRADE(DIMENSIONLESS)
C     WIDTC  11-20 F10.0 XX.        WIDTH AT TOP OF CUT SECTION     (METERS)
C
C
C        READ HEADER CARD
10    READ (IRD,230,END=400) HEAD
      WRITE (IWRI,240) HEAD
      WRITE (IWRI,250) IVERS
      READ (IRD,290) THETA,U,HL,XKST
      KST=XKST
C        THETA IS THE WIND DIRECTION IN DEGREES.
C        U IS THE WIND SPEED IN METERS PER SECOND.
C        KST IS THE STABILITY CLASS
C        HL IS THE HEIGHT OF THE LIMITING LID
      WRITE (IWRI,260) THETA,U,KST,HL
      READ (IRD,290) GS
C        GS IS THE MEASURE BETWEEN COORDINATES (KM).
      WRITE (IWRI,270) GS
      ICHK=1
      N=1
20    READ (IRD,290) XXRR(N),XXSR(N),Z(N)
      IF (XXRR(N).GE.9998.) GO TO 50
C
C       IF XXRR = -9999. END OF PROGRAM.
C       IF XXRR = 9999. NEW PROGRAM FOLLOWS AFTER CARD TYPES 5-7.
C
      IF (XXRR(N).LE.-9998.) ICHK=2
      IF (XXRR(N).LE.-9998.) GO TO 50
      IF (N-52) 40,30,30
30    WRITE (IWRI,280)
      GO TO 400
40    RR(N)=XXRR(N)*GS
      SR(N)=XXSR(N)*GS
      ZR(N)=Z(N)
      N=N+1
      GO TO 20
50    N=N-1
      NLINE=0
      DO 60 I=1,50
      CONT(I)=0.
```

```
60    CLSST(I)=0.
70    READ (IRD,290,END=200) REP1,SEP1,REP2,SEP2,H,WIDTH,CNTR,XNL
      IF (REP1.GE.9998.) GO TO 200
      NLINE=NLINE+1
C        REP1,SEP1 ARE THE COORDINATES OF AN END POINT OF THE LINE
C         SOURCE IN SOURCE COORDINATES.
C        REP2,SEP2 ARE THE COORDINATES OF THE OTHER END POINT OF THE
C         LINE SOURCE IN SOURCE COORDINATES.
C        H IS THE EFFECTIVE EMISSION HEIGHT OF THE SOURCE IN METERS.
C        WIDTH IS THE HIGHWAY WIDTH (M) FOR AT GRADE
C        CNTR IS THE WIDTH OF THE CENTER STRIP (M)
C        XNL IS THE NUMBER OF LANES FOR THE AT-GRADE HIGHWAY.
C
C        IF REP1 = 9999. LAST SOURCE. CARD TYPES 6,7 ARE NOT READ.
C
      WRITE (IWRI,300) NLINE,REP1,SEP1,REP2,SEP2
      NL=XNL
      WRITE (IWRI,310) H
      WRITE (IWRI,320) NL
      READ (IRD,290) (QLS(I),I=1,NL)
C        QLS IS THE LINE SOURCE STRENGTH (GRAMS/SECOND*METER)
      WRITE (IWRI,330) (QLS(I),I=1,NL)
      READ (IRD,290) CUT,WIDTC
C         CUT SECTION.
C         WIDTC IS THE WIDTH OF THE TOP OF THE CUT SECTION (M)
      IF (CUT.LE.0.0001) GO TO 100
C        DQLS IS THE CUT SECTION SOURCE STRENGTH
      DQLS=0.
      DO 80 I=1,NL
80    DQLS=DQLS+QLS(I)
      XNDL=10.
      NL=XNDL
      DQLS=DQLS/XNDL
      WRITE (IWRI,340) WIDTC
      DO 90 I=1,NL
90    QLS(I)=DQLS
      WIDTH=WIDTC
      XNL=XNDL
      CNTR=0.
      GO TO 110
100   WRITE (IWRI,350) WIDTH,CNTR
110   CONTINUE
      WRITE (IWRI,360)
      REP12=REP1-REP2
      SEP12=SEP1-SEP2
      RNGL=ATAN2(REP12,SEP12)
      RNGL=RNGL*57.2958
      IF (RNGL.LT.0.) RNGL=360.-ABS(RNGL)
      DRNG=ABS(THETA-RNGL)
      IF (DRNG.GT.180.) DRNG=DRNG-180.
```

```
      IF (DRNG.GT.90.) DRNG=180.-DRNG
      ANGLE=0.0175*ABS(DRNG)
      CO=COS(ANGLE)
      CS=CO*CO
      FU=1.85*CS*(U**0.164)
      R=FU/U
      RFU=1.
      IF (R.GT.1.) RFU=R
      U=RFU*U
      WSP=ABS(U*SIN(ANGLE))
      RA=REP1*GS
      RB=REP2*GS
      SA=SEP1*GS
      SB=SEP2*GS
      WL=(WIDTH-CNTR)/XNL
      IF (CUT.GT.0.00001) GO TO 130
120   SYON=3.
      SZON=1.5
      GO TO 150
130   IF (U.GT.3.) GO TO 120
      IF (U.LT.1.) GO TO 140
      DUM=(U-1.)/2.
      SYON=10.-7.*DUM
      SZON=5.-3.5*DUM
      GO TO 150
140   SYON=10.
      SZON=5.
150   CONTINUE
      IF (NL.EQ.1) WL=0.
      IF (NL.EQ.1) CNTR=0.
      DELR=RB-RA
      DELS=SB-SA
      DIST=SQRT(DELS*DELS+DELR*DELR)
      NLIM=NL/2
      ALIM=NLIM
      DO 160 ID=1,NLIM
      A=ID
      DL=(-0.5)*CNTR+((-1)*ALIM-0.5+A)*WL
      DUM=DL*0.001/DIST
      RAQ(ID)=RA+DELS*DUM
      RBQ(ID)=RB+DELS*DUM
      SAQ(ID)=SA-DELR*DUM
      SBQ(ID)=SB-DELR*DUM
      QLN(ID)=QLS(ID)
      HLN(ID)=H
160   CONTINUE
      NS=NLIM+1
      AS=NS
      DO 170 ID=NS,NL
      A=ID
```

```
      DL=0.5*CNTR+(0.5+A-AS)*WL
      DUM=DL*0.001/DIST
      RAQ(ID)=RA+DELS*DUM
      RBQ(ID)=RB+DELS*DUM
      SAQ(ID)=SA-DELR*DUM
      SBQ(ID)=SB-DELR*DUM
      QLN(ID)=QLS(ID)
      HLN(ID)=H
170   CONTINUE
      K=NL
      DO 180 IDUM=1,N
180   CON(IDUM)=0.
C    K IS NUMBER OF LINE SOURCES
C    N IS NUMBER OF RECEPTORS
      CALL HWYLNE (K,N)
      WRITE (IWRI,370)
      DO 190 I=1,N
      CONT(I)=CONT(I)+CON(I)
190   CLSST(I)=CLSST(I)+CLSS(I)
      GO TO 70
200   CONTINUE
      IF (NLINE.EQ.1) GO TO 220
      WRITE (IWRI,380) NLINE
      WRITE (IWRI,360)
      DO 210 I=1,N
      WRITE (IWRI,390) XXRR(I),XXSR(I),ZR(I),CONT(I),CLSST(I)
210   CONTINUE
      WRITE (IWRI,370)
220   GO TO (10,400), ICHK
C
230   FORMAT (20A4)
240   FORMAT ('0',/,20A4,/)
250   FORMAT ('0  HIWAY-2 VERSION:',I6)
260   FORMAT (' WIND DIRECTION IS',F7.0,'  DEGREES',/,' WIND SPEED IS',F
     17.1,' METERS/SEC'/' STABILITY CLASS IS',I5,/,' HEIGHT OF LIMITING
     2LID IS',F8.1,' METERS')
270   FORMAT (' THE SCALE OF THE COORDINATE AXES IS ',F10.4,' KM/USER UN
     1IT.'//)
280   FORMAT (1H0,'THE NUMBER OF RECEPTORS IS LIMITED TO 50. YOU HAVE AT
     1 TEMPTED TO READ THE 51ST. NO COMPUTATIONS MADE. ')
290   FORMAT (8F10.0)
300   FORMAT (' ENDPOINTS OF LINE SOURCE',I3,/,F9.3,',',F9.3,' AND',F9.3
     1,',',F9.3)
310   FORMAT (' EMISSION HEIGHT IS',F8.3,' METERS')
320   FORMAT (' EMISSION RATE (GRAMS/SECOND*METER) OF',I4,' LANE(S)')
330   FORMAT (8E12.3)
340   FORMAT (' WIDTH OF TOP OF CUT SECTION IS',F10.3,' M')
350   FORMAT (' WIDTH OF AT-GRADE HIGHWAY IS',F10.1,' M',/,' WIDTH OF CE
     1NTER STRIP IS',F10.1,' M',/)
360   FORMAT (1H0,'  RECEPTOR LOCATION      HEIGHT     CONCENTRATION',/,
```

```
     1'       X',10X,'Y              Z(M)     UGM/METER**3      PPM *')
370   FORMAT (1HO,'*  PPM CONCENTRATIONS CORRECT FOR CARBON MONOXIDE ONL
     1Y.',/////)
380   FORMAT (///,5X,'TOTAL CONCENTRATION FROM ALL',I3,' LINE SOURCE(S)'
     1,/)
390   FORMAT (1H ,3(F10.4,2X),F10.0,F10.3)
400   STOP
C
      END
```

```
C         HIWAY-2 - NEW UNIVAC INTERACTIVE VERSION - MARCH 1980
C         THIS PROGRAM CALCULATES THE CONCENTRATION FROM A LINE SOURCE
C          AT EACH OF A NUMBER OF RECEPTORS.
      COMMON /SOL/ QLN(25),HLN(25),RAQ(25),SAQ(25),RBQ(25),SBQ(25),CON(5
     10),CLSS(50),NLINE
      COMMON /REC/ RR(51),SR(51),ZR(51)
      COMMON /WEA/ THETA,U,KST,HL
      COMMON /PUT/ XXRR(51),XXSR(51),QLS(25),HEAD(20),IWRI
      COMMON /WS/ WSP,SYON,SZON
      DIMENSION Z(51), SVF(48), QQLS(25)
      DATA YES /'YES '/ ,YESL /0171145163040/
      DATA RLOC /'LOC '/ ,RLOCL /0154157143040/
      DATA CHA /'TYPE'/ ,CHAL /0164171160145/
C---INITIALIZATION
      IVERS=80080
      NLINE=1
      ISPEC=0
      IRD=5
      IWRI=6
      READ (IRD,210) DESC
C * * *   ABOVE READ IS PROCESSOR DUMMY READ * * *
C---
C---MODEL AND VERSION DESCRIPTIONS.
C---
      WRITE (IWRI,200)
      READ (IRD,210) DESC
      IF (DESC.EQ.YES.OR.DESC.EQ.YESL) CALL TEXT1
      WRITE (IWRI,220)
      READ (IRD,210) DESC
      IF (DESC.EQ.YES.OR.DESC.EQ.YESL) CALL TEXT2
C---
C---INTERACTIVE INPUT.
      WRITE (6,230)
      READ (IRD,210) HEAD
C---
      WRITE (IWRI,240)
```

```
      READ (IRD,*) GS
10    WRITE (IWRI,250)
      READ (IRD,*) REP1,SEP1,REP2,SEP2
      WRITE (IWRI,260)
      READ (IRD,*) H
      WRITE (IWRI,270)
      READ (IRD,*) THETA
      WRITE (IWRI,280)
      READ (IRD,*) U
      WRITE (IWRI,290)
      READ (IRD,*) HL
      WRITE (IWRI,300)
      READ (IRD,*) XKST
      KST=XKST
      WRITE (IWRI,310)
      READ (IRD,*) NL
      XNL=NL
      WRITE (IWRI,360)
      READ (IRD,*) (QLS(I),I=1,NL)
C---STORE DUMMY NL, QLS FOR PRINTOUT.
      NNL=NL
      DO 50 I=1,NL
50    QQLS(I)=QLS(I)
      WRITE (IWRI,370)
      READ (IRD,210) CUT
      IF (CUT.NE.YES.AND.CUT.NE.YESL) GO TO 60
C         CUT SECTION.
C         WIDTC IS THE WIDTH OF THE TOP OF THE CUT SECTION (M)
      WRITE (IWRI,380)
      READ (IRD,*) WIDTC
      GO TO 70
60    WRITE (IWRI,390)
      READ (IRD,*) WIDTH
      WRITE (IWRI,400)
      READ (IRD,*) CNTR
70    WRITE (IWRI,410)
      READ (IRD,*) NRCO
      IF (NRCO.GT.25) NRCO=25
      WRITE (IWRI,420)
      READ (IRD,*) (XXRR(N),XXSR(N),Z(N),N=1,NRCO)
C---
C---LIST PARAMETERS FOR THIS RUN.
C---
      WRITE (IWRI,430) IVERS
      WRITE (6,440) HEAD
      WRITE (IWRI,450) REP1,SEP1,REP2,SEP2
      WRITE (IWRI,460) H
C---NLL=NL, QQLS=QLS.
      WRITE (IWRI,470) NNL
C        QLS IS THE LINE SOURCE STRENGTH (GRAMS/SECOND*METER)
```

