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Mathematical Modeling Of The Dispersion Of Air Pollutants From Highways

Wesley P. Bauver
University of Massachusetts - Amherst

MATHEMATICAL MODELING OF THE DISPERSION OF AIR POLLUTANTS FROM HIGHWAYS

A Thesis Presented

by

Wesley P. Bauver, II

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Approved as to style and content by:

Dr. Jon G. McGowan, Chairman

Dr. Lawrence E. Ambs, Member

Dr. William P. Goss, Member

Dr. G. Albert Russell, Member

C. Poli, Department Head
Mechanical Engineering

ABSTRACT

This work discusses the theory of the HIWAY and California Line Source highway air pollution dispersion models and describes the EPA emissions model which is used to provide emission factors for these models. A parametric study of the dispersion models is performed to show the effect of the various inputs to these models on predicted pollutant concentrations. These results indicate certain cases in which one model should be used instead of the other.

These models are used to perform air quality, environmental impact assessments of two highway projects in Massachusetts. Mesoscale Analyses are also performed for these highways.

Advances in modeling the dispersion of pollutants from highways and possible modifications to the California Line Source and HIWAY models are also discussed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (CONTINUED)

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

NOMENCLATURE

A	Downwind concentration ratio for parallel winds.
ADT	Average number of vehicles which travel a road in 24 hours.
C	Mixing cell concentration, gm/M^3.
c	Emission factor for low mileage vehicle, gm/mi.
D	Perpendicular distance from road, meters.
d	Emission deterioration factor.
e	Emission factor gm/mi.
f	Combined evaporative and crankcase hydrocarbon emission factor for calendar year gm/mi.
fr	Fraction of total vehicle miles traveled at a single speed.
h	Combined evaporative and crankcase hydrocarbon emission factor for model year, gm/mi.
ht	Height of box, meters.
H	height of plume centerline, meters.
K	Turbulent diffusivity, M^2/sec.
K1	Empirical factor.
l	Length of road segment, meters.
l	Length of box side perpendicular to wind, meters.
L	Mixing height, meters.
m	Weighted annual travel.
M	Number of lanes in a road.
Q	Source strength, gm/sec.
R	Rate of generation of species, gm/M^3 sec.
s	Weighted speed adjustment factor.
S	Emission source strength for species, gm/M^3 sec.
T	Time, seconds.

NOMENCLATURE (Cont'd.)

u	Wind speed, m/sec.
$\overline{u}$	Average wind velocity in the x direction, m/sec.
v	Vehicular average wind speed correction factor.
$\overline{v}$	Average wind velocity in the y direction m/sec.
$\overline{w}$	Average wind velocity in the z direction.
W	Width of highway from shoulder to shoulder, meters.

SUBSCRIPTS

i	i^{th} point source
	i^{th} pollutant species
	i^{th} model year
j	Speed
n	Calendar year
p	Pollutant

GREEK SYMBOLS

ε	Empirical constant.
ϕ	Angle between wind direction and highway alignment.
σ	Standard deviation of a Gaussian Plume.
χ	Concentration.

CHAPTER I

INTRODUCTION

Motor vehicles have been known as major producers of air pollutants for over 20 years. Haagen-Smit[1] published an article which recognized automobiles as contributors to the Los Angeles air pollution problem in 1952. Motor vehicles are identified as major producers of carbon monoxide (CO), unburnt hydrocarbons (C_xH_i) and oxides of nitrogen (NO_x) by recent U.S. data[2]. As shown in Table 1, motor vehicles are a source of pollutants other than these three, however, in much smaller amounts[3].

The Clean Air Act of 1970[4] established national air quality standards for major air pollutants including those produced by motor vehicles. These standards are listed in Table 2. It is necessary to be able to model a dispersion of pollutants from motor vehicles in order to insure the meeting of these standards.

Currently, the state of the art of mathematical modeling does not permit accurate Mesoscale modeling of the dispersion of reactive air pollutants. Due to these accuracy limitations the sole pollution modeling required by the Environmental Protection Agency for the Mesoscale region of a highway is a calculation of the total amounts of carbon monoxide, hydrocarbons, and oxides of nitrogen emitted by the source. Mesoscale is defined by Williamson[5] as the region within 100 kilometers of the pollutant source with the region within a few kilometers defined as the microscale.

Significant research has been done to develop limited mathematical air pollution dispersion models for the microscale level. The early work in this field stems from military interest in poison gas dispersion[6].

TABLE 1. TRANSPORTATION CONTRIBUTION TO THE TOTAL AIR POLLUTION EMISSIONS IN THE UNITED STATES, 1969 (ref. 3)

	CO		HC		NO_x		Particulates		SO_x		Source Total		
	10^6 Tons	U. S. Total	10^6 Tons	% of U. S. Total	10^6 Tons	% of U. S. Total	10^6 Tons	% of U. S. Total	10^6 Tons	% of U.S. Total	10^6 Tons	% of U. S. Total	% of Transportation Total
Motor Vehicles	97.8	64.6	17.1	45.7	8.7	36.5	0.4	1.2	0.3	0.9	124.3	44.2	86.1
Aircraft	2.9	1.9	0.4	1.1	0.4	1.7	0.1	0.3	0.1	0.3	3.9	1.4	2.7
All Other Transportation	10.8	7.1	2.3	6.1	2.1	8.8	0.3	0.8	0.7	2.1	16.2	5.8	11.2
Transportation Total	111.5	73.6	19.8	52.9	11.2	47.0	0.8	2.3	1.1	3.3	144.4	51.4	100.0
U.S. Total	151.4	---	37.4	---	23.8	---	35.2	---	33.4	---	281.2	---	---

Source: Environmental Protection Agency

TABLE 2

FEDERAL AIR QUALITY STANDARDS (ref. 5)

POLLUTANTS	AVERAGING TIME	STANDARDS		
		PRIMARY	SECONDARY	METHOD
Photochemical Oxidents (corrected for NO_2)	1 hr.	160 ug/M^3 (.08 PPM)$^\alpha$	same as primary	Chemiluminesc
Carbon Monoxide	8 hr.	10 mg/M^3 (9 PPM)$^\alpha$	same as primary	Nondispersive infra-red spectroscopy
	1 hr.	40 mg/M^3 (35 PPM)$^\alpha$		
Nitrogen Dioxide	Annual average	100 ug/M^3 (.05 PPM)	same as	Colorimetric using N_2OH
Sulphur Dioxide	Annual average	80 ug/M^3 (.03 PPM)	60 mg/M^3 (.02 PPM)	Pararosaniline
	24 hr.	365 ug/M^3 (.14 PPM)$^\alpha$	260 mg/M^3 (.10 PPM)$^\alpha$	
	3 hr.	-	1300 mg/M^3 (.05 PPM)$^\alpha$	
Suspended Particulate Matter	Annual geometric mean	75 mg/M^3	60 mg/M^3	High Volume Sampling
	24 hr.	260 mg/M^3	150 mg/M^3	
Hydrocarbons (corrected for methane)	3 hr. (6-9 a.m.)	160 mg/M^3 (.24 PPM)$^\alpha$	same as primary	Flame ionization detection using gas chromatography

α Not to exceed more than once a year.

This model evolved from the assumption of Gaussian distribution of pollutants in a plume. Turner's Workbook[6] develops the Gaussian plume equations that are widely in use today. An inherent limitation, in the equations for dispersion based on the Gaussian distribution assumption, is their inability to deal with any reaction of the pollutants. Nitrogen oxides and hydrocarbons are chemically reactive while carbon monoxide is not. For this reason, the Environmental Protection Agency does not require the microscale modeling of nitrogen oxides and hydrocarbons for highway environmental impact statements at this time.

One motor vehicle does not emit enough pollutants to violate air quality standards a short distance from the roadway. The problem arises when there are large concentrations of vehicles along the highway. What must be modeled is the pollutant dispersion from the highway, rather than from individual vehicles.

Presently there are two computer models most widely used to predict dispersion of carbon monoxide from highways. One is HIWAY[7] which was developed by the Environmental Protection Agency. The other is the California Line Source[8] which was developed by the California Department of Public Works.

This work evaluates the HIWAY and California Line source models with respect to their responses to changes in meteorological inputs and highway size as well as determining the strengths and weaknesses of each model. The EPA emissions model which is used to provide emissions factor inputs for these models is also discussed. The HIWAY and California Line Source models are applied to two proposed highway projects in Massachusetts. It also applies these models to two proposed highway projects in Massachusetts.

Suggestions are made for the improvement of the California Line Source and HIWAY models and advancements being made in modeling air pollution dispersion will be discussed.

factor compilation in this supplement.

The first is a tabulation (Table 3) of average emission factors of highway vehicles by calendar year, based on statistical data from the United States. The emission factors given in this table for carbon monoxide, hydrocarbons, and nitrogen oxides in the exhaust are based on an average speed of 19.6 miles per hour. In order to apply these factors to other speeds, the factor is multiplied by the speed adjustment factor shown in Figure 1. For example, the nitrogen oxides emission factor for a vehicle in 1974 at 35 mph would be 5.2 grams/mile times 1.25 or 6.5 grams/mile. To find the amount of pollutant discharged by this vehicle, the speed modified emission factor is multiplied by the total number of miles traveled by the vehicle (VMT). Emission factors for crankcase and evaporative hydrocarbons, particulates, and sulfur oxides are considered to be independent of vehicle speed. Thus the total amounts discharged of these pollutants are calculated by multiplying their emission factors by the VMT. The use of average emission factors is suggested for application over wide areas such as states.

The second method, based on the calculation of localized emission factors is preferred for smaller areas. However if the information required is not available the EPA will accept the use of average values.

Light duty, gasoline-powered vehicles comprise the largest class of highway vehicles, so localized emission factors for these are considered first. These are defined by AP-42[10] as "any motor vehicle either designated primarily for transportation of property and rated at 6000 GVW or less; or designed primarily for transportation of persons and having a capacity of 12 persons or less." Exhaust emission factors for carbon

Table 3

Average Emission Factors For Highway Vehicles Based on Nationwide Statistics (Ref. 8)

			Hydrocarbons						Particulates					
	Carbon Monoxide		Exhaust		Crankcase & Evaporation		Oxides (NO_x as NO_2)		Exhaust		Tire Wear		Sulfur Oxides (SO_2)	
Year	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km	g/mi	g/km
1965	89	55	9.2	5.7	5.8	3.6	4.8	3.0	0.38	0.24	0.20	0.12	0.20	0.12
1970	78	48	7.8	4.8	3.9	2.4	5.3	3.3	0.38	0.24	0.20	0.12	0.20	0.12
1971	74	46	7.2	4.5	3.5	2.2	5.4	3.4	0.38	0.24	0.20	0.12	0.20	0.12
1972	78	42	6.6	4.1	2.9	1.8	5.4	3.4	0.38	0.24	0.20	0.12	0.20	0.12
1973	62	39	6.1	3.8	2.4	1.5	5.4	3.4	0.38	0.24	0.20	0.12	0.20	0.12
1974	56	35	5.5	3.4	2.0	1.2	5.2	3.2	0.38	0.24	0.20	0.12	0.20	0.12
1975	50	31	5.0	3.1	1.5	0.93	5.0	3.1	0.38	0.24	0.20	0.12	0.20	0.12
1976	44	27	4.3	2.7	1.3	0.81	4.8	3.0	0.38	0.24	0.20	0.12	0.20	0.12
1977	37	23	3.7	2.3	1.0	0.62	4.3	2.7	0.38	0.24	0.20	0.12	0.20	0.12
1978	31	19	3.2	2.0	0.83	0.52	3.8	2.4	0.38	0.24	0.20	0.12	0.20	0.12
1979	27	17	2.7	1.7	0.67	0.42	3.4	2.1	0.38	0.24	0.20	0.12	0.20	0.12
1980	23	14	2.4	1.5	0.53	0.33	3.1	1.9	0.38	0.24	0.20	0.12	0.20	0.12
1990	12	7.5	1.3	0.81	0.38	0.24	1.8	1.1	0.38	0.24	0.20	0.12	0.20	0.12

NOTE: This table reflects interim standards promulgated by the EPA Administration on April 11, 1973, and in July 1973.

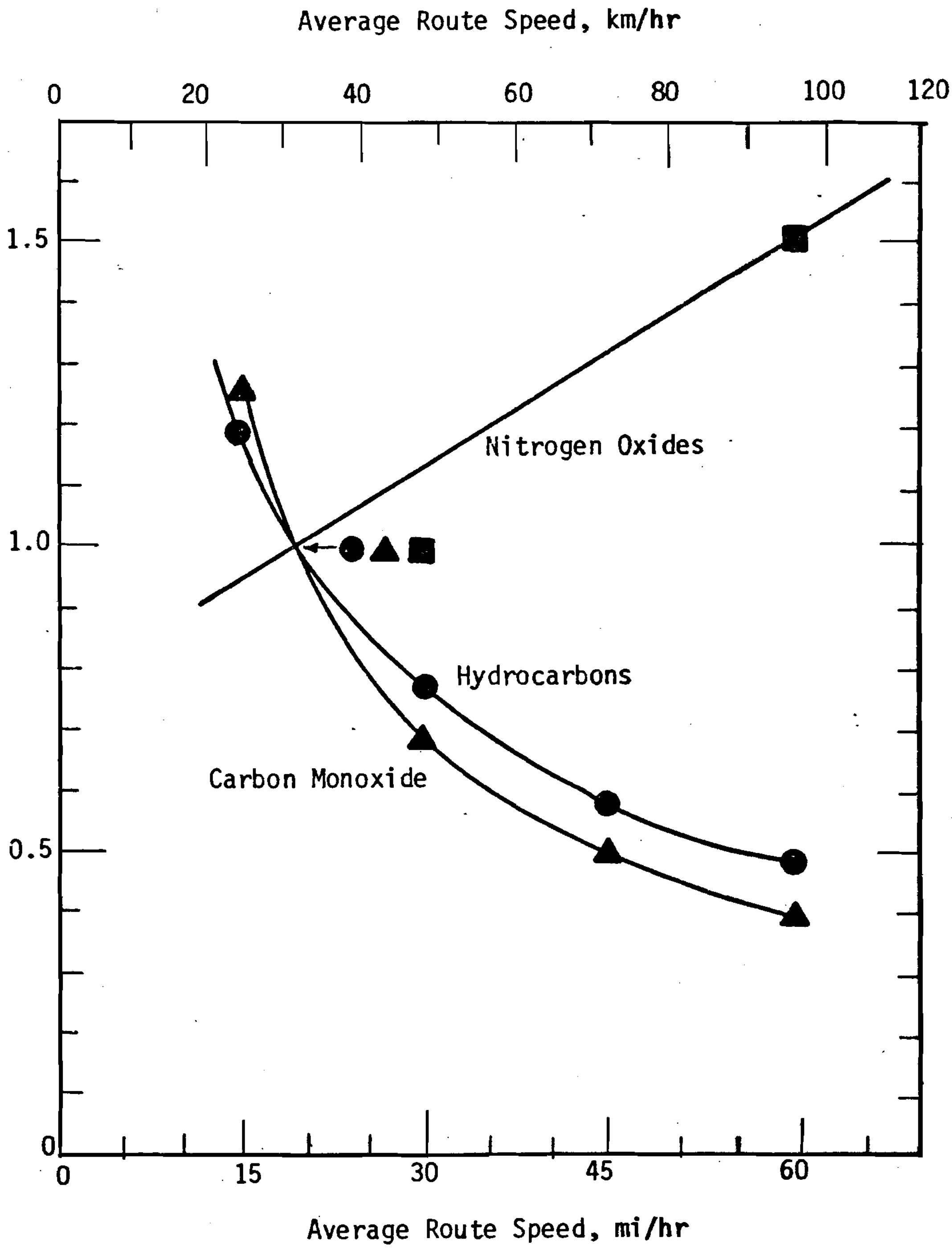

Figure 1 Average speed correction factors for all model years.(ref. 8)

monoxide, hydrocarbons and nitrogen oxides for these vehicles are calculated from

$$e_{np} = \sum_{i=n-12}^{n+1} c_i d_i m_i s_i \qquad (1)$$

where:

e_{np} = Emission factor in grams per vehicle mile for calendar year (n) and pollutant (p)

c_i = The 1975 federal test procedure emission rate for pollutant (p) in g/mi for the i^{th} model year at low mileage

d_i = The controlled vehicle pollutant (p) emission deterioration factor for the i^{th} model year at calendar year (n)

m_i = The weighted annual travel of the i^{th} model year during the calendar year (n). The determination of this variable involves the use of the vehicle model year distribution.

s_i = The weighted speed ajustment factor for the i^{th} model year vehicles.

It is also necessary to calculate an emission factor for gasoline powered vehicles for hydrocarbon emissions due to evaporation and crankcase blowby. This factor is found from:

$$f_n = \sum_{i=n-12}^{n+1} h_i m_i \qquad (2)$$

where:

f_n = The combined evaporative and crankcase hydrocarbon emission factor for calendar year (n)

h_i = The combined evaporative and crankcase emission rate for the i^{th} model year

m_i = The weighted annual travel of the i^{th} model year during calendar year (n)

Values of c_i and h_i are presented in Tables 4 and 5. Those for 1971 and before are the results of light duty exhaust emission rate studies in cities. Later date values are based on federal standards. These values do not apply to California due to that state's more restrictive standards.

Deterioration factors (d_i) for everywhere, except California, are given in Table 6.

The weighted annual mileage (m_i) is calculated for a year by multiplying the fraction of vehicles operational for a model year by the average annual miles travelled. This product is divided by the sum of the numerator plus the product of the fraction of vehicles in use for the year times their average annual mileage for each of the preceding eleven years. It is usually not easy to obtain the information necessary to make these calculations. When it is available, it is usually for cities in which registration statistics reflect the vehicle make-up on the city streets.

The weighted speed factor takes into account different vehicles speed. It is defined as:

$$s_i = \sum_{j=1}^{n} fr_j v_j \qquad (3)$$

where:

s_i = The weighted speed adjustment factor for the i^{th} model year

fr_j = The fraction of total vehicle miles traveled at speed (j)

TABLE 4

CARBON MONOXIDE, HYDROCARBON, AND NITROGEN OXIDE EMISSION FACTORS FOR LIGHT-DUTY VEHICLES AT LOW AND HIGH ALTITUDES EMISSION FACTOR RATING (REF. 8)

	Exhaust Emission Factors at Low Mileage per Model Year[a]									
	Pre-1968	1968	1969	1970	1971	1972[b]	1973 thru 1974[b]	1975[c]	1976	Post 1976
Low altitude (excluding Calif.)										
Carbon Monoxide										
g/mi	87	46	39	36	34	19	19	12.5	1.8	1.8
g/km	54	29	24	22	21	12	12	7.8	1.1	1.1
Exhaust hydrocarbons										
g/mi	8.8	4.5	4.4	3.6	2.9	2.7	2.7	1.3	0.23	0.23
g/km	5.5	2.8	2.7	2.2	1.8	1.7	1.7	0.81	0.14	0.14
Nitrogen oxides										
g/mi	3.6	4.3	5.5	5.1	4.8	4.8	2.3	2.2	1.6	0.31
g/km	2.2	2.7	3.4	3.2	3.0	3.0	1.4	1.4	1.0	0.19
High altitude (excluding Calif.)										
Carbon monoxide										
g/mi	130	74	48	72	75	42	42	20	1.8	1.8
g/km	81	46	30	45	47	26	26	12	1.1	1.1
Exhaust hydrocarbons										
g/mi	10	6.0	5.4	6.1	5.3	4.9	4.9	1.8	0.23	0.23
g/km	6.2	3.7	3.4	3.8	3.3	3.0	3.0	1.1	0.14	0.14
Nitrogen oxides										
g/mi	1.9	2.2	2.6	2.8	3.1	3.1	1.4	1.4	1.3	0.31
g/km	1.2	1.4	1.6	1.7	1.9	1.9	0.87	0.87	0.81	0.19

Notes to Table 4

a) Pre-1968 results are not at low mileage but are arithmetic means of tests of a random sample of vehicles. There is no reason to present low mileage emission rates for pre-1968 vehicles because they are not subject to exhaust control device deterioriation.

b) Estimates based on the relationship of low mileage emissions to standards for 1971 and earlier controlled vehicles.

c) Based on estimates for the interim emissions standards.

NOTE: This Table has bee revised to reflect interim light duty vehicle standards promulgated by the EPA Administrator.

TABLE 5

LIGHT DUTY VEHICLE CRANKCASE AND EVAPORATIVE HYDROCARBON EMISSIONS BY MODEL YEAR FOR ALL AREAS EXCEPT CALIFORNIA (REF. 8)

Model Year	Hydrocarbons g/mi	Hydrocarbons g/km
Pre-1963	7.1	4.4
1963 through 1967	3.8	2.4
1968 through 1970	3.0	1.9
1971	0.5	0.3
1972	0.2	0.1
Post-1972	0.2	0.1

TABLE 6

CARBON MONOXIDE, EXHAUST HYDROCARBON, AND NITROGEN OXIDES DETERIORATION FACTORS FOR LIGHT-DITY, GASOLINE-POWERED VEHICLES IN ALL AREAS EXCEPT CALIFORNIA (REF. 8)

Pollutant and Model Year	Vehicle age, years									
	0	1	2	3	4	5	6	7	8	>9
Carbon monoxide										
Pre-1968(a)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1968	1.00	1.24	1.35	1.41	1.47	1.53	1.58	1.63	1.67	1.72
1969	1.00	1.42	1.53	1.59	1.63	1.68	1.71	1.75	1.79	1.82
1970 through 1974[b]	1.00	1.18	1.32	1.38	1.40	1.44	1.47	1.50	1.51	1.56
1975	1.00	1.04	1.30	1.36	1.43	1.44	1.49	1.56	1.63	1.69
Post-1975	1.00	1.16	1.34	1.50	1.62	1.75	1.88	2.00	2.10	2.22
Exhaust hydrocarbons										
Pre-1968(a)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1968	1.00	1.12	1.18	1.21	1.23	1.26	1.28	1.30	1.32	1.35
1969	1.00	1.10	1.16	1.18	1.21	1.23	1.25	1.28	1.29	1.31
1970 through 1974[b]	1.00	1.05	1.10	1.13	1.15	1.17	1.20	1.22	1.24	1.26
1975 (d)	1.00	1.00	1.13	1.22	1.29	1.37	1.43	1.50	1.56	1.63
Post-1975	1.00	1.14	1.30	1.44	1.55	1.67	1.77	1.88	1.96	2.07
Nitrogen oxides										
Pre-1973[a]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1973 through 1974[c]	1.00	1.11	1.18	1.20	1.21	1.22	1.23	1.24	1.25	1.26
1975	1.00	1.00	1.17	1.23	1.23	1.41	1.45	1.45	1.45	1.45
1976	1.00	1.03	1.07	1.10	1.13	1.17	1.19	1.21	1.24	1.26
Post-1976	1.00	1.17	1.37	1.53	1.67	1.82	1.94	2.06	2.17	2.32

Notes to Table 6

a) Values of 1.00 are given for pre-1968 vehicles because they were not equipped with exhaust control devices and, therefore, are not subject to exhaust control device deterioration. Deterioration in the emission performance of pre-1968 vehicles because of poor maintenance, age, etc., is taken into account by their emission factors, which are based on a random sample of vehicles,

b) Based on test results for 1970 model year vehicles.

c) Based on test results for 1971 (California) model year vehicles.

v_j = The vehicular average speed correction factor for average speed (j)

The values of v_j can be determined from Figure 1. Values of f_j must be determined for a highway by the use of traffic statistics from that area.

It may be necessary to calculate localized emission factors for classes of vehicles other than light gasoline powered. Exhaust emission factors and evaporative and crankcase hydrocarbon emissions factors for heavy-duty, gasoline-fueled vehicles are calculated in the same manner as light-duty gasoline-fueled vehicles. The same values for the deterioration factors and average speed correction factor are employed. Values of the emission rate c_i are given in Table 7. Average emission factors for heavy-duty, diesel-power vehicles are given in Table 8. While emission factors are available for motorcycles, light-duty diesels and gaseous-fueled vehicles, the contributions of these sources of pollutants are currently small enough to be neglected.

2.2 Gaussian Plume Model

Both HIWAY and the California Line Source model are based on the diffusion equations developed in Turner's Workbook[6]. This procedure employs a method of estimating diffusion using commonly observed weather parameters. The concentration of pollutants in a cross section of a plume normal to its direction of movement is assumed to be binormal. The horizontal and vertical spread of the plume have been converted into a horizontal standard deviation (σ_y) and a vertical standard deviation (σ_z). Values of these standard deviations are given in Figures 2 and 3 as functions of downwind distance and a parameter defined as the stability class.

