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Mathematical Approach to Estimating Highway Impact on Air Quality

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California Department of Public Works
Division of Highways
1120 N Street, P.O. Box 1139
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Highway engineers must play an important role in the enhancement and protection of the environment. They will have to consider a variety of factors in the environmental impact of any highway project and complete a number of studies prior to writing an impact statement. One of these studies is concerned with the gathering of field data, analysis of such data, and writing an air quality report. This manual explains a method of predicting pollutant concentrations within an area of study with and without the new highway. The prediction analysis includes both the highway corridor and the mesoscale. The highway corridor is defined as a region extending from the point where the pollutants are generated by traffic (the highway) downwind to the point where ambient pollutant levels are again reached. The mesoscale area is defined as the area throughout which traffic volumes on the surface traffic network are significantly affected by the construction of a new highway.

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FOREWORD

A number of studies must be completed prior to the writing of an Environmental Impact Statement for a highway project. One of these studies is concerned with the gathering of field data, analysis of such data, and writing an air quality report.

The California Division of Highways has embarked on a program of equipping and training district personnel to prepare air quality reports. This requires a two-week training course and the preparation of air quality manuals to be used as guides in the gathering of field data, analysis of results, and writing the report.

This volume is the fourth in a series of eight volumes, the titles of which follows:

1. Meteorology and Its Influence on the Dispersion of Pollutants from Highway Line Sources.
2. Motor Vehicle Emission Factors for Estimates of Highway Impact on Air Quality.
3. Traffic Information Requirements for Estimates of Highway Impact on Air Quality.
4. Mathematical Approach to Estimating Highway Impact on Air Quality.
5. Appendix to Volume 4.
6. Analysis of Ambient Air Quality for Highway Environmental Projects.
7. A Method for Analyzing and Reporting Highway Impact on Air Quality.
8. Synopsis of Air Quality.

The material presented in these volumes is subject to change as further research provides information. The following items are not discussed or, if presented, are subject to care in the interpretation of results.

1. There is no accepted emission factors for oxides of nitrogen relating emissions to speed.
2. There are no statistically validated photochemical models for different meteorological conditions which will permit calculations of oxidant formed downwind from a line source.
3. Further research is required to fully validate model calculations when winds blow parallel to the line source.

ACKNOWLEDGEMENTS

This manual has been authored by Andrew J. Ranzieri under the supervision of Earl C. Shirley, Senior Materials and Research Engineer, Environmental Improvement Section.

The authors wish to express their appreciation to Dr. Leonard Myrup, Associate Professor of Atmospheric Science, University of California, Davis, for his efforts in reviewing this report. Also, special appreciation is given to Bruce W. Oliver of the Environmental Improvement Section for his efforts in reviewing this report.

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Adminstration. The opinions, findings, and conclusions expressed in this publication are those of the California Division of Highways and not necessarily those of the Federal Highway Administration.

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INTRODUCTION

Assessment of the impact of highways on air quality requires the quantitative prediction of pollutant concentrations within the area under study with and without the new highway.

To fully reply to the National Environmental Policy Act of 1969, the predictive mathematical analysis should include (1) a highway corridor analysis and (2) a mesoscale analysis. The highway corridor is defined as a region extending from the point where the pollutants are generated by traffic (the highway) downwind to the point where ambient pollutant levels are again reached. The mesoscale area can be defined as the area throughout which traffic volumes on the surface traffic network are significantly affected by the construction of a new highway.

The primary pollutants from motor vehicles are (1) carbon monoxide (2) hydrocarbons, (3) oxides of nitrogen, and (4) particulates (mainly lead). Hydrocarbons and oxides of nitrogen in the presence of sunlight (ultraviolet radiation) combine in a photochemical process to form smog. The formation of smog is a function of the ambient air temperature, relative concentrations of hydrocarbons and oxides of nitrogen in the atmosphere, and reaction time. This photochemical reaction is a very complex process and the state of the art of air pollution modeling has not yet reached the point where one can estimate the temporal and spatial distribution of the secondary pollutants with confidence.

In the corridor analysis, carbon monoxide is most suitable as a tracer pollutant to define dispersion due to its relative inertness in the photochemical process. Since there is no health standard for hydrocarbons, corridor concentrations of this pollutant will not be estimated. Also, at the present time, there are insufficient data on the variation of oxides of nitrogen with respect to speed from either Environmental Protection Agency or the California Air Resources Board.

For the mesoscale analysis, estimates of pollutant loads in tons per day with and without the proposed facility will be made for carbon monoxide and hydrocarbons. Until such time as better emission factors are developed, oxides of nitrogen will not be estimated.

Lead particulates are not considered in the corridor or mesoscale analysis because of the lack of quantitative data on emission rates and dispersion characteristics. This manual describes a mathematical model to estimate the hourly concentrations of carbon monoxide on and within the highway corridor. It also presents a mathematical method for assessing the impact of highways on the mesoscale environment.

CORRIDOR ANALYSIS

Mathematical Assumptions

The mathematical model presented in this manual is based primarily on the Gaussian Diffusion Equation, that is, the concentrations of pollutants within the plume generated by the vehicles on highways are distributed normally in both the cross-wind and vertical directions. The following are other basic assumptions that went into the development of the mathematical model for highway line sources:

1. Continuous emission sources from vehicles on highways for the time period analyzed.

2. The surface stability classes of the atmosphere are determined from studies made by Pasquill [1] and from an objective system of classifying stabilities from meteorological observations as suggested by Turner [2].

3. The concentration of pollutants on highways within the mechanical mixing cell is independent of surface stability classes. The mechanical mixing cell can be defined as the area on the highway where there is an intense zone of mixing and turbulence caused by the motion of the vehicles. The vertical height of the mixing cell is assumed to be 12 feet. The horizontal width of the mechanical mixing cell is assumed to extend from edge of shoulder to edge of shoulder for medians less than or equal to 30 feet.

4. A uniform wind flow field exists, that is, there is no variation of wind speed with height (wind shear).

5. No aerodynamic effects on air passing over structures, buildings, and other obstructions.

Further discussion of these assumptions along with the limitations and applications is presented later.

Input Data Required For Mathematical Analysis

The required inputs to the mathematical model to estimate hourly pollution concentrations on and within the highway corridor are described below:

1) Traffic volume in number of vehicles per hour.

2) Emission factors of vehicles using the highway as a function of heavy duty vehicle (HDV) mix and average route speed.

3) Meteorological parameters, that is, surface stability of the atmosphere and its associated probability of occurrence along with its corresponding wind rose.

4) Type of highway design, that is, a highway located on a fill or viaduct section, cut section, at grade section, etc.

5) Horizontal and vertical dispersion parameters.

Each of the above inputs into the mathematical model is discussed in detail below.

Traffic

The traffic input data for a proposed highway normally will be the peak and off-peak hourly volumes and their associated time of occurrence. This information can be obtained from District Traffic or Urban Planning Departments and will cover the period from the estimated time of completion of the proposed highway to twenty years thereafter. This is discussed in detail in a report by this department [3].

Emission Factors

The input emission factors [4] for carbon monoxide for the estimated time of completion and twenty years hence can be obtained from reference [4] depending on the percentage of Heavy Duty Vehicles (HDV) and the average route speed. If the estimated HDV mix does not correspond to the exact value used in the figures of reference [4] use a direct linear interpolation between the lower and higher HDV mix to obtain a value for the emission factor.

Wind Speed, Direction, and Stability

The output from the computer program [5] WNDROS or STAROS* will give for a specified time, (1) the probability of occurrence for each surface stability Class A through F inclusively and (2) the wind roses for the associated surface stability classes. Stability Class A is the most favorable meteorological condition in terms of the dispersion of pollutants while Stability Class F is the most unfavorable (worst) meteorological condition and results in the highest ground level concentrations. For a quantitative air quality study, it is necessary to compare two meteorological conditions which are obtained from the computer programs WNDROS or STAROS*. The two conditions are (1) the most probable

*The STAR2 computer program has replaced the STAROS program.

surface stability class and its associated wind rose, and (2) the most unfavorable, or worst meteorological conditions its probability of occurrence, and its associated wind rose. The most probable and the worst meteorological conditions are usually estimated for the time periods when the peak and off-peak traffic hours occur. This is discussed in detail in a report by Beaton et al [5].

Type of Highway Design

The input for the type of highway design consists of one of the following:

1. at grade section

2. elevated highways 30 feet or less

3. elevated highways over 30 feet

4. cut section

For each of the above types of design, with the exception of the at grade section, the height of fill, viaduct, or elevated section must be determined. The same applies to the cut section, that is, the depth of cut must be determined. The geometric characteristics can be obtained from plans furnished by the Design Section.

Horizontal and Vertical Dispersion Parameters

The horizontal and vertical dispersion parameters are used in the mathematical model to characterize the transport and dispersion of pollutants for different meteorological conditions.

These dispersion parameters are a measure of the surface stability of the atmosphere which greatly influences the ground level concentrations. Figures 86 and 87 in Appendix* are plots of the vertical and horizontal dispersion parameters. The use of these parameters is illustrated in Example 2.

Output From Mathematical Analysis

The output of the mathematical model is a series of curves (Figures 1 to 85 in Appendix). These curves are a plot of the ground level concentration ratio $C\bar{u}K/Q$ versus the downwind distance. From these curves estimates of hourly concentrations of carbon monoxide can be made for the highway corridor region. These values are solely due to vehicle emissions and must be added to background concentrations to obtain total pollutant concentration levels.

*The appendix for this volume is published separately as Vol. 5. See note at foot of page v of this book.

These appendix curves are divided into four basic groups as described below:

Group 1: Appendix Figures 1 to 6 are for at grade sections where the wind is not parallel to the highway alignment.

Group 2: Appendix Figures 7 to 54 are for elevated sections, that is, fills, viaducts, and bridges where the wind is not parallel to the highway alignment.

Group 3: Appendix Figures 55 to 78 are for cut sections where the wind is not parallel to the highway alignment. These curves can be used to estimate the concentrations of pollutants generated by highways with shallow cuts. (Depth of cut $\leq$ 30 feet.)

Group 4: Appendix Figures 79 to 85 are for highway sections where the wind is parallel to the highway alignment.

The curves in Appendix Figures 7 to 54 indicate the theoretical relative difference in ground level concentrations for highways on elevated sections compared to at-grade sections. In these figures the curve for H=O represents the at-grade section for winds not parallel to the highway alignment. Detailed field measurements are required to validate this reduction in ground level concentration for elevated sections, however, the relative effects can be seen from the curves. The same reasoning applies to the comparison between at-grade sections and cut sections shown in Appendix Figures 1 to 6 and Appendix Figures 55 to 78, where the winds are not parallel to the highway alignment and for different surface stability classes.