```
      WRITE (IWRI,480) (QQLS(I),I=1,NNL)                                HIW08600
C        XNDL IS THE NUMBER OF LINE SOURCES REPRESENTING THE TOP OF THE HIW08700
C         CUT SECTION.                                                  HIW08800
C         WIDTC IS THE WIDTH OF THE TOP OF THE CUT SECTION (METERS)     HIW08900
      IF (CUT.NE.YES.AND.CUT.NE.YESL) GO TO 100                         HIW09000
C        DQLS IS THE CUT SECTION SOURCE STRENGTH                        HIW09100
      DQLS=0.                                                           HIW09200
      DO 80 I=1,NL                                                      HIW09300
80    DQLS=DQLS+QLS(I)                                                  HIW09400
      XNDL=10.                                                          HIW09500
      NL=XNDL                                                           HIW09600
      DQLS=DQLS/XNDL                                                    HIW09700
      CNTR=0.                                                           HIW09800
      XNL=XNDL                                                          HIW09900
      WIDTH=WIDTC                                                       HIW10000
      WRITE (IWRI,490) WIDTC                                            HIW10100
      DO 90 I=1,NL                                                      HIW10200
90    QLS(I)=DQLS                                                       HIW10300
      GO TO 110                                                         HIW10400
100   WRITE (IWRI,500) WIDTH,CNTR                                       HIW10500
C        THETA IS THE WIND DIRECTION IN DEGREES.                        HIW10600
C        U IS THE WIND SPEED IN METERS PER SECOND.                      HIW10700
C        KST IS THE STABILITY CLASS                                     HIW10800
C        HL IS THE HEIGHT OF THE LIMITING LID                           HIW10900
110   WRITE (IWRI,510) THETA,U,KST,HL                                   HIW11000
C        GS IS THE MEASURE BETWEEN COORDINATES (KM).                    HIW11100
      WRITE (IWRI,520) GS                                               HIW11200
C          CONVERT COORDINATE SYSTEM SO THAT HIGHWAY                    HIW11300
C           IS ORIENTATED ALONG ZERO DEGREES (MATH SYSTEM)              HIW11400
      WRITE (IWRI,530)                                                  HIW11500
C---                                                                    HIW11600
C---COORDINATE MANIPULATION.                                            HIW11700
C---                                                                    HIW11800
      REP12=REP1-REP2                                                   HIW11900
      SEP12=SEP1-SEP2                                                   HIW12000
      RNGL=ATAN2(REP12,SEP12)                                           HIW12100
      RNGL=RNGL*57.2958                                                 HIW12200
      IF (RNGL.LT.0.) RNGL=360.-ABS(RNGL)                               HIW12300
      DRNG=ABS(THETA-RNGL)                                              HIW12400
      IF (DRNG.GT.180.) DRNG=DRNG-180.                                  HIW12500
      IF (DRNG.GT.90.) DRNG=180.-DRNG                                   HIW12600
      ANGLE=0.0175*ABS(DRNG)                                            HIW12700
      CO=COS(ANGLE)                                                     HIW12800
      CS=CO*CO                                                          HIW12900
      FU=1.85*CS*(U**0.164)                                             HIW13000
      R=FU/U                                                            HIW13100
      RFU=1.                                                            HIW13200
      IF (R.GT.1.) RFU=R                                                HIW13300
      U=RFU*U                                                           HIW13400
      WSP=ABS(U*SIN(ANGLE))                                             HIW13500
```

```
      RA=REP1*GS
      RB=REP2*GS
      SA=SEP1*GS
      SB=SEP2*GS
      WL=(WIDTH-CNTR)/XNL
      IF (CUT.EQ.YES.OR.CUT.EQ.YESL) GO TO 130
120   SYON=3.
      SZON=1.5
      GO TO 150
130   IF (U.GT.3.) GO TO 120
      IF (U.LT.1.) GO TO 140
      DUM=(U-1.)/2.
      SYON=10.-7.*DUM
      SZON=5.-3.5*DUM
      GO TO 150
140   SYON=10.
      SZON=5.
150   CONTINUE
      IF (NL.EQ.1) WL=0.
      IF (NL.EQ.1) CNTR=0.
      DELR=RB-RA
      DELS=SB-SA
      DIST=SQRT(DELS*DELS+DELR*DELR)
      NLIM=NL/2
      ALIM=NLIM
      DO 160 ID=1,NLIM
      A=ID
      DL=(-0.5)*CNTR+((-1)*ALIM-0.5+A)*WL
      DUM=DL*0.001/DIST
      RAQ(ID)=RA+DELS*DUM
      RBQ(ID)=RB+DELS*DUM
      SAQ(ID)=SA-DELR*DUM
      SBQ(ID)=SB-DELR*DUM
      QLN(ID)=QLS(ID)
      HLN(ID)=H
160   CONTINUE
      NS=NLIM+1
      AS=NS
      DO 170 ID=NS,NL
      A=ID
      DL=0.5*CNTR+(0.5+A-AS)*WL
      DUM=DL*0.001/DIST
      RAQ(ID)=RA+DELS*DUM
      RBQ(ID)=RB+DELS*DUM
      SAQ(ID)=SA-DELR*DUM
      SBQ(ID)=SB-DELR*DUM
      QLN(ID)=QLS(ID)
      HLN(ID)=H
170   CONTINUE
      DO 180 IDUM=1,NRCO
```

```
      RR(IDUM)=XXRR(IDUM)*GS
      SR(IDUM)=XXSR(IDUM)*GS
      ZR(IDUM)=Z(IDUM)
 180  CON(IDUM)=0.
      K=NL
      N=NRCO
C    K IS NUMBER OF LINE SOURCES
C    N IS NUMBER OF RECEPTORS
      CALL HWYLNE (K,N)
      WRITE (IWRI,540)
C---
C---RERUN OPTIONS.
C---
      WRITE (IWRI,550)
      IF (ISPEC.GT.1) GO TO 190
      WRITE (IWRI,560)
      WRITE (IWRI,570)
      ISPEC=2
190   WRITE (IWRI,580)
      READ (IRD,210) SPEC
      IF (SPEC.EQ.RLOC.OR.SPEC.EQ.RLOCL) GO TO 70
      IF (SPEC.EQ.CHA.OR.SPEC.EQ.CHAL) GO TO 10
C
200   FORMAT (/' DO YOU WANT A DESCRIPTION OF THE EPA "HIWAY-2" MODEL'/'
     1 BEFORE APPLYING IT?(YES OR NO)'/)
210   FORMAT (20A4)
220   FORMAT (/' DO YOU WANT A DESCRIPTION OF THIS VERSION OF "HIWAY-2"?
     1(YES OR NO)'/)
230   FORMAT (' ENTER PROBLEM TITLE OF 64 CHARACTERS OR LESS')
240   FORMAT (' ENTER SCALE FACTOR (KILOMETERS/USER UNIT).')
250   FORMAT (' ENTER LINE(ROAD) ENDPOINTS.(ORDERED PAIRS:X1,Y1,X2,Y2)')
260   FORMAT (' ENTER EMISSION HEIGHT. (METERS)')
270   FORMAT (' ENTER WIND DIRECTION (DEG).  NORTH IS ZERO.')
280   FORMAT (' ENTER WIND SPEED (METERS/SEC).')
290   FORMAT (' ENTER MIXING HEIGHT (METERS).')
300   FORMAT (' ENTER PASQUILL-TURNER STABILITY CLASS (1-6).')
310   FORMAT (' ENTER THE NUMBER OF LANES.')
360   FORMAT (' ENTER LINE SOURCE STRENGTH VECTOR.(A VALUE FOR EACH LANE
     1)')
370   FORMAT (' IS THIS A CUT SECTION?  (YES OR NO)')
380   FORMAT (' ENTER WIDTH OF TOP OF CUT. (METERS)')
390   FORMAT (' ENTER HIGHWAY WIDTH (METERS).')
400   FORMAT (' ENTER WIDTH OF CENTER STRIP (METERS).')
410   FORMAT (' ENTER NUMBER OF RECEPTOR LOCATIONS DESIRED.(MAXIMUM OF 2
     15)')
420   FORMAT (' ENTER RECEPTOR COORDINATE SETS.(X&Y IN SCALE FACTOR UNIT
     1S;Z IN METERS)')
430   FORMAT (/////' HIWAY-2 VERSION:',I6)
440   FORMAT ('0',20A4)
450   FORMAT (' ENDPOINTS OF THE LINE SOURCE'/' ',F9.3,',',F9.3,'  AND',
```

```
     1F9.3,',',F9.3)                                                    HIW23600
460   FORMAT (' EMISSION HEIGHT IS',F8.3,' METERS')                     HIW23700
470   FORMAT (' EMISSION RATE (GRAMS/SECOND*METER) OF',I4,' LANE(S)')   HIW23800
480   FORMAT (6E12.3)                                                   HIW23900
490   FORMAT (' WIDTH OF TOP OF CUT SECTION IS',F10.3,' METERS')        HIW24000
500   FORMAT (' WIDTH OF AT-GRADE HIGHWAY IS',F10.3,' METERS',/,' WIDTH HIW24100
     1OF CENTER STRIP IS',F10.3,' METERS')                              HIW24200
510   FORMAT (' WIND DIRECTION IS',F7.0,'  DEGREES',/,' WIND SPEED IS',FHIW24300
     17.1,' METERS/SEC'/' STABILITY CLASS IS',I5,/,' HEIGHT OF LIMITING HIW24400
     2LID IS',F8.1,' METERS')                                           HIW24500
520   FORMAT (' THE SCALE FACTOR IS ',F10.4,' KM/USER UNIT.'///)        HIW24600
530   FORMAT (1HO,'     RECEPTOR LOCATION        HEIGHT        CONCENTRATIHIW24700
     1ON',/,'         X',10X,'  Y         Z (M)     UGM/M**3     PPM*')  HIW24800
540   FORMAT (/,' * PPM CONCENTRATIONS CORRECT FOR CARBON MONOXIDE ONLY.HIW24900
     1')                                                                HIW25000
550   FORMAT (/////)                                                    HIW25100
560   FORMAT (' YOU HAVE THE OPTION TO RUN THE MODEL FOR A NEW RECEPTOR HIW25200
     1LOCATION')                                                        HIW25300
570   FORMAT (' (LOC),OR TO CHANGE THE ROADWAY TYPE,OR TO END THE PROGRAHIW25400
     1M.')                                                              HIW25500
580   FORMAT (' ENTER LOC, OR TYPE, OR END.')                           HIW25600
      STOP                                                              HIW25700
C                                                                       HIW25800
      END                                                               HIW25900
```

```
      SUBROUTINE DBTSIG (X,XY,KST,SY,SZ)                                SIG00000
      DIMENSION XA(7), XB(2), XD(5), XE(8), XF(9), AA(8), BA(8), AB(3), SIG00010
     1BB(3), AD(6), BD(6), AE(9), BE(9), AF(10), BF(10)                 SIG00020
      DATA XA /.5,.4,.3,.25,.2,.15,.1/                                  SIG00030
      DATA XB /.4,.2/                                                   SIG00040
      DATA XD /30.,10.,3.,1.,.3/                                        SIG00050
      DATA XE /40.,20.,10.,4.,2.,1.,.3,.1/                              SIG00060
      DATA XF /60.,30.,15.,7.,3.,2.,1.,.7,.2/                           SIG00070
      DATA AA /453.85,346.75,258.89,217.41,179.52,170.22,158.08,122.8/  SIG00080
      DATA BA /2.1166,1.7283,1.4094,1.2644,1.1262,1.0932,1.0542,.9447/  SIG00090
      DATA AB /109.30,98.483,90.673/                                    SIG00100
      DATA BB /1.0971,0.98332,0.93198/                                  SIG00110
      DATA AD /44.053,36.650,33.504,32.093,32.093,34.459/               SIG00120
      DATA BD /0.51179,0.56589,0.60486,0.64403,0.81066,0.86974/         SIG00130
      DATA AE /47.618,35.420,26.970,24.703,22.534,21.628,21.628,23.331,2SIG00140
     14.26/                                                             SIG00150
      DATA BE /0.29592,0.37615,0.46713,0.50527,0.57154,0.63077,0.75660,0SIG00160
     1.81956,0.8366/                                                    SIG00170
      DATA AF /34.219,27.074,22.651,17.836,16.187,14.823,13.953,13.953,1SIG00180
     14.457,15.209/                                                     SIG00190
      DATA BF /0.21716,0.27436,0.32681,0.41507,0.46490,0.54503,0.63227,0SIG00200
```

```
     1.68465,0.78407,0.81558/                                     SIG00210
      GO TO (10,40,70,80,110,140), KST                            SIG00220
C        STABILITY A (10)                                         SIG00230
 10   TH=(24.167-2.5334*ALOG(XY))/57.2958                         SIG00240
      IF (X.GT.3.11) GO TO 170                                    SIG00250
      DO 20 ID=1,7                                                SIG00260
      IF (X.GE.XA(ID)) GO TO 30                                   SIG00270
 20   CONTINUE                                                    SIG00280
      ID=8                                                        SIG00290
 30   SZ=AA(ID)*X**BA(ID)                                         SIG00300
      GO TO 190                                                   SIG00310
C        STABILITY B (40)                                         SIG00320
 40   TH=(18.333-1.8096*ALOG(XY))/57.2958                         SIG00330
      IF (X.GT.35.) GO TO 170                                     SIG00340
      DO 50 ID=1,2                                                SIG00350
      IF (X.GE.XB(ID)) GO TO 60                                   SIG00360
 50   CONTINUE                                                    SIG00370
      ID=3                                                        SIG00380
 60   SZ=AB(ID)*X**BB(ID)                                         SIG00390
      GO TO 180                                                   SIG00400
C        STABILITY C (70)                                         SIG00410
 70   TH=(12.5-1.0857*ALOG(XY))/57.2958                           SIG00420
      SZ=61.141*X**0.91465                                        SIG00430
      GO TO 180                                                   SIG00440
C        STABILITY D (80)                                         SIG00450
 80   TH=(8.3333-0.72382*ALOG(XY))/57.2958                        SIG00460
      DO 90 ID=1,5                                                SIG00470
      IF (X.GE.XD(ID)) GO TO 100                                  SIG00480
 90   CONTINUE                                                    SIG00490
      ID=6                                                        SIG00500
 100  SZ=AD(ID)*X**BD(ID)                                         SIG00510
      GO TO 180                                                   SIG00520
C        STABILITY E (110)                                        SIG00530
 110  TH=(6.25-0.54287*ALOG(XY))/57.2958                          SIG00540
      DO 120 ID=1,8                                               SIG00550
      IF (X.GE.XE(ID)) GO TO 130                                  SIG00560
 120  CONTINUE                                                    SIG00570
      ID=9                                                        SIG00580
 130  SZ=AE(ID)*X**BE(ID)                                         SIG00590
      GO TO 180                                                   SIG00600
C        STABILITY F (140)                                        SIG00610
 140  TH=(4.1667-0.36191*ALOG(XY))/57.2958                        SIG00620
      DO 150 ID=1,9                                               SIG00630
      IF (X.GE.XF(ID)) GO TO 160                                  SIG00640
 150  CONTINUE                                                    SIG00650
      ID=10                                                       SIG00660
 160  SZ=AF(ID)*X**BF(ID)                                         SIG00670
      GO TO 180                                                   SIG00680
 170  SZ=5000.                                                    SIG00690
      GO TO 190                                                   SIG00700
```