TABLE 7

HEAVY-DUTY, GASOLINE-POWERED VEHICLE EXHAUST EMISSION FACTORS
FOR CARBON MONOXIDE, HYDROCARBONS AND NITROGEN OXIDES EMISSION FACTOR RATING (REF. 8)

Location	Model Year	Carbon Monoxide g/mi	Carbon Monoxide g/km	Exhaust hydrocarbons g/mi	Exhaust hydrocarbons g/km	Nitrogen oxides g/mi	Nitrogen oxides g/km
All areas except	Pre-1970	140	87	17	11	9.4	5.8
high altitude	1970 through 1973	130	81	16	9.9	9.2	5.7
and California	Post-1973	130	81	13	8.1	9.2	5.7
High altitude	Pre-1970	210	130	19	12	5.0	3.1
only	1970 through 1973	190	120	18	11	4.9	3.0
	Post-1973	190	120	15	9.3	4.9	3.0
California only	Pre-1970	140	87	17	11	9.4	5.8
	1970 through 1971	130	81	16	9.9	9.2	5.7
	1972	130	81	13	8.1	9.2	5.7
	1973 through 1974	130	81	13	8.1	9.2	5.7
	1975	81	50	4.1	2.5	2.8	1.7

Table 8

EMISSION FACTORS FOR HEAVY-DUTY, DIESEL-POWERED VEHICLES
EMISSION FACTOR RATING (Ref. 8)

			Emissions	
Pollutant	$lb/10^3$ gal.	$kg/10^3$ liter	g/mi	g/km
Particulate	13	1.6	1.2	0.75
Sulfur oxides (SO_x as SO_2)	27	3.2	2.4	1.5
Carbon Monoxide	225	27.0	20.4	12.7
Hydrocarbons	37	4.4	3.4	2.1
Nitrogen oxides (NO_x as NO_2)	370	44.0	34	21
Aldehydes (as HCHO)	3	0.4	0.3	0.2
Organic acids	3	0.4	0.3	0.2

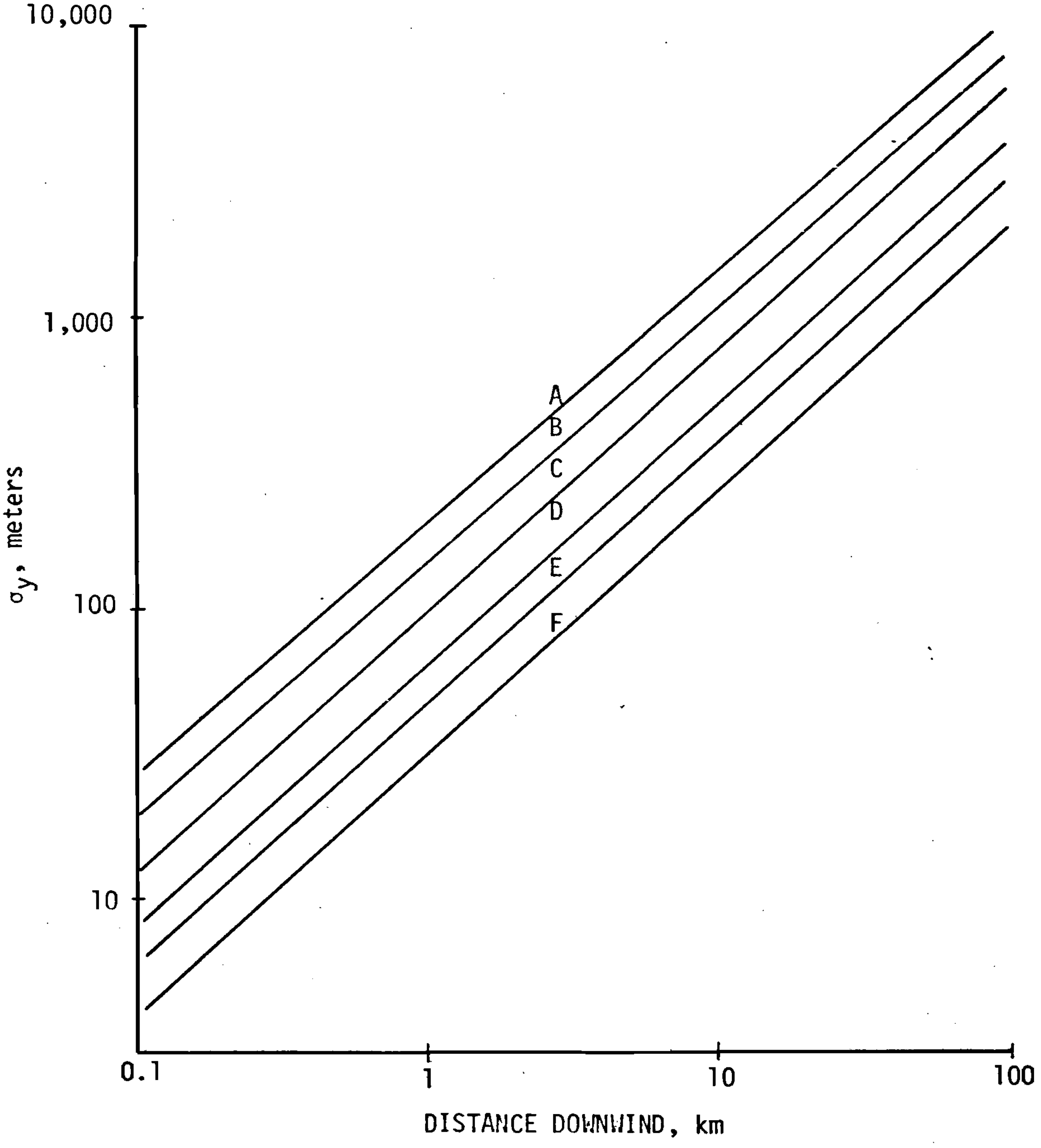

Figure 2 Horizontal dispersion coefficient as a function of downwind distance from the source. (ref. 5)

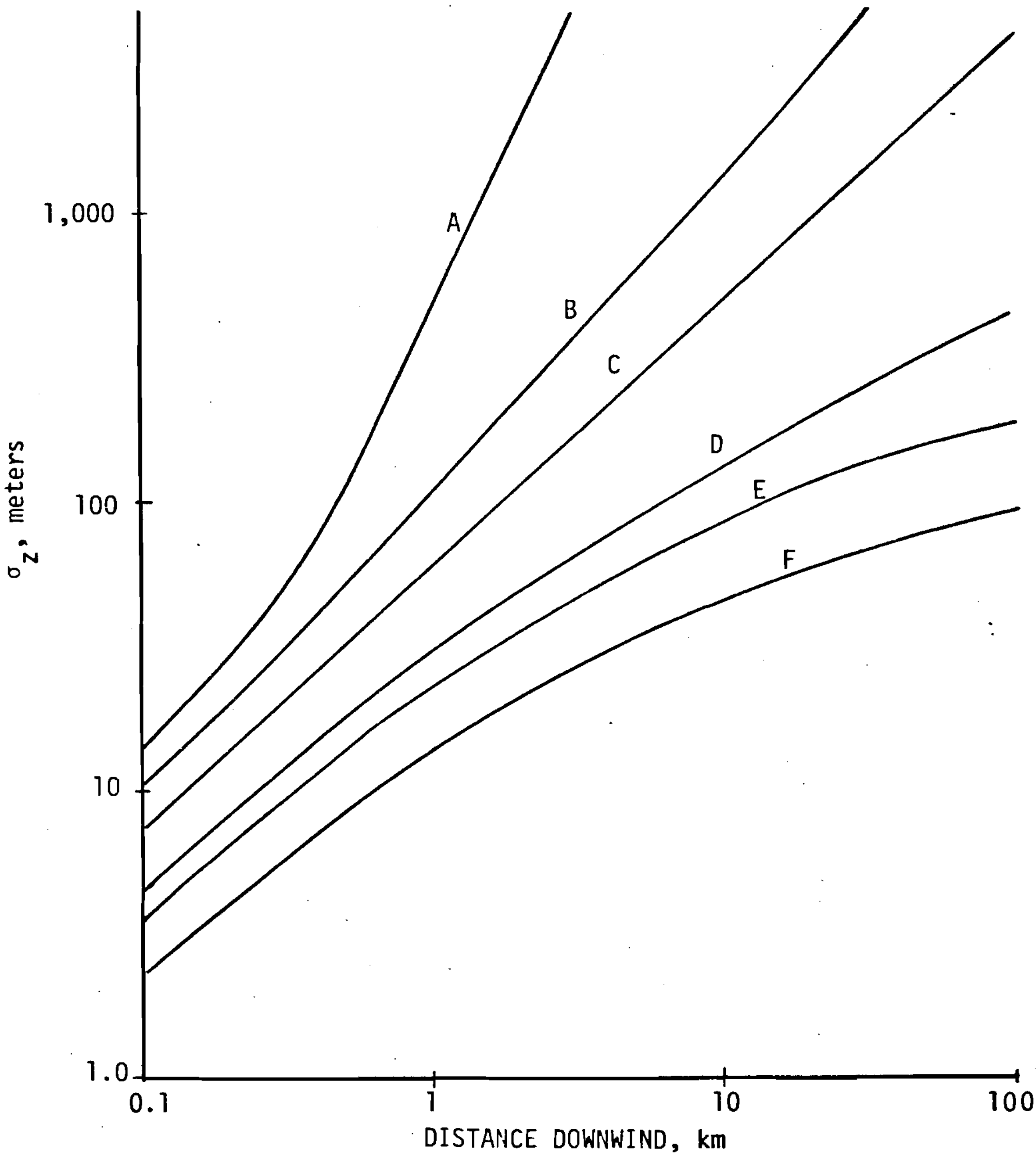

Figure 3 Vertical dispersion coefficient as a function of downwind distance from the source. (ref. 5)

The stability class lumps together the meteorological conditions on which the values of σ_y and σ_z are based. Six atmospheric stability classes are defined by their dependence on the wind speed at a height of about 10 meters and the incoming solar radiation during the day or the cloud cover at night. These classes, which are given in Table 9, reflect the amount of turbulent mixing in the atmosphere. For example, Class A, the most unstable, occurs when a large amount of solar radiation causes large thermal eddies which promote strong vertical mixing. Less mixing occurs when the atmosphere is more thermally homogeneous due to higher winds or less solar radiation. On the opposite end of the scale, the least mixing occurs when there is a temperature inversion in the lower atmosphere (Class F).

Certain assumptions are made when developing the values of σ_y and σ_z as functions of stability class. These include:

1. Sampling time is assumed to be about 10 minutes.
2. The height is limited to the lowest several hundred meters of the atmosphere.
3. The surface is relatively open country.

While the values of σ_y and σ_z used by Turner[6] are the best available, errors in the estimate of σ_z can occur at long distances. Within a few hundred meters of the pollution source, σ_z may be expected to be within a factor of 2. Estimates of σ_y are generally more accurate than those of σ_z.

The following equation is used by Turner[6] to calculate the concentration of a gas in a binormal plume at some point x, y, z in that plume. Modifications of this equation form the basis of HIWAY and the California Line Source model.

TABLE 9

KEY TO STABILITY CATEGORIES (Ref. 6)

Surface Wind Speed (at 10M), m sec^{-1}	DAY Incoming Solar Radiation Strong	Moderate	Slight	NIGHT Thinly Overcast or ≥4/8 Low Cloud	≤3/8 Cloud
2	A	A-B	B		
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
6	C	D	D	D	D

The neutral class, D, should be assumed for overcast conditions during day or night.

$$\chi(x,y,z) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left[\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \quad (4)$$

where:

χ = Concentration at a point in the plume

Q = Source strength (mass/unit time)

u = Wind speed

σ_z = Vertical plume standard deviation at distance x from source

σ_y = Horizontal plume standard deviation at distance x from the highway

H = Height of the plume centerline.

Any set of consistent units may be used. Values of σ_y and σ_z at distance x from the source can be taken from Figure 2 and 3 respectively. Figure 4 shows the coordinate system for this equation.

2.3 California Line Source Model

The California Line Source model uses the concept of a mechanical mixing cell above the highway to account for the initial mixing of pollutants in the air due to turbulence caused by traffic. This mechanical mixing cell assumption is based on studies using smoke candles mounted on cars. Beaton[8] lists the basic assumptions of the model:

1. Continuous emission sources from vehicles on highway.
2. The surface stability classes in Turner's Workbook[6] are used.
3. The concentration of pollutants inside the mixing cell is independent of surface stability. The height of the mixing cell is 12 feet and the width extends from shoulder to shoulder of the road if the center median is 30 ft. or less.

4. Wind speed is not a function of height.

5. There are no aerodynamic effects on air passing over obstructions.

This model distinguishes between cross wind and parallel wind cases.

Cross wind conditions, in which the wind direction differs from the highway direction by more than 12 degrees, are treated separately from parallel wind conditions. Mixing cell concentrations for the cross wind case are calculated from:

$$C = \frac{(1.06)Q}{K_1 u \sin \phi} \tag{5}$$

where:

C = Mixing cell concentration gm/m^3

Q = Emission source strength gm/sec-m

u = Wind speed m/sec

ϕ = Angle between wind direction and highway alignment

K_1 = Empirical factor presently assumed to be 4.24.

The number 1.06 is an empirical factor relating to the height of the mixing cell to concentration.

The value of the source strength term Q is found using the following equation:

$$Q = [1.73 \times 10^{-7}] \times [VPH] \times [e] \tag{6}$$

where:

VPH = Vehicles per hour on the road

e = The emission factor (gm/mile) which is calculated using one of the methods discussed in the previous section.

The numerical constant 1.73×10^{-7} is a conversion factor to give the value of Q in the correct units.

To calculate the pollutant concentration off the roadway in the crosswind case the following equation is used:

$$\chi(x,y,z) = \frac{4.24Q}{K_i \sigma_z u \sin\phi}\frac{1}{2} \left[\exp - \frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2 + \exp - \frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] \qquad (7)$$

Where all symbols have been previously defined. There are no σ_y terms in Equation 7 as there are in Equation 4 because this model assumes an infinite line source of pollution. The height of the plume centerline (H) is assumed to be the height of the highway.

When using the California Line Source computer model (see Appendix A), the user must specify either the cross wind or parallel wind case. For the cross wind case, Equations 5, 6, and 7 are used in the program. Values of σ_z are calculated using polynomial approximations of the curves in Figure 3 in the SIGMAY subroutine.

The parallel wind part of the California Line Source model takes into account the buildup of pollutant levels in the downwind direction. The equation for mixing cell concentration is:

$$C' = A \left(\frac{Q'}{u}\right)\left(\frac{1}{K_1}\right)\left(\frac{30.5}{W}\right) \qquad (8)$$

where:

- C' = Mixing cell concentration for parallel winds gm/m^3
- A = Downwind concentration ratio for parallel winds
- W = Width of roadway from edge of shoulder to edge of shoulder in meters
- 30.5 = Width in meters of highway used in developing the parallel wind model

Q' = Source strength of a 100' length of road

u and K_1 have been prevously defined.

The downwind concentration ratio (A), is dependent upon the stability class, shown in Figures 5 through 11. Subroutine PWA approximates these curves using polynomials. For parallel winds the value of Q' is found from

$$Q' = [e]\ [VPH]\ [5.26 \times 10^{-6}] \qquad (9)$$

where 5.26×10^{-6} is a factor to convert the produce [VPH][e] to gm/sec for a 100 ft. length of highway. VPH and e have been previously defined.

To calculate the pollutant concentration outside the mixing cell for parallel winds the following equation is used:

$$\chi(x,y,z) = \frac{C'}{2}\ [\exp - \frac{1}{2} (\frac{y}{\sigma_y})^2]\ [\exp - \frac{1}{2} (\frac{z+H}{\sigma_z})^2 + \exp - \frac{1}{2} (\frac{z-H}{\sigma_z})^2] \qquad (10)$$

Where all terms have been previously defined. Subroutine SIGMAY calculates values of σ_y using polynomial approximations. This equation gives the pollutant concentration at a point normal to highway where the mixing cell concentration is C'.

2.4 HIWAY Model

The HIWAY model treats each lane of road as a separate series of point sources as opposed to a continuous line source. Concentrations of pollutants are calculated at each receptor by a trapazoidal integration of the concentration calculated at the receptor due to each point source. One point source is set at each end of the specified length of road for each lane as a first approximation. Subsequent approximations add point sources at half the previous segment length. For every calculation of the

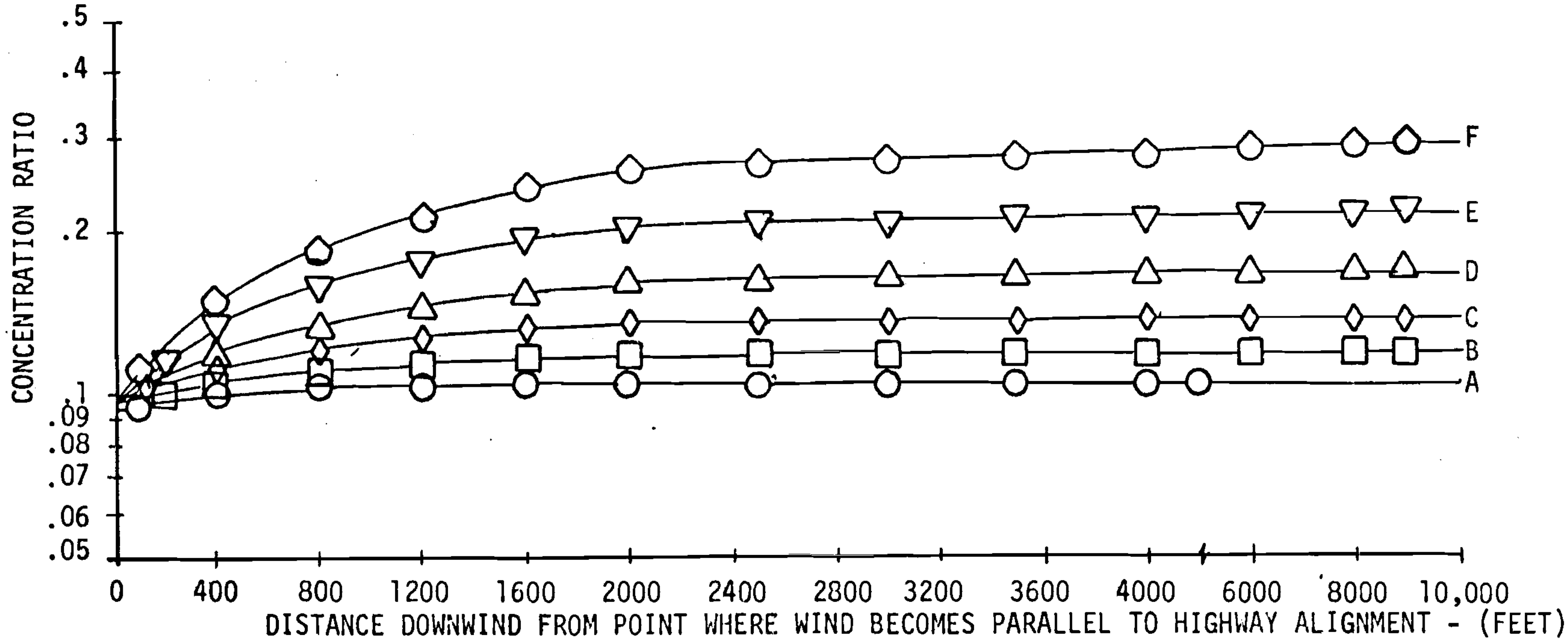

Figure 5 Ground level concentration ratio $\frac{C\bar{u}}{Q} K \left(\frac{W}{30.5}\right)$ downwind from highway line source parallel wind at-grade section for all stability classes (ref. 11)

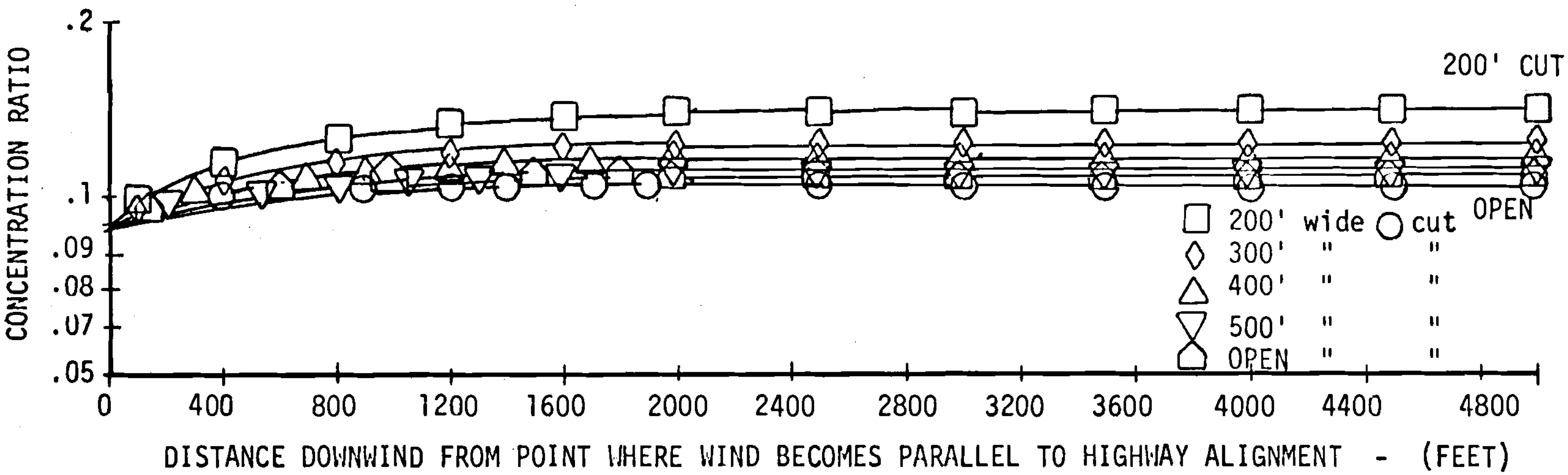

Figure 6 Ground level concentration ratio $\frac{C\bar{u}}{Q} K \left(\frac{W}{30.5}\right)$ downwind from highway line source parallel wind (cut sections) stability class A (ref. 11).

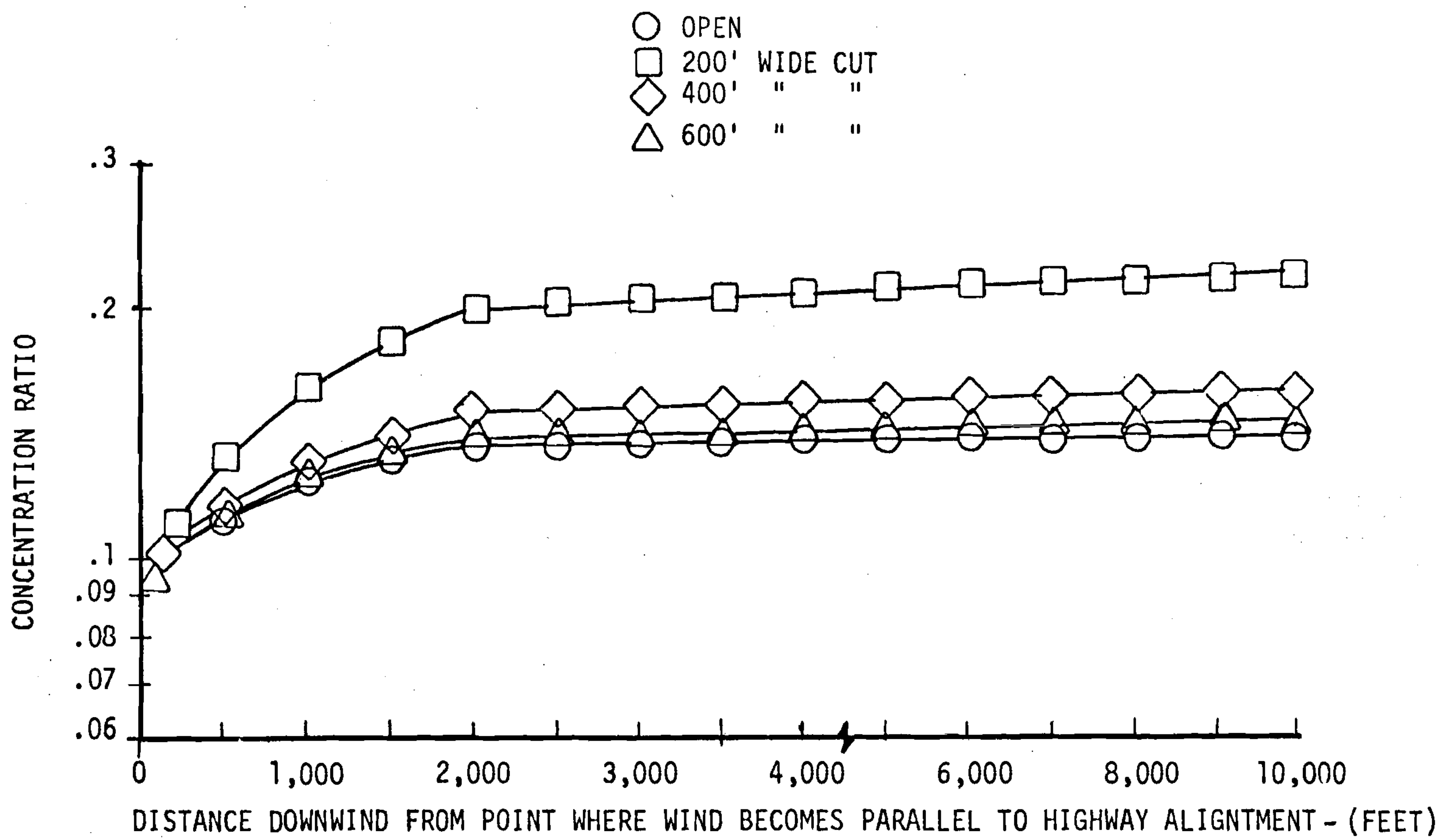

Figure 7 Ground level concentration ratio $\frac{C\bar{u}}{Q} K \left(\frac{W}{30.5}\right)$ downwind from highway line source parallel wind (cut sections) stability class B (ref. 11)