In Appendix Figures 1 through 78 where the winds are not parallel to the highway, the angle of intersection (Ø) between wind direction and the highway centerline has the following application:

Ø = 22.5° corresponds to angles from 12° to 33°

Ø = 45° corresponds to angles from 34° to 56°

Ø = 67.5° corresponds to angles from 57° to 78°

Ø = 90° corresponds to angles from 79° to 101°

Appendix Figures 79 through 85 (where the winds are parallel to the highway alignment) are used where the angle of intersection (Ø) between the wind direction and highway centerline is less than 12°.

Figure 1 illustrates the wind direction and ranges.

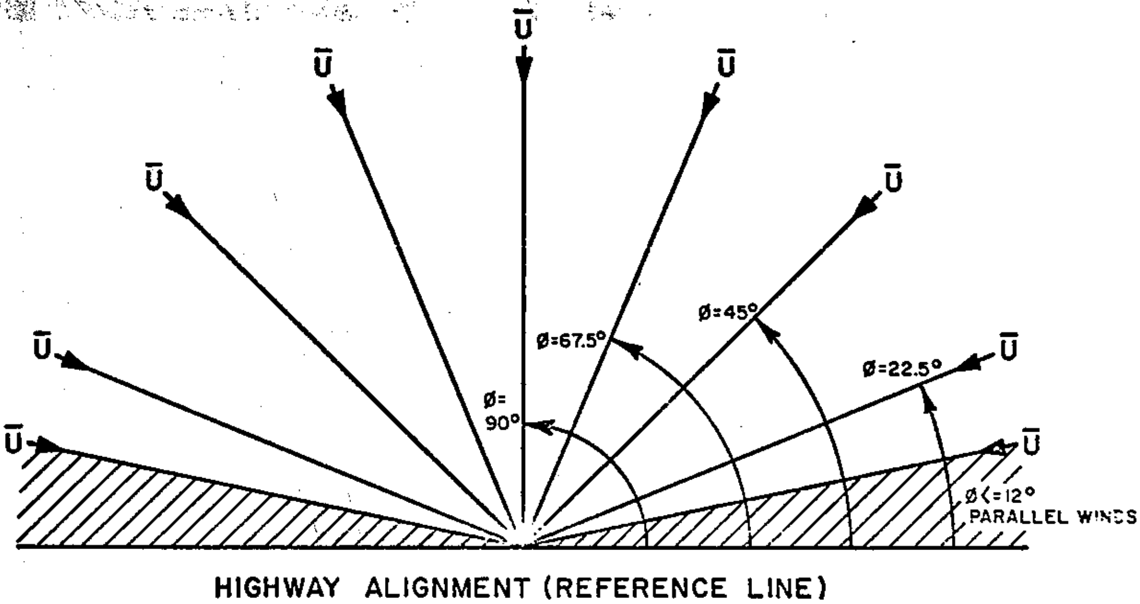


Fig. 1 ANGLE OF INTERSECTION BETWEEN WIND DIRECTION AND HIGHWAY ALIGNMENT IN DEGREES

The variables* on the curves in the Appendix are:

C = Concentration of pollutant in grams per cubic meter (gm/m^3)

$\bar{U}$ = Mean surface wind speed (m/sec)**

Q = Emission source strength $\frac{gm}{sec}$ (winds parallel)

and

$\frac{gm}{sec\text{-}m}$ (winds not parallel)

K = Empirical coefficient determined by field measurements

Until sufficient data become available from the Division of Highways research project [10] assume K = 4.24 on all curves.

The system of units for concentrations should be consistent with the California Air Quality Standards in parts per million by volume or the Environmental Protection Agency Standards in micrograms per cubic meter. The following equations convert the concentration from the curves in grams per cubic meter to parts per million by volume based on a reference temperature of 25°C and pressure of 760 mm of mercury, and from grams per cubic meter to micrograms per cubic meter.

$$ppm = \mu g/m^3 \ \frac{(0.0245)}{M.W.} \qquad (1)$$

Where ppm = Concentration of pollutant in parts per million by colume

$\mu gm/m^3$ = Concentration of pollutant in micrograms per cubic meter

$$1 \ \mu gm/m^3 = 10^{-6} \ gms/m^3 \qquad (2)$$

M.W. = Molecular weight of the pollutant.

*All units used in the model equations are in the metric system.

**$\bar{U}$ is representative of the undisturbed air flow measured at a height of 10 meters above the ground surface over flat level terrain or modified for surface roughness as defined in reference [5].

Calculations for Crosswinds

Mixing Cell Concentrations

The concentration of pollutants on the highway within the mechanical mixing cell for highways located on elevated, cut, or at-grade sections may be estimated (for any surface stability class) by using the following equation for Ø greater than 12°:

$$C = \frac{1.06\,Q}{K_1\,\bar{u}\,\sin\phi} \qquad (3)$$

Where C = Concentration of pollutant gm/m^3

Q = Emission source gm/sec-m

$\bar{U}$ = Wind speed m/sec (1 mph = 0.447 m/sec)*

K_1 = Empirical coefficient determined by field measurements**.

Ø = Angle of wind with respect to highway alignment as determined from the computer program [5] WNDROS or STAROS based on a 16 point compass reporting system. Ø will be one of the following angles using the highway alignment as a reference or base line:

Ø = 22.5°

Ø = 45°

Ø = 67.5°

Ø = 90° (wind direction is perpendicular to highway alignment).

1.06 = Empirical factor relating the height of the mechanical mixing cell to concentration

To compute the source strength term Q in equation 3 use the following equation:

$$Q = [1.73 \times 10^{-7}] \times [\text{vehicles per hour}] \times [\text{emission factor}] \qquad (4)$$

Where the numerical constant is a factor to convert the units of the product (vph)(gm/mi) to gm/m-sec.

*The minimum recommended wind speed is 2 mph or about 1 m/sec.

**Until sufficient data become available from the Division of Highways Research Project [10] assume K_1 = 4.24.

The emission factor used in equation 4 depends on the model year, emission standards, percentage of HDV, average route speed, etc. Values are given by Beaton et al [4] for the primary pollutants emitted by the motor vehicles.

The calculated concentration from equation 3 should be converted to parts per million concentrations by using equation (1).

Ground Level Concentrations

Ground level concentration can be defined as the concentration a receptor would receive five feet above the ground surface.

To compute ground level concentrations downwind from a highway line source use Figures 1 to 78 in the Appendix depending on the type of geometric highway design, wind direction, and surface stability. Examples are given later in this section.

Elevated Receptor Concentrations

To estimate the downwind pollutant concentration for elevated receptors with crosswind conditions use the following equations:

At-Grade Section Elevated Receptor

$$C = \frac{4.24\,Q}{K\,\sigma_Z\,\bar{u}\,\sin\phi}\left[\exp -\frac{1}{2}\left(\frac{Z}{\sigma_Z}\right)^2\right] \qquad (5)$$

Where K = 4.24

C, Q, $\bar{U}$, ϕ = parameters previously described

Z = height of receptor above surrounding terrain in meters

σ_z = vertical dispersion parameter

Elevated Section - Elevated Receptors

$$C = \frac{4.24\,Q}{K\,\sigma_Z\,\bar{u}\,\sin\phi}\left[\exp -\frac{1}{2}\left(\frac{Z+H}{\sigma_Z}\right)^2 + \exp -\frac{1}{2}\left(\frac{Z-H}{\sigma_Z}\right)^2\right] \qquad (6)$$

Where K = 4.24 determined by preliminary field measurements [10]

C, Q, σ_z, $\bar{U}$, ϕ = parameters previously described

H = height of highway above surrounding terrain in meters

Z = height of receptor above surrounding ground surface in meters

This equation is most applicable downwind of the aerodynamic effects of the air flow over the fill, or 5 to 10 times the height of the fill [5].

Cut Section - Elevated Receptors

$$C = \frac{4.24\,Q}{K \sigma_Z \bar{U} \sin \phi} \left[\exp + \frac{1}{2}\left(\frac{Z_0}{\sigma_Z}\right)^2\right] \left[\exp - \frac{1}{2}\left(\frac{Z}{\sigma_Z}\right)^2\right] \quad (7)$$

Where K = 4.24 as previously discussed

C, Q, σ_z, $\bar{U}$, ϕ = parameters previously described

Z_o = depth of cut in meters*

Z = height of receptor above surrounding ground surface in meters

For wide valleys, it is assumed that the change in topography (drop in elevation) is gradual. This minimizes the air flow separation of the streamlines entering the section and causes the air flow to be relatively undisturbed within the valley. If the drop in elevation is abrupt, air flow separation could occur when the wind entered the valley. However, if the highway is located within the valley a distance approximately ten times [5] the height of the drop downwind, the air flow will return to its undisturbed state and estimates can be made of the pollutant concentrations. These aerodynamic effects must be considered because of the assumption that went into the development of the mathematical model.

In come cases, a highway may be located in a wide valley or near a low range of hills with winds not parallel to the highway alignment. For these conditions it is possible to estimate the ground level concentrations of pollutants for the areas above the valley floor. Figure 2 illustrates this special case for a highway at grade.

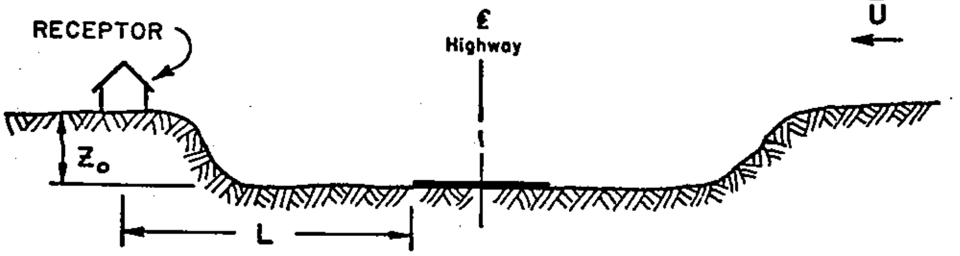


Fig. 2 HIGHWAY LOCATED IN WIDE VALLEY

*The depth of cut (Z_o) at the present time is limited to 30 feet or less until more research is completed [10].

The procedure for determining the concentrations at the receptor's location in Figure 2 can be estimated by using equations 5, 6, or 7 depending on type of highway design.

Calculations for Parallel Winds

Mixing Cell Concentrations

When the prevailing winds become parallel to the highway alignment, a build-up of pollution levels can occur in the downwind direction. This will begin from the point where the wind initially becomes parallel to the highway alignment. The estimated concentrations within the mechanical mixing cell for parallel winds, where the ratio of 30.5/W is less than or equal to one, can be determined from the following equation:

$$C = A\left(\frac{Q}{\bar{U}}\right)\left(\frac{1}{K}\right)\left(\frac{30.5}{W}\right) \qquad (8)$$

Where: C = concentration of pollutant (gm/m^3) within mechanical mixing cell

$\bar{U}$ = wind speed (m/sec)

K = empirical coefficient determined by field measurements*

W = width of roadway from edge of shoulder to edge of shoulder in meters

A = downwind concentration ratio for parallel winds

30.5 = the initial width (meters) of the highway used for the finite element of area in developing the model for parallel winds.