```
180   IF (SZ.GT.5000.) SZ=5000.                                            SIG00710
190   SY=1000.*XY*SIN(TH)/(2.15*COS(TH))                                   SIG00720
      RETURN                                                               SIG00730
C                                                                          SIG00740
      END                                                                  SIG00750
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```
      SUBROUTINE HWYLNE (NQ,NR)                                            LNE00000
      COMMON /SOL/ QLN(25),HLN(25),RAQ(25),SAQ(25),RBQ(25),SBQ(25),CON(5LNE00010
     10),CLSS(50),NLINE                                                    LNE00020
      COMMON /REC/ RR(51),SR(51),ZR(51)                                    LNE00030
      COMMON /WEA/ THETA,U,KST,HL                                          LNE00040
      COMMON /PUT/ XXRR(51),XXSR(51),QLS(25),HEAD(20),IWRI                 LNE00050
      DIMENSION XST(11), YST(11)                                           LNE00060
      DIMENSION T(10)                                                      LNE00070
      DATA KMAX /9/                                                        LNE00080
CC                                                                         LNE00090
CC    MODIFIED OCT. 1979 TO ADD ROMBERG INTEGRATION ENHANCEMENTS.          LNE00100
CC                                                                         LNE00110
      X(R,S)=(R-RREC)*SINT+(S-SREC)*COST                                   LNE00120
C        X IS UPWIND DISTANCE OF R,S FROM RREC,SREC                        LNE00130
      Y(R,S)=(S-SREC)*SINT-(R-RREC)*COST                                   LNE00140
C        Y IS CROSSWIND DISTANCE OF R,S FROM RREC,SREC                     LNE00150
      TR=THETA/57.2958                                                     LNE00160
      SINT=SIN(TR)                                                         LNE00170
      COST=COS(TR)                                                         LNE00180
      PIN=0.02                                                             LNE00190
      UZ=U                                                                 LNE00200
C----CALCULATE CONCENTRATIONS FOR EACH RECEPTOR.                            LNE00210
      DO 840 NC=1,NR                                                       LNE00220
      RREC=RR(NC)                                                          LNE00230
      SREC=SR(NC)                                                          LNE00240
      Z=ZR(NC)                                                             LNE00250
C----SUM CONCENTRATIONS OVER EACH LANE.                                     LNE00260
      DO 830 NS=1,NQ                                                       LNE00270
      R1=RAQ(NS)                                                           LNE00280
      S1=SAQ(NS)                                                           LNE00290
      R2=RBQ(NS)                                                           LNE00300
      S2=SBQ(NS)                                                           LNE00310
      QL=QLN(NS)                                                           LNE00320
      H=HLN(NS)                                                            LNE00330
      X1=X(R1,S1)                                                          LNE00340
      X2=X(R2,S2)                                                          LNE00350
      IF (X1) 10,30,30                                                     LNE00360
10    IF (X2) 20,30,30                                                     LNE00370
20    RC=0.                                                                LNE00380
      GO TO 830                                                            LNE00390
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30    IF (X1-100.) 40,40,50
40    IF (X2-100.) 60,60,50
50    WRITE (IWRI,850)
      GO TO 840
60    DELR=R2-R1
      DELS=S2-S1
      Y1=Y(R1,S1)
      Y2=Y(R2,S2)
      IF (Y1-Y2) 70,370,70
C        IF Y1 = Y2, LINE SOURCE IS PARALLEL TO UPWIND AZIMUTH FROM RECE
70    IF (COST+0.0001) 140,80,80
80    IF (COST-0.0001) 90,90,140
90    IF (DELR+0.0001) 120,100,100
100   IF (DELR-0.0001) 110,110,120
110   SLOC=SREC
      RLOC=R1
      GO TO 260
120   SLP=DELS/DELR
      IF (SLP) 130,370,130
130   SLOC=SREC
      RLOC=(SLOC-S1)/SLP+R1
      GO TO 260
140   IF (SINT+0.0001) 190,150,150
150   IF (SINT-0.0001) 160,160,190
160   IF (DELR+0.0001) 180,170,170
170   IF (DELR-0.0001) 370,370,180
180   SLP=DELS/DELR
      RLOC=RREC
      SLOC=SLP*(RLOC-R1)+S1
      GO TO 260
190   IF (DELR+0.0001) 220,200,200
200   IF (DELR-0.0001) 210,210,220
210   RLOC=R1
      SLOC=(RLOC-RREC)*COST/SINT+SREC
      GO TO 260
220   IF (DELS+0.0001) 250,230,230
230   IF (DELS-0.0001) 240,250,250
240   SLOC=S1
      RLOC=(SLOC-SREC)*SINT/COST+RREC
      GO TO 260
250   TATH=SINT/COST
C        TATH IS TANGENT (THETA)
      SLP=DELS/DELR
C        SLP IS SLOPE OF LINE SOURCE.
      RLOC=(RREC/TATH+S1-SLP*R1-SREC)/(1./TATH-SLP)
      SLOC=(RLOC-RREC)/TATH+SREC
C        RLOC, SLOC IS LOCUS OF UPWIND VECTOR FROM RECEPTOR AND LINEAR
C           EXTENSION OF LINE SOURCE.
260   XLOC=X(RLOC,SLOC)
      IF (XLOC) 370,370,270
```

```
C        XLOC IS POSITIVE IF LOCUS IS UPWIND.
270   IF (S2-S1) 280,280,290
280   SMAX=S1
      SMIN=S2
      GO TO 300
290   SMAX=S2
      SMIN=S1
300   IF (R2-R1) 310,310,320
310   RMAX=R1
      RMIN=R2
      GO TO 330
320   RMAX=R2
      RMIN=R1
C        SEE IF UPWIND LOCUS IS ON LINE SOURCE.
330   IF (RLOC-RMIN) 370,340,340
340   IF (RMAX-RLOC) 370,350,350
350   IF (SLOC-SMIN) 370,360,360
360   IF (SMAX-SLOC) 370,380,380
370   INDIC=1
C        INDIC =1 FOR NO LOCUS ON LINE SOURCE.
      XA=X1
      YA=Y1
      XB=X2
      YB=Y2
      GO TO 390
380   INDIC=2
C        INDIC =2 FOR LOCUS ON LINE SOURCE.
      XA=X1
      YA=Y1
      XB=XLOC
      YB=0.
390   DISX=XB-XA
      DISY=YB-YA
      DISI=SQRT(DISX*DISX+DISY*DISY)
C        DISI IS LENGTH(KM) OF LINE CONSIDERED.
      IF (DISI) 410,400,410
400   CURR=0.
      GO TO 770
410   DDI=DISI*1000./20.
C        ONE-HALF IS INCLUDED IN THE 20.
C        DDI IS ONE-HALF TIMES 1/10 OF DISI (M).
      DX=DISX/10.
      DY=DISY/10.
      PREV=0.
      KNTRL=1
      XI=XA
      YI=YA
      KNT=0
      DO 530 I=1,11
C        STORE EACH XI,YI.
```

```
      XST(I)=XI
      YST(I)=YI
      IF (XST(I)) 420,420,430
420   RC=0.
      GO TO 440
430   XZ=XI
      XY=XI
      CALL HWYRCX (UZ,Z,H,HL,XZ,XY,YI,KST,AN,M,SY,SZ,RC)
440   GO TO (450,490), KNTRL
C        IF RC IS ZERO, CONTINUE UNTIL RC IS POSITIVE.
450   IF (RC) 520,520,460
460   IF (I-1) 470,470,480
470   KNTRL=2
      GO TO 510
C        RESET POINT A TO LAST ONE PREVIOUS.
480   XA=XST(I-1)
      YA=YST(I-1)
      KNTRL=2
      GO TO 510
490   IF (RC) 500,500,510
C        RESET POINT B IF REACH ZERO CONCENTRATION.
500   XB=XI
      YB=YI
      GO TO 540
510   KNT=KNT+1
520   XI=XI+DX
      YI=YI+DY
530   CONTINUE
540   IF (KNT) 560,560,550
550   IF (KNT-6) 390,390,600
C        IF GET TO 560, CONC. FROM THIS SEGMENT IS 0.
560   GO TO (570,580,590), INDIC
570   RC=0.
      GO TO 830
580   FIRST=0.
      GO TO 800
590   RC=FIRST
      GO TO 820
600   CONTINUE
C        DO  A TRAPEZOIDAL INTEGRATION FROM A TO B IN TEN STEPS.
C        IT IS LIKELY THAT A OR B HAVE BEEN REDEFINED.
      DISX=XB-XA
      DISY=YB-YA
      DISI=SQRT(DISX*DISX+DISY*DISY)
C        DISI IS DISTANCE(KM) FROM A TO B
      INDEX=0
      ILIM=3
610   CONTINUE
      FILIM=FLOAT(ILIM)
      FAC=1000./FILIM
```

```
      DELD=DISI*FAC
C        DELD IS 1/FILIM DISI IN METERS.
      DX=DISX/FILIM
      DY=DISY/FILIM
      SUM=0.
      XDUM=XA
      YDUM=YA
      IF (XDUM.LE.0.) GO TO 620
      XZ=XDUM
      XY=XDUM
      CALL HWYRCX (UZ,Z,H,HL,XZ,XY,YDUM,KST,AN,M,SY,SZ,RC)
      SUM=SUM+RC/2.
      ILIM1=ILIM-1
620   DO 630 I=1,ILIM1
      XDUM=XDUM+DX
      YDUM=YDUM+DY
      IF (XDUM.LE.0.) GO TO 630
      XZ=XDUM
      XY=XDUM
      CALL HWYRCX (UZ,Z,H,HL,XZ,XY,YDUM,KST,AN,M,SY,SZ,RC)
      SUM=SUM+RC
630   CONTINUE
      XDUM=XDUM+DX
      YDUM=YDUM+DY
      IF (XDUM.LE.0.) GO TO 640
      XZ=XDUM
      XY=XDUM
      CALL HWYRCX (UZ,Z,H,HL,XZ,XY,YDUM,KST,AN,M,SY,SZ,RC)
      SUM=SUM+RC/2.
C        INTEGRATED VALUE IS CURR.
640   CURR=SUM*DELD
C
      T(1)=CURR
      K=0
      DO 650 KK=2,10
650   T(KK)=0.
C
C     FIRST ESTIMATE COMPLETED HERE.
660   PREV=CURR
C        EVALUATE FOR POINTS IN BETWEEN THOSE ALREADY EVALUATED.
      DELD=DELD/2.
      XDUM=XA+DX/2.
      YDUM=YA+DY/2.
      DO 680 I=1,ILIM
      IF (XDUM.LE.0.) GO TO 670
      XZ=XDUM
      XY=XDUM
      CALL HWYRCX (UZ,Z,H,HL,XZ,XY,YDUM,KST,AN,M,SY,SZ,RC)
C        NOTE ADD THESE TO RC'S FOUND ABOVE.
      SUM=SUM+RC
```

```
670   XDUM=XDUM+DX
680   YDUM=YDUM+DY
      CURR=SUM*DELD
C     SECOND ESTIMATE COMPLETED HERE. ALSO FOURTH,SIXTH,ETC.
C
      K=K+1
      OLD1=T(1)
      T(1)=CURR
      DENOM=4
      DO 690 KK=1,K
      KKK=KK+1
      OLD2=T(KKK)
      T(KKK)=T(KK)+(T(KK)-OLD1)/(DENOM-1)
      OLD1=OLD2
      DENOM=DENOM*4
690   CONTINUE
      CURR=T(KK)
C
      IF (INDEX.EQ.0) TEST=ABS((CURR-PREV)/CURR)
      IF (INDEX.EQ.1) TEST=ABS((CURR-CUROLD)/CUROLD)
C        IF WITHIN PIN OF LAST VALUE (PREV), CONSIDER THIS AS FINAL VALU
      IF (TEST-PIN) 770,700,700
700   ILIM=ILIM*2
      IF (K.GE.KMAX) GO TO 750
      PREV=CURR
C        EVALUATE POINTS IN BETWEEN.
      DELD=DELD/2.
      DX=DX/2.
      DY=DY/2.
      XDUM=XA+DX/2.
      YDUM=YA+DY/2.
      DO 720 I=1,ILIM
      IF (XDUM.LE.0.) GO TO 710
      XZ=XDUM
      XY=XDUM
      CALL HWYRCX (UZ,Z,H,HL,XZ,XY,YDUM,KST,AN,M,SY,SZ,RC)
      SUM=SUM+RC
710   XDUM=XDUM+DX
720   YDUM=YDUM+DY
      CURR=SUM*DELD
C
      K=K+1
      OLD1=T(1)
      T(1)=CURR
      DENOM=4
      DO 730 KK=1,K
      KKK=KK+1
      OLD2=T(KKK)
      T(KKK)=T(KK)+(T(KK)-OLD1)/(DENOM-1)
      OLD1=OLD2
```