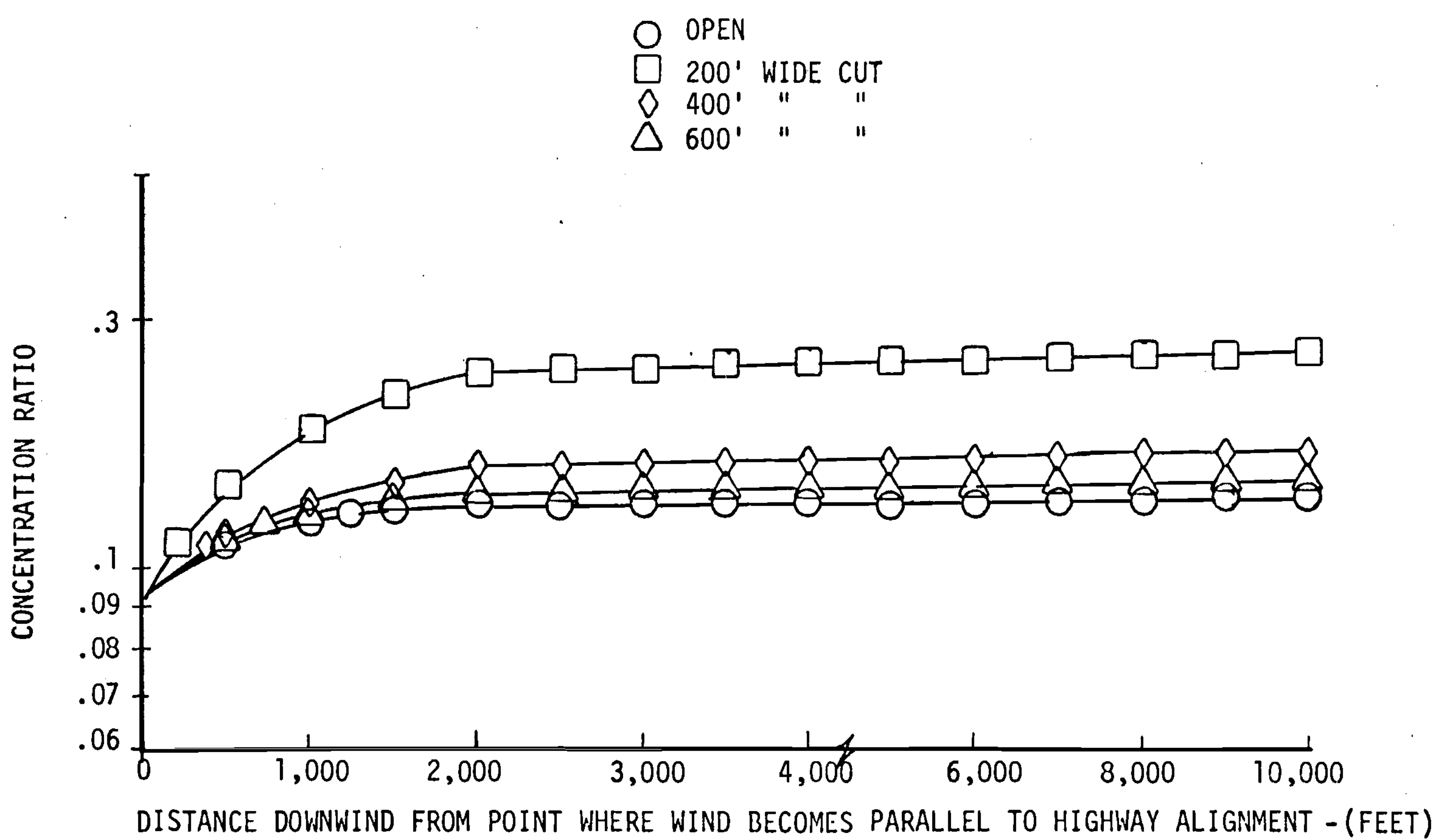

Figure 8 Ground level concentration ratio $\frac{C\bar{u}}{Q} K \left(\frac{W}{30.5}\right)$ downwind from highway line source parallel wind (cut sections) stability class C (ref. 11)

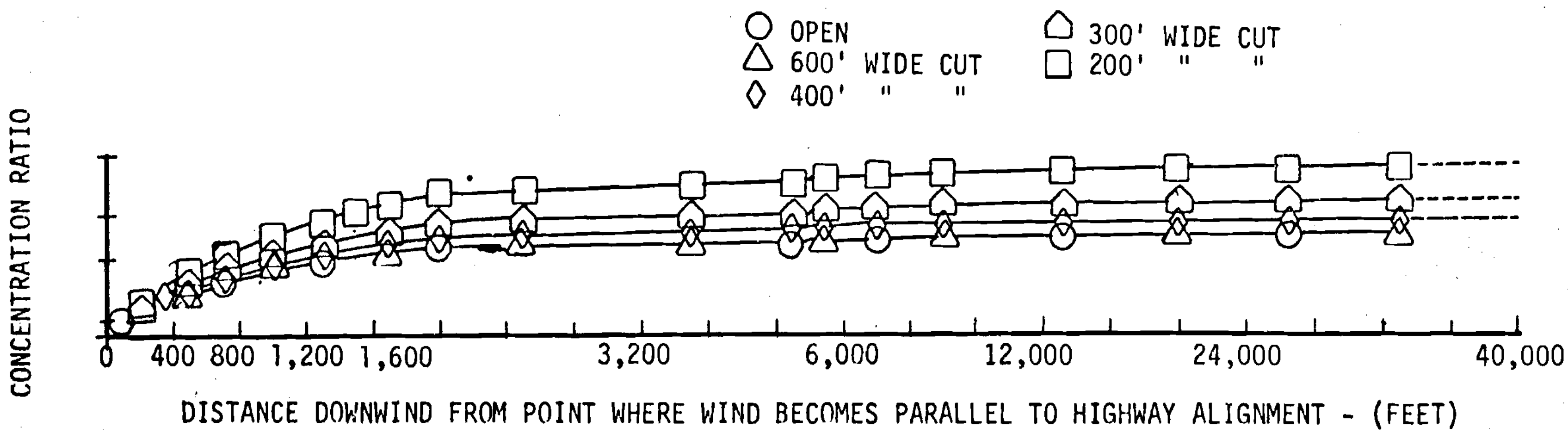

Figure 9 Ground level concentration ratio $\frac{C\bar{u}}{Q}K\left(\frac{W}{30.5}\right)$ downwind from highway line source parallel wind (cut sections) stability class D (ref. 11)

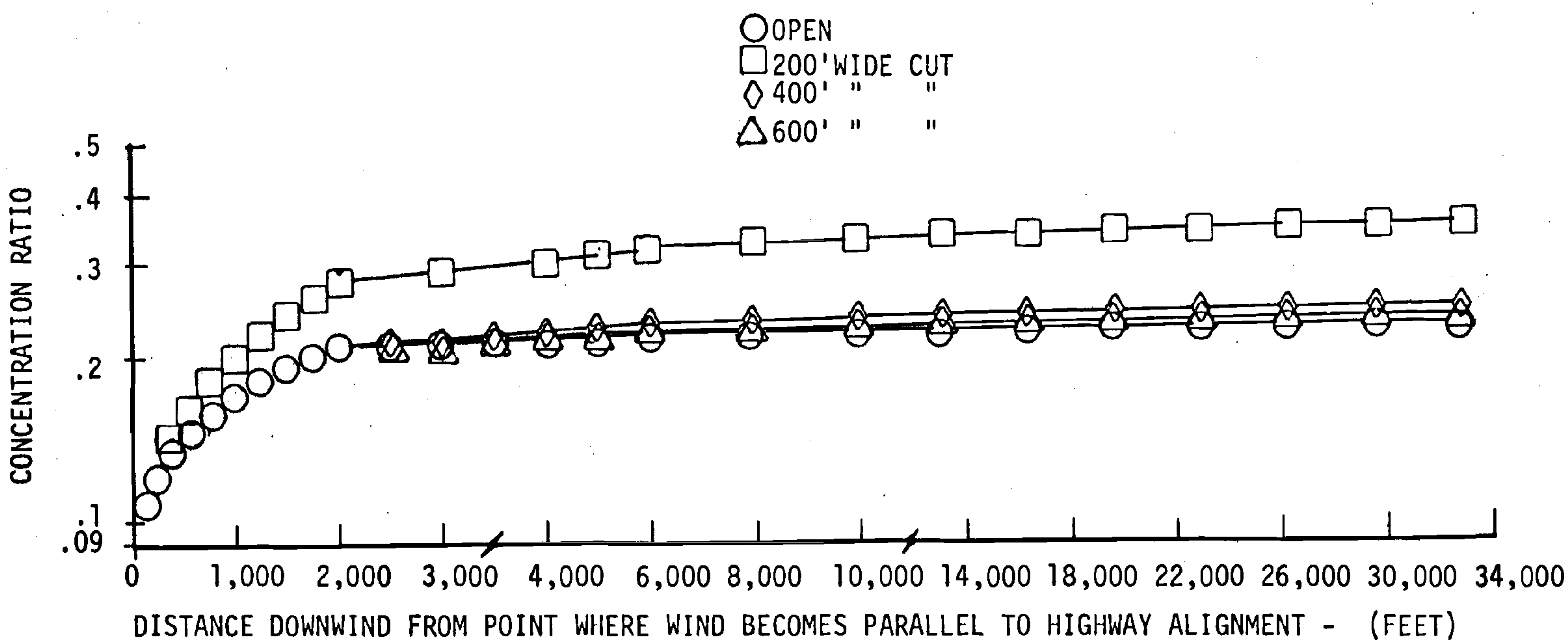

Figure 10 Ground level concentration ratio $\frac{C\bar{u}}{Q} K \left(\frac{W}{30.5}\right)$ downwind from highway line source parallel wind (cut sections) stability class E (ref. 11)

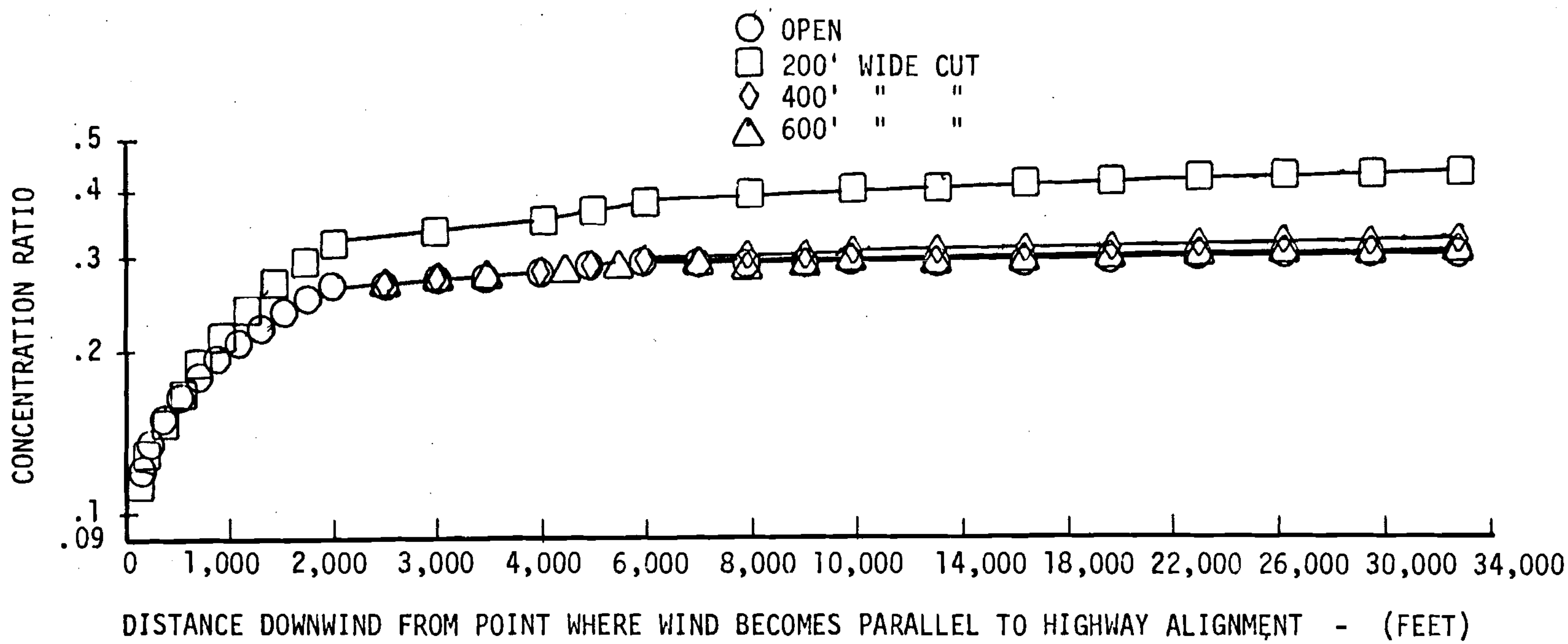

Figure 11 Ground level concentration ratio $\frac{C\bar{u}}{Q} K \left(\frac{W}{30.5}\right)$ downwind from highway line source parallel wind (cut sections) stability class F (ref. 11)

concentration at a receptor after the first approximation, the value calculated is compared to the previously calculated value. If it differs by 2 percent or more, another approximation is made. The pollution concentration, due to each lane is calculated at each receptor using the following equation to integrate the concentrations from each point source:

$$\chi = \frac{Q\Delta\ell}{uM} \left[\frac{1}{2}(f_o + f_n) + \sum_{i=1}^{n-1} F_i\right] \qquad (11)$$

Where:

$\Delta\ell$ = Length of designated road segment

F_i = Dispersion function at receptor due to i^{th} point source

M = Number of lanes specified for road

Q and u have their previously defined values.

Values of Q are calculated using Equation 6 as in the California Line Source model. The value calculated for Q is divided by the number of lanes specified for the road in Equation 11 to give each lane an equal emission strength.

The values of F_i which are used in Equation 11 are calculated from the following form of the Gaussian diffusion equation:

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

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

$$\left. + \exp -\frac{1}{2}\left(\frac{z-H+2nL}{\sigma_z}\right)^2 + \exp -\frac{1}{2}\left(\frac{z+H-2nL}{\sigma_z}\right)^2\right] \qquad (12)$$

Where:

L = Mixing height in meters.

All other variables have their previously defined values.

This equation uses the concept of a mixing height. When an evaluated temperature inversion exists, the diffusion of a pollutant released below the bottom of this inversion is significantly reduced when it reaches the height of the inversion. The height of the bottom of this temperature inversion is assumed to be the limiting height to which the pollutant can disperse. This is defined as the mixing height. The terms within the summation in Equation 12 accounts for the reflection of the plume back and forth between the ground and the mixing height if the mixing height is sufficiently low. Previous work[7] has shown that usually four or five sums of these four terms are enough for convergence.

Since this model calculates concentrations from point sources instead of a line, the same equations are used for both the parallel and cross wind cases. The initial mixing of pollutants above the highway is accounted for in the values of σ_y and σ_z in Equation 12.

Initial values of σ_y and σ_z are calculated at the edge of the roadway by assuming a virtual source upwind of the roadway. This gives non-zero values of the standard deviations which determine the size of the plume at the edge of the road. At present, σ_z is assigned a value of 1.5 meters at the downwind edge of the highway and σ_y is assigned a value of 3 meters as an initial value. Values of σ_z and σ_y are calculated as polynomials in the SIGMA subroutine of HIWAY. See Appendix B.

CHAPTER III

PARAMETRIC STUDY AND COMPARISON OF HIWAY AND CALIFORNIA LINE SOURCE MODELS

This section examines the response of these models to certain input variables. There are two purposes for this. The first is to determine for which values of these variables the highest concentrations are predicted. The second is to compare the response or sensitivity of each model to changes in these variables. This information is useful since the EPA requires a prediction of the highest probable carbon monoxide concentrations for the air quality analyses of a highway environmental impact statement.

Inputs which will be considered are:

1. Wind direction,
2. Wind speed,
3. Stability class and mixing height,
4. Highway width.

Wind direction and speed, stability class and mixing height are all meteorological inputs which can vary for any highway. Highway width has a large effect on the output of these models in some cases and is included for this reason.

In determining the reactions of the models to changes in an input, the common inputs for each model are each assigned the same value. All the program runs executed to determine the effects of meteorological parameters and highway width used an emission factor of 50 gm/ni. This was the EPA national average emission factor for CO in 1975. A speed correction factor of 1 and a traffic volume of 2000 vehicles per hour were assigned. These values were picked arbitrarily since they are used in the calculation of the amount of pollutants, and not the dispersion of them. For the cases in which highway width is not studied, it is set at 100 ft. with a 30 ft. center median, primarily because these models were developed for roads of this size. HIWAY has an input for the number of lanes which the California Line Source model does not have. This was set at 4 lanes on all runs except those considering highway width, to correspond with the 4 lanes of traffic assumed in the development of the California Line Source model. The California Line Source model also does not have a mixing height input. The mixing height is set so it will not influence any calculations in the HIWAY model except for those done in the study specifically considering mixing height. The data used in the figures in this section was obtained by running both models varying only the variable of interest and treating all others as described.

3.1 Effect of Wind Direction

Both HIWAY and California Line Source will permit angular variations in wind direction from parallel to perpendicular to the highway. For a wind angle (ϕ) of 12 degrees or less, the California model becomes independent of ϕ and calculates concentrations using its parallel wind subroutines. The California model therefore always gives highest concentrations for wind directions within 12 degrees of the highway as seen in Figures 12 and 13.

HIWAY does not use a special model for small wind angles. This allows for considerable differences in calculated concentrations for wind angles close to parallel. HIWAY is most responsive to wind angle changes in the range from 0 degrees to about 60 degrees. The California model is most

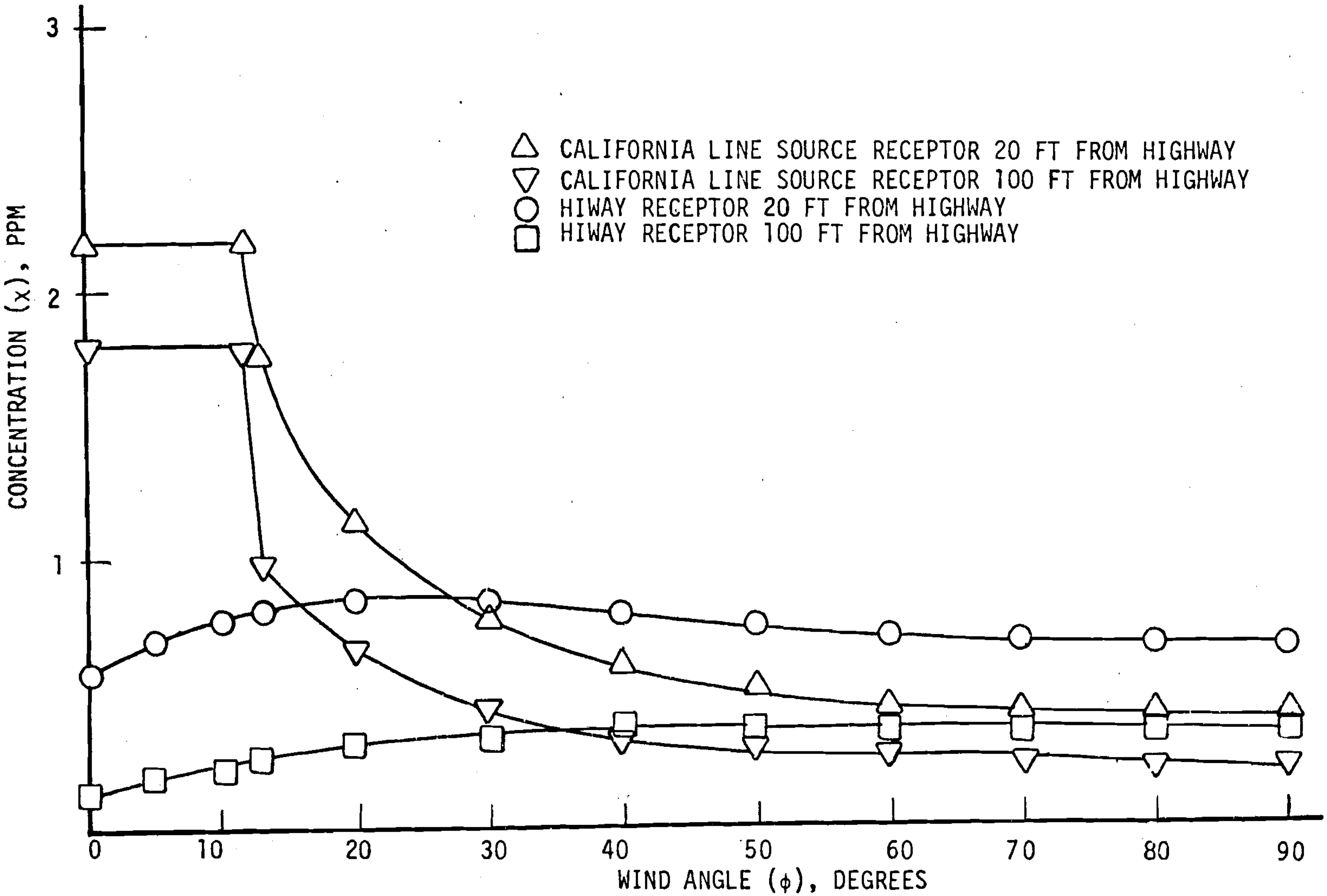

Figure 12 Concentration versus wind angle wind speed 11.2 MPH stability class 1

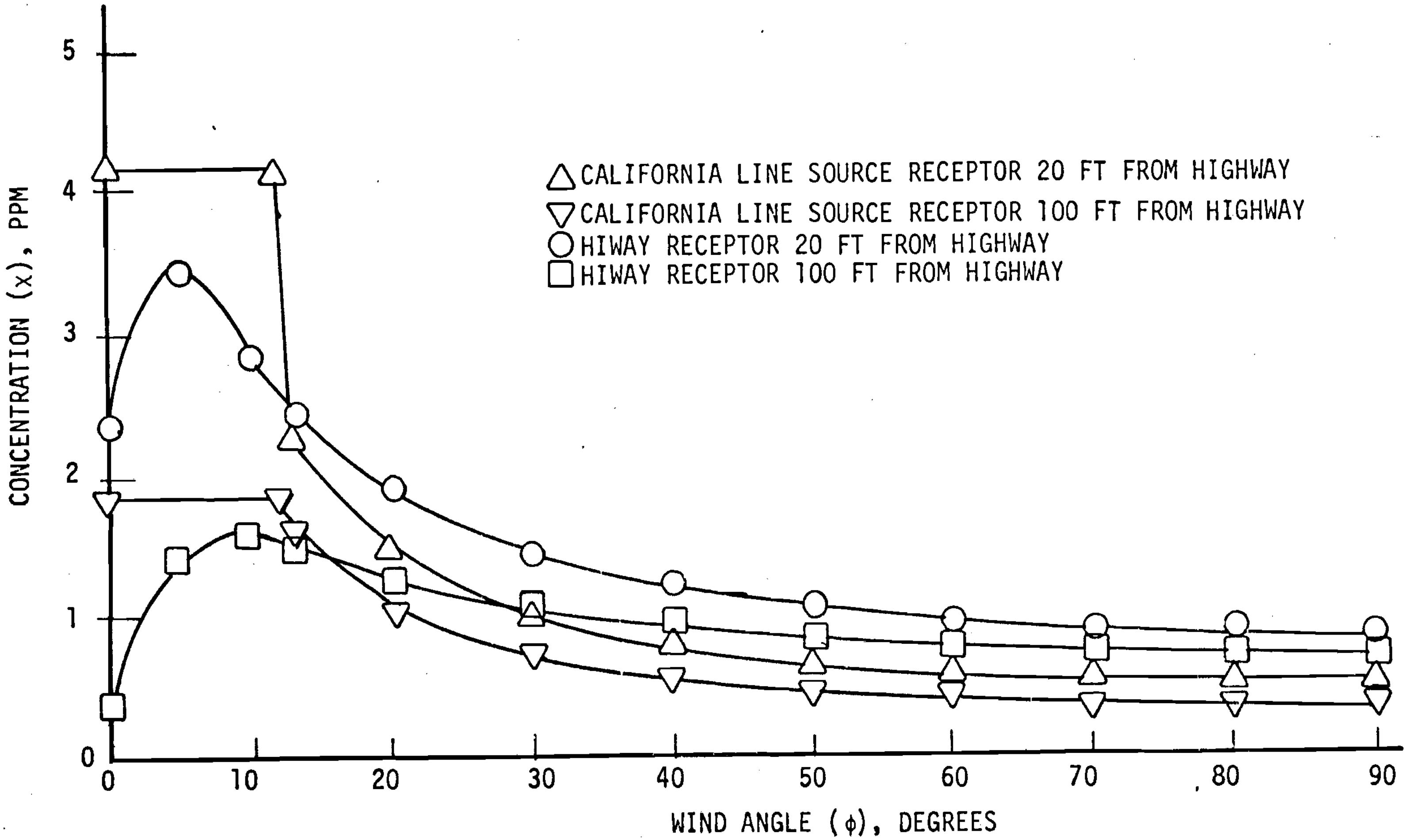

Figure 13 Concentration versus wind angle wind speed 11.2 MPH stability class 5

responsive to changes in wind angle between 12 degrees and 60 degrees. As depicted in Figures 12 and 13, there is little variation in predicted pollution concentration in either model for wind angle changes above 40 degrees from parallel. These figures show results for the 'best' and 'worst' stability classes. The stability classes between those shown in Figure 12 (stability class A or 1 and Figure 13 (stability class E or 5) also follow this trend.

The angle at which peak concentrations occur differs with stability class for HIWAY. Distance from the edge of the roadway must also be considered. For stability class 1 (Figure 12) the highest concentrations at 100 ft. from the edge of the road occur at wind angles greater than 50 degrees. At 20 ft. the highest concentrations are found between 20 degrees and 30 degrees, beyond which peak readings decrease with increases in wind angle. The wind angle at which peak concentrations occur decrease with increasing stability. For stability class 5 (Figure 13) highest concentrations are calculated around a wind angle of 5 degrees at 20 ft. out and at around a wind angle of 10 degrees at 100 ft. from the road.