The downwind concentration ratio can be defined as

$$\frac{C\bar{U}K}{Q}\left(\frac{W}{30.5}\right)$$

and can be determined from curves in Figures 79 to 85 in the Appendix.

Q = source emission strength (gm/sec)

*Until sufficient data becom es available from the Division of Highways Research Project [10] assume K = 4.24.

For parallel winds the source emission strength (Q) can be calculated using the following equation:

$$Q = [\text{emission factor}] \times [\text{vehicles/hour}] \times [5.26 \times 10^{-6}] \quad (9)$$

Where the numerical constant is a factor to convert units of the product (vph)(gm/mi) to gm/sec for a length of highway of 100 feet.

Ground Leval Concentrations

To estimate the ground level pollutant concentration at a distance away from the highway (when the wind is parallel to the alignment) and the highway located at an at-grade section, an elevated section, or a cut section use the following equations:

At Grade Section

$$\text{ppm} = [\text{ppm}]_{M.C.}\left[\exp -\frac{1}{2}\left(\frac{Y}{\sigma_y}\right)^2\right] \quad (10)$$

Elevated Section

$$\text{ppm} = [\text{ppm}]_{M.C.}\left[\exp -\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]\left[\exp. -\frac{1}{2}\left(\frac{Y}{\sigma_y}\right)^2\right] \quad (11)$$

Cut Section

$$\text{ppm} = [\text{ppm}]_{M.C.}\left[\exp +\frac{1}{2}\left(\frac{Z_o}{\sigma_z}\right)^2\right]\left[\exp. -\frac{1}{2}\left(\frac{Y}{\sigma_y}\right)^2\right] \quad (12)$$

Where: ppm = concnetration in parts per million of carbon monoxide at a point away from the highway.

$[\text{ppm}]_{M.C.}$ = concentration of CO at the highway within the mechanical mixing cell normal to the point in question. This is calculated from Figures 79 to 85 depending on the surface stability of the atmosphere and type of highway design

H = height of elevated section in meters (1 meter = 3.28 feet)

Z_o = depth of cut section, in meters, with relation to the surrounding terrain

Y = normal distance in meters from receptor to near edge of highway shoulder

σ_Y, σ_Z = horizontal and vertical turbulent parameters in meters. These values are obtained from Figures 86 and 87 depending on the receptor's normal distance (Y) from the highway and on the stability class

Elevated Receptor Concentrations

To estimate pollutant concentrations normal to highway for elevated receptors with parallel wind conditions use the following equations:

At-Grade Section - Elevated Receptor

$$ppm = [ppm]_{M.C.}\left[\exp -\frac{1}{2}\left(\frac{Y}{\sigma_y}\right)^2\right]\left[\exp -\frac{1}{2}\left(\frac{Z}{\sigma_z}\right)^2\right] \qquad (13)$$

Where Z = height of receptor above surrounding terrain in meters

Elevated Section - Elevated Receptor

$$ppm = [ppm]_{M.C.}\left[\exp -\frac{1}{2}\left(\frac{Y}{\sigma_y}\right)^2\right]\left[\exp -\frac{1}{2}\left(\frac{Z+H}{\sigma_z}\right)^2 + \exp -\frac{1}{2}\left(\frac{Z-H}{\sigma_z}\right)^2\right] \qquad (14)$$

Where H = height of highway above sourrounding terrain in meters

Z = height of receptor above the surrounding ground surface in meters

Cut Section - Elevated Receptor

$$ppm = [ppm]_{M.C.}\left[\exp -\frac{1}{2}\left(\frac{Y}{\sigma_y}\right)^2\right]\left[\exp +\frac{1}{2}\left(\frac{Z_o}{\sigma_z}\right)^2\right]\left[\exp -\frac{1}{2}\left(\frac{Z}{\sigma_z}\right)^2\right] \qquad (15)$$

Where Z_o = depth of cut in meters*

Z = height of receptor above surrounding terrain in meters

All of the other parameters in the above equations have been previously described.

*Applicable for cut section with depths less than or equal to 30 feet.

Special Cases

Equations 8, 10, 11, 12, 13, 14, 15 and Figures 79 to 85 are applicable when the width of the highway is 100 feet or greater from shoulder to shoulder.

When estimating concentrations from highways with a total width from shoulder to shoulder of less than 100 feet, the above equations underestimate the size of the mechanical mixing cell resulting in unreasonably high concentrations.

To estimate downwind concentrations within the mechanical mixing cell, equation (8) must be modified. The ratio 30.5/W is <u>inverted</u> which allows for the decrease in width of the highway by reducing the size of the mechanical mixing cell.

The revised equation becomes:

$$C = A\left(\frac{Q}{\bar{U}}\right)\left(\frac{1}{K}\right)\left(\frac{W}{30.5}\right) \qquad (16)$$

Where C, Q, $\bar{U}$, A, K and W have been previously defined.

More research will be required to fully develop and verify this or other approaches [10]. When these conditions exist consult with the headquarters Materials and Research Department in Sacramento for guidance and assistance.

Superposition with Cross or Parallel Wind Conditions

In crosswind cases where the median of a highway is greater than 30 feet a superposition principle can be applied to estimate downwind concentrations of CO. For this analysis each lane direction will be assumed to generate its own mechanical mixing cell. Traffic data and speeds are required for both directions. Estimates of pollution concentrations can be estimated by using Figures 1 through 78 and equations 3, 4, 5, 6 and 7 depending on the receptor's location for each directional lane. These results will be additive to estimate the receptor's total concentration above background.

In special cases (where the wind is parallel to the highway) with the median greater than 30 feet, estimates of CO concentrations can also be made using a superposition principle for each directional lane. The calculation procedures are similar to those discussed when the total width of highway was less than 100 feet. In this case the equations are applicable to each directional lane. The total concentration for a receptor is the additive sum of the effects of both directions. This superposition principle will require more research [10] to fully define the exact limits of the mechanical mixing cell for different types of highway design. Until such data become available consult with the Materials and Research Department in Sacramento for guidance and assistance.

Discussions of Assumptions

The mathematical model described in this report is based on the "Gaussian Diffusion Equation". Modifications were made to accommodate the mechanical mixing cell caused by the motion of moving vehicles. This section will discuss the basic assumptions made in the derivation of the model and their relation to the "real world". The assumptions that will influence or affect the concentration levels from highway line sources are discussed in detail below.

1) Assumption: Vehicles using highways for the time period analyzed constitute a continuous and level source of emissions.

Real World: Experience has shown when driving on a highway or freeway the operating mode is not continuously a cruise mode or steady state speed. Freeway interchanges, on-ramps, off-ramps, and other areas of friction force the driver to change the operating mode of his vehicle. During peak traffic in heavily populated areas "stop and go" type driving conditions may exist with consequent high traffic densities. Vehicle emission factors vary widely with average trip speed on pre- 1975 model vehicles [7 and 8]. For these model years the concentrations of CO and HC tend to be reduced at higher average trip speeds while the NO_x concentrations tend to increase at higher average trip speeds. The 1975 and later model year vehicles will be relatively "pollution free" and emissions will be less of a function of route speed. At the present time, heavy off-peak traffic hours with high traffic density would be most nearly representative of a continuous, level source because of the limited amount of traffic congestion.

Other investigators [9] have suggested a "Gaussian Puff Model" to simulate a source but the puff strength still must be determined. More field data derived from studies such as the California Division of Highways Research Project in Los Angeles [10], will aid in evaluating this assumption to its fullest extent. Until such information becomes available, emission factors based on the California 7-mode test procedure and the 1972 Federal test procedure will be used in the model to estimate the source strength (Q).

The emission factors derived from the California seven mode test cycle should be conservative for all new highways. The California seven-mode test cycle is based on the driving habits during peak hour traffic in downtown Los Angeles. This provides built-in conservatism on new highway construction where traffic volumes in general do not exceed the design capacity. However, during latter years when the traffic volumes build up the seven mode test cycle may tend to approach the "real world" situation.

2) Assumption: Stability classes based on studies made by Pasquill [1] and Turner [2] modified for the mechanical mixing cell provide an adequate measure of atmospheric turbulence.

Real World: These stability classes are based on measurements made in flat open country or rural areas. These stability factors, when applied to urban areas, are less reliable. This difference is reported by various investigators [11] and [12] as that due primarily to the (1) influence of the urban area's larger surface roughness and (2) heat island effects upon the stability regime over the urban areas. The greatest difference occurs on calm clear nights. On such nights, conditions over rural areas are very stable. However, over urban areas they are slightly unstable or near neutral lapse rate conditions to a height several times the average building height, with a stable layer above. Therefore, the best application of these stability classes is to rural areas.

Another consideration in the reliability of the Pasquill stability classes is that no estimates of atmospheric turbulence have been made for horizontal distances from the source of less than 0.1 km (328 ft.). Since CO concentrations, as dispersed from highways, reach their highest values at distances less than 0.1 km, this is the most critical.

The dispersion parameters derived by Pasquill (σ_y and σ_z) can be modified to estimate pollutant concentrations in this critical region. To accomplish these modifications the California Division of Highways made a series of experiments using smoke candles mounted on exhaust pipes of automobiles [14]. These vehicles were driven at speeds of 15, 30 and 60 mph on a airport runway. The surrounding terrain was flat and open. During the tests the sky conditions were cloudy and overcast simulating a nuetral stability condition. Measurements of the edge of the visible plume as it dispersed were made after the initial mechanical mixing. These measurements were then used to estimate the turbulent parameters for Stability D to a distance of approximately 300 feet downwind. The actual measurement of the edge of plume has inherent inaccuracies because of the lack of contrast of the gray smoke plume with the overcast skies. Another possible inaccuracy is whether the particles have similar dispersion characteristics as automotive exhaust gases.

Two other variables which were not considered in making the modified dispersion parameters were different meteorological conditions and surface roughness. To fully evaluate all of the variables mentioned, more extensive research will be required [10]. Until that time, the modified values of σ_y and σ_z should be used when estimating pollutant concentrations in assessing the impact of the highway on the air environment.

3) Assumption: The concentration of pollutants on the freeway within the mechanical mixing cell is independent of stability classes or environmental lapse rates.

Real World: One primary difficulty with the classical Gaussian Equation is that it is generally applicable only for point sources. Solutions of this equation must be modified to apply to continuous line sources.

The California Division of Highways has adopted the concept of the mechanical mixing cell [13]. Dr. Eschenroeder of General Research Corporation [13] derived the mathematical equations showing that the height of the mechanical mixing cell is approximately twice the height of the vehicle. Tests were made by the Division of Highways [14] to validate this concept. Smoke candles were mounted on exhaust pipes of cars driven at various speeds. The results indicate that his theory correlated well with the measurements over the limited range of meteorological conditions tested. Other investigators [12] and [15] in their studies of the urban heat island effect noticed that if a surface base inversion exists, the automobile traffic resulted in vertical mixing and weakened the inversion near the ground. Thus it is reasonable to assume that the pollutant concentration within the mixing cell is constant [13]. No field measurements have been made to verify this; however, extensive measurements will be the subject of future research [10].