```
      DENOM=DENOM*4
730   CONTINUE
      CURR=T(KK)
C
      IF (INDEX.EQ.0) TEST=ABS((CURR-PREV)/CURR)
      IF (INDEX.EQ.1) TEST=ABS((CURR-CUROLD)/CUROLD)
C        THIRD ESTIMATE COMPLETED HERE. ALSO FIFTH,SEVENTH, ETC.
      IF (TEST-PIN) 770,740,740
740   ILIM=ILIM*2
      DX=DX/2.
      DY=DY/2.
      IF (K.GE.KMAX) GO TO 750
      GO TO 660
750   IF (INDEX.EQ.1) GO TO 760
      CUROLD=CURR
      INDEX=1
      ILIM=4
      GO TO 610
760   WRITE (6,860) NS,NC,NLINE,TEST
C        AT 770 HAVE FINAL VALUE OF INTEGRATION IN CURR.
770   IF (INDEX.EQ.1) CURR=AMIN1(CURR,CUROLD)
      GO TO (780,790,810), INDIC
780   RC=CURR
      GO TO 820
790   FIRST=CURR
800   INDIC=3
      XA=XLOC
      YA=0.
      XB=X2
      YB=Y2
      GO TO 390
810   RC=FIRST+CURR
820   CON(NC)=CON(NC)+RC*QL
830   CONTINUE
      CON(NC)=1.0E+6*CON(NC)
      CLSS(NC)=0.00087*CON(NC)
      WRITE (IWRI,870) XXRR(NC),XXSR(NC),ZR(NC),CON(NC),CLSS(NC)
840   CONTINUE
C
850   FORMAT (1H0,'RECEPTOR IS 100KM OR MORE FROM SOURCE')
860   FORMAT (/' ***** THE INTEGRATED VALUE FOR LANE ',I2,' RECEPTOR NO.
     1 ',I3,/,' FROM LINE ',I3,' HAS',' A RELATIVE ERROR OF',E10.2,' ***
     2**')
870   FORMAT (1H ,3(F10.4,2X),F10.0,F10.3)
      RETURN
C
      END
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```
      SUBROUTINE HWYRCX (U,Z,H,HL,X,XY,Y,KST,AN,M,SY,SZ,RC)
C        THIS IS THE 1979 VERSION OF HWYRCX.
C        D. B. TURNER, RESEARCH METEOROLOGIST* MODEL DEVELOPMENT BRANCH,
C         DIVISION OF METEOROLOGY, ENVIRONMENTAL PROTECTION AGENCY.
C           ROOM 314B, NCHS BUILDING, RTP. PHONE (919) 549-8411 EXT 4564
C          MAILING ADDRESS- DM, EPA, RESEARCH TRIANGLE PARK, NC 27711
C         * ON ASSIGNMENT FROM NATIONAL OCEANIC AND ATMOSPHERIC
C               ADMINISTRATION, DEPARTMENT OF COMMERCE.
C        SUBROUTINE HWYRCX CALCULATES CHI/Q CONCENTRATION VALUES, HWYRCX
C         CALLS UPON SUBROUTINE HWYSIG TO OBTAIN STANDARD DEVIATIONS.
C        THE INPUT VARIABLES ARE....
C         U     WIND SPEED (M/SEC)
C         Z     RECEPTOR HEIGHT (M)
C         H     EFFECTIVE STACK HEIGHT (M)
C         HL=L  HEIGHT OF LIMITING LID (M)
C         X     DISTANCE RECEPTOR IS DOWNWIND OF SOURCE (KM)
C         XY    X+VIRTUAL DISTANCE USED FOR AREA SOURCE APPROX. (KM)
C         Y     DISTANCE RECEPTOR IS CROSSWIND FROM SOURCE (KM)
C         KST   STABILITY CLASS
C        THE OUTPUT VARIABLES ARE....
C         AN    THE NUMBER OF TIMES THE SUMMATION TERM IS EVALUATED
C                AND ADDED IN.
C         RC    RELATIVE CONCENTRATION (SEC/M**3)
C        THE FOLLOWING EQUATION IS SOLVED --
C          RC = (1/(2*PI*U*SIGMA Y*SIGMA Z))* (EXP(-0.5*(Y/SIGMA Y)**2))
C           (EXP(-0.5*((Z-H)/SIGMA Z)**2) + EXP(-0.5*((Z+H)/SIGMA Z)**2)
C             PLUS THE SUM OF THE FOLLOWING 4 TERMS K TIMES (N=1,K) --
C              TERM 1- EXP(-0.5*((Z-H-2NL)/SIGMA Z)**2)
C              TERM 2- EXP(-0.5*((Z+H-2NL)/SIGMA Z)**2)
C              TERM 3- EXP(-0.5*((Z-H+2NL)/SIGMA Z)**2)
C              TERM 4- EXP(-0.5*((Z+H+2NL)/SIGMA Z)**2)
C        THE ABOVE EQUATION IS SIMILAR TO EQUATION (5.8) P 36 IN
C         WORKBOOK OF ATMOSPHERIC DISPERSION ESTIMATES WITH THE ADDITION
C         OF THE EXPONENTIAL INVOLVING Y.
C        IWRI IS CONTROL CODE FOR OUTPUT
      IWRI=6
      IF (KST.GE.5) GO TO 50
C        IF THE SOURCE IS ABOVE THE LID, SET RC = 0., AND RETURN.
      IF (H-HL) 10,10,20
10    IF (Z-HL) 50,50,40
20    IF (Z-HL) 40,30,30
30    WRITE (IWRI,460)
40    RC=0.
      RETURN
C        IF X IS LESS THAN 1 METER, SET RC=0. AND RETURN.  THIS AVOIDS
C         PROBLEMS OF INCORRECT VALUES NEAR THE SOURCE.
50    IF (X-0.001) 40,60,60
C        CALL HWYSIG TO OBTAIN VALUES FOR SY AND SZ
60    CALL HWYSIG (X,XY,KST,SY,SZ)
C         SY = SIGMA Y, THE STANDARD DEVIATION OF CONCENTRATION IN THE
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C         Y-DIRECTION (M)
C         SZ = SIGMA Z, THE STANDARD DEVIATION OF CONCENTRATION IN THE
C         Z-DIRECTION (M)
      C1=1.
      IF (Y) 70,90,70
70    YD=1000.*Y
C        YD IS CROSSWIND DISTANCE IN METERS.
      DUM=YD/SY
      TEMP=0.5*DUM*DUM
      IF (TEMP-50.) 80,40,40
80    C1=EXP(TEMP)
90    IF (KST-4) 100,100,110
100   IF (HL-5000.) 190,110,110
C        IF STABLE CONDITION OR UNLIMITED MIXING HEIGHT,
C         USE EQUATION 3.2 IF Z = 0, OR EQ 3.1 FOR NON-ZERO Z.
110   C2=2.*SZ*SZ
      IF (Z) 40,120,140
120   C3=H*H/C2
      IF (C3-50.) 130,40,40
130   A2=1./EXP(C3)
C        WADE EQUATION 3.2.
      RC=A2/(3.14159*U*SY*SZ*C1)
      M=1
      RETURN
140   A2=0.
      A3=0.
      CA=Z-H
      CB=Z+H
      C3=CA*CA/C2
      C4=CB*CB/C2
      IF (C3-50.) 150,160,160
150   A2=1./EXP(C3)
160   IF (C4-50.) 170,180,180
170   A3=1./EXP(C4)
C        WADE EQUATION 3.1.
180   RC=(A2+A3)/(6.28318*U*SY*SZ*C1)
      M=2
      RETURN
C        IF SIGMA-Z IS GREATER THAN 1.6 TIMES THE MIXING HEIGHT,
C         THE DISTRIBUTION BELOW THE MIXING HEIGHT IS UNIFORM WITH
C         HEIGHT REGARDLESS OF SOURCE HEIGHT.
190   IF (SZ/HL-1.6) 210,210,200
C        WADE EQUATION 3.5.
200   RC=1./(2.5066*U*SY*HL*C1)
      M=3
      RETURN
C        INITIAL VALUE OF AN SET = 0.
210   AN=0.
      IF (Z) 40,370,220
C        STATEMENTS 220 TO 360 CALCULATE RC, THE RELATIVE CONCENTRATION,
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C          USING THE EQUATION DISCUSSED ABOVE.  SEVERAL INTERMEDIATE
C          VARIABLES ARE USED TO AVOID REPEATING CALCULATIONS.
C          CHECKS ARE MADE TO BE SURE THAT THE ARGUMENT OF THE
C          EXPONENTIAL FUNCTION IS NEVER GREATER THAN 50 (OR LESS THAN
C          -50).  IF 'AN' BECOMES GREATER THAN 45, A LINE OF OUTPUT IS
C          PRINTED INFORMING OF THIS.
C        CALCULATE MULTIPLE EDDY REFLECTIONS FOR RECEPTOR HEIGHT Z.
 220   A1=1./(6.28318*U*SY*SZ*C1)
       C2=2.*SZ*SZ
       A2=0.
       A3=0.
       CA=Z-H
       CB=Z+H
       C3=CA*CA/C2
       C4=CB*CB/C2
       IF (C3-50.) 230,240,240
 230   A2=1./EXP(C3)
 240   IF (C4-50.) 250,260,260
 250   A3=1./EXP(C4)
 260   SUM=0.
       THL=2.*HL
 270   AN=AN+1.
       A4=0.
       A5=0.
       A6=0.
       A7=0.
       C5=AN*THL
       CC=CA-C5
       CD=CB-C5
       CE=CA+C5
       CF=CB+C5
       C6=CC*CC/C2
       C7=CD*CD/C2
       C8=CE*CE/C2
       C9=CF*CF/C2
       IF (C6-50.) 280,290,290
 280   A4=1./EXP(C6)
 290   IF (C7-50.) 300,310,310
 300   A5=1./EXP(C7)
 310   IF (C8-50.) 320,330,330
 320   A6=1./EXP(C8)
 330   IF (C9-50.) 340,350,350
 340   A7=1./EXP(C9)
 350   T=A4+A5+A6+A7
       SUM=SUM+T
       IF (T-0.01) 360,270,270
 360   RC=A1*(A2+A3+SUM)
       M=5
       RETURN
C        CALCULATE MULTIPLE EDDY REFLECTIONS FOR GROUND LEVEL RECEPTOR H
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370    A1=1./(6.28318*U*SY*SZ*C1)                                   RCX01500
       A2=0.                                                        RCX01510
       C2=2.*SZ*SZ                                                  RCX01520
       C3=H*H/C2                                                    RCX01530
       IF (C3-50.) 380,390,390                                      RCX01540
380    A2=2./EXP(C3)                                                RCX01550
390    SUM=0.                                                       RCX01560
       THL=2.*HL                                                    RCX01570
400    AN=AN+1.                                                     RCX01580
       A4=0.                                                        RCX01590
       A6=0.                                                        RCX01600
       C5=AN*THL                                                    RCX01610
       CC=H-C5                                                      RCX01620
       CE=H+C5                                                      RCX01630
       C6=CC*CC/C2                                                  RCX01640
       C8=CE*CE/C2                                                  RCX01650
       IF (C6-50.) 410,420,420                                      RCX01660
410    A4=2./EXP(C6)                                                RCX01670
420    IF (C8-50.) 430,440,440                                      RCX01680
430    A6=2./EXP(C8)                                                RCX01690
440    T=A4+A6                                                      RCX01700
       SUM=SUM+T                                                    RCX01710
       IF (T-0.01) 450,400,400                                      RCX01720
450    RC=A1*(A2+SUM)                                               RCX01730
       M=4                                                          RCX01740
C                                                                   RCX01750
460    FORMAT (1HO,'BOTH H AND Z ARE ABOVE THE MIXING HEIGHT SO A RELIABLRCX01760
      1E COMPUTATION CAN NOT BE MADE.')                             RCX01770
       RETURN                                                       RCX01780
C                                                                   RCX01790
       END                                                          RCX01800