With other inputs held constant as discussed previously, calculated concentrations from the California model are always higher than those from HIWAY for wind angles of 12 degrees or less. Figures 12 and 13 show this for stability classes 1 and 5. Similar results were obtained for the stability classes between these. Between wind angles of 12 and 40 degrees, the stability class and distance affect which model predicts higher concentrations. At wind angles greater than 40 degrees, HIWAY predicts higher concentrations for all stability classes within 100 ft. of the edge of the road. For both models calculations of concentrations beyond 100 ft. were quite close for all wind angles and stabilities.

3.2 Effect of Wind Speed

The effect of wind speed on HIWAY and California Line Source is quite similar. There is always an inverse relation between wind speed and pollutant concentration. Figure 14 shows the effect of wind speed on the concentration at a receptor 20 ft. from the road for stability class 5. It can be seen that as wind speed approaches 2 mph the concentration raises rapidly. The Gaussian diffusion equations, on which the models are based, are considered invalid for wind speeds below 2 mph. California Line Source prints an error message if a wind speed less than 2 mph is called for. HIWAY prints out no error message but should not be used for wind speeds of less than 2 mph.

3.3 Effect of Stability Class and Mixing Height

The stability class values affect the HIWAY and California Line Source results quite differently. With everything else held constant, HIWAY predicts higher concentrations for higher stability classes close to the highway. As the distance from the roadway increases, the values of pollution calculated for different stability classes come closer together. Figure 15 shows this for a wind direction parallel to the highway. Similar results are obtained for other wind angles.

California Line Source does not react to changes in stability class in the same manner as HIWAY, in either its parallel or cross wind models. For wind angles in the parallel winds range, within about 100 ft. of the highway, higher predicted concentrations are found at higher stability classes as expected. At about 100 ft. from the road, the predicted concentrations come together and beyond this distance higher concentrations

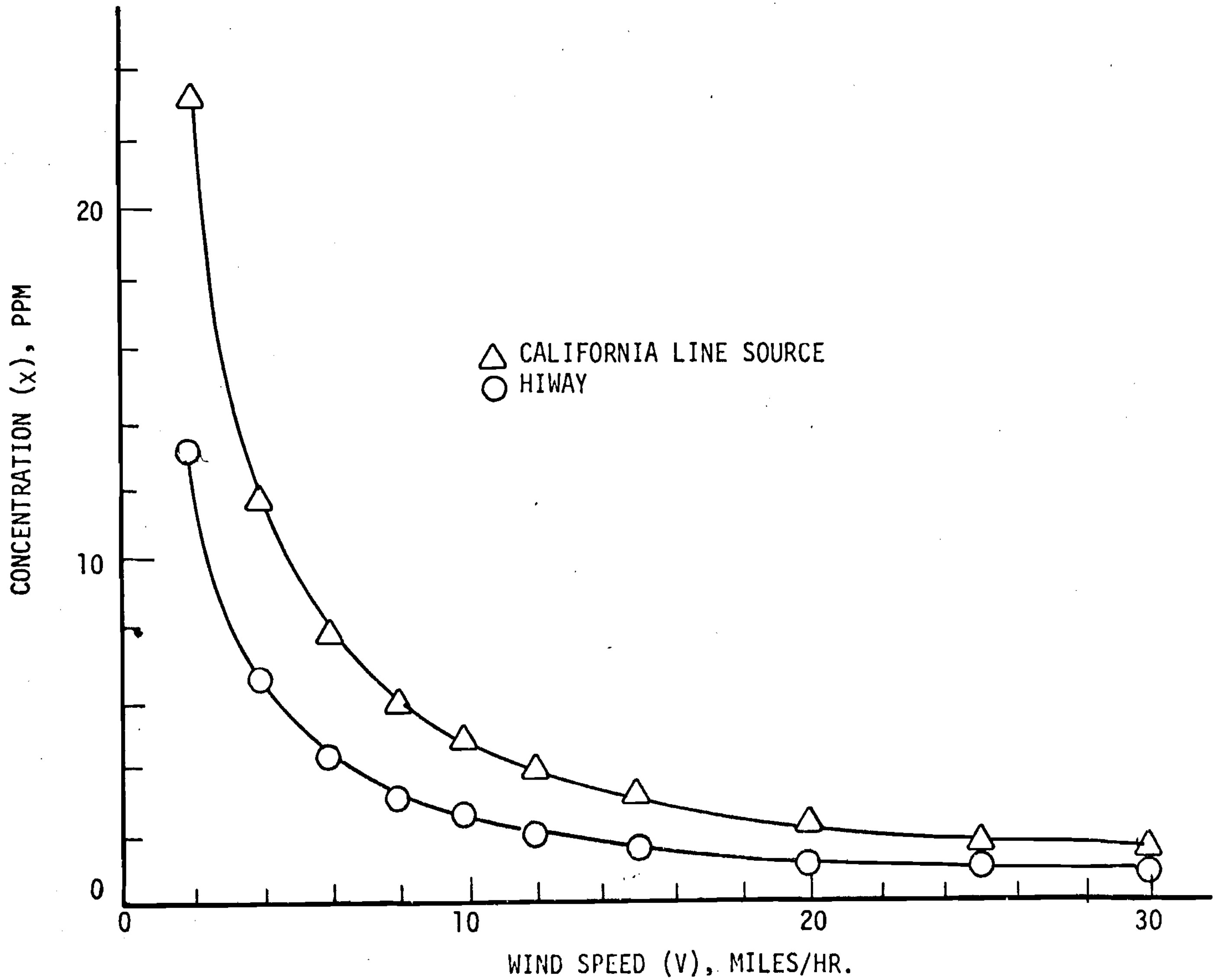

Figure 14 Concentration versus wind speed parallel wind stability class 5

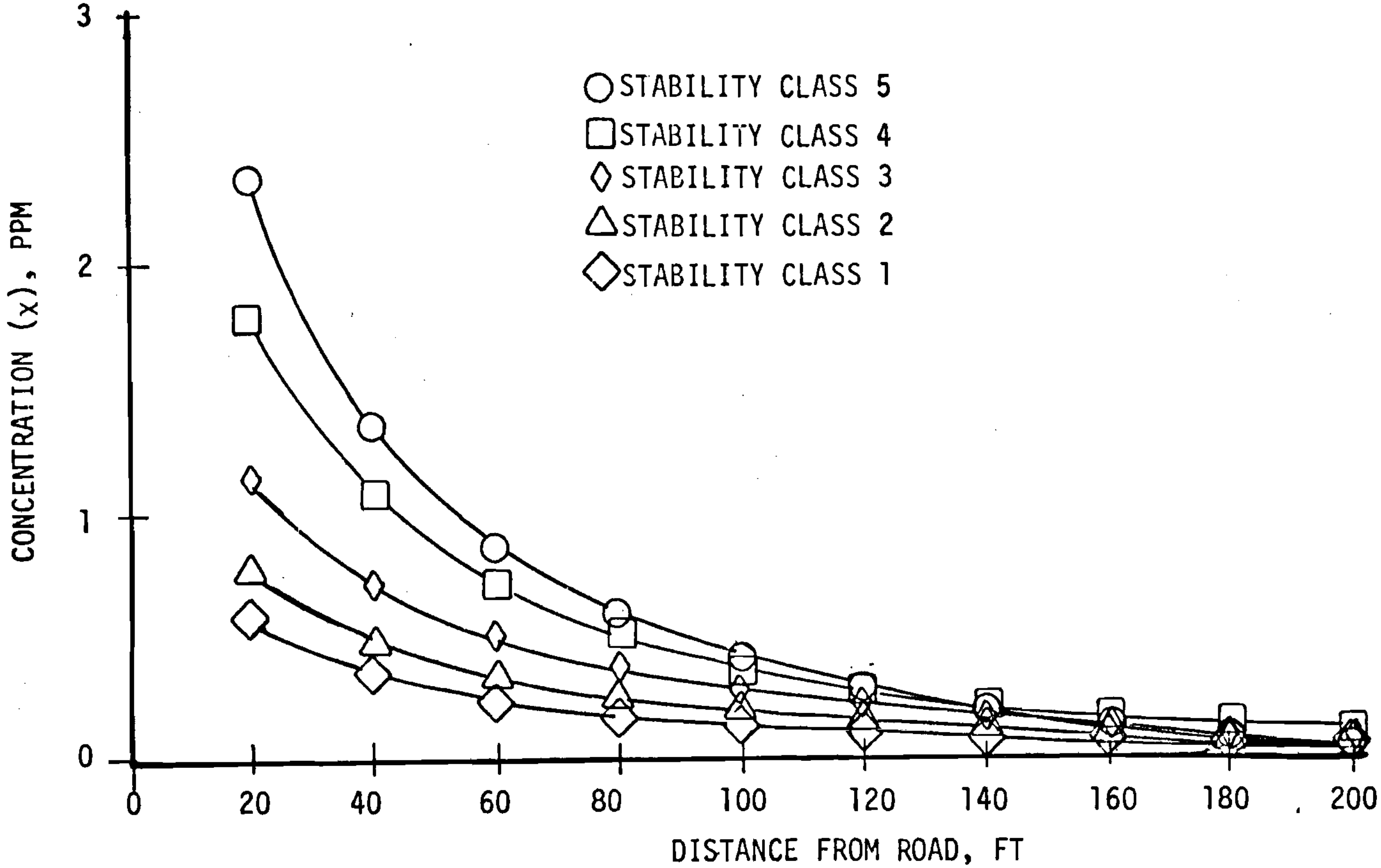

Figure 15   Concentration versus distance HIWAY parallel wind

are found with progressively lower stability classes as seen in Figure 16.

For wind angles utilizing California Line Source's crosswind model, the mixing cell concentration is assumed to be independent of stability class. This results in the same concentrations being calculated at the edge of the highway for all stability classes. As the distance from the highway increases, the calculated concentrations depend upon the stability class. Higher concentrations are calculated for progressively higher stability classes. Figure 17 shows the case for a wind angle of 90 degrees.

California Line Source will accept all six stability classes as inputs while HIWAY will accept only classes 1 through 5. This gives California Line Source the ability to predict concentrations in temperature inversion conditions which extend all the way to the ground, since this is the definition of stability case 6.

HIWAY treats temperature inversions by use of the mixing height concept discussed in Chapter II. A value for mixing height must be inputted for each run of HIWAY. If the effect of the plume being reflected down due to a mixing height is not desired, the mixing height must be inputted at a large enough distance above the road so that the plume does not reach it. Figure 18 shows the result of calculations made using HIWAY with different mixing heights. A mixing height of ten feet results in significantly higher concentrations than a fifty foot mixing height. Going from a fifty foot mixing height to a 100 ft. one is seen to have a much smaller effect on the calculated values while going to a 500 ft. mixing height gives no change at all. A mixing height of 500 ft. or more will therefore effectively eliminate the effects of plume reflection at the mixing height.

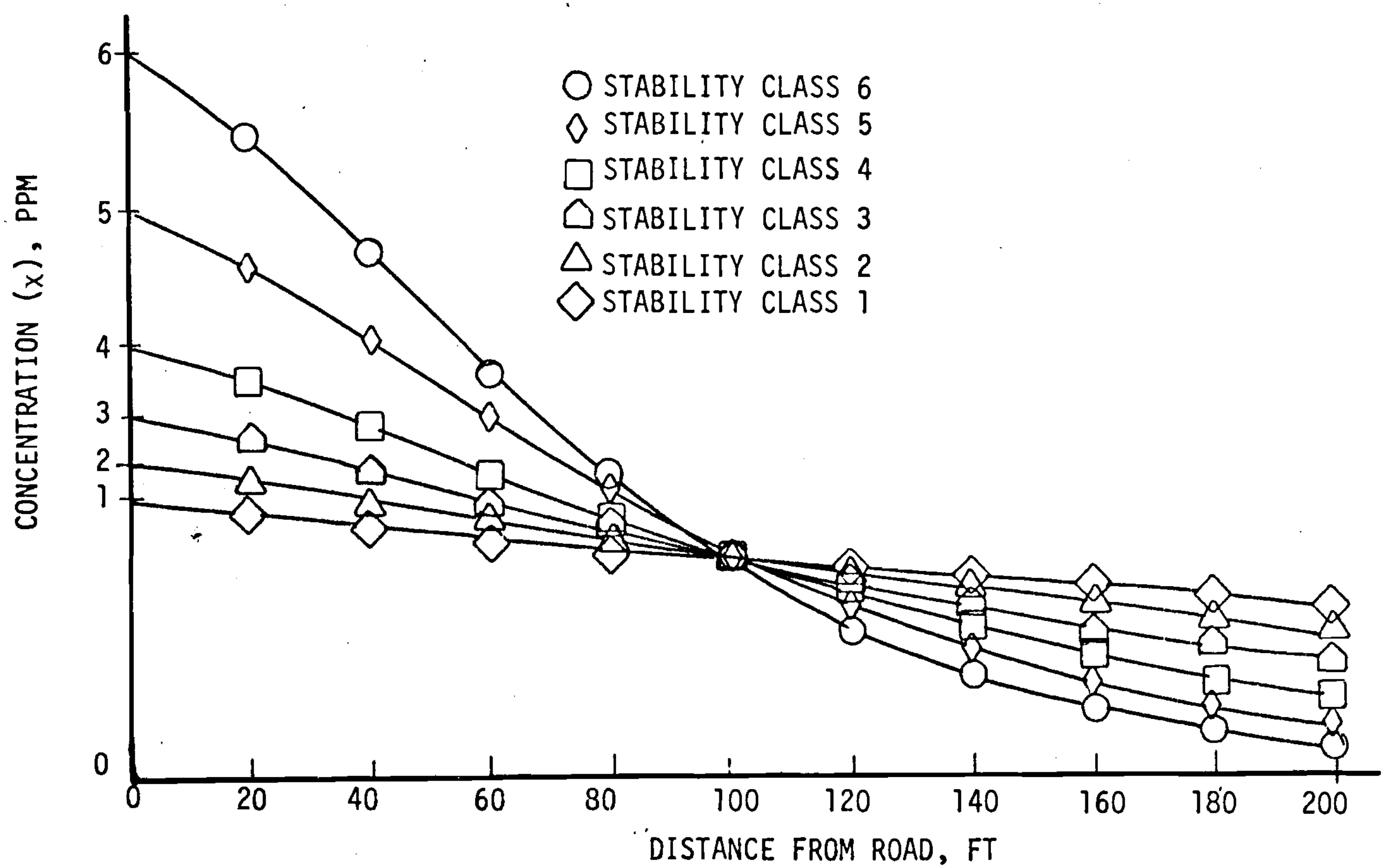

Figure 16 Concentration versus distance California Line Source

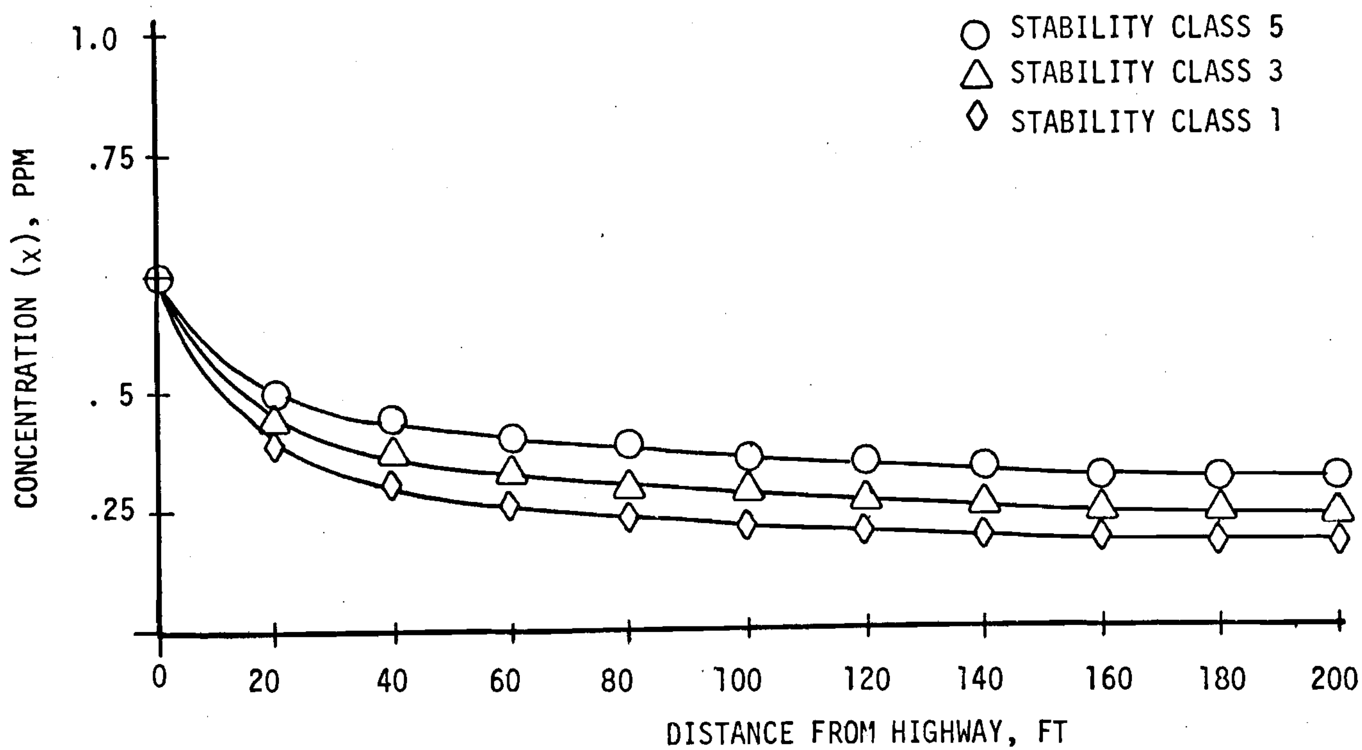

Figure 17 Concentration versus distance California Line Source

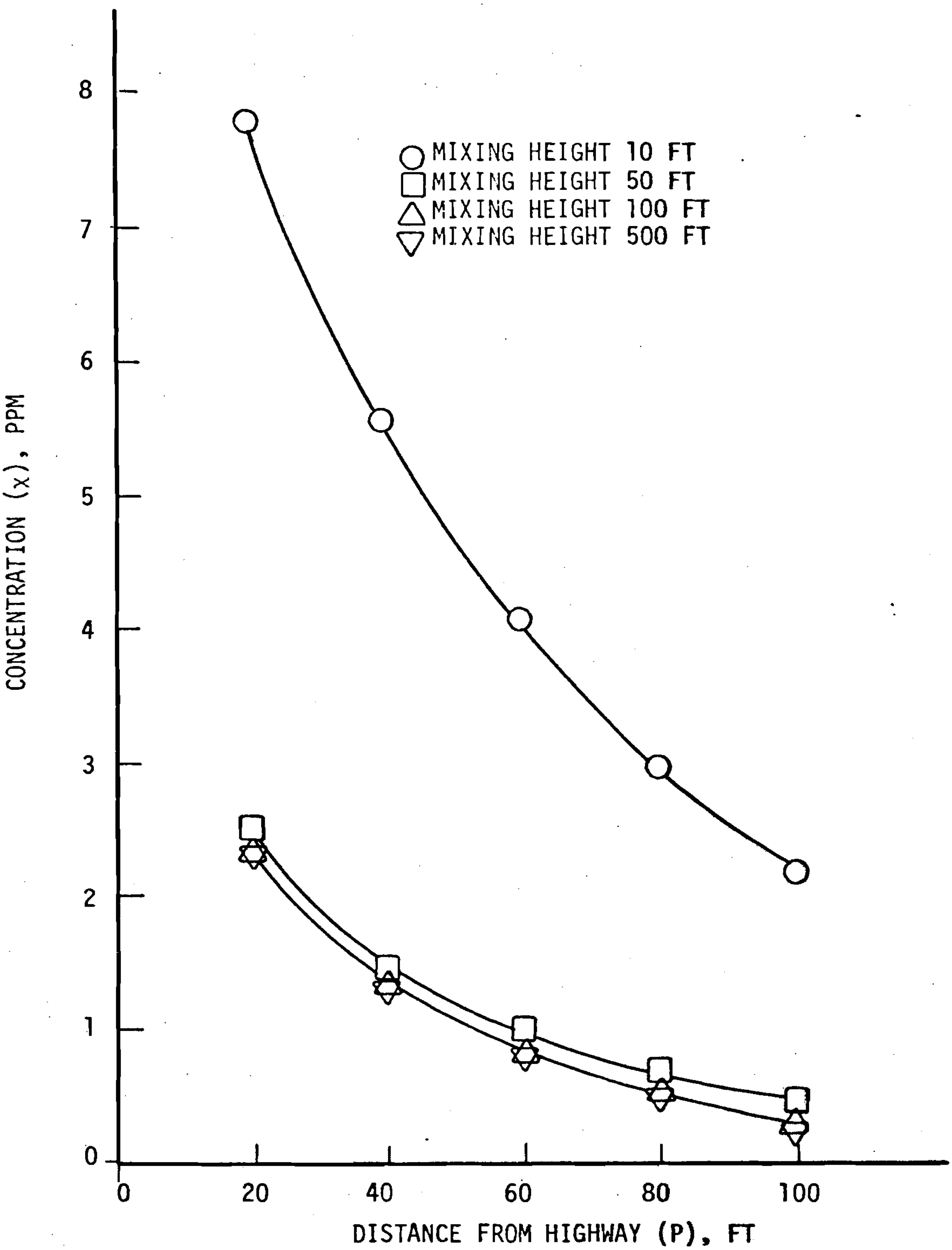

Figure 18 Concentration versus distance HIWAY parallel wind stability class 5

Tests run with other wind angles and stability classes showed similar results.

Since the mixing height is treated as a lid above which pollutants cannot pass, it is possible to case HIWAY to calculate very high concentrations by making the mixing height very close to the ground. For example, setting the mixing height at 1 ft. would cause HIWAY to calculate pollutant concentrations assuming all pollutants are trapped in a 1 ft. high box. Naturally, very high concentrations would be calculated, but these results would be unreasonable since in reality the pollutants would be distributed to heights greater than 1 ft. by mechanically induced turbulence from traffic.

3.4 Effect of Highway Width

California Line Source was developed for a 100 ft. wide highway with a 30 ft. center median. For this reason it would be expected to give best results for roads in this general size. The parallel wind model of California Line Source has an input for highway width which is supposed to take into account the effect of using roads with widths other than 100 ft. For roads of less than 100 ft., it is assumed the mixing cell concentration increases because the same amount of pollutants are being put into a smaller volume. Conversely, mixing cell concentrations decrease for highways above 100 ft. in width.

Figure 19 shows the effect of the highway width upon the concentrations calculated by California Line Source and HIWAY for a wind angle of 0 degrees. As the road width gets smaller, California Line Source predicts rapidly rising concentrations. HIWAY predicts lower concentrations as the road becomes narrow and larger concentrations as the road becomes wider.

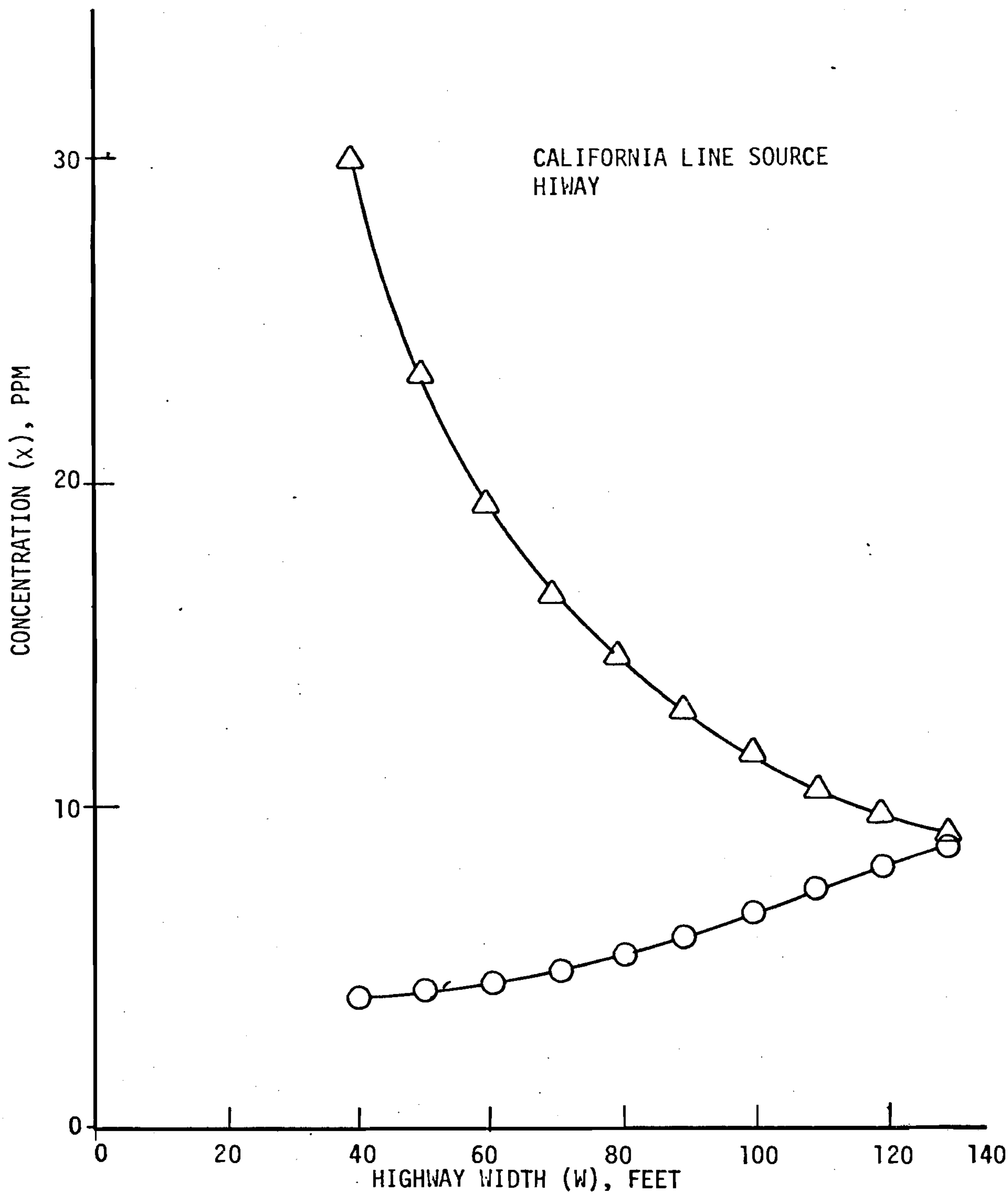

Figure 19 Concentration versus highway width parallel wind 4 MPH stability class 5

Because of the assumption of a 30 ft. median, the correction factor used in the California Line Source model applies only to roads with a median of about this size. Beaton, et al.[8] suggest treating highways with a center median of greater than 30 ft. as two highways. However, if this is done the group of lanes on each side of the median will be assumed by the model to have a 30 ft. median.