It might be important to note that, from the California Division of Highways' tests on the mechanical mixing cell, two other observations were made. Tests made when the wind speeds were 5 mph or less, showed that the smoke plume was dispersed mainly in the vertical direction. This indicates that, at low wind speeds in the range of 8-12 mph, the plume remained close to the ground for some distance before any diffusion occurred. This indicates that, at relatively high wind speeds, pollutant plumes emitted from moving vehicles tend to be sheared off and the inertial forces of the wind dominate the initial dispersion. These observations can be related to the case where a house is located next to a freeway. Under calm or light wind conditions, the pollution levels at the house may be at the lowest; however, under strong wind conditions the concentrations may be at the highest level due to the inertial effects of the wind. This will require further field measurements of pollutant concentrations on the California Division of Highways' Research Project [10]

4) Assumption: A uniform wind flow field, without wind shear, exists in the area of interest.

Real World: Accuracy and representativeness of the mean wind speed is overwhelmingly important in making air pollution calculations. For example one effect of elevating a freeway is to increase the effective mean wind speed due to rapid increase of wind speed with height near the ground (wind shear). This rate of increase of wind speed with height can be calculated as a function of the surface roughness of the surrounding terrain and atmospheric stability. By definition wind shear includes not only the change in wind speed with height, but also the directional change. In assessing the impact of highways on the air environment for the microscale analysis the directional change of wind with height up to 100 meters is neglegible compared to the speed change [21]. At heights greater than 100 meters the wind shear is related to both wind speed and direction [21]. There are various equations that can be used as a guide to estimate the wind speed for an elevated section where surface wind measurements are not available [22]. It is intended that these wind speeds estimated with these equations may be used in the mathematical model to estimate pollutant concentrations. However, Turner [16] indicates that, because the basic Gaussian Model uses mean surface values of wind speed and direction, neither the variation of wind speed nor wind direction with height need be taken into account. This is usually not a problem in neutral or unstable conditions but can cause over estimation of downwind concentrations with stable conditions. Recently mathematical models [17, 18 and 19] have been developed using the atmospheric diffusion equation that includes wind shear, which from a physical standpoint is more realistic. More field measurements for model validation [10] are required in order to reach a firm conclusion as to the best theoretical approach to use. Until this information is available use the mean surface wind speed in the highway line source dispersion model to estimate pollutant concentrations.

5) Assumption: There are no aerodynamic forces affecting the dispersion of pollutants from highways on fill sections, viaduct sections and cut sections, nor any aerodynamic forces affecting estimates of ground level concentrations in urban areas near houses, buildings, etc.

Real World: The type of geometric highway design plays a very important role on immediate downwind ground level pollutant concentrations. As was discussed in the Division of Highways' manual [5] on meteorology, concerning the mean flow of air around a cubical building, the building could be considered a highway located on a fill section. Under these conditions the ground level concentrations of pollutants may be high within the cavity zone as turbulent eddies can pick up a cloud of pollutants near the highway and quickly transport it back to ground level. Previous studies by Johnson [20] have indicated this same effect in street canyons. The concentration of pollutants within the cavity zone are a function of the height of fill, traffic volume, and the meteorological conditions. Within the cavity zone the Gaussian Model is not applicable; however, the model is theoretically valid when the surface wind profile returns to its undisturbed upwind state. A highway located on either a viaduct section or an at grade section most nearly satisfies the assumption of no aerodynamic effects of the highway structure. A highway located in a cut section can influence the ground level concentrations by the aerodynamic effects of the turbulent eddies within the cut. More research is required to quantify effects of this type of section [10].

Applications, Accuracy and Limitations of Model

The mathematical analysis presented in this report has not been validated with field measurements. In general, it should give approximate estimates for hourly concentrations of carbon monoxide over most meteoroological conditions. It is anticipated that the best estimates for carbon monoxide would be for flat open country when the wind is not parallel to the highway alignment.

The model has the capability to estimate hourly concentrations of pollutants for any time period throughout a day. An example might be to estimate the CO concentration at a school located 500 feet from a highway between 9 a.m. in the morning and 4 p.m. in the afternoon. To analyze this condition the following procedures should be followed:

1) The meteorological records within the project area must be analyzed for the appropriate time period in terms of wind speed, direction, and surface stability. This analysis can be made with computer programs that are available [5].

2) Off-peak traffic estimates for the hours under study must be made along with the average trip speed. These estimates can be provided by the Traffic or Urban Planning Departments.

3) The off-peak traffic volume emission factors can be estimated from reference [4] for an average trip speed for the hours under study.

4) These inputs are used in the mathematical model to estimate the hourly pollutant concentrations.

The model in its present form will give less reliable estimates for the following circumstances:

1. When there are local disturbances of air flow, e.g., in the immediate vicinity of highway fills, buildings or other obstructions. This is caused by the aerodynamic effect of air flowing around such obstacles. The exact limits of the estimated pollution concentrations will have to be determined with field measurements [10].

2 When the airflow is channeled into a narrow canyon or when it contains circulation or drainage set up by the heating and cooling of undulating or hilly terrain.

3. When an elevated inversion layer exists near enough to the surface to influence surface concentrations. The resultant higher air pollution concentrations would not be predictable with the existing model. The occurrence of such inversions would not be detectable with ordinary meteorological measurements. It is conceivable that augmented surface concentrations due to this effect may be important during the early morning peak traffic period. During this period of fumigation the remnant of the early morning radiation is often present aloft relatively near the surface. It is possible to include in the model the effect of an elevated inversion by including in the analysis a reflection surface at the level of the inversion base [16]. This is very difficult to measure because of the lack of quantitative data concerning this phenomenum.

4. When the wind speed approaches zero the concentrations estimated from the highway line source dispersion model mathematically approach infinity. It is recommended that the minimum wind speed be 2 mph or about 1 m per sec.

5. The model is not photochemical model and does not estimate the concentrations of photochemical pollutants such as ozone and other secondary pollutants.

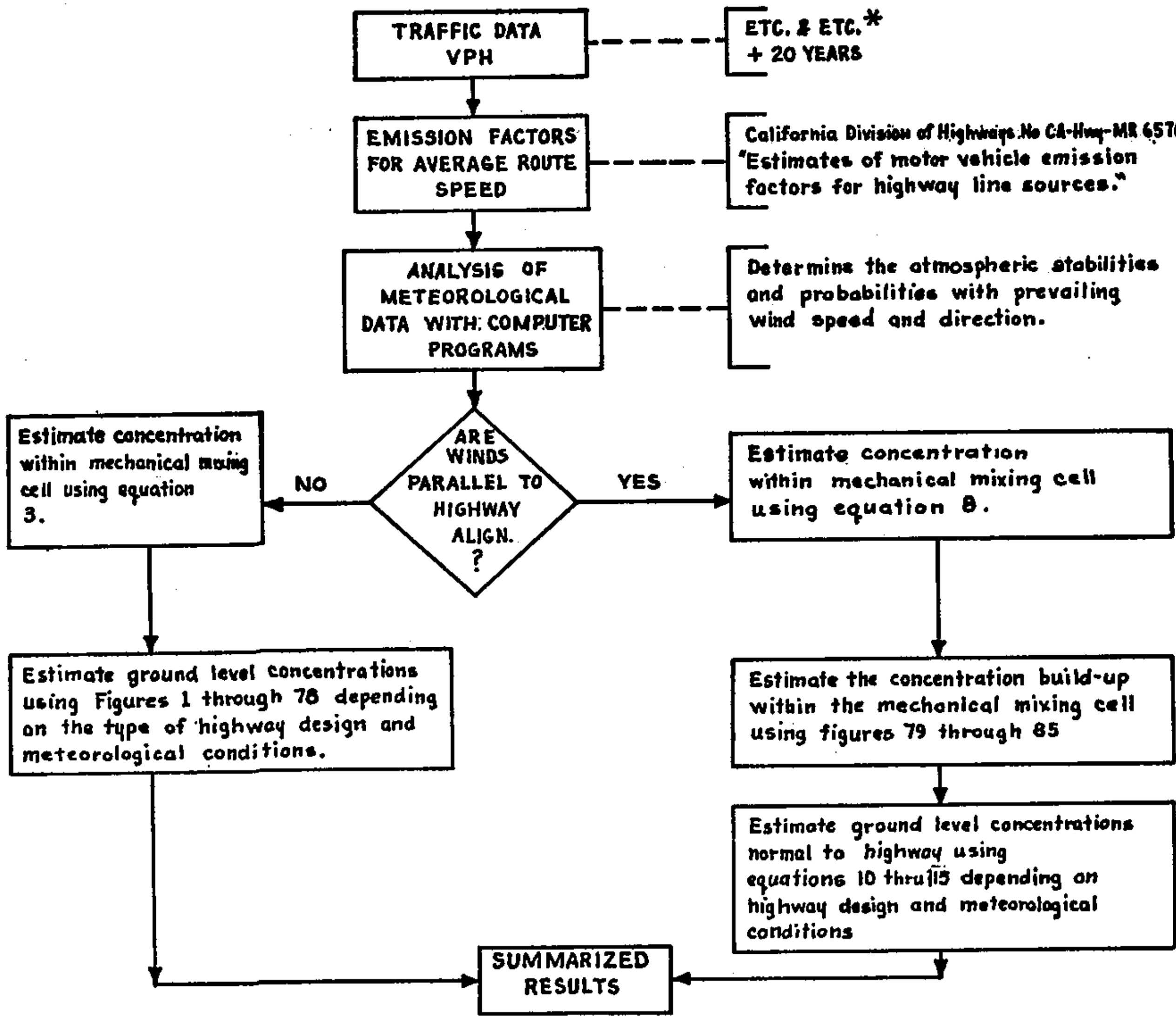
6. Adjacent to interchanges or intersections.

These conditions violate some of the basic assumptions that went into the development of the model. Engineering judgment should be exercised when such conditions exist in estimating pollutant concentrations. Guidance and assistance can be obtained from the Materials and Research Department in Sacramento.

Confidence in the model is built only after extensive checks are made with field measurements. This validation involves checking theory against what happens in the "real world" by direct measurements of the parameters involved. In this way the model can relate the concentrations estimated to those measured in the field.

Presently the California Division of Highways has entered into a contract [10] with the federal Highway Administration (FHWA) to monitor pollutants along and in the vicinity of traffic corridors for different meteorological conditions, traffic characteristics, roadway configurations, and topography. The data that are taken will be used to validate this and other existing models. It is intended that, with the information from this research project, highway engineers will be able to estimate concentrations of pollutants on and within the highway corridor with a greater degree of confidence. However, in the interim period, the model presented in this report can be used to give estimates of pollution concentrations on and within the highway corridor. It should be stressed again that the assumptions made in development of the model should be considered when relating the estimated pollution levels from the model to the "real world" situation. Figure 3 shows a general approach, for using the model, in the form of a flow chart. This approach is recommended.