       SUBROUTINE HWYSIG (X,XY,KST,SIGY,SIGZ)                       HSG00000
       COMMON /WS/ WSP,SYON,SZON                                    HSG00010
       DIMENSION SPGZ(3), SPGY(3)                                   HSG00020
       DATA SPGZ /30.144,12.093,8.698/                              HSG00030
       DATA SPGY /52.203,22.612,16.895/                             HSG00040
       IF (X.EQ.0.) X=0.0001                                        HSG00050
       XP=X                                                         HSG00060
       SIGZO=SZON                                                   HSG00070
       RAT=SYON/SZON                                                HSG00080
       IF (WSP.LE.3.91) SIGZO=3.57-0.53*WSP                         HSG00090
C                                                                   HSG00100
C         IF X.LE. 300 METERS USE CURVES AS GIVEN IN THIS SUBROUTINE.  HSG00110
C         IF X.GT. 300 METERS THEN DETSIG IS CALLED TO COMPUTE      HSG00120
C         THE SIGMAS USING THE DISPERSION AT 300 METERS DUE TO      HSG00130
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C         THE ROADWAY AS THE INITIAL DISPERSION.
C
      IF (X.GT.0.3) X=0.3
      IF (KST.LE.3) SIGZA=110.62*(X**0.93198)
      IF (KST.EQ.4) SIGZA=85.49*(X**0.92332)
      IF (KST.GE.5) SIGZA=61.141*(X**0.91465)
      IF (SZON.GT.SIGZO) SIGZO=SZON
      SIGZ=SQRT(SIGZA*SIGZA+SIGZO*SIGZO)
      SIGYO=RAT*SIGZO
      IF (KST.LE.3) TH=(13.333-1.5096*ALOG(X))/57.2958
      IF (KST.EQ.4) TH=(14.333-1.7706*ALOG(X))/57.2958
      IF (KST.GE.5) TH=(12.5-1.0857*ALOG(X))/57.2958
      SIGYA=1000.*X*SIN(TH)/(2.15*COS(TH))
      SIGY=SQRT(SIGYA*SIGYA+SIGYO*SIGYO)
      IF (XP.LE.0.3) RETURN
      IF (KST.GE.5) GO TO 20
      IF (KST.EQ.4) GO TO 10
C
C         SZO AND SYO ARE THE INITIAL DISPERSION DUE TO THE
C         ROADWAY.
C
      SZO=SQRT(SIGZ*SIGZ-SPGZ(1)*SPGZ(1))
      SYO=SQRT(SIGY*SIGY-SPGY(1)*SPGY(1))
      CALL DBTSIG (XP,XP,2,SIGY,SIGZ)
      SIGZ=SQRT(SIGZ*SIGZ+SZO*SZO)
      SIGY=SQRT(SIGY*SIGY+SYO*SYO)
      RETURN
10    CONTINUE
      SZO=SQRT(SIGZ*SIGZ-SPGZ(2)*SPGZ(2))
      SYO=SQRT(SIGY*SIGY-SPGY(2)*SPGY(2))
      CALL DBTSIG (XP,XP,4,SIGY,SIGZ)
      SIGZ=SQRT(SIGZ*SIGZ+SZO*SZO)
      SIGY=SQRT(SIGY*SIGY+SYO*SYO)
      RETURN
20    CONTINUE
      SZO=SQRT(SIGZ*SIGZ-SPGZ(3)*SPGZ(3))
      SYO=SQRT(SIGY*SIGY-SPGY(3)*SPGY(3))
      CALL DBTSIG (XP,XP,5,SIGY,SIGZ)
      SIGZ=SQRT(SIGZ*SIGZ+SZO*SZO)
      SIGY=SQRT(SIGY*SIGY+SYO*SYO)
      RETURN
C
      END
```

APPENDIX C

SUGGESTIONS FOR IMPROVEMENT OF THE EPA-HIGHWAY MODEL

Appendix C is a copy of the article which discusses the recommended changes to the HIWAY model that was received from New York State Department of Environmental Conservation. HIWAY-2, presented in the User's Guide, is essentially the same as HIWAY #4, presented in this appendix. The performance of HIWAY-2 with the GM and New York State's data sets is indicated by the performance of HIWAY #4.

Suggestions for Improvement of The EPA-HIWAY Model

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New York State Department of Environmental Conservation

Previous studies have indicated that the EPA-HIWAY model significantly overestimates the pollutant concentrations for stable atmospheric conditions, especially under parallel wind-road orientation angles with low wind speed. This overestimation is due to the fact that the model's dispersion parameters do not properly account for the traffic-induced turbulence near roadways. In this paper, the Pasquill-Gifford dispersion curves used by the model are modified based on the recent studies that have quantified the nature of the traffic-induced turbulence and its influence on the pollutant dispersion in the near-field. The results show that the model performance is significantly improved when these new dispersion curves in conjunction with an aerodynamic drag factor, which in a rough way accounts for the change in the mean wind field due to the moving vehicles, are used in the HIWAY model.

Previous investigations by Chock,[1] Noll, *et al.*,[2] Sistla, *et al.*,[3] and Rao, *et al.*,[4] indicated that the EPA-HIWAY model[5] overestimates pollutant concentrations adjacent to the highway. This overestimation is more significant under stable atmospheric conditions and for parallel wind-road orientation angles with low wind speeds. Petersen[6] used the wind fluctuation data in a modified version of the original HIWAY model which specifies the dispersion parameters as a function of wind fluctuation statistics and found that there was significant improvement in the model performance over the current version of the HIWAY model. This modified version of the model requires the standard deviations of the horizontal wind direction and elevation angles as a function of averaging time and sampling duration as input to the model. These sophisticated data are not generally available and the model cannot be applied without having this information. The most important finding of Petersen[6] is that the ambient turbulence mechanisms will be properly represented when on-site turbulence data are used. Rao, *et al.*[7,8] and Eskridge, *et al.*[9,10] clearly demonstrated that the dispersion in the near-field is completely dictated by the locally generated turbulence and that the ambient atmospheric stability plays an insignificant role in dispersing pollutants in the immediate vicinity of the roadway.

This paper presents a new set of dispersion curves applicable for pollutant dispersion estimation near roadways based on the data collected in the General Motors (GM) Study[11] and in the New York (NY) State Study.[12] Further, an empirical aerodynamic drag factor is developed to handle pollutant dispersion under low wind speed conditions when traffic-generated effects dominate dispersion. When the original Pasquill-Gifford (P-G) curves used in the HIWAY model are replaced by these new dispersion curves and the aerodynamic drag factor is included, the performance of the HIWAY model is significantly improved. Several statistical tests are made to compare the simulation capabilities of the original HIWAY model and the modified HIWAY model. These results are compared to the results of the GM model,[13] since it was identified in the previous investigations that the GM model was in very good agreement with the observed data. However, the GM model has a tendency to underestimate the pollutant concentrations. Although the modified HIWAY model does not have as good regression statistics as the GM model in some cases, the modified HIWAY has a slight tendency to be conservative. This is desirable since HIWAY is used by the regulatory agencies for their decision-making purposes.

Data Bases

During October, 1975, the General Motors Corporation conducted several tracer gas experiments over a simulated roadway. Cadle, *et al.*[11] discussed the details of the experiment and the data set. The meteorological data consisted of three components of wind velocity at 1 sec intervals from 20 anemometers located on six towers and two stands adjacent to the test track. Sulfur hexafluoride (SF_6) was used as a tracer and samples were collected over a period of 30 minutes at 20 locations. A total of 61 tracer runs were used in this study. Figure 1 shows the locations of various instruments. The other data set used in this study was obtained by the New York State Department of Environmental Conservation in a similar experiment on the Long Island Expressway. A total of 23 tracer experiments were included in the New York study and Figure 2 shows the location of SF_6 samplers in this study. The details of this experiment can be found in Rao, *et al.*[12]

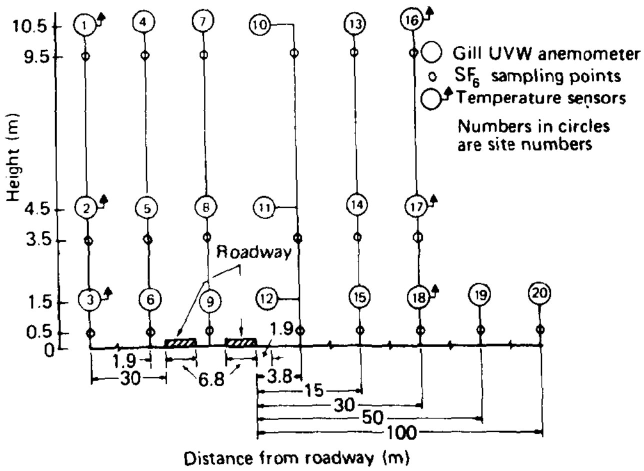

Figure 1. Instrument layout in the General Motors dispersion experiment.

Modifications to the HIWAY Model

Basically, three parameters are necessary in estimating dispersion from a ground level line source. These are the mean wind speed, and the standard deviations of the plume spread in the horizontal and vertical directions. The gaussian dispersion equation has a singularity at zero wind speed, and hence the gaussian assumptions become invalid at very low wind speeds. Hence, all gaussian models perform poorly when the wind speeds are less than 1 m/sec.

Rao, *et al.*[7] studied the effects of aerodynamic drag due to moving vehicles on the wind profiles adjacent to the roadway, and determined that there is a pronounced acceleration of wind in the lowest 8 m, especially in the cases of wind directions nearly parallel to the roadway. Thus, even when the ambient wind speeds are quite low, near the roadway itself there is an acceleration of wind. As for the plume spread, the HIWAY model employs Pasquill-Gifford (P-G) curves extrapolated upwind to 1 m from the source. These curves were originally developed for downwind distances beginning at 100 m from a point source and, hence, do not properly describe the dispersion in the near-field. Rao, *et al.*[8] indicated that the wake effects due to the moving vehicles on the roadway are superimposed upon the naturally occuring turbulence and play a dominant role in dispersing the pollutants in the near-field.

Hence, there are two possible ways to modify the line source dispersion equation to account for the enhanced dispersion due to the traffic flow, namely, (1) application of an aerodynamic drag factor, and (2) application of a new set of dispersion curves that properly reflect the turbulence characteristics adjacent to the roadways.

Wind Speed Correction Factor

As previously indicated, the assumptions in the gaussian equation are violated under low wind speed conditions. Since the concentration of the pollutants is inversely proportional to the wind speed, the concentration approaches infinity asymptotically as the wind speed approaches zero. This situation is obviously unrealistic. Carpenter and Clemeña[14] argued that the inverse linear relationship is valid only for relatively high wind speeds, and hence, requires a correction factor for low wind speeds. Based on observational data, they suggested that the concentration is inversely proportional to $(U + 1.92\,e^{-0.22U})$ where U is the wind speed. This relation suggests that the concentration is inversely proportional to 1.92 at zero wind speed, and as the wind speed increases the concentration becomes inversely proportional to U. Since the original HIWAY model performed poorly for low wind speeds, the wind speed correction formulation as suggested by Carpenter and Clemeña was included in the HIWAY model.

Aerodynamic Drag Factor