HIWAY has the advantage of having a center median of variable width and a variable number of lanes of traffic. This makes it a better choice to use for highways that differ much from the 100 ft. road with a 30 ft. median, used in the California model. In using HIWAY for these cases none of its basic assumptions are violated.

The cross wind model of California Line Source has no provision for highway width. California Line Source would be expected to give best results for a 100 ft. road with a 30 ft. median since it was developed for this configuration. HIWAY has inputs for road width for all angles but the effects of width are negligible for cross wind conditions.

3.5 Summary

Both models were run using the meteorological conditions causing highest concentrations to determine which predicts highest concentrations for worst case conditions. Stability class 5 was used because this is the worst class that can be used in both models. A parallel wind of 2 mph is used and also one of 4 mph. For the reasons discussed previously, a 100 ft. highway with a 30 ft. median and a 1000 ft. mixing height are used. All other inputs were the same for both models. The results are shown in Figure 20.

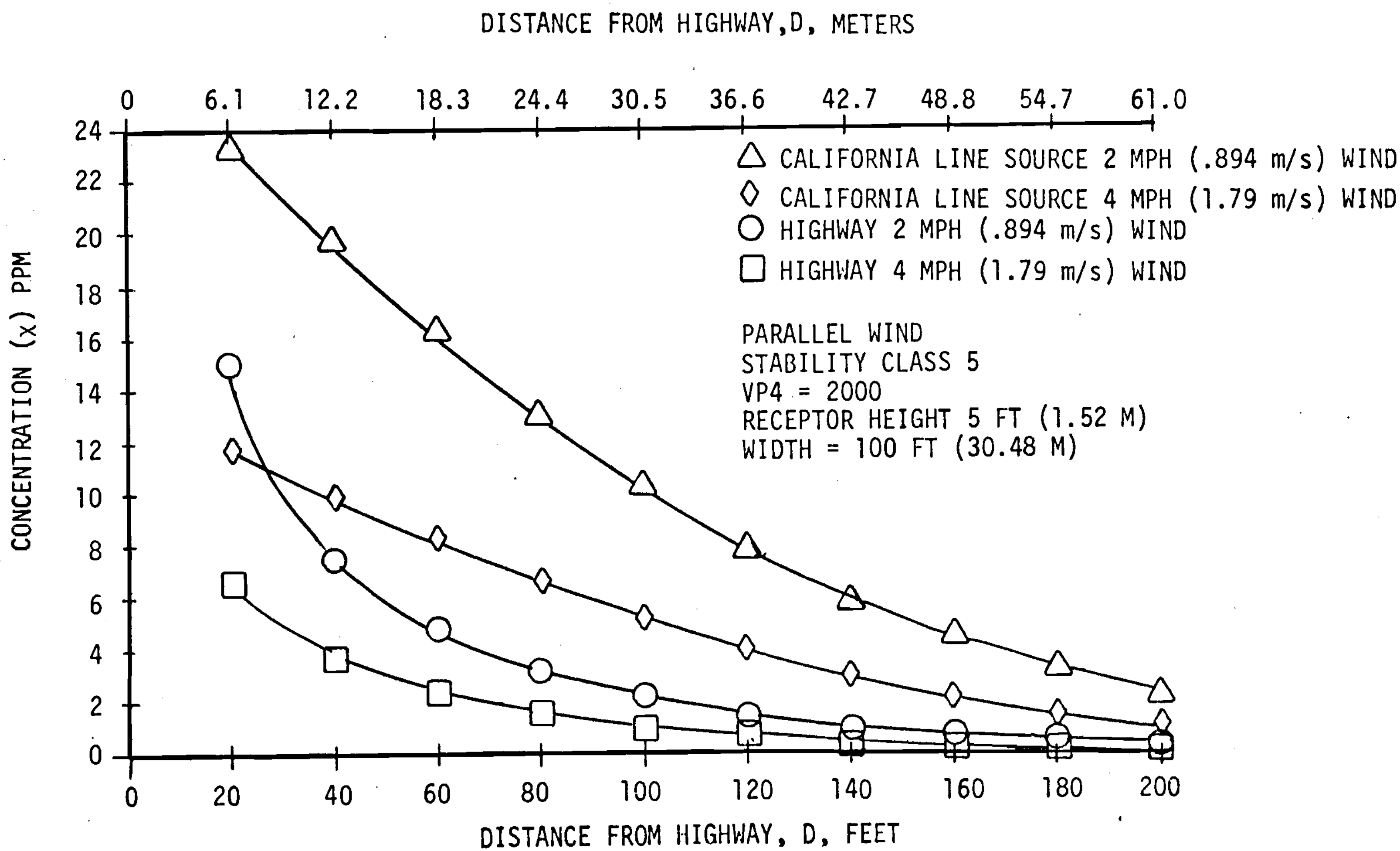

Figure 20 Concentration versus distance

For highways of less than 80 ft. or more than about 120 ft. in width; or those with no center median, use of the HIWAY model is suggested because none of the assumptions on which it is based are violated. When the California Line Source model can be used, stability class 6 should be used for worst case conditions of a hour or less although it is unreasonable to expect a ground based temperature inversion to last for long periods of time.

When the worst case concentration is required at a sensitive receptor more than 100 ft. from the highway, the California Line Source model should be used with stability class 1 and parallel winds, if the highway is close to 100 ft. in width. This will result in highest calculated concentrations.

CHAPTER IV

AIR POLLUTION ANALYSES FOR TWO ENVIRONMENTAL IMPACT STATEMENTS

The Environmental Protection Agency's "Guidelines for Review of Environmental Impact Statements[13]" states that a highway air pollution analysis is limited by the state-of-the-art to a microscale analysis for the carbon monoxide and particutate impacts and a mesoscale analysis of the carbon monoxide, hydrocarbon, and nitrogen oxide impacts. These guidelines also state that a microscale CO analysis should be made for all new major highways regardless of population and for minor highways or modifications increasing capacity in heavily developed areas. They do not suggest microscale particular modeling for any case. For any project other than one in a metropolitan area, a mesoscale analysis consisting of a calculation of the total emissions of carbon monoxide, hydrocarbons, and oxides of nitrogen is sufficient. Whenever any analysis is made, it should include the effects that will occur if the project is not carried out so these can be compared to the effects of building the road or changing it. The potential impact of alternate routes should also be analyzed. Both the microscale and mesoscale analysis should be performed for the estimated time of completion and for twenty years afterwards.

The microscale analysis should include "worst case" predictions of carbon monoxide concentrations for the highest 1 hour and 8 hour concentrations. Maximum 1 hour concentrations occur during the highest hourly traffic and the worst possible meteorological conditions. This includes atmospheric stability class 6, if it is available on the model being used, and winds of just above 2 mph, parallel to the road alignment. Maximum 8 hour concentrations are calculated using the highest 8 hour traffic volumes and the worst meteorological conditions that could reasonably be expected to last for 8 hours. Habeggar, et al.[14] suggests using higher wind speeds and stability class 5 for 8 hour periods because it is unlikely very low wind speeds or a ground based temperature inversion would last this long.

It can be shown that mesoscale estimates of pollutants discharged can be calculated from:

$$\text{Tons of pollutant per day} = (\text{ADT})\ (e)\ (\text{SCF})\ (\ell)\ (2.0858 \times 10^{-10}) \qquad (14)$$

Where:

ADT = Average number of vehicles which travel the road in 24 hours

e = Emission factor, gm/mi

s = Speed correction factor (from Figure 1)

ℓ = Length of the road, ft.

2.0585×10^{-10} is a conversion factor needed to obtain tons/day

This calculation must be performed for each pollutant. It must be used twice for hydrocarbons; once using the exhaust emission factor, and again using the evaporative and crankcase emission factor. When using the evaporative and crankcase emission factor, SCF always equals 1 since this factor is assumed to be independent of speed. The results of the two hydrocarbon calculations are added together.

Following are typical air quality analyses for environmental impact statements. Two different types of projects are considered. The first is the modification to an existing road, Route 33 in Chicopee, Massachusetts. The second is a new length of road which is part of the Route 52 in Auburn, Massachusetts. The HIWAY and California Line Source models are used in the microscale analyses of these projects. Total amounts of CO, HC, and NO_x are calculated for the mesoscale analyses using Equation 14.

4.1 Route 33, Chicopee, Massachusetts

This proposed project consists of improving Route 33 in the area shown in Figure 21. At present this is a two to four lane road of about 40 ft. in width with a 30 ft. median. There are no main alternates to this project.

4.1.1 Mesoscale analysis

The first phase of this analysis is the calculation of the average amounts of pollutants produced by the traffic on the project road. For the mesoscale analysis, Route 33 is broken into segments of different lengths to account for traffic volumes. Major side streets are also considered in this analysis. Lengths and traffic volumes for these segments and side roads were supplied by the Massachusetts DPW and can be found in Table 10. No change occurs in traffic levels for the no build case from 1975 to 1995 due to the assumption that the road reached its maximum loading in 1968. This is verified by traffic counts taken in 1973 and 1974. Assumed speeds (needed for determination of the speed correction factor (s) from Figure 1 used in the mesoscale analysis are based on speed limits and traffic conditions, and are listed in Table 11.

Amounts of CO, HC, and NO_x are calculated for each road segment using Equation 14. Emission factors for use in Equation 14 and in the microscale analysis are taken from Table 3. Based on these calculations, Tables 12 through 15 show the calculated amounts of pollutants for each road

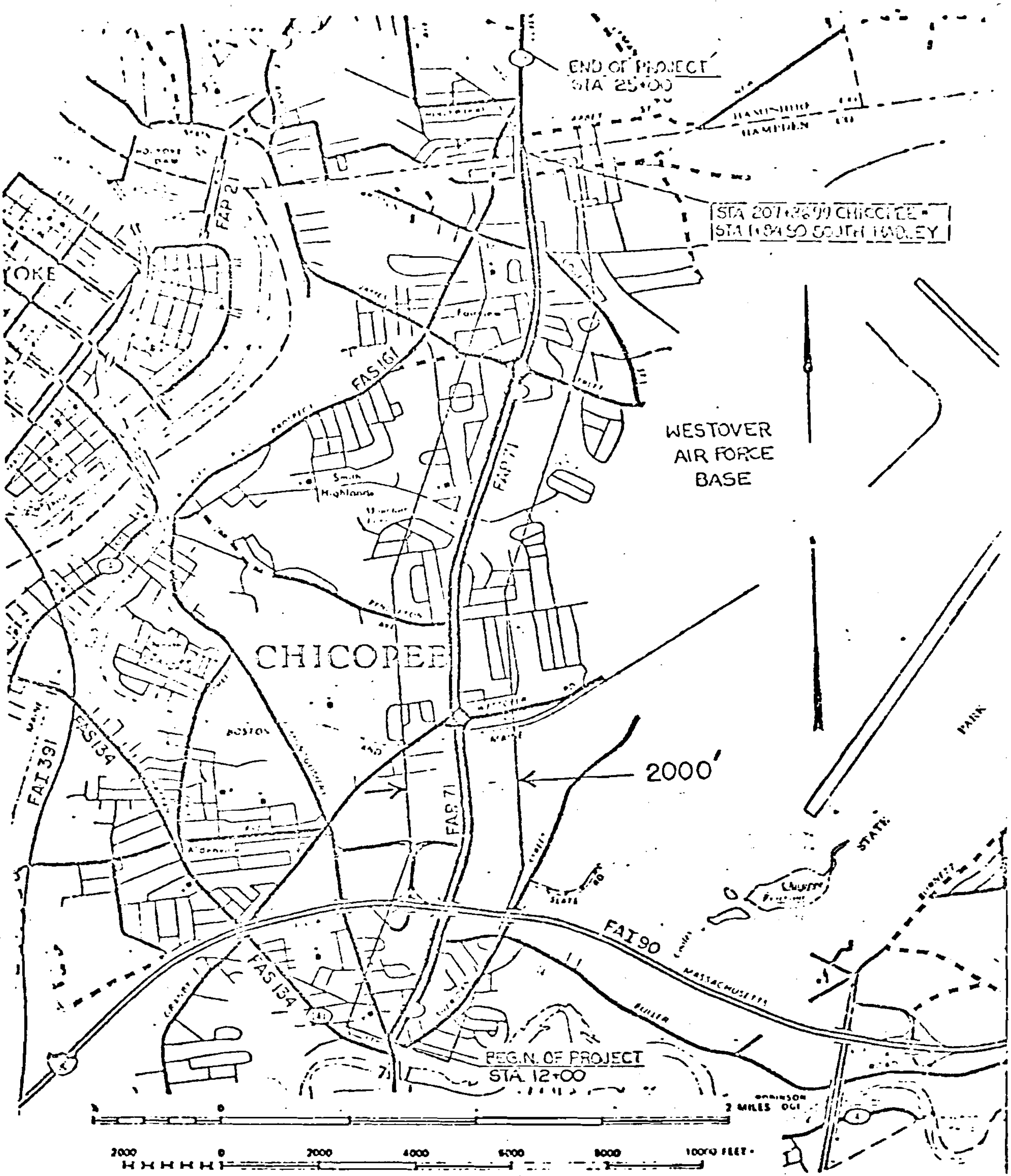

Figure 21

A Diagram Showing the Mesoscale Corridor

(I-90 was not included in the analysis)

TABLE 10

TRAFFIC DATA FOR MESOSCALE ANALYSIS*

Road	Length (ft)	Traffic ADT-No Build 1968	Traffic ADT-No Build 1975	Traffic ADT-No Build 1995	Traffic ADT-Build 1975	Traffic ADT-Build 1990	Traffic ADT-Build 1995
Route 33							
A. Montgomery to Fuller	2550	14650	14650	14650	14560	25240	27646
B. Fuller to Mass Pike Turnoff	2050	19800	19806	19806	19806	38285	42486
C. Mass Pike Turn-off to Westover	2700	21520	21520	21520	21520	43375	48342
D. Westover to Pendleton	2150	19190	19190	19190	19190	40620	45490
E. Pendleton to Irene	2200	18640	18640	18640	18640	37375	41632
F. Irene to James	3400	21545	21545	21545	21545	37303	40628
G. James to New Ludlow	4200	12135	12135	12135	12135	23655	26278
H. Fuller Street	1000	7210	7210	7210	7210	19205	21931
I. Westover	2000	8545	8545	8545	8545	14637	16022
J. Pendleton	2000	2915	2915	2915	2915	6097	6820
K. James	2000	13980	13980	13980	13980	23240	25344
L. Brilton	2000	2852	2852	2852	2852	4230	4543
M. Mass Pike Turnoff	1000	3400	3400	3400	3400	7920	8947

*Based on the best information available at this time.

TABLE 11

AVERAGE SPEEDS ASSUMED FOR MESOSCALE ANALYSIS
FOR BOTH ROUTE 33 AND SIDE STREETS

	1975	1995
Build	30 mph	25 mph
No Build	20 mph	20 mph

TABLE 12

TOTALS FOR MESOSCALE ANALYSIS (TONS/DAY)

Case 1 Build, 1975

	CO	HC	NOx
A	.262	.0418	.0132
B	.284	.0454	.0144
C	.407	.0188	.687
D	.289	.0461	.0487
E	.287	.0459	.0484
F	.513	.0819	.0865
G	.357	.0570	.0602
H	.0505	.00806	.00851
I	.1197	.01910	.02020
J	.0408	.00652	.00688
K	.01958	.0313	.0330
L	.0399	.00638	.00674
M	.0388	.00540	.00570
	2.70328	.41366	.42113

TABLE 13

TOTALS FOR MESOSCALE ANALYSIS (TONS/DAY)

Case 2 No Build, 1975

	CO	NC	NOx
A	.3900	.0508	.0390
B	.4240	.0552	.0424
C	.6070	.0789	.0607
D	.4310	.0560	.0431
E	.4290	.0557	.0429
F	.7650	.0995	.0765
G	.5330	.0692	.0533
H	.0753	.009790	.007530
I	.1786	.0232	.0179
J	.0609	.007920	.006090
K	.2920	.0380	.0292
L	.0596	.007750	.005960
M	.0355	.004520	.003550
	4.2809	.556580	.428130

TABLE 14

TOTALS FOR MESOSCALE ANALYSIS (TONS/DAY)

Case 3 Build, 1995

	CO	HC	NOx
A	.1414	.0219	.0283
B	.1747	.0270	.0351
C	.2620	.0405	.0525
D	.1962	.0304	.0394
E	.1838	.0284	.0368
F	.2770	.0429	.0556
G	.2210	.0343	.0444
H	.0385	.005960	.007730
I	.0643	.009950	.0123
J	.0274	.004230	.005490
K	.1017	.015730	.0204
L	.018230	.002820	.003660
M	.017950	.002780	.003600
	1.724180	.266870	.345288

TABLE 15

TOTALS FOR MESOSCALE ANALYSIS (TONS/DAY)

Case 4 No Build, 1995

	CO	NC	NOx
A	.0937	.013120	.014050
B	.1017	.014260	.015270
C	.1457	.0204	.0218
D	.1035	.014490	.015520
E	.1028	.0144	.015430
F	.1837	.0257	.0276
G	.1278	.017890	.019170
H	.018080	.002530	.002710
I	.0429	.0060	.006430
J	.014620	.002050	.002190
K	.0701	.009820	.010520
L	.014310	.002000	.002150
M	.008530	.001194	.001280
	1.027540	.143854	.154120

segment for the build and no build conditions for 1975 and 1995. Totals of each pollutant for each case are presented in Table 16. Total amounts of CO and HC decrease in the build case in 1975 due to the increased speed on the roads. The amount of NO_x changes very little. The build condition has higher calculated amounts of all three pollutants in 1995 due to increased traffic volume. Both build and no build conditions have lower predicted total amounts of pollutants due to increased emission controls.

4.1.2 Microscale analysis

This phase of the air quality analysis consists of calculating the concentrations of carbon monoxide on or near the highway. The highest concentration of CO occurs on the roadway but the only people in contact with these levels are motorists who are usually not exposed for long periods of time. People living in homes close to the road are exposed for long periods of time, though to lower concentrations. The closest estimated distance from the highway for any home on the Route 33 project is 30 ft. Microscale predictions for all cases include concentrations at this distance. In the cases where the California Line Source model is used, the concentrations on the roadway are also predicted. The California Line Source model is employed for all build cases since the dimensions of the new highway fit perfectly the assumptions of highway width used in this model. For the no build cases, the forty foot width of the highway dictates the use of HIWAY, so a mixing cell concentration cannot be calculated.

Calculations of maximum one hour calculations are made with the following assumptions:

TABLE 16

AVERAGE AMOUNTS OF POLLUTANTS
GENERATED BY TRAFFIC WITHIN THE CORRIDOR*

	1975			1995		
	CO	HC	NOx	CO	HC	NOx
Build	2.70	0.40	0.42	1.72	0.27	0.35
No Build	4.28	0.56	0.43	1.03	0.14	0.15

*In tons per day.

1. Winds are parallel to the highway.
2. Winds are very low speed (2.1 mph).
3. Traffic flow is at a one hour peak.

Peak one hour traffic for this project is specified as 11% of the average daily traffic. Stability class 6 is used in the California Line Source Model and stability class 5 in HIWAY.

Maximum eight hour concentrations are calculated assuming:

1. Winds are parallel to the highway.
2. Winds are low speed (5.75 mph).
3. Traffic flow is at an 8 hour peak.

Peak 8 hour traffic for this project is specified as 9% of the average daily traffic. Stability class 5 is used for both models. In all cases, the mixing height input of the HIWAY model is set at 1000 ft. so it does not influence calculations. A receptor height of 5 ft. is used in all calculations to represent the height of a person breathing the pollutants. Average speeds used for determining speed correction factors for the microscale case are presented in Table 17. Using the HIWAY model, worst case carbon monoxide concentrations for 1975 and 1995 for both build and no build conditions are shown in Table 18. In all cases except the 1975 maximum one hour calculation, the build case has higher predicted values than the no build case due to the increased traffic. Also, all 1995 predictions are lower than the corresponding 1975 ones due to increased emissions controls. The maximum one hour concentration for the 1975 no build case is predicted to be above federal standards. Other 1975 predictions are high but within limits set by the standards. 1995 predictions are well below standards. Background levels of CO should be considered in the microscale analysis if they will cause a substantial

TABLE 17

AVERAGE SPEEDS USED IN MICROSCALE CALCULATIONS

Average Speeds Used in Microscale Analysis in Miles per Hr.

	1 Hr.	8 Hr.	1 Hr.	8 Hr.
Build	27	30	22	25
No Build	17	20	17	20

TABLE 18

RESULTS OF MICROSCALE COMPUTER ANALYSIS
FOR CONCENTRATIONS OF CARBON MONOXIDE

CO Levels in Parts per Million

	1975				1995			
	Max. 1 hour		Max. 8 hour		Max. 1 hour		Max. 8 hour	
	Road	S.R.	Road	S.R.	Road	S.R.	Road	S.R.
Build	32	26	9.6	7.8	14	12	4.2	3.6
No Build	*	30	*	7.0	*	7.4	*	1.7

S.R. = Sensitive Receptor 20 ft. from road.

*Computer model not accurate for this case.

effect of air quality. Present levels of background CO are about 1 PPM[15] and will have no significant effect on air quality.

4.2 Route 52, Auburn, Massachusetts

The proposed project is the section of divided superhighway shown in Figure 22. This length of road will connect two already completed segments of Route 52. There is no road now along the proposed route. When completed, Route 52 will reduce the traffic on Route 12 which is considered the main alternate route.

For this analysis, Route 12 is broken into three parts to deal with different traffic and highway widths. The first segment runs from the intersection of Route 12 and Federal Hill Road north to the junction of Routes 12 and 20. Segment 2 is the road where these two routes are combined. Segment 3 is Route 12 from the eastern divergence of Routes 12 and 20 to Interstate 290.

Since Route 12 is the main alternate to Route 52, both build and no build calculations are made for each segment for the years 1978 and 1995. Build calculations are made for Route 52 for the same years. Traffic counts and predictions from the Massachusetts DPW are listed in Table 19. Estimated speeds are presented in Table 20 and road dimensions are in Table 21.