When assessing the impact of highways on the environment, the alternative of no highway must be considered in the analysis. This model can be used to estimate the CO concentrations within the highway corridor for existing highways, city streets, etc. which will be replaced by the new highway. This will allow a comparison of the changes in CO concentrations for the study area with and without the new highway.



*ETC = Estimated Time of completion.

Fig. 3. Systems flow chart for highway line source dispersion model.

EXAMPLE NO. 1

AIR POLLUTION CONCENTRATION ESTIMATE FOR PROPOSED FREEWAY

AT-GRADE SECTION

Given:

(1) A sketch of a proposed highway and meteorological sources is given in Figure 4. The median is 30 feet wide. Estimated time of completion (ETC) of proposed freeway AB is January 1975.

(2) Peak traffic volume is estimated to be 8,000 vehicles per hour with a 5% HDV mix. The average route speed is estimated to be 50 mph at the time of completion.

(3) Peak traffic hours are estimated to be from 7 AM to 9 AM.

(4) The meteorological data were analyzed with computer program STAROS. The computer output is given on the following pages for the morning traffic hours. This analysis was made for the month of January only.

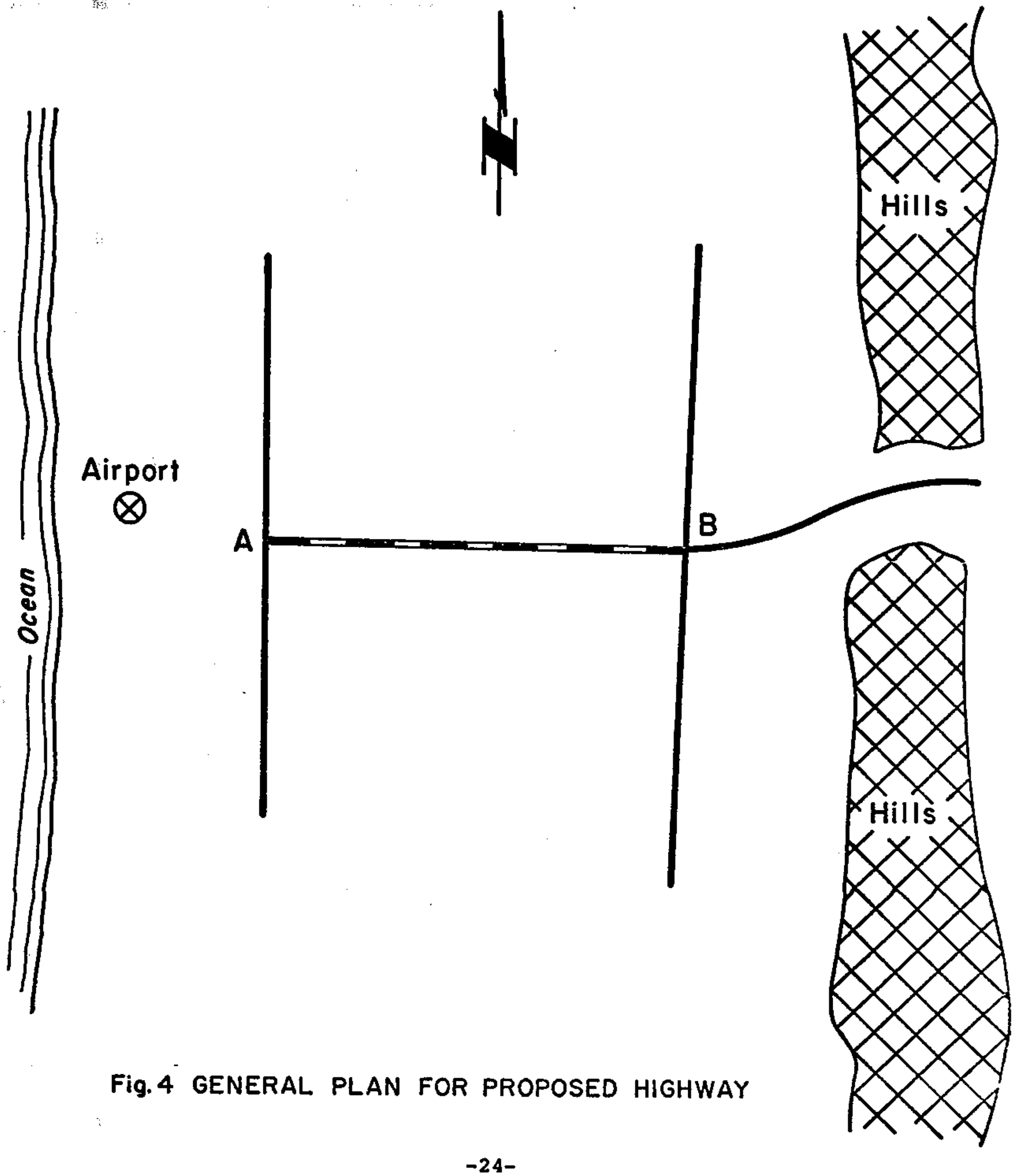


Fig. 4 GENERAL PLAN FOR PROPOSED HIGHWAY

WEATHER STATION NAME: HAYWARD AIRPORT LOCATION: HAYWARD CAL
YEARS OF RECORD: 67-68-69-70-71 MONTH : JANUARY
HOURS OF DAY: 7-8-9
PROJECT ID: 19701 762561 657092S USER: A.R. DISTRICT 19

STABILITY CLASS DESIGNATION 1

NO. OF OCCURANCES IN THIS CLASSIFICATION IS ZERO
THEREFORE THERE ARE NO RESULTS

WEATHER STATION NAME: HAYWARD AIRPORT LOCATION: HAYWARD CAL
YEARS OF RECORD: 67-68-69-70-71 MONTH : JANUARY
HOURS OF DAY: 7-8-9
PROJECT ID: 19701 762561 657092S USER: A.R. DISTRICT 19

STABILITY CLASS DESIGNATION 2

...IN THE FOLLOWING TABLE THE CALMS ARE DISTRIBUTED....
......FREQUENCY DISTRIBUTION TABLE.......

DIRECTION	VELOCITY,MPH											
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47	TOT	AVE.	%TOT
N	0	1	0	0	0	0	0	0	0	1	5.5	2.9
NNE	1	0	1	0	0	0	0	0	0	2	5.2	5.3
NE	1	9	0	0	0	0	0	0	0	10	5.0	23.6
ENE	0	1	2	0	0	0	0	0	0	3	8.3	7.6
E	1	4	0	0	0	0	0	0	0	5	4.5	11.8
ESE	0	5	1	0	0	0	0	0	0	6	6.2	14.1
SE	0	4	0	0	0	0	0	0	0	4	5.5	8.8
SSE	0	1	0	0	0	0	0	0	0	1	5.5	2.9
S	1	1	0	0	0	0	0	0	0	3	3.5	5.9
SSW	0	0	0	0	0	0	0	0	0	0	.0	.0
SW	0	0	0	0	0	0	0	0	0	0	.0	.0
WSW	0	1	0	0	0	0	0	0	0	1	5.5	2.9
W	1	1	1	0	0	0	0	0	0	4	5.3	8.2
WNW	0	3	0	0	0	0	0	0	0	3	5.5	5.9
NW	0	0	0	0	0	0	0	0	0	0	.0	.0
NNW	0	0	0	0	0	0	0	0	0	0	.0	.0
CALM	8	0	0	0	0	0	0	0	0	8	.0	.0
TOT	6	32	5	0	0	0	0	0	0	43	.0	.0

TOTAL NO. OF OBSERVATIONS = 465
OCCURANCE WITHIN THIS STABILITY CLASS = 43

..........RELATIVE FREQUENCY DISTRIBUTION................

RELATIVE FREQUENCY OF OCCURANCE OF B STABILITY CLASS= 9.25 PCT

DIRECTION	VELOCITY,MPH									
	0-3	4-8	8-12	13-18	19-24	25-31	32-38	39-46	47	%TOT
N	.00	.27	.00	.00	.00	.00	.00	.00	.00	.27
NNE	.27	.00	.22	.00	.00	.00	.00	.00	.00	.49
NE	.27	1.91	.00	.00	.00	.00	.00	.00	.00	2.18
ENE	.00	.27	.43	.00	.00	.00	.00	.00	.00	.70
E	.27	.82	.00	.00	.00	.00	.00	.00	.00	1.09
ESE	.00	1.09	.22	.00	.00	.00	.00	.00	.00	1.30
SE	.00	.82	.00	.00	.00	.00	.00	.00	.00	.82
SSE	.00	.27	.00	.00	.00	.00	.00	.00	.00	.27
S	.27	.27	.00	.00	.00	.00	.00	.00	.00	.54
SSW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
SW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WSW	.00	.27	.00	.00	.00	.00	.00	.00	.00	.27
W	.27	.27	.22	.00	.00	.00	.00	.00	.00	.76
WNW	.00	.54	.00	.00	.00	.00	.00	.00	.00	.54
NW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
NNW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00

WEATHER STATION NAME: HAYWARD AIRPORT LOCATION: HAYWARD CAL
YEARS OF RECORD: 67-68-69-70-71 MONTH : JANUARY
HOURS OF DAY: 7-8-9
PROJECT ID: 19701 762561 657092S USER: A.R. DISTRICT 19

STABILITY CLASS DESIGNATION 3

...IN THE FOLLOWING TABLE THE CALMS ARE DISTRIBUTED....
......FREQUENCY DISTRIBUTION TABLE.......

DIRECTION	VELOCITY,MPH										
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47	TOT	AVE.	%TOT
N	0	2	2	0	0	0	0	0	0	4	8.0	19.3
NNE	0	0	2	1	0	0	0	0	0	3	11.8	15.8
NE	0	0	2	0	0	0	0	0	0	2	10.0	10.5
ENE	0	2	1	0	0	0	0	0	0	3	7.2	14.0
E	0	0	0	0	0	0	0	0	0	0	.0	.0
ESE	0	0	2	0	0	0	0	0	0	2	10.0	10.5
SE	0	0	1	0	0	0	0	0	0	1	10.0	5.3
SSE	0	2	0	1	0	0	0	0	0	3	9.2	14.0
S	0	0	1	0	0	0	0	0	0	1	10.0	5.3
SSW	0	0	0	0	0	0	0	0	0	0	.0	.0
SW	0	0	0	0	0	0	0	0	0	0	.0	.0
WSW	0	0	0	0	0	0	0	0	0	0	.0	.0
W	0	0	0	0	0	0	0	0	0	0	.0	.0
WNW	0	0	0	0	0	0	0	0	0	0	.0	.0
NW	0	0	0	0	0	0	0	0	0	0	.0	.0
NNW	0	0	1	0	0	0	0	0	0	1	10.0	5.3
CALM	2	0	0	0	0	0	0	0	0	2	.0	.0
TOT	0	5	12	2	0	0	0	0	0	19	.0	.0

TOTAL NO. OF OBSERVATIONS = 465
OCCURANCE WITHIN THIS STABILITY CLASS = 19

..........RELATIVE FREQUENCY DISTRIBUTION................