Analysis of the GM data revealed that the aerodynamic drag factor must be a function of the wind-road orientation angle. This is because the amount of acceleration in the lower layers is most significant under parallel wind-road orientation (see Rao, *et al.*[7]). Hence, an aerodynamic drag factor which is a function of wind-road angle is developed and is incorporated into the HIWAY model. The relation developed is $U = AU_0^{0.164}\cos^2\theta$ where U is the adjusted wind speed used in the model, U_0 is the ambient wind speed (m/sec), θ is the wind-road angle, and A is a constant related to the traffic speed. It is observed that A equals 1.85 for the traffic speed conditions such as those simulated in the GM experiment. This relation takes its full effect for parallel wind ($\theta = 0$) situations and has no effect for perpendicular wind cases. If the ambient wind speed, U_0, is less than the wind speed, U, computed according to the above relation, then only the adjusted wind speed, U, is used in the model. If the ambient wind speed is greater than the adjusted wind speed, no changes to the wind speed are made (i.e. if $U_0 \geq U$, then $U = U_0$). Thus, this allows correction for only low ambient wind speed situations (when ambient wind speeds are less than 2 m/sec).

Dispersion Parameters

The applicability of the dispersion values used in the HIWAY model can be evaluated by comparing the calculated σ_z, standard deviation of the plume spread in the vertical, to those used in the HIWAY model. Since measurements of concentrations at various receptors downwind of the source and meteorological conditions during the experiment are available, the vertical dispersion parameter can be computed from the line source equation:[15]

$$C = \frac{\sqrt{2}}{\sqrt{\pi}}\frac{Q}{\bar{u}\sin\theta\sigma_z}\exp\left(-\frac{1}{2}\frac{Z^2}{\sigma_z^2}\right) \quad (1)$$

Where C is the observed concentration, $\bar{u}$ is the mean wind speed, θ is the angle between the wind direction and the orientation of the road ($60° \leq \theta \leq 90°$), Z is the height of the receptor, and σ_z is the vertical diffusion parameter. At each tower location, using the gaussian plume assumption that σ_z is not a function of height and that the wind is uniform in the layer, σ_z can be calculated by transposing Eq. (1) into the form

$$\sigma_z^2 = \frac{Z_2^2 - Z_1^2}{2\ln(C_1/C_2)} \quad (2)$$

Where Z_2 and Z_1 are the two levels at a given downwind distance at which C_2 and C_1 are the concentrations measured. In Eq. (2), the concentrations at heights 0.5 m (Z_1) and 3.5 m (Z_2) at the nearest roadside tower are used to compute σ_z. Once this value is known, the variation of σ_z with downwind distance (x) is calculated from the relation

$$\frac{C(\text{at } x_1)}{C(\text{at } x_2)} = \frac{\sigma_{z,x_2}}{\sigma_{z,x_1}}\exp\left[\frac{Z^2}{2\sigma^2_{z,x_1}\sigma^2_{z,x_2}}(\sigma^2_{z,x_1} - \sigma^2_{z,x_2})\right] \quad (3)$$

The concentration at the 0.5 m (z) height is used to calculate σ_z at each downwind distance. Figure 3 provides a comparison between the computed σ_z values using both the GM and NY data sets, and those used in the HIWAY model. The local atmospheric stability for each experimental run at the GM site is determined according to the methods outlined in Rao, *et al.*[4] Since most of the experiments of the NY site were conducted under unstable situations, the stability class B is assumed for all experiments. It is evident from this diagram that the computed σ_z values for all ambient stability conditions lie within the stability categories A to C of the P-G curves. Petersen[6] specified the plume spread in horizontal (σ_y) and vertical (σ_z) directions as a function of standard deviations of the azimuth angle (σ_θ) and elevation angle (σ_ϕ) and found that for downwind distances less than 300 m dispersion is

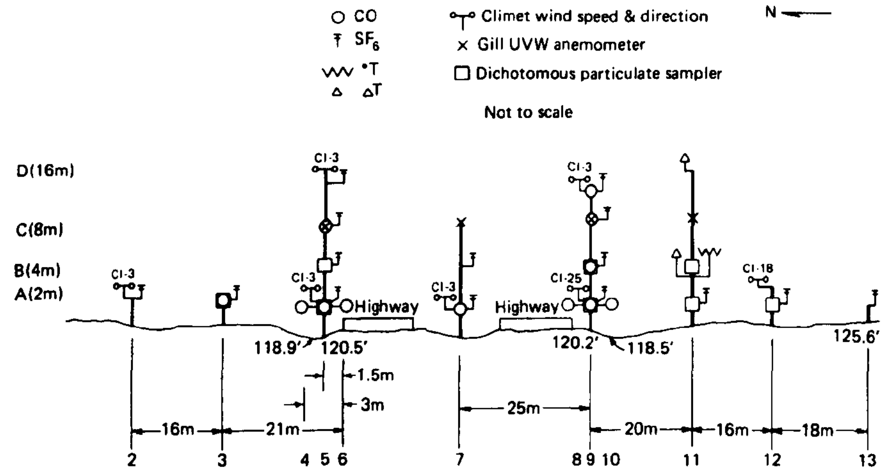

Figure 2. Specific locations of various instruments in the New York experiment.

typically associated with P-G dispersion classes B to C. These results clearly indicate that the present dispersion values in the HIWAY model are unrealistic and need to be modified.

The calculated σ_z from Eq. (2) at the nearest roadside receptor is plotted against the cross-road wind speed in Figure 4, where actual local stability for each data point is also indicated in the diagram. These results show that σ_z must be a function of not only atmospheric stability but also cross-road wind speeds compared to high cross-road wind speed situations. Under low cross-road wind speeds, the plume takes a longer time to reach a receptor away from the source region, and, consequently, the local turbulence mechanism has a longer time to act upon the plume and spread it a great deal more.

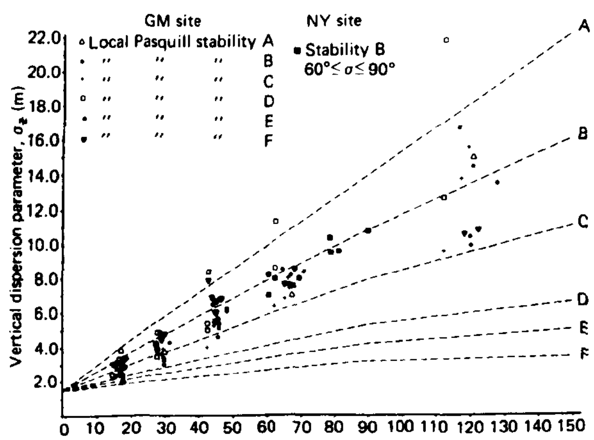

Figure 3. Comparison between σ_z specified as a function of downwind distance and atmospheric stability according to P-G curves and those computed by solving the gaussian equation with the observed concentration data in both GM and New York experiments.

Based on the knowledge gained on the influence of the local turbulence over the naturally occurring turbulence, the vertical dispersion parameter is defined as

$$\sigma_z{}^2 = \sigma_{z_t}{}^2 + \sigma_{z_a}{}^2 \qquad (4)$$

where σ_{z_t} and σ_{z_a} represent contributions from wake-induced turbulence and ambient turbulence, respectively. The contribution of the wake effects to the initial dispersion is given as

$$\sigma_{z_t} = 3.57 - 0.53\, U_\perp \qquad (5)$$

where $U_\perp$ is the cross-road wind speed (see Figure 4) in m/sec. For all cross-road wind speeds greater than 3.91 m/sec, σ_{z_t} is held as constant at 1.5 m. The ambient atmospheric stability is defined in terms of three stability classes, namely, unstable, neutral, and stable. The contribution of ambient stability to the dispersion is specified as

$$\sigma_{z_a} = \begin{cases} 110.62\, x^{0.93198} \text{ for unstable} \\ 86.49\, x^{0.92332} \text{ for neutral} \\ 61.141\, x^{0.91465} \text{ for stable} \end{cases} \qquad (6)$$

where x is the downwind distance from the source in kilometers. In order to be consistent with the above formulation, the standard deviation in cross-wind direction, σ_y, is specified as

$$\sigma_y{}^2 = \sigma_{y_t}{}^2 + \sigma_{y_a}{}^2 \qquad (7)$$

where $\sigma_{y_t} = 2\sigma_{z_t}$; and σ_{y_a} is defined as

$$\sigma_{y_a} = 1000 \times \sin\theta/(2.15 \cos\theta) \qquad (8)$$

Here x is in kilometers and θ is specified as

$$\theta = \begin{cases} (18.333 - 1.8096 \ln x)/57.2958 \text{ for unstable} \\ (14.333 - 1.7706 \ln x)/57.2958 \text{ for neutral} \\ (12.5 - 1.0857 \ln x)/57.2958 \text{ for stable} \end{cases} \qquad (9)$$

In the above equations, both σ_z and σ_y are in meters.

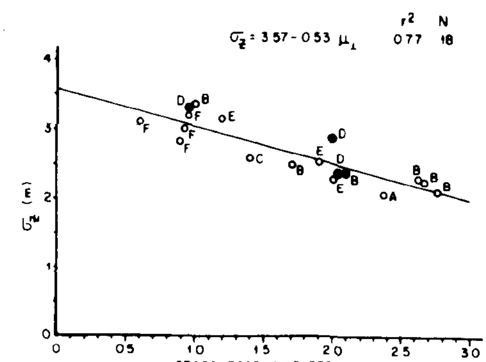

Figure 4. Computed σ_z at the nearest roadside receptor (~4 m from edge of road) as a function of cross-road wind speed.

The present formulation for the dispersion parameters eliminates the concept of virtual point source used in the original HIWAY model. The new set of dispersion curves, computed according to the above equations, is compared to the P-G curves of the HIWAY model in Figure 5.

Results

The following versions of the HIWAY model are employed to simulate the tracer release experiments conducted in the GM and NY studies.

HIWAY #1—original HIWAY model,

HIWAY #2—HIWAY model with the wind speed correction factor suggested by Carpenter and Clemaña,[14]

HIWAY #3—HIWAY model with the modified set of dispersion curves,

HIWAY #4—HIWAY model with the modified dispersion curves and the aerodynamic drag factor.

The performances of each of the above versions of the HIWAY model are compared to the GM model developed by Chock,[13] and the numerical wake model developed by Eskridge, *et al.*[10] The same meteorological conditions described by Rao, *et al.*[4] for the GM data set and Sistla, *et al.*[3] for the NY data set are used in these model evaluations.

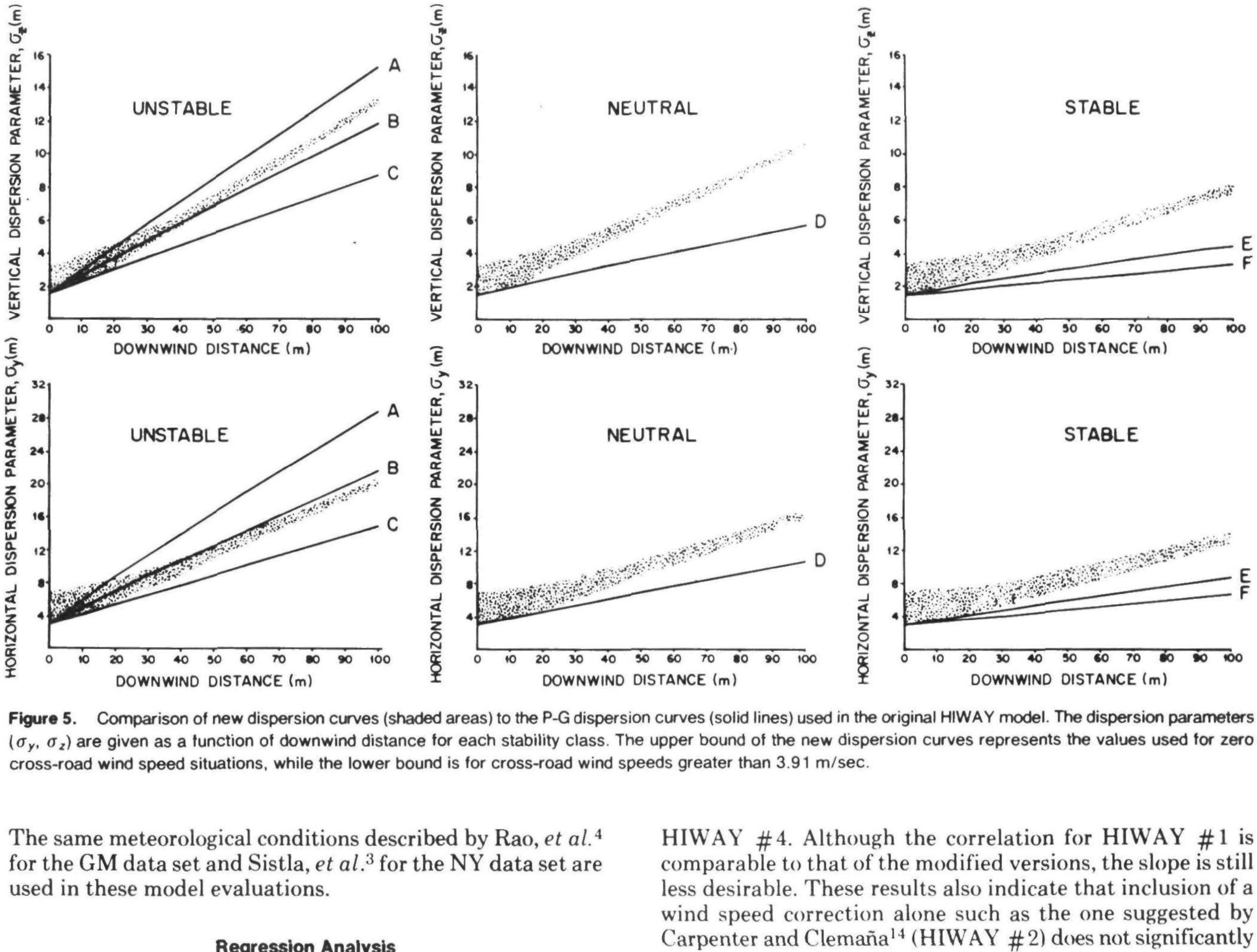

Figure 5. Comparison of new dispersion curves (shaded areas) to the P-G dispersion curves (solid lines) used in the original HIWAY model. The dispersion parameters (σ_y, σ_z) are given as a function of downwind distance for each stability class. The upper bound of the new dispersion curves represents the values used for zero cross-road wind speed situations, while the lower bound is for cross-road wind speeds greater than 3.91 m/sec.

Regression Analysis

The GM data are segregated according to wind-road orientation angle and the results of regression analysis are shown in Table I. Although the correlation when all data combined for HIWAY #3 is about the same as HIWAY #1, the slope is about three times that of HIWAY #1. This indicates that the overpredictions of the original HIWAY are reduced somewhat in the modified HIWAY model. The simulation of HIWAY #4, which employs an aerodynamic drag factor as a function of wind-road orientation angle, is much better than the other HIWAY versions, and is quite comparable to the simulation of the GM model. When the data are divided according to the stability classes (see Table II), again HIWAY #3 has a better slope than HIWAY #1. The correlations of HIWAY #4 show even further improvement over HIWAY #3. HIWAY #4 shows a considerable improvement over HIWAY #1 for stable atmospheric conditions. When the data are grouped according to wind speed class (see Table III), HIWAY #4 provides a better simulation than the other HIWAY versions for low wind speeds.

The aerodynamic drag factor is applied only if the adjusted wind speed according to the relation 1.85 $U_0^{0.164} \cos^2 \theta$ is greater than the ambient wind speed (U_0). It should be noted that this correction is not applicable when U_0 approaches zero. No attempts were made to make the correction valid for $U_0 = 0$ since the basic gaussian dispersion equation becomes invalid at this point. The cut-off wind speed is about 30 cm/sec. The reason for this cut-off is that commonly used wind instruments themselves cannot measure wind speeds reliably when the wind speeds are less than about 30 cm/sec.

When the data with wind speeds greater than 1 m/sec are used, the simulation of HIWAY #3 is quite close to that of HIWAY #4. Although the correlation for HIWAY #1 is comparable to that of the modified versions, the slope is still less desirable. These results also indicate that inclusion of a wind speed correction alone such as the one suggested by Carpenter and Clemaña[14] (HIWAY #2) does not significantly improve the model's ability to simulate the dispersion process. The spatial variation of the regression statistics of all the HIWAY versions and the GM model is shown in Table IV. These results show that the predictions of HIWAY #4 are comparable to the GM model for receptors close to the roadway. In general, all models appear to overpredict as the distance from the road increases. The numerical wake model developed by Eskridge, *et al.*[10] has an r^2 of 0.63, slope of 0.77, intercept of 0.18, and standard error of estimate of 0.47 for a sample size of 551 data points. The regression results for HIWAY #4 are comparable (see Table I) to those of the wake model indicating that the modified HIWAY model is as good