4.2.1 Mesoscale analysis

The calculation of the average number of tons of pollutants produced by vehicular traffic affected by this project forms this part of the air quality analysis. Pollutants considered are carbon monoxide,

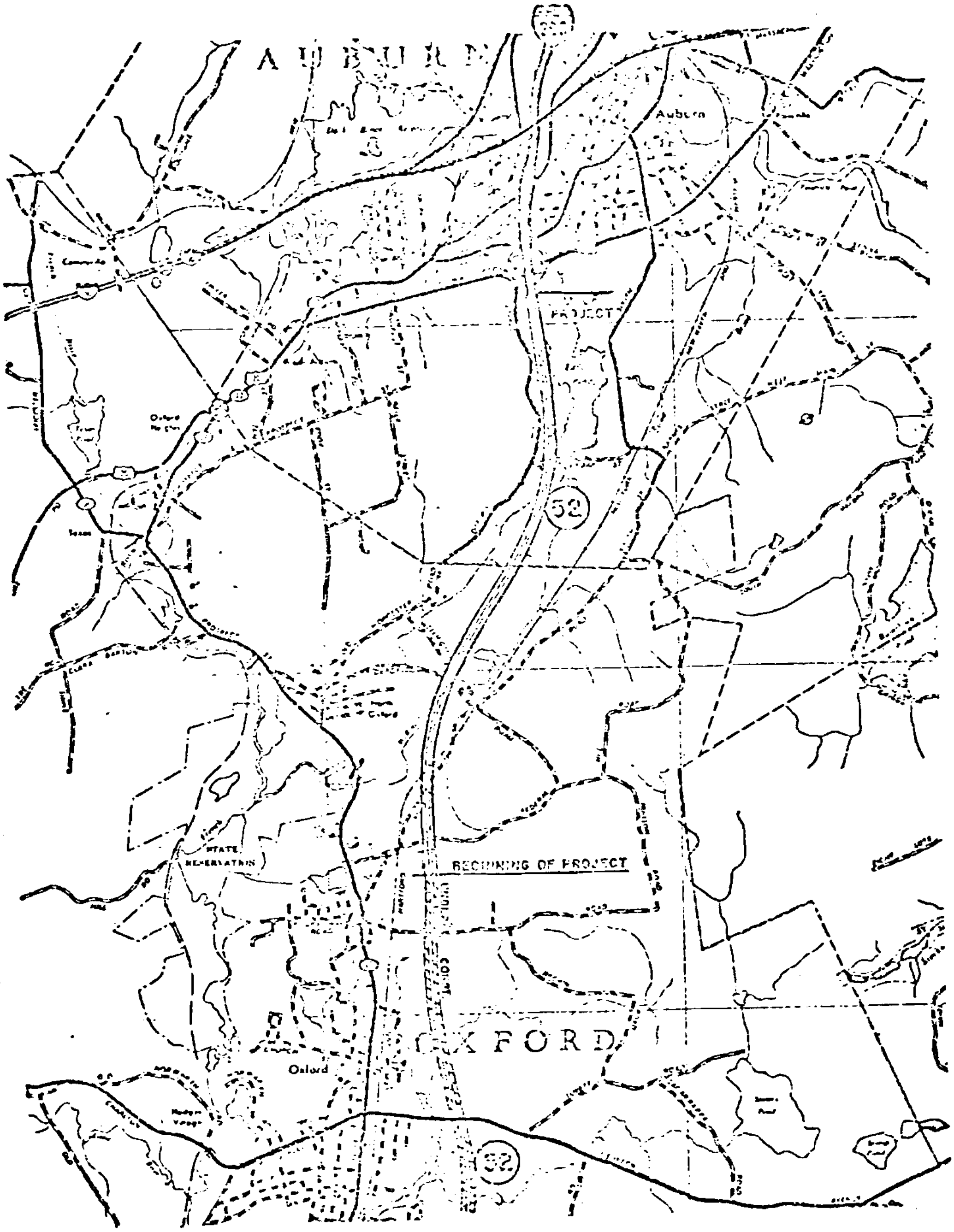

Figure 22

Proposed Section of Route 52

TABLE 19

AVERAGE DAILY TRAFFIC FOR ANALYSIS CORRIDORS

	1978	1995
Route 52	19400	28000
Route 12 Segment 1 Build	8460	14100
Route 12 Segment 1 No Build	14100	22000
Routes 12 & 20 Segment 2 Build	16920	28200
Route 12 Segment 2 No Build	28200	56400
Route 12 Segment 3 Build	8040	13400
Route 12 Segment 3 No Build	13400	26800

TABLE 20

ESTIMATED SPEEDS ON ROUTES 52, 20, and 12
IN PROJECT AREA, MILES PER HOUR

	1978		1995	
	Peak 1 hr.	Peak 8 hr.	Peak 1 hr.	Peak 8 hr.
Route 52	55	55	55	55
Route 12 Segment 1 Build	37.5	40	35	40
Route 12 Segment 1 No Build	35	40	35	40
Routes 12 & 20 Segment 2 Build	35	37.5	30	35
Routes 12 & 20 Segment 2 No Build	30	35	30	35
Route 12 Segment 3 Build	42.5	45	40	45
Route 12 Segment 3 No Build	40	45	30	35

TABLE 21

DIMENSIONS OF ROUTES 52, 20, AND 12 IN PROJECT AREA

	Length (ft.)	Width (ft.)
Route 52	17400	180 (100 ft. median)
Route 12 Segment 1	15600	40
Routes 12 & 20 Segment 2	3170	60
Route 12 Segment 3	7500	40

hydrocarbons, and nitrogen oxides. Equation 14 is used to make these calculations. The values for emission factors, both in this equation and in the microscale analysis, are from Table 3. Speed correction factors based on the speeds in Table 20 are computed from Figure 1. Results of the mesoscale calculations are given in Table 22. In all cases, the total amounts of pollutants generated are higher for the build case due to higher traffic volumes. By 1995, the reduced emission factors offset the increased traffic enough to cause a small reduction in total amounts of pollutants.

4.2.2 Microscale analysis

Because Route 12 is only 60 ft. at its widest point and Route 52 has a 100 ft. center median, the HIWAY model was applied to all microscale calculations. Predictions began at a distance of 20 ft. from the road since this is the closest distance at which HIWAY is considered accurate. They are also made at a distance of 40 ft. to provide an estimate of concentrations at sensitive receptors within this distance. Calculations are made for worst one hour and eight hour concentrations for all alternatives. The assumptions used in these calculations are the same as those used in the Route 33 calculations except that stability class 5 is used in all cases since class 6 is not available for the HIWAY model. Peak 1 hour traffic is assumed to be 8% of average daily traffic, and peak hourly traffic for maximum 8 hour conditions is assumed to be 5.55% of average daily traffic. These values are in the range used by Massachusetts DPW engineers to calculate VPH values. Worst 1 hour concentrations for all segments of Route 12 and for Route 52, in the years

Table 22

Mesoscale Analysis Results - Average Amounts of Pollutants Generated by Traffic Within the Corridors*

	1978			1995		
	CO	C_xH_y	NO_x	CO	C_xH_y	NO_x
Route 52	.917	.171	.388	.512	.099	.265
Route 12 Segment 1 Build	.469	.079	.133	.303	.056	.105
Route 12 Segment 1 No Build	.783	.132	.220	.473	.087	.164
Routes 12 & 20 Segment 2 Build	.201	.033	.153	.148	.024	.040
Routes 12 & 20 Segment 2 No Build	.353	.057	.085	.273	.048	.081
Route 12 Segment 3 Build	.195	.034	.063	.126	.024	.050
Route 12 Segment 3 No Build	.325	.056	.011	.306	.054	.019
TOTALS:						
Build	1.782	.317	.737	1.089	.203	.461
No Build	1.461	.245	.316	1.052	.189	.264

*In tons per day

1978 and 1995, are shown in Table 23. Worst 8 hour concentrations are in Table 24. Highest concentrations occur for the no build option along segment 2 of Route 12. These concentrations are still below federal standards. All other calculated concentrations are well below these standards.

No background carbon monoxide concentrations are available for this site. However, background levels are not expected to be a problem here since there are no other major CO sources close by.

TABLE 23

CALCULATED MAXIMUM 1 HOUR CARBON MONOXIDE CONCENTRATIONS FOR ROUTE 52 PROJECT*

	1978					1995				
Concentrations at	20 ft	40 ft	60 ft	80 ft	100 ft	20 ft	40 ft	60 ft	80 ft	100 ft
Route 52	2.92	1.92	1.42	1.12	.97	1.63	1.07	.79	.62	.51
Route 12 Segment 1 Build	2.47	1.76	1.39	1.15	.98	1.68	1.20	.94	.78	.67
Route 12 Segment 1 No Build	6.45	3.59	2.72	2.20	1.86	2.62	1.87	1.47	1.22	1.04
Routes 12 & 20 Segment 2 Build	4.11	2.49	1.68	1.20	.88	2.95	1.79	1.21	.86	.63
Routes 12 & 20 Segment 2 No Build	7.61	4.61	3.11	2.22	1.63	5.90	3.58	2.42	1.72	1.26
Route 12 Segment 3 Build	1.91	1.31	1.01	.79	.67	1.30	.89	.69	.54	.46
Route 12 Segment 3 No Build	4.32	2.73	1.99	1.55	1.25	1.62	1.10	.85	.67	.56

*Concentrations in Parts per Million

TABLE 24

CALCULATED MAXIMUM 8 HOUR CARBON MONOXIDE CALCULATIONS FOR ROUTE 52 PROJECT*

	1978					1995				
Concentrations at	20 ft	40 ft	60 ft	80 ft	100 ft	20 ft	40 ft	60 ft	80 ft	100 ft
Route 52	2.02	1.33	.98	.77	.63	1.13	.75	.55	.43	.35
Route 12 Segment 1 Build	1.63	1.16	.91	.76	.64	1.05	.75	.59	.49	.42
Route 12 Segment 1 No Build	3.41	2.25	1.70	1.38	1.16	1.64	1.17	.92	.76	.65
Routes 12 & 20 Segment 2 Build	2.71	1.64	1.11	.79	.58	1.84	1.11	.75	.54	.39
Routes 12 & 20 Segment 2 No Build	4.75	2.87	1.94	1.38	1.01	3.67	2.23	1.50	1.02	.79
Route 12 Segment 3 Build	1.27	.87	.67	.52	.44	.90	.62	.48	.37	.32
Route 12 Segment 3 No Build	2.72	1.72	1.25	.98	.79	1.00	.68	.53	.41	.35

*Concentrations in Parts per Million

CHAPTER V

ADVANCES IN MODELING

This section considers some advanced concepts being developed for modeling air pollution dispersion. The first to be discussed will be those which are applicable to modifying Gaussian diffusion models such as HIWAY and California Line Source.

5.1 Mixing Cell Modifications

Since the highest pollution concentrations occur on or near the highway it is important to be able to accurately model concentrations in this region. Habegger, et al.[14] suggest a model which accounts for mixing on and near the highway due to natural winds and traffic produced air turbulence. This model assumes that the concentration in the axially symmetric wake produced by a moving vehicle can be approximated by:

$$\chi(x,y) = \frac{Q}{2\pi\varepsilon \quad x^{2/3}} \exp\left\{-\frac{y^2}{2\,\varepsilon\, x^{2/3}}\right\} \qquad (15)$$

Where ε is an empirical constant and all other variables have their previously defined meanings. The coordinate system for this equation is shown in Figure 23. When there is a constant flow of traffic along a highway, the principle of superposition is assumed to hold and the concentration at a receptor can be calculated using:

$$\chi(D,\phi) = \frac{Q_L}{\pi\varepsilon\mu(\cos\theta)^{2/3}} \int_0^{\ell} \frac{\exp\left\{-(\sin\theta - \frac{d}{\cos\theta})^2 / 2\varepsilon(\cos\theta)^{2/3} Z^{2/3}\right\} dz}{Z^{2/3}} \qquad (16)$$

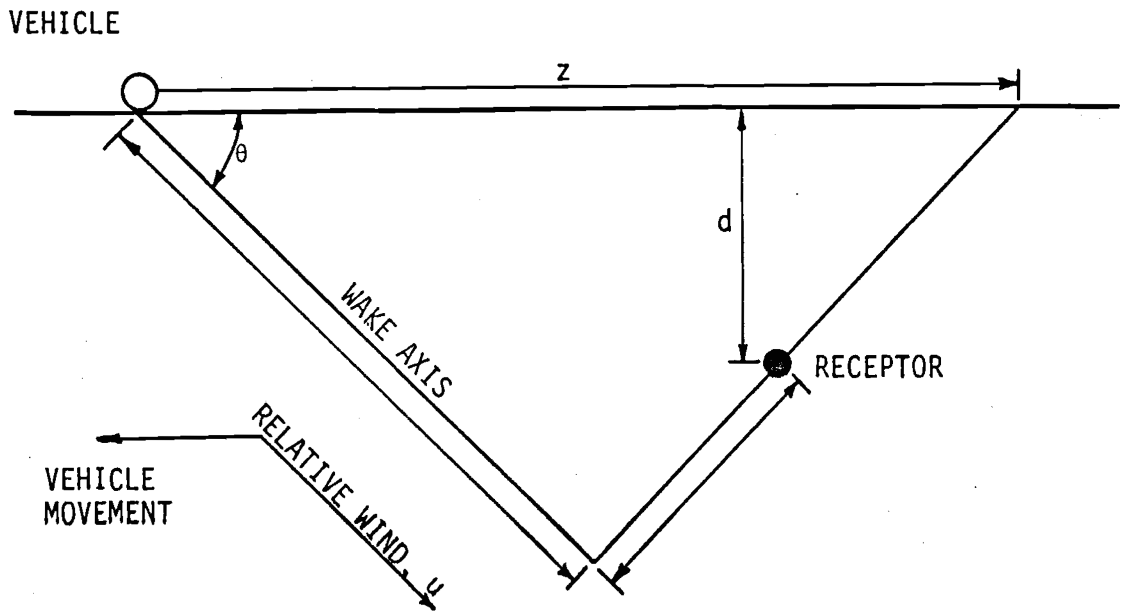

Figure 23   Coordinate system for equation 15

Where:

ℓ = Effective length of roadway

Q_L = Emission sources strength per unit length

D = Perpendicular distance from road

All other symbols have their previously defined values. This equation also uses the same coordinate system shown in Figure 23. A value of ε has not yet been experimentally determined. The development of this constant may provide a superior method of calculating mixing cell concentrations.

Egan, et al.[16] have developed another method of dealing with mixing cell concentrations. It is based on a two-dimensional equation which takes into account horizontal advection and vertical advection and diffusion. The equation used is:

$$\frac{\partial \chi}{\partial t} = -\mu \frac{\partial \chi}{\partial x} - \omega \frac{\partial \chi}{\partial z} + \frac{\partial}{\partial z} \left(K \frac{\partial \chi}{\partial z}\right) + Q \qquad (17)$$

Where:

t = Time in seconds

u(xz) = Horizontal wind velocity m/sec

ω(xz) = Vertical wind velocity m/sec

K(xz) = Turbulent diffusivity m^2 sec

All other terms have their previously defined meanings and (x,z) are downwind and vertical directions (meters) in a two-dimensional Cartesian system. This equation must be solved using finite difference techniques. A vertical cross section enclosing the highway is divided into grid elements and the partial differentials in Equation 17 are approximated by finite differences. By setting the horizontal grid dimensions equal to the width of a road lane and the vertical dimension equal to the assumed height of the mixing cell, a volume source emission rate can be used to simulate traffic in these lanes. This method has the advantage of being able to handle background concentrations by setting the boundary conditions of the finite difference equations equal to the background concentration.

5.2 Terrain Effects

The standard deviations of plume size used in Gaussian diffusion equations were developed for uncomplicated open terrain. For this reason these models are most applicable to non-urban areas. Even in rural areas, however, there are obstructions to air flow which cause wind conditions different than the assumed uniform profile. Rough ground will in general increase turbulence and promote better mixing of pollutants. Other terrain effects may increase pollutant concentrations. Work done by Egan, et al.[16] indicates that when reverse flow occurs a pollution buildup may occur. Empirical values could be developed for the effects of these on concentrations at a distance from the pollutant source as in the street canyon model used by APRAC-IA[17]. This canyon model accounts for the buildup of pollutants between large buildings in cities. In this way the effects of major terrain irregularities can be included in the calculations of pollution dispersion in non-urban areas.

5.3 Possible Modifications of the HIWAY and California Line Source Models

More research may permit one of the advanced mixing cell modifications previously discussed to be added to the California Line Source model without the necessity of making other major changes in the program.

This is primarily because mixing cell concentrations are calculated separately from downwind concentrations in this program. A new mixing cell subroutine can simply replace the present ones. Any mixing cell modification applied to the California Line Source model should treat each lane as a separate mixing cell. It should also allow for a center median of variable width. This will make it necessary to calculate downwind concentrations from each lane separately and sum the results. More computer time will be required, but the model will be applicable to roads of any horizontal configuration without its basic assumptions being violated.

HIWAY is not as easy to modify with respect to mixing cell concentrations because it uses a series of point sources. The diffusion equations used would have to be modified to use a volume source. The first modification of HIWAY should be adding the ability to treat stability class 6 in the same manner as the other classes. This would require only the addition of values of σ_y and σ_z for this class and modification of control statements to include the additional variables.

If empirical values are developed for the effects of terrain changes on concentrations, these could be added to either model in a subroutine which would multiply the calculated concentration by these factors in the regions specified.

5.4 Other models

There are methods of calculating the dispersion of air pollutants other than Gaussian plume models. One of the simplest is the box model described by Habegger, et al.[15]. This model assumes pollutant concentrations are homogeneous within a defined region or box. If a wind perpendicular to a side of the box of length l removes the pollutant the concentration in the box can be calculated from:

$$\chi = \frac{Q}{uhtl} \tag{18}$$

where:

ht = The height of the box

l = Length of box side perpendicular to wind

All other variables have their previously defined values. This model is useful for mixing cell calculations. Its use is limited however, because it assumes rapid turbulent diffusion as compared to wind transport.

A much more useful model is the conservation of mass model. This model attempts to calculate pollution dispersion by solving the equations of conservation of mass for the pollutant. Darling (3) gives the basic equation which is used as:

$$\frac{\partial \chi_i}{\partial t} + \bar{u}\frac{\partial \chi_i}{\partial x} + \bar{\nu}\frac{\partial \chi_i}{\partial y} + \bar{\omega}\frac{\partial \chi_i}{\partial z} = \frac{\partial}{\partial x}\left(K_x \frac{\partial \chi_i}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial \chi_i}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial \chi_i}{\partial z}\right) + R_i + S_i \tag{19}$$

Where:

χ_i = The concentration of pollutant species

$\bar{u},\bar{\nu},\bar{\omega}$ = Average wind velocities in the x, y, and z directions

R_i = Rate of generation of species, by photochemical reactions

S_i = Emission source strength for species.

This equation assumes the air is incompressible and molecular diffusion is negligible. This method has few of the limitations of Gaussian plume models, being capable of handling time varying concentrations, three-dimensional wind fields and photochemical reactions. Values of K_x, K_y, K_z and R_i however, are not as well researched as those of σ_y and σ_z.

The methods dicussed comprise those used in the majority of dispersion models used at present. References 3 and 16 list many of these models and the methods of calculation they use.

CHAPTER VI

CONCLUSIONS

The HIWAY and California Line Source Models can be used with some limitations to predict carbon monoxide concentrations from highways. The EPA emissions model or EPA regional emission factors should be used to determine input emission factors for these models.

Because of the assumptions they are based on, the California Line Source and HIWAY models should not be used for some highways. Both models were developed assuming fairly open terrain. Therefore, neither would be very accurate in an urban area. The California Line Source model should not be used for roads of less than 80 feet or more than 120 feet in width or on those with no center median. HIWAY can be used with roads of any width, with or without medians. For distances very close to the highway, such as within 20 feet, California Line Source will give more realistic concentrations due to its mixing cell assumption than will HIWAY. California Line Source should be used to predict worst one-hour concentrations for roads for which its basic assumptions are not violated, because it has provisions for the worst atmospheric conditions.

For predicting worst eight-hour concentrations, either model may be used, preferably the one which best takes into account the conditions at the particular highway.