RELATIVE FREQUENCY OF OCCURANCE OF C STABILITY CLASS= 4.09 PCT

DIRECTION	VELOCITY,MPH									
	0-3	4-8	8-12	13-18	19-24	25-31	32-38	39-46	47	%TOT
N	.00	.36	.43	.00	.00	.00	.00	.00	.00	.79
NNE	.00	.00	.43	.22	.00	.00	.00	.00	.00	.65
NE	.00	.00	.43	.00	.00	.00	.00	.00	.00	.43
ENE	.00	.36	.22	.00	.00	.00	.00	.00	.00	.57
E	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
ESE	.00	.00	.43	.00	.00	.00	.00	.00	.00	.43
SE	.00	.00	.22	.00	.00	.00	.00	.00	.00	.22
SSE	.00	.36	.00	.22	.00	.00	.00	.00	.00	.57
S	.00	.00	.22	.00	.00	.00	.00	.00	.00	.22
SSW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
SW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WSW	.00	.00	.00	.00	.00	.00	.0	.0	.00	.00
W	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WNW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
NW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
NNW	.00	.00	.22	.00	.00	.00	.00	.00	.00	.22

WEATHER STATION NAME: HAYWARD AIRPORT LOCATION: HAYWARD CAL
YEARS OF RECORD: 67-68-69-70-71 MONTH : JANUARY
HOURS OF DAY: 7-8-9
PROJECT ID: 19701 762561 657092S USER: A.R. DISTRICT 19

STABILITY CLASS DESIGNATION 4

...IN THE FOLLOWING TABLE THE CALMS ARE DISTRIBUTED....
......FREQUENCY DISTRIBUTION TABLE.......

DIRECTION	VELOCITY,MPH										
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47	TOT	AVE.	%TOT
N	0	2	0	0	0	0	0	0	0	2	5.5	1.0
NNE	0	2	8	3	1	0	0	0	0	14	11.3	6.4
NE	0	9	13	7	0	0	0	0	0	29	9.9	13.1
ENE	0	2	9	4	0	0	0	0	0	15	10.8	6.9
E	0	4	6	0	0	0	0	0	0	10	8.1	4.8
ESE	0	7	5	5	0	0	0	0	0	17	9.8	7.6
SE	0	4	21	16	8	1	0	0	0	50	13.5	22.9
SSE	0	4	7	13	9	1	0	0	0	34	15.0	15.6
S	0	2	4	0	1	0	0	0	0	7	10.2	3.3
SSW	0	2	2	4	4	0	0	0	0	12	14.7	5.5
SW	0	0	1	4	4	0	0	0	0	9	17.6	4.1
WSW	0	0	2	2	1	0	0	0	0	5	14.5	2.3
W	0	4	1	1	1	0	0	0	0	7	9.6	3.4
WNW	0	0	1	4	0	0	0	0	0	5	14.4	2.3
NW	0	0	0	0	1	0	0	0	0	1	21.5	.5
NNW	0	0	0	1	0	0	0	0	0	1	15.5	.5
CALM	25	0	0	0	0	0	0	0	0	25	.0	.0
TOT	0	45	80	64	30	2	0	0	0	221	.0	.0

TOTAL NO. OF OBSERVATIONS = 465
OCCURANCE WITHIN THIS STABILITY CLASS = 221

...........RELATIVE FREQUENCY DISTRIBUTION.................

RELATIVE FREQUENCY OF OCCURANCE OF D STABILITY CLASS= 47.53 PCT

DIRECTION	VELOCITY,MPH									
	0-3	4-8	8-12	13-18	19-24	25-31	32-38	39-46	47	%TOT
N	.00	.48	.00	.00	.00	.00	.00	.00	.00	.48
NNE	.00	.48	1.72	.65	.22	.00	.00	.00	.00	3.06
NE	.00	1.94	2.80	1.51	.00	.00	.00	.00	.00	6.24
ENE	.00	.48	1.94	.86	.00	.00	.00	.00	.00	3.28
E	.00	.97	1.29	.00	.00	.00	.00	.00	.00	2.26
ESE	.00	1.45	1.08	1.08	.00	.00	.00	.00	.00	3.60
SE	.00	.97	4.52	3.44	1.72	.22	.00	.00	.00	10.86
SSE	.00	.97	1.51	2.80	1.94	.22	.00	.00	.00	7.42
S	.00	.48	.86	.00	.22	.00	.00	.00	.00	1.56
SSW	.00	.48	.43	.86	.86	.00	.00	.00	.00	2.63
SW	.00	.00	.22	.86	.86	.00	.00	.00	.00	1.94
WSW	.00	.00	.43	.43	.22	.00	.00	.00	.00	1.08
W	.00	.97	.22	.22	.22	.00	.00	.00	.00	1.61
WNW	.00	.00	.22	.86	.00	.00	.00	.00	.00	1.08
NW	.00	.00	.00	.00	.22	.00	.00	.00	.00	.22
NNW	.00	.00	.00	.22	.00	.00	.00	.00	.00	.22

WEATHER STATION NAME: HAYWARD AIRPORT LOCATION: HAYWARD CAL
YEARS OF RECORD: 67-68-69-70-71 MONTH : JANUARY
HOURS OF DAY: 7-8-9
PROJECT ID: 19701 762561 657092S USER: A.R. DISTRICT 19

STABILITY CLASS DESIGNATION 5
......FREQUENCY DISTRIBUTION TABLE.......

DIRECTION	VELOCITY,MPH										
	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47	TOT	AVE.	%TOT
N	0	0	1	0	0	0	0	0	0	1	10.0	1.5
NNE	0	1	5	0	0	0	0	0	0	6	9.2	8.8
NE	0	2	12	0	0	0	0	0	0	14	9.4	20.6
ENE	0	9	8	0	0	0	0	0	0	17	7.6	25.0
E	0	8	3	0	0	0	0	0	0	11	6.7	16.2
ESE	0	2	3	0	0	0	0	0	0	5	8.2	7.4
SE	0	3	3	0	0	0	0	0	0	6	7.7	8.8
SSE	0	0	1	0	0	0	0	0	0	1	10.0	1.5
S	0	0	0	0	0	0	0	0	0	0	.0	.0
SSW	0	0	0	0	0	0	0	0	0	0	.0	.0
SW	0	0	0	0	0	0	0	0	0	0	.0	.0
WSW	0	0	0	0	0	0	0	0	0	0	.0	.0
W	0	0	0	0	0	0	0	0	0	0	.0	.0
WNW	0	1	2	0	0	0	0	0	0	3	8.5	4.4
NW	0	1	2	0	0	0	0	0	0	3	8.5	4.4
NNW	0	0	1	0	0	0	0	0	0	1	10.0	1.5
CALM	0	0	0	0	0	0	0	0	0	0	.0	.0
TOT	0	27	41	0	0	0	0	0	0	68	.0	.0

TOTAL NO. OF OBSERVATIONS = 465
OCCURANCE WITHIN THIS STABILITY CLASS = 68

..........RELATIVE FREQUENCY DISTRIBUTION................

RELATIVE FREQUENCY OF OCCURANCE OF E STABILITY CLASS= 14.62 PCT

DIRECTION	VELOCITY,MPH									
	0-3	4-8	8-12	13-18	19-24	25-31	32-38	39-46	47	%TOT
N	.00	.00	.22	.00	.00	.00	.00	.00	.00	.22
NNE	.00	.22	1.08	.00	.00	.00	.00	.00	.00	1.29
NE	.00	.43	2.58	.00	.00	.00	.00	.00	.00	3.01
ENE	.00	1.94	1.72	.00	.00	.00	.00	.00	.00	3.66
E	.00	1.72	.65	.00	.00	.00	.00	.00	.00	2.37
ESE	.00	.43	.65	.00	.00	.00	.00	.00	.00	1.08
SE	.00	.65	.65	.00	.00	.00	.00	.00	.00	1.29
SSE	.00	.00	.22	.00	.00	.00	.00	.00	.00	.22
S	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
SSW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
SW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WSW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
W	.00	.00	.00	.00	.00	.00	.00	.00	.00	.0
WNW	.00	.22	.43	.00	.00	.00	.00	.00	.00	.65
NW	.00	.22	.43	.00	.00	.00	.00	.00	.00	.65
NNW	.00	.00	.22	.00	.00	.00	.00	.00	.00	.22

WEATHER STATION NAME: HAYWARD AIRPORT LOCATION: HAYWARD CAL
YEARS OF RECORD: 67-68-69-70-71   MONTH : JANUARY
HOURS OF DAY: 7-8-9
PROJECT ID: 19701 762561 657092S USER: A.R. DISTRICT 19

STABILITY CLASS DESIGNATION 6

...IN THE FOLLOWING TABLE THE CALMS ARE DISTRIBUTED....
......FREQUENCY DISTRIBUTION TABLE.......

DIRECTION	VELOCITY,MPH 0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47	TOT	AVE.	%TOT
N	0	2	0	0	0	0	0	0	0	2	5.5	2.3
NNE	0	2	0	0	0	0	0	0	0	2	5.5	2.3
NE	2	14	0	0	0	0	0	0	0	16	5.0	18.6
ENE	2	24	0	0	0	0	0	0	0	26	5.2	30.2
E	0	18	0	0	0	0	0	0	0	18	5.5	20.9
ESE	0	6	0	0	0	0	0	0	0	6	5.5	7.0
SE	0	2	0	0	0	0	0	0	0	2	5.5	2.3
SSE	0	4	0	0	0	0	0	0	0	4	5.5	4.7
S	2	0	0	0	0	0	0	0	0	2	1.5	2.3
SSW	0	0	0	0	0	0	0	0	0	0	.0	.0
SW	0	2	0	0	0	0	0	0	0	2	5.5	2.3
WSW	0	0	0	0	0	0	0	0	0	0	.0	.0
W	0	0	0	0	0	0	0	0	0	0	.0	.0
WNW	0	0	0	0	0	0	0	0	0	0	.0	.0
NW	0	2	0	0	0	0	0	0	0	2	5.5	2.3
NNW	0	4	0	0	0	0	0	0	0	4	5.5	4.7
CALM	44	0	0	0	0	0	0	0	0	44	.0	.0
TOT	6	81	0	0	0	0	0	0	0	87	.0	.0

TOTAL NO. OF OBSERVATIONS =   465
OCCURANCE WITHIN THIS STABILITY CLASS =   87

...........RELATIVE FREQUENCY DISTRIBUTION................