Table I. Ensemble regression statistics for dispersion models. Included in the table are the explained variance (r^2), slope (b), intercept (a), standard error of estimate (S_0/p) between observed (dependent variable) and predicted (independent variable), sample size (N) for each data subset. R is the ratio of mean observed to mean predicted concentrations for that data subset. Here the GM data are segregated according to wind-road orientation angle.

Data subset	Statistical parameter	HIWAY #1	HIWAY #2	HIWAY #3	HIWAY #4	GM
Perpendicular	r^2	0.65	0.73	0.81	0.81	0.92
$60° \le \theta \le 90°$	b	0.41	1.17	0.80	0.80	0.99
	a	0.37	0.21	0.12	0.12	0.12
	S_0/p	0.39	0.34	0.29	0.29	0.19
	R	0.75	1.57	0.94	0.94	1.15
	N	173	173	173	173	173
Oblique	r^2	0.37	0.52	0.51	0.61	0.77
$30° < \theta < 60°$	b	0.22	0.78	0.49	0.66	0.97
	a	0.65	0.44	0.41	0.27	0.25
	S_0/p	0.60	0.52	0.52	0.47	0.36
	R	0.61	1.39	0.82	0.89	1.15
	N	128	128	128	128	128
Parallel	r^2	0.24	0.64	0.28	0.71	0.83
$0° \le \theta < 30°$	b	0.08	0.53	0.23	0.91	0.94
	a	0.80	0.27	0.69	−0.04	0.03
	S_0/p	0.67	0.46	0.65	0.41	0.32
	R	0.40	0.73	0.72	0.88	1.00
	N	293	293	293	293	293
All data	r^2	0.26	0.54	0.35	0.70	0.83
Combined	b	0.11	0.54	0.31	0.81	0.94
	a	0.75	0.42	0.58	0.10	0.12
	S_0/p	0.64	0.50	0.59	0.40	0.30
	R	0.50	0.96	0.79	0.89	1.06
	N	594	594	594	594	594

as the numerical model in predicting pollutant concentrations adjacent to this simple at-grade roadway configuration.

Cumulative Frequency Distributions

In order further to assess the model performance, various frequency distribution plots are developed. These plots depict the model performance in an overall statistical sense rather than the usual one-to-one relationship afforded by the regression statistics. Figure 6 shows the frequency distribution of observed concentration and the concentration distributions predicted by the HIWAY #1, HIWAY #3, and HIWAY #4 models. It is evident from this plot that HIWAY #3 and HIWAY #4 simulate the observed concentration distribution quite well compared to the original HIWAY model. The original HIWAY model consistently overestimates the concentrations.

The cumulative frequency plots of $(O - P)/O$ where O is the observed and P is the predicted concentration give more insight into the model's behavior. Such plots for HIWAY #1, HIWAY #4, and for the GM model are shown in Figures 7 to 9. It is preferable that these plots have a gaussian shape with

Table II. Same as Table I except that the data are divided according to the stability class.

Data subset	Statistical parameter	HIWAY #1	HIWAY #2	HIWAY #3	HIWAY #4	GM
Unstable	r^2	0.61	0.68	0.60	0.76	0.91
(A to C)	b	0.54	1.10	0.72	0.99	1.18
	a	0.22	0.11	0.15	−0.03	0.04
	S_0/p	0.37	0.34	0.38	0.29	0.18
	R	0.76	1.29	0.89	0.95	1.24
	N	276	276	276	276	276
Neutral	r^2	0.69	0.57	0.75	0.78	0.80
(D)	b	0.45	0.65	0.90	1.02	1.01
	a	0.18	0.25	0.03	−0.05	0.05
	S_0/p	0.39	0.46	0.35	0.32	0.31
	R	0.56	0.89	0.93	0.97	1.06
	N	100	100	100	100	100
Stable	r^2	0.23	0.52	0.29	0.65	0.82
(E & F)	b	0.08	0.46	0.22	0.73	0.90
	a	0.93	0.51	0.80	0.15	0.07
	S_0/p	0.75	0.60	0.72	0.50	0.36
	R	0.37	0.82	0.68	0.83	0.95
	N	218	218	218	218	218
Downwind ground level	r^2	0.21	0.53	0.34	0.68	0.84
(0.5m) receptors only	b	0.09	0.57	0.33	0.84	0.99
	a	1.00	0.50	0.78	0.18	0.12
	S_0/p	0.78	0.60	0.71	0.50	0.35
	R	0.47	0.95	0.88	0.98	1.09
	N	260	260	260	260	260

Table III. Same as Table I except that the data are grouped according to the wind speed class.

Data subset	Statistical parameters	HIWAY #1	HIWAY #2	HIWAY #3	HIWAY #4	GM
$U < 1$ m/sec	r^2	0.24	0.36	0.34	0.67	0.82
	b	0.05	0.36	0.16	0.62	0.78
	a	1.03	0.84	0.85	0.22	0.26
	S_0/p	0.74	0.68	0.69	0.48	0.36
	R	0.29	1.12	0.49	0.75	0.98
	N	85	85	85	85	85
$1 \le U < 2.5$ m/sec	r^2	0.65	0.60	0.71	0.74	0.87
	b	0.40	0.66	0.84	0.93	1.10
	a	0.30	0.34	0.01	−0.05	0.02
	S_0/p	0.43	0.46	0.39	0.37	0.26
	R	0.59	1.02	0.85	0.88	1.12
	N	339	339	339	339	339
$U \ge 2.5$ m/sec	r^2	0.69	0.68	0.84	0.84	0.82
	b	0.41	0.53	1.18	1.18	0.86
	a	0.24	0.25	−0.07	−0.07	0.12
	S_0/p	0.37	0.38	0.27	0.27	0.29
	R	0.58	0.79	1.09	1.09	1.01
	N	170	170	170	170	170
All data with $U > 1$ m/sec	r^2	0.66	0.61	0.72	0.75	0.84
	b	0.41	0.61	0.88	0.95	1.00
	a	0.28	0.32	0.03	−0.02	0.07
	S_0/p	0.41	0.44	0.38	0.36	0.28
	R	0.59	0.94	0.91	0.94	1.09
	N	509	509	509	509	509

the peak at zero and rapid fall off on either side. The HIWAY #1 yields a distribution pattern (see Figure 7) that deviates very significantly from the gaussian shape. HIWAY #4 gives a rather smooth distribution (see Figures 8) and is quite similar to distribution from the GM model (see Figure 9).

It is possible to derive information as to how the model simulates the dispersion mechanism by comparing $(O - P)/O$ cumulative plots of normalized concentrations. The normalization is done by dividing each data point predicted by the model by the corresponding maximum predicted for that run. The observed data for that run are also normalized by the observed maximum for the run. In this way, any uncertainties in the estimation of source strength and meteorological variables will be removed since direct comparisons of observed and predicted concentration profiles can be made. The spatial variation of concentration is related only to the spatial variation of dispersion parameters. Hence, comparison of normalized concentration profiles will provide information on how well a model handles the diffusion process.

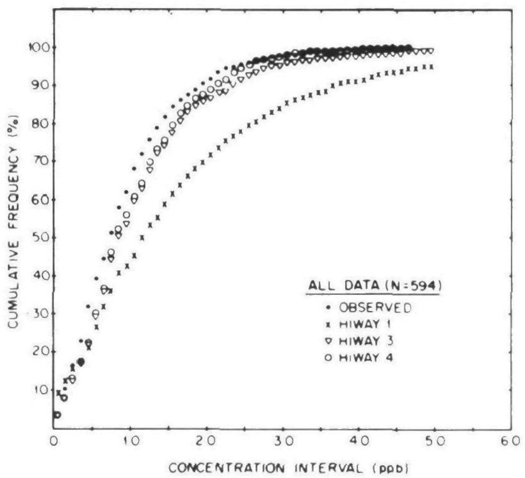

Figure 6. Cumulative frequency distribution of observed concentration is compared to the distribution provided by the original and modified HIWAY models.

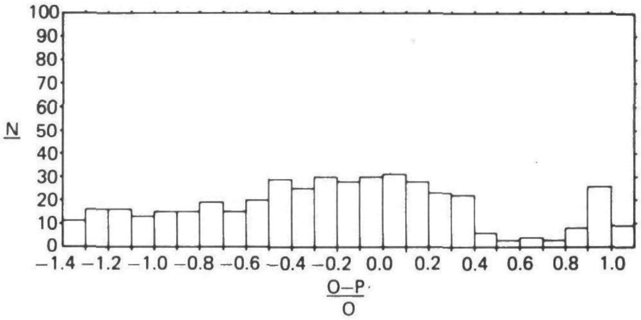

Figure 7. Cumulative plot of $(O - P)/O$, where O is the observed and P is the predicted concentration for the original HIWAY model. 25% of the data lie to the left of −1.4 (N = 594).

Comparing the cumulative plots of $(O_n - P_n)/O_n$, where the subscript n denotes normalized concentrations, for HIWAY #1 (see Figure 10) and HIWAY #4 (see Figure 11), it is seen that the distribution for the former is not as smooth as the latter. The distribution for HIWAY #4 is skewed to the negative side indicating that the predicted concentration profile is more than the observed profile thereby yielding conservative estimates of pollutant levels. The distribution for the GM model (see Figure 12) has a gaussian shape while HIWAY #4 resembles more of a log-normal curve with negative skewness. It is of particular interest to note that the

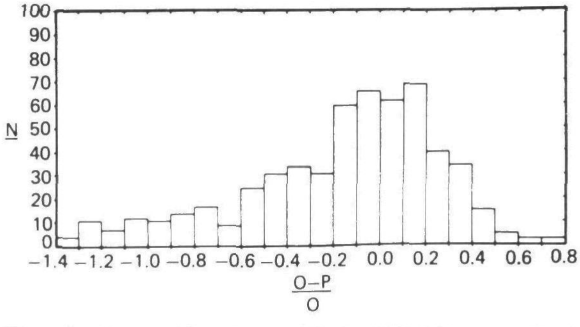

Figure 8. Same as Figure 7 except for the HIWAY #4 model. 5% of the data lie to the left of −1.4 (N = 594).

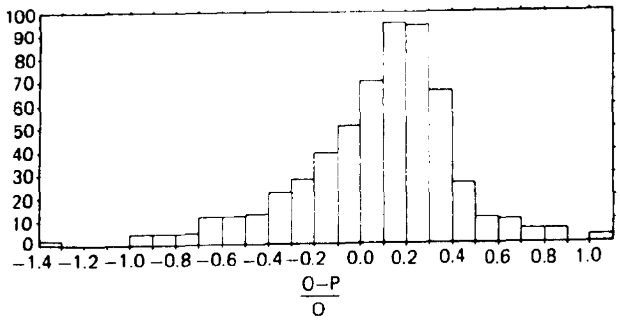

Figure 9. Same as Figure 7 except for the GM model. 2% of the data lie to the left of −1.4 (N = 594).

distribution for HIWAY #4 reaches its peak about zero and rapidly falls off to the right of the peak. This feature is quite important for a regulatory model since environmental health decisions will be made using the model predictions. The regression statistics for normalized predictions and observations after removing mutual values of unity are given in Table V. These results indicate that when all the data are considered, HIWAY #3 and HIWAY #4 simulate the dispersion process better than HIWAY #1 and are as good as the GM model.

The original HIWAY and the modified HIWAY version are employed to simulate the experiments conducted in the New York study. Table VI presents the regression statistics for the HIWAY #1, HIWAY #4, and the GM models for the New York data set. These results also show significant improvement of the HIWAY #4 model over the original HIWAY model. The results of HIWAY #4 (using the same aerodynamic drag factor developed with the GM data set) are quite comparable to those of the GM model.

More quantitative information as to the actual percentage of prediction to within a factor of 2 of the observed concentration is derived from these diagrams, and the results are summarized in Table VII. For the GM data set, it is evident from this table that the original HIWAY model predicts concentrations 56% of the time to within a factor of 2 of the observed, while the modified models (HIWAY #3 and HIWAY #4) show a prediction to within a factor of 2 of the observed in excess of 80% of the time. However, it should be noted that the predictions are skewed toward overestimation. Although the GM model has by far the best percentage in the category of within a factor of 2, it is skewed toward underestimation.

For regulatory purposes, the ability of a model in providing accurate estimates of pollutant levels in the upper 50th percentile of concentration is of greater importance than the overall predictability in the entire range of concentrations. To show how the modified model behaves in the upper half

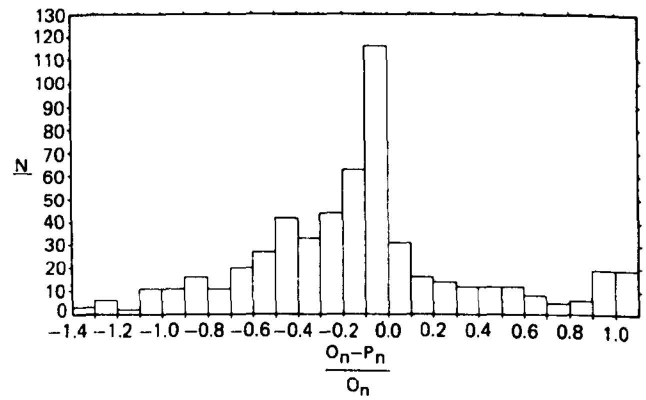

Figure 10. Cumulative plots of normalized concentrations of $(O_n - P_n)/O_n$ for the original HIWAY model. The observed and predicted concentration at various locations for a given run are divided by their corresponding maximums for that run. 5% of the data lie to the left of −1.4 (N = 594).

Table IV. Same as Table I except that the data are divided according to the distances of the receptors from the roadway.

Data subset	Statistical parameter	HIWAY #1	HIWAY #3	HIWAY #4	GM
Towers 2 & 4	r^2	0.27	0.31	0.75	0.86
(4 meters	b	0.10	0.26	0.90	0.92
from highway)	a	1.11	0.93	0.09	0.22
	S_0/p	0.88	0.86	0.52	0.39
	R	0.52	0.80	0.96	1.09
	N	182	182	182	182
Tower 5	r^2	0.55	0.54	0.63	0.75
(15 meters	b	0.30	0.58	0.72	0.89
from highway)	a	0.50	0.33	0.21	0.18
	S_0/p	0.36	0.37	0.33	0.27
	R	0.60	0.87	0.91	1.09
	N	137	137	137	137
Towers 1 & 6	r^2	0.17	0.27	0.43	0.56
(30 meters	b	0.05	0.17	0.41	0.73
from highway)	a	0.65	0.55	0.36	0.19
	S_0/p	0.32	0.30	0.27	0.23
	R	0.41	0.68	0.80	0.99
	N	183	183	183	183
Tower 7	r^2	0.73	0.31	0.40	0.77
(50 meters	b	0.31	0.33	0.42	0.60
from highway)	a	0.22	0.39	0.33	0.17
	S_0/p	0.15	0.20	0.19	0.14
	R	0.61	0.83	0.87	1.00
	N	46	46	46	46
Tower 8	r^2	0.48	0.41	0.50	0.68
(100 meters	b	0.21	0.45	0.55	0.55
from highway)	a	0.28	0.16	0.13	0.17
	S_0/p	0.14	0.14	0.13	0.11
	R	0.60	0.80	0.83	0.93
	N	46	46	46	46

Table V. Regression statistics between normalized observed and normalized predicted for the original HIWAY, HIWAY #3 and HIWAY #4, and the GM model for the GM data set. The regression analyses here show how well the models predict the concentration profile.

Data subset	Statistical parameter	HIWAY #1	HIWAY #3 & #4	GM
All data	r^2	0.61	0.85	0.79
	b	0.65	0.76	0.85
	a	0.08	−0.01	0.03
	S_0/p	0.12	0.07	0.08
	N	533	533	533