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APPENDIX A


```
PROGRAM CALIF(TAPE1,TAPE06,INPUT,OUTPUT)
 6505  DIMENSION NNN(16)
 6515  PRINT 1
1 FORMAT (◆INPUT 1 IF YOU WANT PARALLEL WIND CALCULATIONS ONLY◆
+/◆INPUT 0 FOR THE CROSS WIND CALCULATION ◆)
READ(1,1109) (NNN(JJ),JJ=1,16)
6530 READ(1,) LMN,NCASE
 6535  DO 319 MMN=1,NCASE,1
7004 READ(1,) LMN,KK
 7006  IF (KK.EQ.1) GO TO 2
 7030  CALL SAMPL1
GOTO9876
2 CALL SAMPL2
9876 WRITE(06,1109)(NNN(JJ),JJ=1,16)
319 CONTINUE
1109 FORMAT(10A8,/,10A8)
REWIND06
CALL PAGENEW
CALL SAVE(6HTAPE06,7HOUTPUT,0,0,0)
 7041  STOP
       END
       SUBROUTINE SAMPL1
INTEGER CLAS
REAL MW
READ(1,) LMN,NREP
DO 10 K=1,NREP
IF(K.EQ.1) 7062,2
2 READ(1,) LMN,D
GO TO 7056
7062 READ(1,) LMN,VPH,EF,U,PHI,H,Z,D,CLAS,MW
       REAL      MW
 7056  WRITE(06,80  )
  80 FORMAT(////◆ MODEL POLLUTION CONCENTRATION◆,
+ /◆ CALCULATION FOR CROSS WINDS◆)
  81 FORMAT (◆INPUT VPH,EF,U,PHI,H,Z,D,CLAS,MW◆)
 7066  WRITE(06,90  )
  90 FORMAT (/// 4X,◆INPUT PARAMETERS:◆)
 7070  WRITE(06,100 )       VPH,EF,U,PHI,H,Z,D,CLAS,MW
  100  FORMAT ( /◆VPH =◆,F10.2,◆VEHICLES/HR◆,
+   /◆EF  =◆,F10.2,◆GRAMS/MILE◆,
+       / ◆U   =◆,F10.2,◆MILES/HR◆,
+/◆PHI =◆,F10.2,◆DEGREES◆,
+/◆H   =◆,F10.2,◆FEET◆,
+/◆Z   =◆,F10.2,◆FEET◆,
+/◆D   =◆,F10.2,◆FEET◆,
+/◆CLAS=◆,I7,3X,◆(1-6 = A-F)◆,
+/◆MW  =◆,F10.2,◆(UNITLESS)◆)
       CALL XWIND(VPH,EF,U,PHI,H,Z,D,CLAS,MW,PPM,CMIX,PPMX)
 7092     WRITE(06,300 )
 300 FORMAT(  // 4X,◆POLLUTION CONCENTRATIONS =◆)
 7096  WRITE(06,200 )PPM,CMIX,PPMX
 200 FORMAT(  /◆PPM = ◆   ,F10.2,◆PARTS PER MILLION AT D FEET◆
+       ◆ FROM ROADWAY◆,
+       /◆CMIX=◆,F12.6,◆GRAMS/CUBIC METER ON ROADWAY◆,
+/◆PPMX=◆,F10.2,◆PARTS PER MILLION ON ROADWAY◆,/)
10 CONTINUE
       RETURN
       END
       SUBROUTINE SAMPL2
INTEGER CLAS
```

```
REAL MW
READ(1,) LMN,NREP
DO 10 K=1,NREP
IF(K.EQ.1) 7132,2
2 READ(1,) LMN,D
GO TO 7126
7132 READ(1,) LMN,VPH,EF,U,PHI,H,Z,D,CLAS,MW,DWD,W,WDTH
      REAL      MW
 7126  WRITE(06,80  )
  80 FORMAT (///◆MODEL POLLUTION CONCENTRATION◆,
+ /◆CALCULATION FOR PARALLEL WINDS◆)
81 FORMAT(◆INPUT VPH,EF,U,PHI,H,Z,D,CLAS,MW,DWD,W,WDTH◆)
 7136  WRITE(06,90  )
  90 FORMAT (// 4X,◆INPUT PARAMETERS:◆)
 7140  WRITE(06,100 )    VPH,EF,U,PHI,H,Z,D,CLAS,MW
  100  FORMAT ( /◆VPH =◆,F10.2,◆VEHICLES/HR◆,
+     /◆EF  =◆,F10.2,◆GRAMS/MILE◆,
+       / ◆U   =◆,F10.2,◆MILES/HR◆,
+/◆PHI =◆,F10.2,◆DEGREES◆,
+/◆H   =◆,F10.2,◆FEET◆,
+/◆Z   =◆,F10.2,◆FEET◆,
+/◆D   =◆,F10.2,◆FEET◆,
+/◆CLAS=◆,I7,3X,◆(1-6 = A-F)◆,
+/◆MW  =◆,F10.2,◆(UNITLESS)◆)
 7160  WRITE(06,101 )     DWD,W,WDTH
 101 FORMAT(◆DWD =◆,F10.2,◆FEET◆,
+/◆W   =◆,F10.2,◆FEET◆,
+/◆WDTH=◆,F10.2,◆FEET◆)
       CALL PWIND(VPH,EF,U,PHI,H,Z,D,CLAS,MW,DWD,W,WDTH,
+  PPM,CMIX,PPMX)
 7172  WRITE(06,300 )
 300 FORMAT(  / 4X,◆POLLUTION CONCENTRATIONS =◆)
 7176  WRITE(06,200 )PPM,CMIX,PPMX
 200 FORMAT(  /◆PPM =◆,F10.2,◆ PARTS PER MILLION AT D FEET◆
+      ◆ FROM ROADWAY◆,
+       /◆CMIX=◆,F11.6,◆GRAMS/CUBIC METER ON ROADWAY◆,
+/◆PPMX=◆,F10.2,◆ PARTS PER MILLION ON ROADWAY◆,/)
10 CONTINUE
       RETURN
 7187  END
 7188  SUBROUTINE XWIND(VPH,EF,U,PHI,H,Z,D,CLAS,MW,PPM,CMIX,PPMX)
       INTEGER  CLAS
       REAL      MW,K1,K2,K3,K4,K
       K1 = 4.24
       K2 = 4.24
       K3 = 4.24
       K4 = 4.24
2150 IF (PHI .GE. 12.5) GO TO 2190
2170 WRITE(06,2171)
2171 FORMAT(// 10X,◆ SE PARALLEL WIND MODEL.◆)
2180 STOP
2190 IF (U .GE. 2.) GO TO 2220
2200 WRITE(06,2201)
2201 FORMAT(// 10X,◆ ODEL NOT VALID FOR WIND SPEEDS LESS THAN 2
+  MPH◆)
2210 STOP
2220 IF (D .EQ. 0.) GO TO 2260
2230 IF (Z .GE. 0.) GO TO 2260
2240 WRITE(06,2241)
2241 FORMAT ( // 10X,◆MODEL NOT VALID FOR DEPRESSED RECEPTORS◆)
```

```
2250 STOP
2260 IF (H .LT. -30.) GO TO 2340
2270 IF (D .GT. 0.) GO TO 2360
2280 IF (D.LT. 0.) GO TO 2320
2290 IF (Z-H .LE. 12.) GO TO 2460
2300 WRITE(06,2301)
2301 FORMAT(// 10X,* ODEL NOT VALID DIRECTLY ABOVE MIXING CELL*)
 7366  GO TO 2330
2320 WRITE(06,2321)
2321 FORMAT(// 10X,* ODEL NOT VALID FOR UPWIND CONDITIONS.*)
2330 STOP
2340 WRITE(06,2341)
2341 FORMAT(// 10X,* ODEL NOT VALID FOR DEEP CUT SECTIONS.*)
2350 STOP
2360 IF (H .GT. -10.) GO TO 2460
2370 IF (CLAS .LT. 5) DMIN = 100.
2380 IF (CLAS .EQ. 5 .AND. H .GE. -20.) DMIN = 100.
2390 IF (CLAS .EQ. 5 .AND. H .LT. -20.) DMIN = 200.
2400 IF (CLAS .EQ. 6 .AND. H .GE. -25.) DMIN = 100.
2410 IF (CLAS .EQ. 6 .AND. H .LT. -25.) DMIN = 200.
2420 IF (D .GE. DMIN) GO TO 2460
2430 WRITE(06,2431)
2431 FORMAT(// 10X,* ODEL NOT VALID THIS CLOSE TO FWY FOR CUT
+SECTIONS*)
2440 STOP
2460 HMET = H/3.28
2470 ZMET = Z/3.28
2480 Q    = 1.73E-7*VPH*EF
2490 UBAR = U/2.23
2500 PHIR = PHI/57.295
2510 CMIX = (1.06*Q)/(K1*UBAR*SIN(PHIR))
2520 PPMX = CMIX*.0245E6/MW
2530 X    = D/3281.
2540 CALL XCON(Z,ZMET,H,K2,K3,K4,HMET,UBAR,PHIR,CLAS,X,Q,C)
2550 IF(D .EQ. 0.) C=CMIX
2560 PPM = C*.0245E6/MW
2570 RETURN
     END
     SUBROUTINE   XCON(Z,ZMET,H,K2,K3,K4,HMET,UBAR,PHIR,CLAS,X,
+    Q,C)
     INTEGER  CLAS
     REAL     K1,K2,K3,K4,K
2590 CALL SIGMAZ(CLAS,X,SIGZ)
2600 IF (Z .LE. 5.) ZMET = 0.
2610 IF (H .GE. 10.) GO TO 2680
2620 IF (H .LE. -10.) GO TO 2750
2640 K = K3
2650 EXPT = EXP(-((ZMET/SIGZ)**2)/2.)
2660 GO TO 2770
2680 K = K2
2690 IF (ZMET .EQ. 0.) GO TO 2720
2700 EXPT = EXP(((ZMET+HMET)/SIGZ)**2/(-2.))
+   +EXP(((ZMET-HMET)/SIGZ)**2/(-2.))
 7531  EXPT=.5*EXPT
2710 GO TO 2770
2720 EXPT = EXP(-((HMET/SIGZ)**2)/2.)
2730 GO TO 2770
2750 K = K4
2760 EXPT = EXP((HMET/SIGZ)**2./2.)*EXP(-((ZMET/SIGZ)**2.)/2.)
2770 C=4.24*Q*EXPT/(K*SIGZ*UBAR*SIN(PHIR))
```

```
2780 RETURN
     END
     SUBROUTINE    PWIND  (VPH,EF,U,PHI,H,Z,D,CLAS,MW,DWD,W,WDTH,
+     PPM,CMIX,PFMX)
     INTEGER  CLAS
     REAL      MW,K1,K2,K3,K4,K
     K1 = 4.24
     K2 = 4.24
     K3 = 4.24
     K4 = 4.24
2160 IF(PHI .LT. 12.5) GO TO 2190
2170 WRITE(06,2171)
2171 FORMAT(// 10X,*SE CROSS WIND MODEL.* )
2180 STOP
2190 IF(D .EQ. 0.) GO TO 2230
2200 IF(Z .GE. 0.) GO TO 2230
2210 WRITE(06,2211)
2211 FORMAT(// 10X,*DIEL NOT VALID FOR DEPRESSED RECEPTORS.* )
2220 STOP
2230 IF(U .GE. 2.) GO TO 2238
2232 WRITE(06,2231)
2231 FORMAT(// 10X,*DIEL NOT VALID FOR WIND SPEEDS LESS THAN
+MILES PER HOUR*)
2236 STOP
2238 IF(H .LT. -30.) GO TO 2310
2240 IF(D .GT.   0.) GO TO 2330
2250 IF(D .LT.   0.) GO TO 2290
2260 IF(Z-H .LE.12.) GO TO 2360
2270 WRITE(06,2271)
2271 FORMAT(// 10X,*DIEL NOT VALID DIRECTLY ABOVE MIXING CELL*)
2280 STOP
 2290  WRITE(06,2291)
2291 FORMAT(// 10X,*DIEL NOT VALID FOR UPWIND CONDITIONS.* )
2300 STOP
 2310  WRITE(06,2311)
2311 FORMAT(// 10X,*DIEL NOT VALID FOR DEEP CUT SECTIONS.* )
2320 STOP
2330 IF(H .LT. 0. .AND. D .LT. 100.) GO TO 2340
2332 GO TO 2360
2340 WRITE(06,2341)
2341 FORMAT(/,/,10X,MODEL NOT VALIF WITHIN 100 FT OFSHOLD*)
2350 STOP
2360 CONTINUE
2370 WIDE = WDTH
2380 IF(H .GE. .0) WIDE = 700.
2390 CALL FWA(WIDE,CLAS,DWD,A)
2400 IF(H .EQ. -30.) GO TO 2470
2410 IF(H .GE.   0.) GO TO 2470
2430 A1=A
2440 WIDE=700.
2450 CALL FWA(WIDE,CLAS,DWD,A)
2460 A = A + (A1-A)*H/(-30.)
2470 CONTINUE
2480 HMET = H/3.28
2490 ZMET = Z/3.28
2500 WMET = W/3.28
2510 YMET = D/3.28
2520 UBAR = U/2.23
2530 Q     = (5.26E-6)*VPH*EF
2540 X     = D/3281.
```

```
2550 CALL RCON(Z,ZMET,H,K1,K2,K3,K4,HMET,UBAR,YMET,WMET,CLAS,X,Q,
     W,      A,C,CMIX)
2570 IF(D .EQ. 0.) C=CMIX
2580 PPM = C*.0245E6/MW
2590 PPMX = CMIX*.0245E6/MW
2600 RETURN
     END
     SUBROUTINE   RCON(Z,ZMET,H,K1,K2,K3,K4,HMET,UBAR,YMET,WMET,
   CLAS, X,Q,W,A,C,CMIX)
     INTEGER  CLAS
     REAL     K1,K2,K3,K4,K
2620 CALL SIGMAZ(CLAS,X,SIGZ)
2625 CALL SIGMAY(CLAS,X,SIGY)
2640 IF(Z .LE. 5.) ZMET=0.
2650 IF(H .GT. 0.) GO TO 2720
2660 IF(H .LT. 0.) GO TO 2790
2680 K = K3
2690 EXPT = EXP(-((YMET/SIGY)**2)/2.)*EXP(-((ZMET/SIGZ)**2)/2.)
2700 GO TO 2810
2720 K = K2
2730 IF(ZMET .EQ.0.) GO  TO 2760
2740 EXPT = (EXP(-((YMET/SIGY)**2)/2.))
    *(EXP(-(((ZMET+HMET)/SIGZ)**2)/2.)
     +EXP(-(((ZMET-HMET)/SIGZ)**2)/2.))
 7957  EXPT=.5*EXPT
2750 GO TO 2810
2760 EXPT = EXP(-((YMET/SIGY)**2)/2.)
    *EXP(-((HMET/SIGZ)**2)/2.)
2770 GO TO 2810
2790 K = K4
2800 EXPT = EXP(-((YMET/SIGY)**2)/2.)
    *EXP(+((HMET/SIGZ)**2)/2.)
    *EXP(-((ZMET/SIGZ)**2)/2.)
2810 IF(W .LT. 40.0) GO TO 2840
*THE ABOVE STATEMENNT HAS BEEN CHANGED FROM ORIGINAL PROGRAM
2820 C=30.5*A*Q*EXPT/(K*UBAR*WMET)
2825 CMIX = 30.5*A*Q/(K1*UBAR*WMET)
2830 RETURN
2840 C=WMET*A*Q*EXPT/(K*UBAR*30.5)
 7989  WRITE(06,2851)
2845 CMIX = WMET*A*Q/(K1*UBAR*30.5)
 2851  FORMAT(*ROADWAY LESS THAN 40 FEET,MODEL RESULTSQUESTIONABLE
2850 RETURN
     END
     SUBROUTINE    RWA(WIDE,CLAS,DWD,A)
 7999   REAL LNW,LNW1
     INTEGER  CLAS
2940 IF(WIDE .GT. 200.) GO TO 2970
2945 ASSIGN 2960 TO IBR
2950 GO TO (3370,3520,3880,4340,4510,4920), CLAS
2960 GO TO 5080
2970 IF(WIDE.LT.700.)GO TO 3000
2975 ASSIGN 2990 TO IBR
2980 GO TO (3100,3450,3740,4030,4430,4760), CLAS
2990 GO TO 5080
3000 IWID = WIDE/100.
3005 ASSIGN 3020 TO IBR
3010 GO TO (5110,5120,5130,5140,5160,5160), CLAS
3020 LNW1 = LNW
3030 A1 = A
```

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3035 ASSIGN 3050 TO IER
3040 GO TO (5180,5190,5200,5210,5220,5230), CLAS
3050 A = A1+(A-A1)/(LNW-LNW1)*(ALOG(WIDE)-LNW1)
3060 GO TO 5080
3100 IF(DWD .LT. 1000.) A = .000019*DWD-.999
3110 IF(DWD .GE. 1000.) A = -.98
3120 LNW = 6.55108
3130 GO TO IER, (2960,2990,3020,3050)
3150 IF(DWD .LT. 1000.) A = .000027*DWD-.998
3160 IF(DWD .GE. 1000.) A = .000002*DWD-.973
3170 LNW = 6.39693
3180 GO TO IER, (2960,2990,3020,3050)
3190 CONTINUE
3200 IF(DWD .LT. 1000.) A = .0000333*DWD-1.0003
3210 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .00002*DWD-.987
3220 IF(DWD .GE. 2000.) A = -.947
3230 LNW = 6.21461
3240 GO TO IER, (2960,2990,3020,3050)
3250 CONTINUE
3260 IF(DWD .LT. 1000.) A = .0000333*DWD-.992
3270 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .00002*DWD-.979
3280 IF(DWD .GE. 2000.) A = -.939
3290 LNW = 5.99146
3300 GO TO IER, (2960,2990,3020,3050)
3310 CONTINUE
3320 IF(DWD .LT. 1000.) A = .0000467*DWD-.986
3330 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000032*DWD-.971
3340 IF(DWD .GE. 2000.) A = -.907
3350 LNW = 5.70378
3360 GO TO IER, (2960,2990,3020,3050)
3370 CONTINUE
3380 IF(DWD .LT. 1000.) A = .0000883*DWD-.974
3390 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000032*DWD-.918
3400 IF(DWD .GE. 2000.) A = -.854
3410 LNW = 5.29832
3420 GO TO IER, (2960,2990,3020,3050)
3450 IF(DWD .LT. 1000.) A = .000048*DWD-.999
3460 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000023 *DWD-.974
3470 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .0000035*DWD-.935
3480 IF(DWD .GE. 4000.) A = -.921
3490 LNW = 6.55108
3500 GO TO IER, (2960,2990,3020,3050)
3520 IF(DWD .LT. 1000.) A = .00014*DWD-.973
3530 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000066 *DWD-.899
3540 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000011 *DWD-.789
3550 IF(DWD .GE. 4000.) A = .00000166*DWD-.752
3560 LNW = 5.29832
3570 GO TO IER, (2960,2990,3020,3050)
3580 CONTINUE
3590 IF(DWD .LT. 1000.) A = .000068*DWD-.989
3600 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000045*DWD-.966
3610 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000003*DWD-.882
3620 IF(DWD .GE. 4000.) A = .00000216*DWD-.879
3630 LNW = 5.99146
3640 GO TO IER, (2960,2990,3020,3050)
3650 CONTINUE
3660 IF(DWD .LT. 1000.) A = .00004*DWD-.979
3670 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000032*DWD-.971
3680 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000002*DWD-.911
3690 IF(DWD .GE. 4000.) A = .00000166*DWD-.91
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3700 LNW = 6.39693
3710 GO TO IER, (2960,2990,3020,3050)
3740 IF(DWD .LT. 1000.) A = .000088*DWD-.991
3750 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000037*DWD-.940
3760 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000003*DWD-.872
3770 IF(DWD .GE. 4000.) A = .000001*DWD-.864
3780 LNW = 6.55108
3790 GO TO IER, (2960,2990,3020,3050)
3810 IF(DWD .LT. 1000.) A = .000072*DWD-.975
3820 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000049 *DWD-.952
3830 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .0000045*DWD-.863
3840 IF(DWD .GE. 4000.) A = .000002*DWD-.853
3850 LNW = 6.39693
3860 GO TO IER, (2960,2990,3020,3050)
3880 IF(DWD .LT. 1000.) A = .00018*DWD-.97
3890 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000091 *DWD-.881
3900 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .0000085*DWD-.716
3910 IF(DWD .GE. 4000.) A = .000004*DWD-.698
3920 LNW = 5.29832
3930 GO TO IER, (2960,2990,3020,3050)
3950 IF(DWD .LT. 1000.) A = .000106*DWD-.992
3960 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000065 *DWD-.951
3970 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .0000055*DWD-.832
3980 IF(DWD .GE. 4000.) A = .00000233*DWD-.819
3990 LNW = 5.99146
4000 GO TO IER, (2960,2990,3020,3050)
4030 IF(DWD .LT. 1000.) A = .000117*DWD-.968
4040 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000058*DWD-.909
4050 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000005*DWD-.803
4060 IF(DWD .GE..4000.) A = .00000162*DWD-.789
4070 LNW = 6.55108
4080 GO TO IER, (2960,2990,3020,3050)
4090 CONTINUE
4100 IF(DWD .LT. 1000.) A = .000117*DWD-.968
4110 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000058  *DWD-.90
4120 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000005  *DWD-.80
4130 IF(DWD .GE. 4000. .AND. DWD .LT.12000.) A = .00000325*DWD-.79
4140 IF(DWD .GE.12000.) A = -.757
4150 LNW = 6.39693
4160 GO TO IER, (2960,2990,3020,3050)
4170 CONTINUE
4180 IF(DWD .LT. 1000.) A = .000117*DWD-.968
4190 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000081  *DWD-.93
4200 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000008  *DWD-.78
4210 IF(DWD .GE. 4000. .AND. DWD .LT.12000.) A = .00000375*DWD-.76
4220 IF(DWD .GE.12000.) A = -.724
4230 LNW = 5.99146
4240 GO TO IER, (2960,2990,3020,3050)
4250 CONTINUE
4260 IF(DWD .LT. 1000.) A = .00017*DWD-.985
4270 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000098  *DWD-.91
4280 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000009  *DWD-.73
4290 IF(DWD .GE. 4000. .AND. DWD .LT.12000.) A = .00000687*DWD-.72
4300 IF(DWD .GE.12000.) A = -.644
4310 LNW = 5.70378
4320 GO TO IER, (2960,2990,3020,3050)
4340 IF(DWD .LT. 1000.) A = .000215*DWD-.969
4350 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000125 *DWD-.879
4360 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000009 *DWD-.647
4370 IF(DWD .GE. 4000. .AND. DWD .LT.12000.) A = .0000055*DWD-.633
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4380 IF(DWD .GE.10000.) A = -.567
4390 LNW = 5.29832
4400 GO TO IER, (2960,2990,3020,3050)
4430 IF(DWD .LT. 1000.) A =.00015*DWD-.92
4440 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .00009   *DWD-.86
4450 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000007  *DWD-.69
4460 IF(DWD .GE. 4000. .AND. DWD .LT.10000.) A = .00000133*DWD-.67
4470 IF(DWD .GE.10000.) A = -.658
4480 LNW = 6.55108
4490 GO TO IER, (2960,2990,3020,3050)
4510 IF(DWD .LT. 1000.) A = .00025*DWD-.949
4520 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000146  *DWD-.84
4530 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000015  *DWD-.58
4540 IF(DWD .GE. 4000. .AND. DWD .LT.10000.) A = .00000652*DWD-.54
4550 IF(DWD .GE.10000.) A = .00000091*DWD-.493
4560 LNW = 5.29832
4570 GO TO IER, (2960,2990,3020,3050)
4580 CONTINUE
4590 IF(DWD .LT. 1000.) A = .00015*DWD-.92
4600 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000091 *DWD-.86
4610 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .0000080*DWD-.696
4620 IF(DWD .GE. 4000. .AND. DWD .LT.10000.) A = .0000073*DWD-.693
4630 IF(DWD .GE.10000.) A = -.620
4640 LNW = 5.99146
4650 GO TO IER, (2960,2990,3020,3050)
4660 CONTINUE
4670 IF(DWD .LT. 1000.) A = .00015*DWD-.92
4680 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .00009 *DWD-.86
4690 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000009*DWD-.698
4700 IF(DWD .GE. 4000. .AND. DWD .LT.10000.) A = .000001*DWD-.666
4710 IF(DWD .GE.10000.) A = -.656
4720 LNW = 6.39693
4730 GO TO IER, (2960,2990,3020,3050)
4760 IF(DWD .LT. 1000.) A = .000216*DWD-.904
4770 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000111  *DWD-.79
4780 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000013  *DWD-.60
4790 IF(DWD .GE. 4000. .AND. DWD .LT.10000.) A = .00000466*DWD-.57
4800 IF(DWD .GE.10000.) A = .00000058*DWD-.529
4810 LNW = 6.55108
4820 GO TO IER, (2960,2990,3020,3050)
4830 CONTINUE
4840 IF(DWD .LT. 1000.) A = .000216*DWD-.904
4850 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000111  *DWD-.79
4860 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000013  *DWD-.60
4870 IF(DWD .GE. 4000. .AND. DWD .LT.10000.) A = .00000463*DWD-.57
4880 IF(DWD .GE.10000.) A = .00000058*DWD-.529
4890 LNW = 6.39693
4900 GO TO IER, (2960,2990,3020,3050)
4920 IF(DWD .LT.1000.) A = .000254*DWD-.91
4930 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000163  *DWD-.81
4940 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000022  *DWD-.53
4950 IF(DWD .GE. 4000. .AND. DWD .LT.10000.) A = .00000933*DWD-.48
4960 IF(DWD .GE.10000.) A = .00000108*DWD-.404
4970 LNW = 5.29832
4980 GO TO IER, (2960,2990,3020,3050)
4990 CONTINUE
5000 IF(DWD .LT. 1000.) A = .000216*DWD-.904
5010 IF(DWD .GE. 1000. .AND. DWD .LT. 2000.) A = .000111  *DWD-.79
5020 IF(DWD .GE. 2000. .AND. DWD .LT. 4000.) A = .000013  *DWD-.60
5030 IF(DWD .GE. 4000. .AND. DWD .LT.10000.) A = .00000733*DWD-.58
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```
5040 IF(DWD .GE.10000.) A = .00000058*DWD-.513
5050 LNW = 5.99146
5060 GO TO IBR, (2960,2990,3020,3050)
5080 A=EXP(A*2.302585)
5090 RETURN
5110 GO TO (3370,3370,3310,3250,3190,3150), IWID
5120 GO TO (3520,3520,3520,3580,3580,3650), IWID
5130 GO TO (3880,3880,3880,3950,3950,3810), IWID
5140 GO TO (4340,4340,4250,4170,4170,4090), IWID
5150 GO TO (4510,4510,4510,4580,4580,4660), IWID
5160 GO TO (4920,4920,4920,4990,4990,4830), IWID
5180 GO TO (3310,3310,3250,3190,3150,3100), IWID
5190 GO TO (3580,3580,3580,3650,3650,3450), IWID
5200 GO TO (3950,3950,3950,3810,3810,3740), IWID
5210 GO TO (4250,4250,4170,4090,4090,4030), IWID
5220 GO TO (4580,4580,4580,4660,4660,4430), IWID
5230 GO TO (4990,4990,4990,4830,4830,4760), IWID
     END
     SUBROUTINE   SIGMAY(CLAS,X,SIGY)
     INTEGER  CLAS
5350 IF(CLAS .GT. 0 .AND. CLAS .LT. 7) GO TO 5380
5360 WRITE(06,5361)
5361 FORMAT(// 10X,*TABILITY CLASS NOT RECOGNIZABLE.* )
5370 STOP
5380 IF(X .LE. 10.) GO TO 5400
5390 WRITE(06,5391)
5391 FORMAT(//10X,*DISTANCE TOO GREAT -DISTANCE NOT APPLICABLE*)
5400 IF(X .GE. .001) GO TO 5450
5410 SIGY = 8.
5430 RETURN
5450 CONTINUE
5460 GO TO (5890,5940,5990,6040,6090,6140), CLAS
5890 IF(X .LT. .9)    SIGY= 242.36*X**.494
5900 IF(X .GE. .9 .AND. X .LT. 2.) SIGY= 247.5 *X**.692
5910 IF(X .GE. 2.)    SIGY= 215.2 *X**.898
5920 RETURN
5940 IF(X .LT.  .9)    SIGY=169.*X**.442
5950 IF(X .GE.  .9 .AND. X .LT. 1.5) SIGY=172.*X**.707
5960 IF(X .GE. 1.5)    SIGY=161.*X**.874
5970 RETURN
5990 IF(X .LT.  .8)    SIGY= 120.  *X**.392
6000 IF(X .GE.  .8 .AND. X .LT. 1.5) SIGY= 128.4 *X**.692
6010 IF(X .GE. 1.5)    SIGY= 121.77*X**.817
6020 RETURN
6040 IF(X .LT.  .6)    SIGY= 86.96*X**.346
6050 IF(X .GE.  .6 .AND. X .LT. 1.5) SIGY= 98.65*X**.588
6060 IF(X .GE. 1.5)    SIGY= 89.6 *X**.826
6070 RETURN
6090 IF(X .LT.  .7)    SIGY= 65.*X**.304
6100 IF(X .GE.  .7 .AND. X .LT. 1.5) SIGY= 70.*X**.494
6110 IF(X .GE. 1.5)    SIGY= 61.*X**.82
6120 RETURN
6140 IF(X .LT.  .6)    SIGY= 49. *X**.263
6150 IF(X .GT.  .6 .AND. X .LT. 1.5) SIGY= 53.5*X**.435
6160 IF(X .GT. 1.5 .AND. X .LT. 3.0) SIGY= 49. *X**.653
6170 IF(X .GT. 3.0)    SIGY= 38.6*X**.876
6180 RETURN
     END
     SUBROUTINE   SIGMAZ(CLAS,X,SIGZ)
     INTEGER  CLAS
```

```
2820 IF (CLAS .LT. 1) GO TO 3380
2830 IF (CLAS .GT. 6) GO TO 3380
2840 IF (X .GT. 10.)  GO TO 3360
2850 IF (X .GE. .001) GO TO 2940
2860 SIGZ = 4.
2870 RETURN
2940 GO TO (3000,3070,3140,3210,3270,3320), CLAS
3000 IF (X .LT. .04)  SIGZ=47.4*X**.357
3010 IF (X .GE. .04 .AND. X .LT. .1) SIGZ=91.*X**.562
3020 IF (X .GE. .1  .AND. X .LT. .2) SIGZ=148.*X**.782
3030 IF (X .GE. .2  .AND. X .LT. .4) SIGZ=300.*X**1.22
3040 IF (X .GE. .4)   SIGZ=489.*X**1.74
3050 RETURN
3070 IF (X .LT. .1)     SIGZ=34.9*X**.314
3080 IF (X .GE. .1  .AND. X .LT. .2) SIGZ=62. *X**.565
3090 IF (X .GE. .2  .AND. X .LT. .4) SIGZ=78. *X**.71
3100 IF (X .GE. .4  .AND. X .LT. 1.) SIGZ=105.*X**1.04
3110 IF (X .GE. 1.)     SIGZ=105.*X**1.104
3120 RETURN
3140 IF(X .LT. .15)   SIGZ=28.4*X**.283
3150 IF(X .GE. .15 .AND. X .LT. .3) SIGZ=45.8*X**.536
3160 IF(X .GE. .3  .AND. X .LT. .6) SIGZ=49. *X**.594
3170 IF(X .GE. .6  .AND. X .LT. 1.) SIGZ=58. *X**.922
3180 IF(X .GE. 1.0)   SIGZ=58. *X**.909
3190 RETURN
3210 IF(X .LT. .2)    SIGZ=22.4*X**.249
3220 IF(X .GE. .2  .AND. X .LT. .5) SIGZ=26.9*X**.36
3230 IF(X .GE. .5  .AND. X .LT. 1.) SIGZ=31.4*X**.534
3240 IF(X.GE.1.0)SIGZ=31.4*X**.652 $  RETURN
3270 IF(X.LT..3)SIGZ=17.44*X**.213
3280 IF(X.GE..3.AND.X.LT..7)SIGZ=20.32*X**.340
3290 IF(X .GE. .7)    SIGZ=21.98*X**.561
3300 RETURN
3320 IF(X .LT. .5)    SIGZ=13.6 *X**.177
3330 IF(X .GE. .5  .AND. X .LT. 1.5)SIGZ=14.68*X**.289
3340 IF(X .GE. 1.5)   SIGZ=13.2 *X**.552
3350 RETURN
3360 WRITE(06,3361)
3361 FORMAT(// 10X,**ISTANCE TOO GREAT MODEL NOT APPLICABLE* )
3370 STOP
3380 WRITE(06,3381)
3381 FORMAT(// 10X,*TABILITY CLASS IS NOT RECOGNIZABLE.* )
3390 STOP
     END
```