RELATIVE FREQUENCY OF OCCURANCE OF   F STABILITY CLASS= 18.71 PCT

DIRECTION	VELOCITY,MPH 0-3	4-8	8-12	13-18	19-24	25-31	32-38	39-46	47	%TOT
N	.00	.44	.00	.00	.00	.00	.00	.00	.00	.44
NNE	.00	.44	.00	.00	.00	.00	.00	.00	.00	.44
NE	.44	3.05	.00	.00	.00	.00	.00	.00	.00	3.48
ENE	.44	5.22	.00	.00	.00	.00	.00	.00	.00	5.66
E	.00	3.92	.00	.00	.00	.00	.00	.00	.00	3.92
ESE	.00	1.31	.00	.00	.00	.00	.00	.00	.00	1.31
SE	.00	.44	.00	.00	.00	.00	.00	.00	.00	.44
SSE	.00	.87	.00	.00	.00	.00	.00	.00	.00	.87
S	.44	.00	.00	.00	.00	.00	.00	.00	.00	.44
SSW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
SW	.00	.44	.00	.00	.00	.00	.00	.00	.00	.44
WSW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
W	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
WNW	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
NW	.00	.44	.00	.00	.00	.00	.00	.00	.00	.44
NNW	.00	.87	.00	.00	.00	.00	.00	.00	.00	.87

WEATHER STATION NAME: HAYWARD AIRPORT LOCATION: HAYWARD CAL
YEARS OF RECORD: 67-68-69-70-71 MONTH : JANUARY
HOURS OF DAY: 7-8-9
PROJECT ID: 19701 762561 657092S USER: A.R. DISTRICT 19

STABILITY CLASS DESIGNATION 9

...IN THE FOLLOWING TABLE THE CALMS ARE DISTRIBUTED....
......FREQUENCY DISTRIBUTION TABLE.......

DIRECTION	0-3	4-7	8-12	13-18	19-24	25-31	32-38	39-46	47	TOT	AVE.	%TOT
	VELOCITY,MPH											
N	0	7	3	0	0	0	0	0	0	10	6.8	2.2
NNE	2	6	16	4	1	0	0	0	0	28	9.7	6.1
NE	4	37	27	7	0	0	0	0	0	75	7.9	16.1
ENE	2	45	20	4	0	0	0	0	0	71	7.2	15.2
E	2	41	9	0	0	0	0	0	0	52	6.1	11.1
ESE	0	22	11	5	0	0	0	0	0	38	8.1	8.2
SE	0	17	25	16	8	1	0	0	0	67	11.8	14.4
SSE	0	11	8	14	9	1	0	0	0	43	13.4	9.3
S	4	4	5	0	1	0	0	0	0	13	7.3	2.9
SSW	0	2	2	4	4	0	0	0	0	12	15.0	2.6
SW	0	2	1	4	4	0	0	0	0	11	15.5	2.3
WSW	0	2	2	2	1	0	0	0	0	7	12.1	1.5
W	2	6	2	1	1	0	0	0	0	11	7.9	2.5
WNW	0	6	3	4	0	0	0	0	0	13	9.8	2.7
NW	0	4	2	0	1	0	0	0	0	7	9.2	1.4
NNW	0	4	2	1	0	0	0	0	0	7	8.3	1.4
CALM	106	0	0	0	0	0	0	0	0	106	.0	.0
TOT	15	214	138	66	30	2	0	0	0	465	.0	.0

TOTAL NO. OF OBSERVATIONS = 465
OCCURANCE WITHIN THIS STABILITY CLASS = 465

..........RELATIVE FREQUENCY DISTRIBUTION.................

RELATIVE FREQUENCY OF OCCURANCE OF ALL STABILITY CLASS= 100.00 PCT

DIRECTION	0-3	4-8	8-12	13-18	19-24	25-31	32-38	39-46	47	%TOT
	VELOCITY,MPH									
N	.00	1.60	.65	.00	.00	.00	.00	.00	.00	2.25
NNE	.40	1.20	3.44	.86	.22	.00	.00	.00	.00	6.12
NE	.80	8.01	5.81	1.51	.00	.00	.00	.00	.00	16.12
ENE	.40	9.61	4.30	.86	.00	.00	.00	.00	.00	15.17
E	.40	8.81	1.94	.00	.00	.00	.00	.00	.00	11.14
ESE	.00	4.80	2.37	1.08	.00	.00	.00	.00	.00	8.25
SE	.00	3.60	5.38	3.44	1.72	.22	.00	.00	.00	14.36
SSE	.00	2.40	1.72	3.01	1.94	.22	.00	.00	.00	9.28
S	.80	.80	1.08	.00	.22	.00	.00	.00	.00	2.89
SSW	.00	.40	.43	.86	.86	.00	.00	.00	.00	2.55
SW	.00	.40	.22	.86	.86	.00	.00	.00	.00	2.34
WSW	.00	.40	.43	.43	.22	.00	.00	.00	.00	1.45
W	.40	1.20	.43	.22	.22	.00	.00	.00	.0	2.46
WNW	.00	1.20	.65	.86	.00	.00	[illegible]	[illegible]	[illegible]	2.71
NW	.00	.80	.43	.00	.22	.00	.00	.00	.00	1.45
NNW	.00	.80	.43	.22	.00	.00	.00	.00	.00	1.45

Find:

Estimate ground level concentrations of carbon monoxide (CO) within the mechanical mixing cell and for distances of 50, 100, 500 and 1,000 feet downwind. Make all estimates for the peak morning traffic.

Solution:

(1) From the computer output for 5 years of record the most probable meteorological conditions are:

1. Stability Class D, occurring 47.53% of the time (say 48%).

2. The prevailing wind direction for Stability D is from the SE occurring 22.9% of the time with a corresponding wind speed interval of 8 to 12 mph (21 observations).

(2) The worst meteorological conditions are:

1. Stability F, occurring 18.71% of the time (say 19%).

2. The prevailing wind direction for Stability F is from the ENE occurring 30.2% of the time with a corresponding wind speed interval of 4 to 7 mph (24 observations).

The concentrations of the pollutants will be estimated for the most probable and the worst (unfavorable) meteorological conditions.

(3) The prevailing wind direction of SE and ENE are not parallel to the highway alignment (see Figure 4). These prevailing directions correspond to 45° and 22.5° angles (based on a 16 point reporting system) with respect to the highway alignment.

The source emission strength (Q) is estimated by equation 4:

$$Q = (1.73 \times 10^{-7}) \text{ (vehicles per hour) (emission factor)}$$

The emission factor for 5% HDV mix on freeways with an average route speed of 50 mph is obtained from reference [4]. The emission factor for CO is 18 gm/mi.

$$Q_{CO} = 1.73 \times 10^{-7} \ (8000) \ 18 = 0.0249 \ \frac{\text{gms}}{\text{sec-m}}$$

(4) Compute the concentration of CO within the mechanical mixing cell by using equation 3 (with $K_1 = 4.24$)

$$C = \frac{1.06\,Q}{K_1 \bar{u} \sin \emptyset}$$

(a) Most probable meteorological conditions:

(Stability D with wind speeds from 8 to 12 mph with wind direction 45° with respect to the highway alignment).

Convert wind speed in mph to m/sec.

1 m/sec = 2.23 mph

8 mph = 3.59 m/sec.

12 mph = 5.38 m/sec.

For a wind speed of 3.59 m/sec. or 8 mph the concentration is:

$$C = \frac{1.06\,(0.0249)}{4.24\,(3.59)\,\sin 45°} = 0.00245\ \text{gm/m}^3$$

Convert the concentration of CO from gm/m^3 to ppm using equation (1)

$$\text{ppm} = \mu\text{g/m}^3 \left(\frac{0.0245}{\text{MW}}\right)$$

Molecular Weight CO = 28 gm/mole

$$1\ \mu\text{g/m}^3 = \text{gm/m}^3 \times 10^6$$

$$\mu\text{g/m}^3 = 0.00245 \times 10^6 = 2450$$

$$\text{ppm} = \frac{2450\,(0.0245)}{28} = 2.14$$ <u>say 2 ppm</u>

This concentration of 2 ppm is for a wind speed of 8 mph (3.59 m/sec). The wind speed class interval was 8 mph to 12 mph. The concentration within the mechanical mixing cell is inversely proportional to wind speed (see equation 3); therefore, multiply the concentration of 2 ppm by the ratio of wind speeds to estimate the CO concentration with wind of 12 mph.

$$\text{ppm} = 2.1 \left(\frac{8}{12}\right) = 1.4\ \text{ppm}$$ <u>say 1 ppm</u>

Therefore, the estimated concentration of CO on the freeway within the mechanical mixing cell varies from 1 ppm to 2 ppm above the ambient levels. This estimate is for the most probable meteorological condition. These estimated concentrations occur only during the peak traffic hours, and may last for a time period of one hour or less.

(b) Worst meteorological conditions; (Stability F with wind speeds from 4 to 7 mph with wind direction 22.5° with respect to highway alignment).

Convert wind speed in mph to m/sec.

4 mph = 1.79 m/sec.

7 mph = 3.14 m/sec.

For a wind speed of 1.79 m/sec. or 4 mph the concentration is:

$$C = \frac{1.06(0.0245)}{4.24(1.79)\sin 22.5°} = 0.00905 \text{ gm/m}^3$$

$$\mu g/m^3 = 0.00905 \times 10^6 = 9050$$

$$ppm = 9050 \frac{(.0245)}{28} = 7.9 \quad \underline{\text{say 8 ppm}}$$

The estimated concentration within the mechanical mixing cell for wind speed of 7 mph or 3.14 m/sec. is:

$$ppm = \frac{4}{7}(7.9) = 4.5 \quad \underline{\text{say 5 ppm}}$$

Therefore, the estimated concentration of CO on the freeway within the mechanical mixing cell varies from 5 ppm to 8 ppm above ambient levels. These are the worst possible meteorological conditions occurring during the peak traffic hours only and lasting for a period of time of one hour or less.

(5) Estimate the horizontal dispersion of CO in the highway corridor at 50, 100, 500 and 1,000 feet in the downwind direction.

(a) Most probable meteorological conditions: (Stability D wind speeds 8 to 12 mph.)

Using Figure 4 in Appendix A with Ø = 45° (prevailing wind from SE) estimates of the concentrations can be made using the following format:

Distance Downwind ft.	Ø	$\frac{C\bar{u}K}{Q}$	(8 to 12 mph) C -gm/m^3	CO ppm*
50	45°	0.80	0.00129-0.00086	1.1 - 0.8
100	↓	0.60	0.00097-0.00064	0.8 - 0.6
500	↓	0.43	0.00069-0.00046	0.6 - 0.4
1000	45°	0.36	0.00058-0.00039	0.5 - 0.3

The tabulated values of CO in ppm give the estimated range of ground level concentrations.

(b) Worst meteorological conditions: (Stability F, wind speed 4 to 7 mph.)