of the cumulative frequency distribution, measured concentrations in the range of the 50th percentile through the 100th percentile are separated out and the capability of the models in predicting concentrations to within a factor of 2 is presented in Table VIII. The modified HIWAY models show considerable improvement over the original HIWAY version. For the GM data set, the GM model shows an exact prediction of 12% and an overprediction of 19% while HIWAY #4 shows 14% and 37% respectively. A similar trend can be seen when the analysis is applied to the NY Data set.

Model Sensitivity to Wind Direction

In order to see the sensitivity of the model predictions to the wind-road orientation angles, contours of normalized concentration $\chi_p u/Q$ (where χ_p is the predicted concentration) for the original HIWAY model and HIWAY #3 for stable atmospheric conditions as a function of wind-road angle and distance from the median are developed and shown in Figure 13. Also included in this diagram are the contours of observed $\chi_0 u/Q$ (where χ_0 is the measured concentration) and those predicted by the GM model for stable atmospheric conditions for the purpose of comparison with the original and modified HIWAY models. Only results for HIWAY #3 are included since it has been shown (see Table V) that the simulation of dispersion process of HIWAY #3 and #4 are similar, except that HIWAY #4 has an aerodynamic drag factor to handle special situations such as low wind speed conditions. These plots for the model predictions are developed for unit wind speed and unit source strength for a receptor height of 2 m. Whereas the maximum measured value is of the order of 900

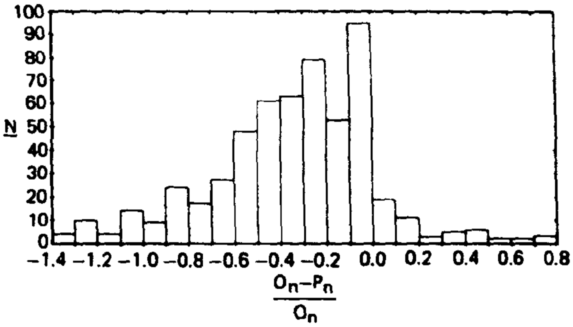

Figure 11. Same as Figure 10 except for the HIWAY #4 model. 6% of the data lie to the left of −1.4 (N = 594).

Table VI. Ensemble regression statistics for the original HIWAY, HIWAY #4, and the GM models for the New York data set.

Data subset	Model	r^2	b	a	S_0/p	N	Mean observed	Mean predicted
Parallel	GM	0.92	0.93	0.33	0.65	39	3.34	3.25
	HIWAY #4	0.81	0.66	0.71	1.02	39	3.34	3.97
	HIWAY #1	0.72	0.39	1.16	1.24	39	3.34	5.52
Oblique	GM	0.73	0.97	0.28	0.88	53	2.16	1.93
	HIWAY #4	0.74	0.81	0.24	0.86	53	2.16	2.36
	HIWAY #1	0.57	0.56	0.54	1.12	53	2.16	2.89
Perpendicular	GM	0.87	0.83	0.62	0.75	41	2.89	2.72
	HIWAY #4	0.86	0.63	0.77	0.79	41	2.89	3.35
	HIWAY #1	0.67	0.39	1.36	1.21	41	2.89	3.95
$U < 2$ m/sec	GM	0.89	0.84	0.66	0.75	34	3.48	3.36
	HIWAY #4	0.91	0.63	0.68	0.67	34	3.48	4.47
	HIWAY #1	0.73	0.33	1.45	1.17	34	3.48	6.24
$2 \leq U \leq 5$ m/sec	GM	0.80	0.88	0.58	0.95	59	3.09	2.86
	HIWAY #4	0.70	0.69	0.68	1.14	59	3.09	3.48
	HIWAY #1	0.61	0.52	0.98	1.30	59	3.09	4.06
$U > 5$ m/sec	GM	0.88	1.06	0.02	0.40	40	1.54	1.43
	HIWAY #4	0.86	1.05	−0.03	0.43	40	1.54	1.50
	HIWAY #1	0.85	0.79	−0.02	0.45	40	1.54	1.96
Stability 2	GM	0.78	0.88	0.84	0.94	46	3.42	2.93
	HIWAY #4	0.70	0.63	1.08	1.10	46	3.42	3.72
	HIWAY #1	0.55	0.34	1.84	1.35	46	3.42	4.67
Stability 3	GM	0.93	0.96	0.14	0.52	54	2.33	2.29
	HIWAY #4	0.89	0.80	0.21	0.64	54	2.33	2.66
	HIWAY #1	0.85	0.59	0.34	0.76	54	2.33	3.36
Stability 4	GM	0.78	0.87	0.30	0.68	27	1.89	1.84
	HIWAY #4	0.79	0.75	0.25	0.67	27	1.89	2.18
	HIWAY #1	0.63	0.48	0.51	0.86	27	1.89	2.87
Stability 6	GM	0.95	0.77	0.61	0.68	6	4.66	5.28
	HIWAY #4	0.97	0.59	−0.34	0.53	6	4.66	7.35
	HIWAY #1	0.66	0.29	1.95	1.86	6	4.66	9.36
All data	GM	0.86	0.90	0.43	0.78	133	2.73	2.56
	HIWAY #4	0.81	0.68	0.59	0.90	133	2.73	3.14
	HIWAY #1	0.66	0.42	1.07	1.20	133	2.73	3.98

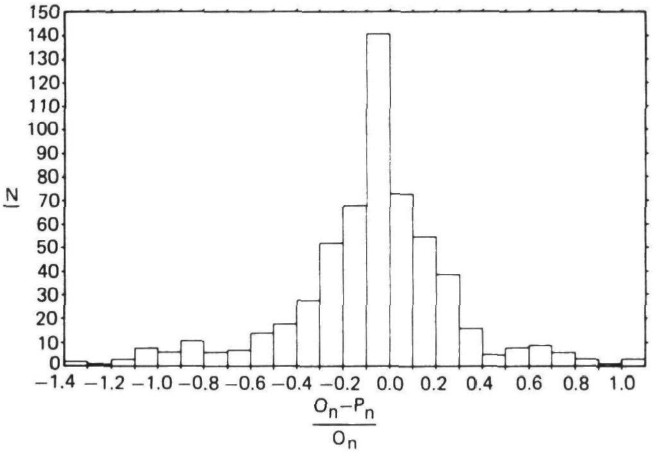

Figure 12. Same as Figure 10 except for the GM model. 2% of the data lie to the left of −1.4 (N = 594).

m^{-1} adjacent to the roadway for near parallel wind conditions, the original HIWAY model predicts a value of 4000 m^{-1} for F-stability, and 2500 m^{-1} for E-stability. The modified HIWAY model predicts 1100 m^{-1} for stable situations. The GM model, on the other hand, predicts a value of 600 m^{-1} in the immediate vicinity of the roadway for near parallel wind situations. These diagrams clearly indicate that the predictions of the modified HIWAY model are much better than the original HIWAY model and are in good agreement with the measured data.

Summary and Conclusions

1. The computed vertical dispersion parameters are found to lie between A and C of the P-G stability categories.
2. Based on the information on the characteristics of the local turbulence mechanisms, a new set of dispersion curves applicable to roadway dispersion problems and an aerodynamic drag factor to handle dispersion under low wind speeds are developed.
3. When the P-G curves are replaced by these new dispersion curves, it is seen that the model predicts concentrations (GM data set) to within a factor of two of the observed 82% of the time compared to 56% of the time for the original HIWAY model.
4. Although the model predictions are significantly improved, a slight tendency to overpredict concentrations still exists which makes the model very useful to the regulatory agencies in their decision-making process.
5. The modified HIWAY model provides a better simulation of the physics of the near-roadway dispersion compared to the original HIWAY model.
6. The fact that the modified model shows improvement in prediction with two different data sets adds to the confidence with which this model can be applied to major roadways.
7. With the aerodynamic drag factor, HIWAY can be applied with greater confidence to handle dispersion even under low wind speeds.

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References

1. D. P. Chock, "General Motors sulfate dispersion experiment: assessment of the EPA-HIWAY model," *JAPCA* **27**:39 (1977).
2. K. E. Noll, T. L. Miller and M. Claggett, "A comparison of three highway line source models," *Atmos. Environ.* **12**:1323 (1978).
3. G. Sistla, P. Samson, M. Keenan and S. T. Rao, "A study of pollutant dispersion near highways," *Atmos. Environ.* **13**:669 (1979).

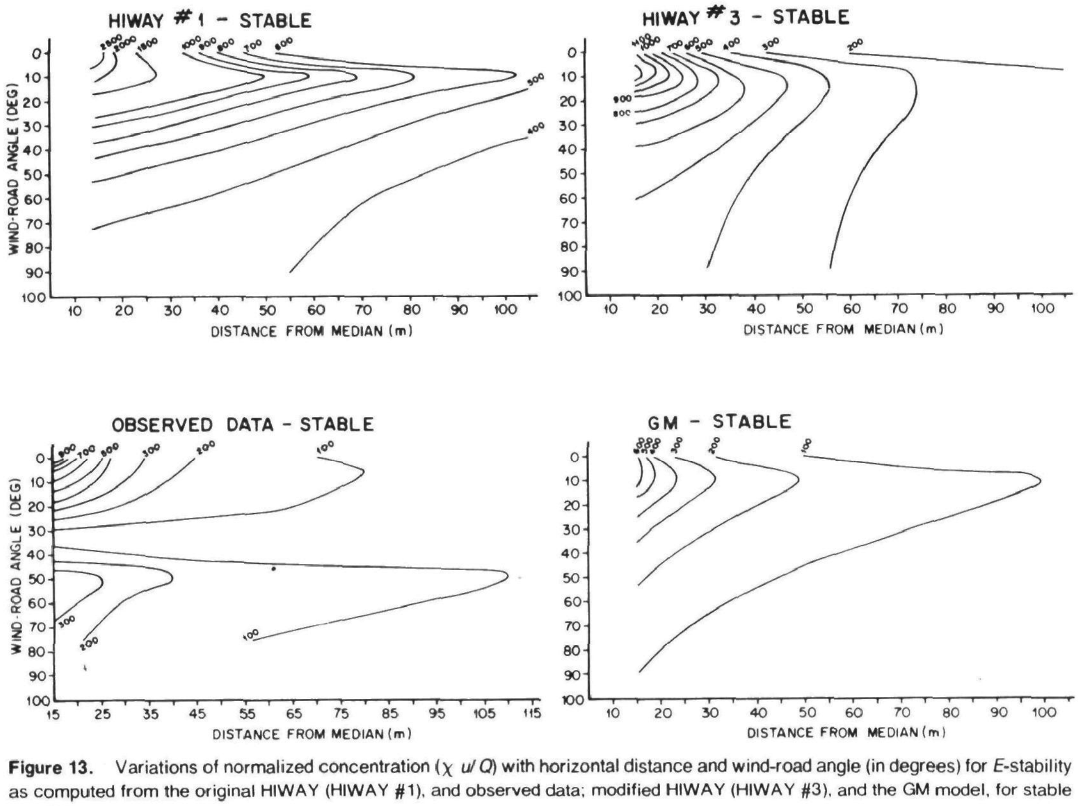

Figure 13. Variations of normalized concentration (χ u/Q) with horizontal distance and wind-road angle (in degrees) for E-stability as computed from the original HIWAY (HIWAY #1), and observed data; modified HIWAY (HIWAY #3), and the GM model, for stable conditions.

Table VII. Quantitative evaluation of the dispersion models tested. Here, the models' ability to predict concentrations to within a factor of two of the observed are compared.

Model	Mode	Sample size	% of prediction within a factor of 2	% of exact prediction	% of overprediction (Obs < Pred ≤ 2 Obs)	% of underprediction (½ Obs ≤ Pred ≤ Obs)
HIWAY	All GM data	594	56	5	37	14
#1	$U > 1$ m/sec	509	61	6	39	16
HIWAY	All GM data	594	62	6	30	26
#2	$U > 1$ m/sec	509	64	6	31	27
HIWAY	All GM data	594	82	10	41	30
#3	$U > 1$ m/sec	509	86	11	43	32
HIWAY	All GM data	594	85	11	44	30
#4	$U > 1$ m/sec	509	87	11	43	33
GM	All GM data	594	88	10	27	48
	$U > 1$ m/sec	509	87	10	22	55
HIWAY #1	All NY data	133	72	7	42	23
HIWAY #4	All NY data	133	87	12	48	27
GM	All NY data	133	80	14	30	36

4. S. T. Rao, G. Sistla, M. T. Keenan and J. S. Wilson, "An evaluation of some commonly used highway dispersion models," *JAPCA* 30:239 (1980).
5. J. R. Zimmerman and R. S. Thompson, "User's Guide for HIWAY, A Highway Air Pollution Model," EPA-650/4-74-008, 1975.
6. W. B. Petersen, "A Pilot Study on Dispersion Near Roadways," EPA-600/4-78-044, 1978.
7. S. T. Rao, L. Sedefian and U. H. Czapski, "Characteristics of turbulence and dispersion of pollutants near major roadways," *J. Appl. Meteor.* 36:283 (1979)
8. S. T. Rao, P. J. Samson and R. E. Eskridge, "Traffic-induced turbulence near roadways," to be published.
9. R. E. Eskridge and J. C. R. Hunt, "Highway modeling: Part I—Prediction of velocity and turbulence fields in the wake of vehicles," *J. Appl. Meteor.* 36:387 (1979).
10. R. E. Eskridge, F. S. Binkowski, J. C. R. Hunt, T. L. Clark and K. E. Demerjian, "Highway modeling: Part II—Advection and diffusion of SF_6 tracer gas," *J. Appl. Meteor.* 36:401 (1979).
11. S. H. Cadle, D. P. Chock, J. M. Heuss and P. R. Monson, "Results of the General Motors Sulfate Dispersion Experiments," General Motors Research publication, GMR-2107, 1976.
12. S. T. Rao, M. Chen, M. Keenan, G. Sistla, R. Peddada, G. Wotzak and N. Kolak, "Dispersion of Pollutants Near Highways—Experimental Design and Data Acquisition Procedures," EPA-600/4-78-037, 1978.
13. D. P. Chock, "A simple line-source model for dispersion near roadways," *Atmos. Environ.* 12:823 (1978).
14. W. A. Carpenter and G. G. Clemaña, "Analysis and Comparitive Evaluation of AIRPOL-4", Virginia Highway and Transportation Research Council, VHTRC 75-R55, 1975.
15. D. B. Turner, "Workbook of Atmospheric Dispersion Estimates," USEPA, Research Triangle Park, NC, 1970.

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Table VIII. Same as Table VII except that the concentration data are in the range of 50th percentile through 100th percentile.

Model	Mode	Sample size	% of prediction within a factor of 2	% of exact prediction	% of overprediction (Obs < Pred ≤ 2 Obs)	% of underprediction (½ Obs ≤ Pred ≤ Obs)
HIWAY #1	GM data upper 50th percentile	155	70	7	43	20
HIWAY #2	GM data upper 50th percentile	155	65	5	23	37
HIWAY #3	GM data upper 50th percentile	155	96	13	37	46
HIWAY #4	GM data upper 50th percentile	155	97	14	37	46
GM	GM data upper 50th percentile	155	95	12	19	64
HIWAY #1	NY data upper 50th percentile	60	82	8	43	31
HIWAY #4	NY data upper 50th percentile	60	100	13	50	37
GM	NY data upper 50th percentile	60	100	17	30	53

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16. ABSTRACT

A computer model, called HIWAY-2, that can be used for estimating the concentrations of nonreactive pollutants from highway traffic is described. This steady-state Gaussian model can be applied to determine air pollution concentrations at receptor locations downwind of "at-grade" and "cut section" highways located in relatively uncomplicated terrain. For an at-grade highway, each lane of traffic is modeled as though it were a finite, uniformly emitting line source of pollution. For the cut section, the top of the cut is considered an area source. The area source is simulted by using ten line sources of equal source strength. The total source strength equals the total emissions from the lanes in the cut.

The air pollution concentration representative of hourly averaging times at a downwind receptor location is found by a numerical integration along the length of each lane and a summing of the contributions from each lane. With the exception of receptors directly on the highway or within the cut, the model is applicable for any wind direction, highway orientation, and receptor location. The model was developed for situations in which horizontal wind flow occurs. The model cannot consider complex terrain or large obstructions to the flow such as buildings or large trees.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Air Pollution *Atmospheric Models Algorithms *Dispersion *Highways Traffic		13B 14A 12A

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