```
10000 SUBROUTINE PAGENEW
10010* THIS PROGRAM LISTS A FILE IN 8.5 X 11 PAGE FORMAT.  IT ALSO
10030 INTEGER NAME,PAGE
10035 DIMENSION FILE(80,60)
10040 PAGE=1
10045 L=1
10060 NAME=9H    CALIF
10065* 2 PRINT3
10066 2 CONTINUE
10067* DELETE THIS STATEMENT LATER
10070 3 FORMAT(*-----------------------------------------------------*
10075+*----------------------*,/)
10080* PRINT4,NAME,PAGE
10085 4 FORMAT(10X,10H**********,7HPROGRAM,1X,A9,10H**********,10X,
10090+4HPAGE,I3,/)
10095 17 DO5 J=L,60
10100 IF(EOF,06) 6,7
10105 7 READ(06,8)(FILE(I,J),I=1,72).
10110 8 FORMAT(72A1)
10115 DO9 K=1,30
10120 IF(FILE(K,J).EQ.1HS)10,11
10125 10 IF(FILE(K+1,J).EQ.1HU.AND.FILE(K+2,J).EQ.1HB.AND.FILE(K+3,J)
10130+.EQ.1HR.AND.FILE(K+4,J).EQ.1HO.AND.FILE(K+5,J).EQ.1HU.AND.
10135+FILE(K+6,J).EQ.1HT.AND.FILE(K+7,J).EQ.1HI.AND.FILE(K+6,J)
10140+.EQ.1HN.AND.FILE(K+9,J).EQ.1HE)12,11
10145 11 IF(FILE(K,J).EQ.1HF)13,9
10150 9 CONTINUE
10155 13 IF(FILE(K+1,J).EQ.1HU.AND.FILE(K+2,J).EQ.1HN.AND.FILE(K+3,J)
10160+.EQ.1HC.AND.FILE(K+4,J).EQ.1HT.AND.FILE(K+5,J).EQ.1HI.AND.FILE(K+6
10165+.EQ.1HO.AND.FILE(K+7,J).EQ.1HN)14,20
10170* 20 PRINT8,(FILE(I,J),I=1,72)
10171 20 CONTINUE
10172* DELETE THIS STATEMNET LATER
10175 5 CONTINUE
10180* PRINT15
10185 15 FORMAT(/)
10190 PAGE=PAGE+1
10191 L=1
10195 GOTO2
10200 12 NAME=9H    CALIF
10205 PAGE=PAGE+1
10210 18 DO21 JJ=J,62
10215* PRINT16
10220 16 FORMAT(1H )
10225 21 CONTINUE
10230* PRINT3
10235* PRINT4,NAME,PAGE
10240 L=2
10245* PRINT8,(FILE(I,J),I=1,72)
10250 GOTO17
10255 14 NAME=NAME
10260 PAGE=PAGE+1
10265 GOTO18
10270 6 DO19 J=J,62
10275* PRINT16
10280 19 CONTINUE
10285* PRINT3
10290 RETURN
10295 END
```

APPENDIX B

```
            ***********PROGRAM HIWAY     ***********            PAGE  1

PROGRAM HIWAY(INPUT,OUTPUT,TAPE6,TAPE5)
DIMENSION NNN(16)
* THIS PROGRAM CALCULATES THE CONCENTRATION FROM A LINE SOURCE
*    :    AT EACH OF A NUMBER OF RECEPTORS. SUBROUTINE RELCO
*         IS CALLED WHICH IN TURN CALLS SUBROUTINE SIGMA.
DIMENSION XVZ(6),XVY(6),ALX(24)
      DIMENSION XRRR(30),YRRR(30),ZRRR(30)
      COMMON /A/ SY(6),SZ(6,6)
DATA XVZ/.012,.012,.017,.027,.035,.058/
DATA XVY/.009,.013,.020,.032,.044,.044/
IWRI=6
      XMET=.3048
    7 FORMAT(3F9.3,I2,F10.3)
    8 FORMAT(I4)
    9 FORMAT(8F10.4)
   10 FORMAT(2F10.3)
   11 FORMAT(I2)
   12 FORMAT(4F10.3,I3,2F10.3)
   13 FORMAT(8F10.3)
   14 FORMAT(20A4)
   15 FORMAT(1H0, 20A4)
   16 FORMAT(1X, 28HWIDTH OF AT-GRADE HIGHWAY IS ,F10.3,3H  M /
+     1X,24HWIDTH OF CENTER STRIP IS , F10.3  )
   17 FORMAT(1X, 37HEMISSION RATE (GRAMS/SECOND*METER) OF ,I4,
+     8H LANE(S) )
   18 FORMAT(1H ,36HTHE SCALE OF THE COORDINATE AXES IS ,F10.4,4H KM
+//)
   19 FORMAT(1H,*COORDINATES OF THE ENDPOINTS OF THE LINE SOURCE*
+* IN METRES*,/,F10.3,1H,,F10.3,7H  AND  ,F10.3,1H,,F10.3)
   20 FORMAT(1H0,17HWIND DIRECTION IS,F7.0,25H  DEGREES   WIND SPEED
+   ,F7.1,11H METERS/SEC/19H STABILITY CLASS IS,I2,1X,
+     25HHEIGHT OF LIMITING LID IS,F8.1,6HMETERS   )
   23 FORMAT(1X, 18HEMISSION HEIGHT IS , F8.3, 7H METERS    )
28 FORMAT(3X,*RECEPTOR LOCATION*,8X,*RECEPTOR*,4X,*CONCENTRATION*,/,
+,6X,*RR*,10X,*SR*,8X,*HEIGHT(M)*,6X,*PPM*)
30 FORMAT(1X,3(F10.4,2X),F10.2)
   31 FORMAT(1H1)
READ(5,999) (NNN(III),III=1,16)
999 FORMAT(8A10,/,8A10)
35 PRINT2001
 2001 FORMAT (*INPUT  NUMBER OF CASES(NCASE)*)
READ(5,) LMN,NCASE
444 FORMAT(4X,I3)
      DO 1000 IDOW=1,NCASE
WRITE(IWRI,732)
732 FORMAT(///)
WRITE(IWRI,999)(NNN(III),III=1,16)
READ(5,) LMN,RER1,SER1,RER2,SER2,IXNL,CNTR,WIDTH
445 FORMAT(4X,4F7.0,I2,F4.0,F5.0)
      XNL=IXNL
*     READ(5,) LMN,  NUMBER OF RECEPTORS FOR THIS CASE
2002 FORMAT (*INPUT NUMBER OF RECEPTACLES*)
446 FORMAT(5X,I2)
READ(5,) LMN,NRECP
      DO 2050 LK=1,NRECP
2003 FORMAT (*INPUT XRRR(LK),YRRR(LK),ZRRR(LK)*)
READ(5,) LMN,XRRR(LK),YRRR(LK),ZRRR(LK)
447 FORMAT(5X,F6.0,2(1X,F4.0))
 2050 CONTINUE
 2004 FORMAT (*INPUT H,Q, THETA,U,KST,HL*)
```

```
READ(5,*) LMN,H,EF,SCF,ADT,THETA,U,KST,HL
Q=EF*SCF*ADT*1.72E-7
      HL=HL*XMET
      B=Q/XNL
      DO 5002 I=1,IXNL
      QLS(I)=B
 5002 CONTINUE
WRITE(IWRI,31)
      REP1=REP1*XMET
      REP2=REP2*XMET
      SEP1=SEP1*XMET
      SEP2=SEP2* XMET
      H=H*XMET
      WIDTH=WIDTH*XMET
      CNTR=CNTR*XMET
*        REP1,SEP1 ARE THE COO-DINATES OF AN END POINT OF THE LINE
*         SOURCE IN SOURCE COO-DINATES.
*        REP2,SEP2 ARE THE COO-DINATES OF THE OTHER END POINT OF THE
*         LINE SOURCE IN SOURCE COORDINATES.
*        H IS THE EFFECTIVE EMISSION HEIGHT OF THE SOURCE IN METERS.
*      CNTR IS THE WIDTH OF THE CENTER STRIP (M)
*        WIDTH IS THE HIGHWAY WIDTH  (M) FOR AT GRADE
*        XNL IS THE NUMBER OF LANES FOR THE AT-GRADE HIGHWAY.
      NL=XNL
      IF(XNL.GT.1.) XNL=XNL-1.
      DELW=(WIDTH-CNTR)/XNL
      WRITE(IWRI,19)REP1,SEP1,REP2,SEP2
      WRITE(IWRI,23)H
      WRITE(IWRI,17)NL
 1921 FORMAT(8F11.5)
*        QLS IS THE LINE SURCE STRENGTH (GRAMS/SECOND*METER)
WRITE(IWRI,2)(QLS(I),I=1,NL)
    2 FORMAT(8F12.6)
      CUT=0.0
*        XNDL IS THE NUMBER OF LINE SOURCES REPRESENTING THE TOP OF
*         CUT SECTION.
*      WIDTC IS THE WIDTH OF THE TOP OF THE CUT(M)
      IF(CUT.EQ.0.)GOTO101
*        DQLS IS THE CUT SECTION SOURCE STRENGTH
      DQLS=0.
      DO 40 I=1,NL
   40 DQLS=DQLS+QLS(I)
      NL=XNDL
      IF(XNDL.GT.1.) XNDL=XNDL-1.
      DOWNL=NL
      DQLS = DQLS/DOWNL
      DELW=WIDTC/XNDL
      WRITE(IWRI,29)WIDTC
   29 FORMAT(32H WIDTH OF TOP OF CUT SECTION IS ,F10.3,3H M  )
      DO100I=1,NL
  100 QLS(I)=DQLS
      GOTO102
  101 WRITE(IWRI,16)WIDTH,CNTR
  102 CONTINUE
*        THETA IS THE WIND DIRECTION IN DEGREES.
*        U IS THE WIND SPEED IN METERS PER SECOND.
*        KST IS THE STABILITY CLASS
*        HL IS THE HEIGHT OF THE LIMITING LID
WRITE(IWRI,20)THETA,U,KST,HL
      GS=.001
```

```
        GS IS THE MEASURE BETWEEN COORDINATES (KM).
      WRITE(IWRI,18) GS
      WRITE(IWRI,28)
         CONVERT COORDINATE SYSTEM SO THAT HIGHWAY
          IS ORIENTATED ALONG ZERO DEGREES (MATH SYSTEM)
      X1=REP1
      Y1=SEP1
      X2=REP2
    Y2=SEP2
      DX=X2-X1
      DY=Y2-Y1
      CALL ATH(DX,DY,ANGH,DANG)
      REP1=Y1*SIN(ANGH)+X1*COS(ANGH)
      SEP1=Y1*COS(ANGH)-X1*SIN(ANGH)
      REP2=Y2*SIN(ANGH)+X2*COS(ANGH)
      SEP2=Y2*COS(ANGH)-X2*SIN(ANGH)
         CONVERT WIND DIRECTION WRT HIGHWAY
      THETA=THETA+DANG
      IF(THETA.LT.0.)THETA=THETA+360.
      IF(THETA.GE.360.)THETA=THETA-360.
      T =THETA/57.2958
         T IS THE WIN DIRECTION IN RADIANS
SINT=SIN(T)
      COST=COS(T)
         SINT AND COST ARE THE SINE AND COSINE OF THE WIND DIRECTIO
         P IS THE LENGTH OF THE LINE SOURCE
      P=(((REP2-REP1)*(REP2-REP1)+(SEP2-SEP1)*(SEP2-SEP1))**0.5)*GS
      DO  975  JDOW = 1,NRECP
      XXRR=XRRR(JDOW)* XMET
      XXSR=YRRR(JDOW)*XMET
      Z=ZRRR(JDOW) *  XMET
         XXRR,XXSR ARE THE COORDINATES OF THE RECEPTOR
         Z IS THE RECEPTOR HEIGHT IN METERS
      IF(XXRR.EQ.9999.)GOTO35
      CNTS=0.
      CLS=0.
         CONVERT RECEPTOR COORDINATES WRT HIGHWAY
      XRR=XXSR*SIN(ANGH)+XXRR*COS(ANGH)
      XSR=XXSR*COS(ANGH)-XXRR*SIN(ANGH)
      RR=XRR
 5051 FORMAT(1X,I4,2X,4E20.7)
      DO600IL=1,NL
      DOWIL= IL-1
      IF(CUT.NE.0.)GOTO76
      IF(IL.GT.NL/2.AND.IL.NE.1)CNTS=CNTR
   76 IF(THETA.GT.90.0 .AND. THETA.LE.270.0 ) GO TO 77
      SR =  XSR - DELW * DOWIL -CNTS + WIDTH/2.0
      GOTO78
   77 SR =  XSR + DELW * DOWIL +CNTS - WIDTH/2.0
   78 ESTD=0.
         CALCULATE DOWNWIND AND CROSSWIND DISTANCES OF RECEPTOR IR,I
          FO THE ENDPOINTS OF THE LINE SOURCE
      R1=(   1-RR)*GS
      S1=(   1-SR)*GS
      R2=     -RR)*GS
      S2=     -SR)*GS
      X1=R    NT+S1*COST
      Y1=S    NT-R1*COST
      X2=R    NT+S2*COST
      Y2=S    NT-R2*COST
```

```
 5052 FORMAT(1X,3E15.5)
 5054 FORMAT(1X,3E18.7)
C      X1,Y1 ARE THE DOWNWIND AND CROSSWIND DISTANCES (KM)
C       OF RECEPTOR IR,IC FROM ENDPOINT REP1,SEP1 OF THE LINE SOUR
C      X2,Y2 ARE THE DOWNWIND AND CROSSWIND DISTANCES (KM)
C       OF RECEPTOR IR,IC FROM ENDPOINT REP2,SEP2 OF THE LINE SOUR
C      TEST FOR AT LEAST ONE ENDPOINT UPWIND OF RECEPTOR - OTHERWI
C        CONCENTRATION  = 0.
C      CHECK FOR RECEPTOR DOWNWIND OF SOURCE.  IF NOT, SET CONC. =
      IF (X1)  4402,105,4403
 4403 IF (X2) 4404,110,110
 4404 CONTINUE
      Y2=Y2-((Y2-Y1)/(X2-X1)) * X2
      X2=0.0
      R=((X2-X1)**2 + (Y2-Y1)**2)**.5
      GO TO 110
 4402 IF (X2) 500,500,4405
 4405 CONTINUE
      Y1= Y1-((Y2-Y1)/(X2-X1))* X1
      X1 = 0.0
      R=((X2-X1)**2 + (Y2-Y1)**2)**.5
      GO TO 110
  105 IF(X2) 500,110,110
C      CHECK FOR RECEPTOR BETWEEN CENTERLINE OF PLUMES FROM ENDPO
C        IF IT IS DIVIDE SOURCE INTO TWO SEGMENTS (INDX=2), GO TO
  110 IF(Y1) 112,120,112
  112 IF(Y2) 115,120,115
  115 Y3=SIGN(Y1,Y2)
      IF(Y3-Y1) 150,120,150
  120 XA=X1
      XB=X2
      YA=Y1
      YB=Y2
      RR=R
      INDX=1
      GO TO 210
  150 XA=X1
      YA=Y1
      XP=X1+(X2-X1)*ABS(Y1)/(ABS(Y1)+ABS(Y2))
      XB=XP
      YB=0.
      RR=R*ABS(Y1)/(ABS(Y1)+ABS(Y2))
      INDX=2
  210 M=0
      DX=XB-XA
      DY=YB-YA
      XZA=XA+XVZ(KST)
      XZB=XB+XVZ(KST)
      XYA=XA+XVY(KST)
      XYB=XB+XVY(KST)
      ESTR=0.0
      CALL RELCO(U,Z,H,HL,XZA,XYA,YA,KST,AN,RC1,XVZ,XVY)
      CALL RELCO(U,Z,H,HL,XZB,XYB,YB,KST,AN,RC2,XVZ,XVY)
      CURR=(RC1+RC2)*RR/2.
      IF(CURR) 215,215,220
  215 ESTC=0.0
      GO TO 300
  220 PREV=CURR
      SUBT=0.0
      M=2*M+1
```

```
      DX=DX/2.
      DY=DY/2.0
      DO 250 K=1,M,2
      DOWK = K
      X =  XA + DOWK * DX
      Y =  YA + DOWK * DY
      XZ=X+XVZ(KST)
      XY=X+XVY(KST)
      CALL PELCO(U,Z,H,HL,XZ,XY,Y,KST,AN,RC,XVZ,XVY)
  250 SUBT=SUBT+RC
      DOWM  = M+1
      CUPR  =  PREV/2.0 + SUBT * PP/DOWM
      ESTC=(4.*CUPR-PREV)/3.
      IF(ESTC) 215,215,255
        ESTC AND ESTP ARE CURRENT AND PREVIOUS RICHARDSONS
          EXTRAPOLATIONS.
 255 RAT=ABS((ESTC-ESTP)/ESTC)
        RAT IS A COMPARISON BETWEEN THE CURRENT AND PREVIOUS VALUE
          WHEN RAT BECOMES LESS THAN 0.02 THE CURRENT VALUE IS ACCE
          FOR THE VALUE OF THE INTEGRAL.
      IF (ABS(ESTC) .LT.       .000001 ) GO TO 300
      IF(RAT-0.005) 300,260,260
  260 ESTP=ESTC
      GO TO 220
  300 ESTD=ESTC+ESTD
      IF(INDX-1) 500,500,310
  310 XA=XP
      YA=0.
      XB=X2
      YB=Y2
      PP=P*ABS(Y2)/(ABS(Y1)+ABS(Y2))
      INDX=1
      GO TO 210
  500 CLSS=ESTD*QLS(IL)*1000.
  600 CLS=CLSS+CLS
     CONVERT TO PPM
      CLS=  CLS * 870.0
      WRITE(IWRI,30) XXRR,XXSR,Z,CLS
  375 CONTINUE
 1000 CONTINUE
 5000 CONTINUE
REWIND 6
CALL PAGENEW
      RETURN
      END
      SUBROUTINE PELCO(U,Z,H,HL,X,XY,Y,KST,AN,RC,XVZ,XVY)
      DIMENSION XVZ(6),XVY(6)
      COMMON /A/ GY(6),GZ(6,5)
        SUBROUTINE PELCO CALCULATES CHI/Q CONCENTRATION VALUES, RE
          CALLS UPON SUBROUTINE SIGMA TO OBTAIN STANDARD DEVIATIONS
        THE INPUT VARIABLES ARE....
         U     WIND SPEED (M/SEC)
         Z     RECEPTOR HEIGHT (M)
         H     EFFECTIVE STACK HEIGHT (M)
         HL=L HEIGHT OF LIMITING LID (M)
         X     DOWNWIND DISTANCE FOR CALCULATING SIGMAZ (KM)
         XY    DOWNWIND DISTANCE FOR CALCULATING SIGMAY (KM)
         Y     DISTANCE RECEPTOR IS CROSSWIND FROM SOURCE (KM)
         KST   STABILITY CLASS
        THE OUTPUT VARIABLES ARE....
```

```
          AN    THE NUMBER OF TIMES THE SUMMATION TERM IS EVALUATED
                 AND ADDED IN.
          RC    RELATIVE CONCENTRATION (SEC/M**3)
         THE FOLLOWING EQUATION IS SOLVED --
           RC = (1/(2*PI*U*SIGMA Y*SIGMA Z))* (EXP(-0.5*(Y/SIGMA Y)
             (EXP(-0.5*((Z-H)/SIGMA Z)**2) + EXP(-0.5*((Z+H)/SIGMA Z
               PLUS THE SUM OF THE FOLLOWING 4 TERMS K TIMES (N=1,K)
                 TERM 1- EXP(-0.5*((Z-H-2NL)/SIGMA Z)**2)
                 TERM 2- EXP(-0.5*((Z+H-2NL)/SIGMA Z)**2)
                 TERM 3- EXP(-0.5*((Z-H+2NL)/SIGMA Z)**2)
                 TERM 4- EXP(-0.5*((Z+H+2NL)/SIGMA Z)**2)
         THE ABOVE EQUATION IS SIMILAR TO EQUATION (5.8) P 36 IN
          WORKBOOK OF ATMOSPHERIC DISPERSION ESTIMATES WITH THE ADD
          OF THE EXPONENTIAL INVOLVING Y.
          IWRI IS CONTROL CODE FOR OUTPUT
        IWRI = 6
          IF X IS LESS THAN ZERO,   SET RC=0. AND RETURN.  THIS AVO
           PROBLEMS OF INCORRECT VALUES NEAR THE SOURCE.
        IF(X-XVZ(KST))30,30,5
      5 IF(XY-XVY(KST))30,300,300
          CALL SIGMA TO OBTAIN VALUES FOR SY AND SZ
    300 CALL SIGMA (X,XY,KST,SY,SZ)
          SY = SIGMA Y, THE STANDARD DEVIATION OF CONCENTRATION IN
          Y-DIRECTION (M)
          SZ = SIGMA Z, THE STANDARD DEVIATION OF CONCENTRATION IN
          Z-DIRECTION (M)
          INITIAL VALUE OF AN SET = 0.
        AN=0.
          IF THE RECEPTOR IS ABOVE THE LID, PRINT THAT OUT, SET RC =
           AND RETURN.
        IF(Z-HL)10,10,20
     20 WRITE(IWRI,1)
      1 FORMAT(1X,RECEPTOR HIGHER THAN LID)
     30 RC=0.
        RETURN
          IF THE SOURCE IS ABOVE THE LID, SET RC = 0., AND RETURN.
     10 IF(H-HL)40,40,30
          YD IS CROSSWIND DISTANCE IN METERS.
          STATEMENTS 40 TO 250 CALCULATE RC, THE RELATIVE CONCENTRAT
           USING THE EQUATION DISCUSSED ABOVE.  SEVERAL INTERMEDIATE
           VARIABLES ARE USED TO AVOID REPEATING CALCULATIONS.
           CHECKS ARE MADE TO BE SURE THAT THE ARGUMENT OF THE
           EXPONENTIAL FUNCTION IS NEVER GREATER THAN 50 (OR LESS TH
           -50).  IF AN BECOMES GREATER THAN 45, A LINE OF OUTPUT
           PRINTED INFORMING OF THIS.
     40 YD = 1000.*Y
        C1 = 0.5*(YD/SY)*(YD/SY)
        IF(C1-50.)50,30,30
     50 A1=1./(6.28318*U*SY*SZ*EXP(C1))
        C2=2.*SZ*SZ
        CA = Z-H
        CB = Z+H
        C3 = CA*CA/C2
        C4 = CB*CB/C2
        IF(C3-50.)60,70,70
     60 A2=1./EXP(C3)
        GO TO 80
     70 A2=0.
     80 IF(C4-50.)90,100,100
     90 A3=1./EXP(C4)
```

```
      GO TO 110
  100 A3=0.
  110 SUM=0.
      THL = 2.* HL
  120 AN=AN+1.
      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.)130,140,140
  130 A4=1./EXP(C6)
      GO TO 150
  140 A4=0.
  150 IF(C7-50.)160,170,170
  160 A5=1./EXP(C7)
      GO TO 180
  170 A5=0.
  180 IF(C8-50.)190,200,200
  190 A6=1./EXP(C8)
      GO TO 210
  200 A6=0.
  210 IF(C9-50.)220,230,230
  220 A7=1./EXP(C9)
      GO TO 240
  230 A7=0.
  240 T=A4+A5+A6+A7
      SUM=SUM+T
      IF(T-0.01)250,260,260
  260 IF(AN-45.)120,270,270
  270 WRITE(IMPI,2)X,Y,H,T,SUM
    2 FORMAT(1X,N GREATER THAN 45,/,6X,X = ,F7.0,5X,Y = ,F7.0
     H = ,F5.1,5X,T = ,F7.3,5X,SUM = , F7.3)
  250 RC=A1*(A2+A3+SUM)
      RETURN
      END
      SUBROUTINE SIGMA(X,XY,KST,SY,SZ)
      COMMON /A/ GY(6),GZ(6,5)
      AZ=X*1000.
      AY=XY*1000.
      IF(AZ-5000.)641,643,640
  640 IZ=1
      GOTO644
  641 IF(AZ.GE.500.) GOTO643
      IZ=3
      GOTO644
  643 IZ=2
  644 SZ=GZ(IZ,KST)*AZ**GZ(IZ+3,KST)
      SY=GY(KST)*AY**0.903
      RETURN
      END
      SUBROUTINE ATH(DX,DY,ANGH,DANG)
      RAD=57.2958
      IF(DX)5,6,7
    5 IF(DY.EQ.0.)GOTO9
      ANGH=ATAN(DY/DX)*RAD+180.
```

```
      GOTO16
    9 ANGH=180.
      GOTO16
    6 IF(DY)10,11,12
   10 ANGH=270.
      GOTO16
   11 ANGH=0.
      GOTO16
   12 ANGH=90.
      GOTO16
    7 IF(DY)13,14,15
   13 ANGH=ATAN(DY/DX)*RAD+360.
      GOTO16
   14 ANGH=360.
      GOTO16
   15 ANGH=ATAN(DY/DX)*RAD
   16 DANG=ANGH
      ANGH=ANGH/RAD
      RETURN
      END
      BLOCK DATA
      COMMON /A/ GY(6),GZ(6,5)
 DATA GY/.4,.295,.2,.13,.098,.066/
      DATA GZ/2*0.0002539,0.0383,2*2.0886,1.2812,2*0.04936,0.1393,
      2*1.1137,0.9467,0.1154,0.1014,0.112,0.9109,0.926,0.91,0.7368,
      0.2591,0.0856,0.5642,0.6869,0.865,1.2969,0.2527,0.0818,
      0.4421,0.6341,0.8155/
      END
```

```
          ***********PROGRAM HIWAY     **********           PAGE  9
SUBROUTINE PAGENEW
* THIS PROGRAM LISTS OUTPUT IN 8.5 X 11 PAGE FORMAT
INTEGER NAME,PAGE,PAGE1
DIMENSION FILE(80,60)
PAGE=1
NAME=9H    HIWAY
10 PRINT1
1 FORMAT(*-----------------------------------------------------*
+*-----------------*,/)
PRINT2,NAME,PAGE
2 FORMAT(10X,10H**********,7HPROGRAM,2X,A9,10H**********,10X,
+4HPAGE,I3,/)
DO5 J=1,60
IF(EOF,6)4,11
11 READ(6,3)(FILE(I,J),I=1,72)
3 FORMAT(72A1)
PRINT3,(FILE(I,J),I=1,72)
5 CONTINUE
PAGE=PAGE+1
PRINT6
PRINT6
GO TO 10
4 K=60-J
DO7 JJ=J,62
6 FORMAT(1H )
PRINT6
7 CONTINUE
PRINT1
END
```