Using Figure 6 in Appendix A with Ø = 22.5° (prevailing winds from ENE) estimate the concentrations as follows:

Distance Downwind ft.	Ø	$\frac{C\bar{u}K}{Q}$	(4 to 7 mph) C -gm/m^3	CO ppm*
50	22.5°	1.8	0.00581-0.00331	5.1 - 2.9
100	↓	1.6	0.00517-0.00294	4.5 - 2.6
500		1.2	0.00378-0.00215	3.3 - 1.9
1000	22.5°	1.0	0.00322-0.00184	2.8 - 1.6

All estimates of pollutant concentrations are above or additive to the ambient levels. These estimates are only for the peak traffic hours with an assumed average trip speed of 50 mph. These estimates do not represent typical hourly concentrations throughout a day.

If the average trip speed is reduced to 35 mph estimates of CO concentrations can be made using the ratio of emission factors for 35 mph and 50 mph. The concentration is a direct function of traffic volume and emission factor, assuming historical meteorology remains constant. If the peak hourly volumes remain constant then the estimated pollutant concentrations for a 35 mph average trip speed are just a ratio of emission factors. The emission factor for CO for 35 mph is 25 gm/mi. The procedure is as follows:

(a) Most probable meteorological conditions

(1) Distance ft.	(2) ppm**	(3) Emission Factor Ratio	(4) ppm***
0	1.3 - 2.1	25/18	1.8 - 2.9
50	0.8 - 1.1	25/18	1.1 - 1.5
100	0.6 - 0.8	25/18	0.8 - 1.1
500	0.4 - 0.6	25/18	0.6 - 0.8
1000	0.3 - 0.5	25/18	0.4 - 0.7

*It is recommended that all concentrations be rounded off to the nearest whole number. However, this is an illustrative example to show the dispersion of CO in the downwind direction.

**The estimated range of concentrations based on an emission factor for 50 mph (18 gm/mi).

***The estimated concentration range of CO based on an emission factor for 35 mph. This is equal ot column (2) times column (3).

EXAMPLE NO. 2

AIR POLLUTION CONCENTRATION ESTIMATE FOR PROPOSED FREEWAY

AT-GRADE SECTION

Given:

(1) Same data as given in Sample Problem No. 1 except that the estimated completion date is for July 1975.

(2) The analysis of the meteorological data for 5 years of record for the hours of 7 AM to 9 AM is summarized below:

Meteorological Conditions	Wind Speed MPH	Direction	Stability
Most Probable	8 - 12	W	C (49%)
Worst	4 - 7	W	D (10%)

Find:

Estimate (1) the ground level concentrations of CO within the mechanical mixing cell 10,000 feet downwind where the wind becomes initially parallel to the highway and (2) for distances of 50 and 200 feet normal to the highway alignment.

Solution:

(1) The prevailing wind direction from the West results in winds that are parallel to the highway alignment (see Figure 4).

Therefore, to estimate the source strength Q equation 6 must be used.

$Q = (5.26 \times 10^{-6})$ (Vehicles per hour) (Emission Factor)

The emission factors for CO is the same as Problem No. 1.

$$Q_{CO} = 5.26 \times 10^{-6}\ (8000)\ (18) = 0.757\ \frac{gm}{sec}$$

(2) To compute the concentration of CO within the mechanical mixing cell 10,000 feet downwind where the wind initially becomes parallel to highway use Figure 79 in Appendix.

Most probable meteorological conditions (Stability C):
(Stability C with wind speeds from 8 to 12 mph).
Convert wind speeds in mph to m/sec.

1 m/sec. = 2.23 mph
8 mph = 3.58 m/sec.
12 mph = 5.38 m/sec.

From Figure 79, Appendix A

$$\frac{C\bar{u}}{Q} K\left(\frac{W}{30.5}\right) = 0.14$$

For a wind speed of 8 mph or 3.58 m/sec. the concentration on the highway is:

$$C = \frac{0.140}{K\bar{u}}\left(\frac{30.5}{W}\right) = \frac{0.14(0.757)}{4.24(3.58)}\left(\frac{30.5}{38.4}\right) = 0.00554\,gm/m^3$$

Convert the concentration in gm/m^3 to ppm using Equation (1).

$$ppm = \mu g/m^3\ \frac{(0.0245)}{MW}$$

$$ppm = 5540\ \frac{(0.0245)}{28} = 4.8\ ppm$$ say 5 ppm

For a wind speed of 12 mph or 5.38 m/sec. the concentration is:

$$ppm = \frac{8}{12}\ (4.8) = 3.2$$ say 3 ppm

Therefore, 10,000 feet downwind where the wind initially becomes parallel to highway alignment, the CO concentration is estimated to range from 3 to 5 ppm above the ambient levels.

(3) To estimate the ground level concentration of CO for a point located 10,000 feet downwind and 50 and 200 feet away from the highway, use equation 7.

$$ppm = [PPM]_{M.C.} \times \left[\exp -1/2\ (y/\sigma_y)^2\right]$$

The estimated concentration with the mechanical mixing cell 10,000 feet downwind ranges from 3 to 5 ppm.

Y = 50 feet = 15.2m

For Stability Class C and a distance downwind of 50 feet normal to highway, Figures 87 in Appendix gives σ_y = 22m.

For $\bar{u}$ = 8 mph

$$ppm = 4.8\left[\exp -\frac{1}{2}\left(\frac{15.2}{22}\right)^2\right] = 3.9$$

For $\bar{u}$ = 12 mph

$$ppm = \frac{8}{12}\ (3.9 = 2.6$$

If the normal distance from highway is 200 feet rather than 50 feet (y = 200 ft = 61(m) and σ_y = 40m.

For $\bar{u}$ = 8 mph

$$ppm = 4.8 \left[\exp - \frac{1}{2}\left(\frac{61}{40}\right)^2\right] = 1.6$$

For $\bar{u}$ = 12 mph

$$ppm = \frac{8}{12}(1.6) = 1.1$$

Therefore, if you are 10,000 feet (downwind from the point where the winds become parallel to the highway alignment) and 50 feet normal to the highway the estimated CO concentration ranges from 2.6 to 3.9 ppm. If the normal distance from the highway is 200 feet the estimate CO concentration ranges from 1.1 to 1.6 ppm. These concentrations are for the peak traffic volumes and may last only for one hour or less.

(4) Worst meteorological conditions (Stability D):

From Figure 79, Appendix

$$\frac{C\bar{u}}{Q} K \left(\frac{W}{30.5}\right) = 0.175$$

For a wind speed of 4 mph or 1.79m/sec. the concentration on the highway is:

$$C = \frac{0.175(0.757)}{4.24(1.79)}\left(\frac{30.5}{38.4}\right) = 0.01386 \text{ gm/m}^3$$

$$ppm = 13860 \frac{(0.0245)}{28} = 12.1 \quad \underline{\text{say 12 ppm}}$$

For wind speed of 7 mph the concentration is:

$$ppm = \frac{4}{7}(12.1) = 6.9 \quad \underline{\text{say 7 ppm}}$$

Therefore, for Stability Class D with wind speeds of 4 to 7 mph, the concentrations (10,000 feet downwind where wind becomes parallel to highway) ranges from 7 to 12 ppm above ambient levels.

(5) Estimate CO ground level concentration 50 feet normal to edge of pavement:

$$ppm = [ppm]_{M.C.}\left[\exp - \frac{1}{2}\left(\frac{Y}{\sigma_y}\right)^2\right]$$

$Y = 50' = 15.2\text{ m}$ $\sigma_y = 22\text{ m}$

For $\bar{U}$ = 4 mph

$$ppm = 12\left[\exp - \frac{1}{2}\left(\frac{15.2}{22}\right)^2\right] = \underline{9.4}$$

For $\bar{U}$ = 7 mph

$$ppm = \frac{4}{7}(9.4) = \underline{5.4}$$

Estimate CO ground level concentration 200 feet normal to edge of pavement:

$Y = 200' = 61 \text{ m} \quad \sigma_y = 35 \text{ m}$

For $\bar{U} = 4$ mph

$$ppm = 12\left[\exp -\frac{1}{2}\left(\frac{61}{35}\right)^2\right] = \underline{2.6}$$

For $\bar{U} = 7$ mph

$$ppm = \frac{4}{7}(2.6) = \underline{1.5}$$

Therefore, for Stability Class D the concentration 50 feet normal to the highway ranges from 5.4 to 9.4 ppm while at 200 feet it ranges from 1.5 to 2.6 ppm.

EXAMPLE NO. 3

AIR POLLUTION CONCENTRATION ESTIMATE FOR PROPOSED FREEWAY

ELEVATED SECTION

Given:

Same data as in Problem No. 1 except height of fill is 25 feet.

Find:

Estimate the gound level concentration for CO within the mechanical mixing cell and at distances 50, 100, 500, and 1,000 feet downwind.

Solution:

(1) The most probable meteorological conditions occur under Stability Class D with wind speed from 8 to 12 mph and a prevailing direction from the SE (Ø = 45°).

(2) The source emission strength Q for 1975 for CO is 0.0249 $\frac{gm}{m/sec.}$

(3) The concentration of CO within the mechanical mixing cell is the same as in Problem No. 1. The estimated CO concentrations range from 1 to 2 ppm for the most probable meteorological conditions.

(4) The worst meteorological conditions occur under Stability Class F with wind speeds from 4 to 7 mph and a prevailing direction of ENE (Ø = 22.5°).

(5) The estimated CO concentrations within the mechanical mixing cell for Stability Class F are the same as in Problem 1 and range from 5 to 8 ppm for the worst meteorological conditions.

(6) Estimate the horizontal dispersion of CO at distances of 50, 100, 500, and 1,000 feet in the downwind direction.

(a) Most probable meteorological conditions: Estimate the ground level concentrations using Figure 10 in Appendix and the following format:

(1) Distance Downwind ft.	(2) Ø	(3) Elevated $\frac{CuK}{Q}$	(4) At-Grade $\frac{CuK}{Q}$	(5) Ratio (3)÷(4)	(6) At-Grade CO ppm	(7) Elevated CO ppm (5) x (6)
50	45°	0.38	0.80	0.475	0.8 - 1.1	0.4 - 0.5
100		0.45	0.60	0.750	0.6 - 0.8	0.5 - 0.6
500		0.37	0.43	0.860	0.4 - 0.6	0.3 - 0.5
1000	45°	0.32	0.36	0.889	0.3 - 0.5	0.3 - 0.4

By elevating the highway on a fill 25 feet high, the estimated ground level CO concentrations between 50 and 100 feet are reduced by approximately 30% for most probable meteorological conditions. This estimate assumes there is no aerodynamic effect of the fill on the ground level concentrations.

(B) Worst meteorological conditions: (Stability F, Ø = 22.5°) using Figure 30 in the Appendix A and the following format:

(1) Distance Downwind ft.	(2) Ø	(3) Elevated CuK/Q	(4) At-Grade CuK/Q	(5) Ratio (3)÷(4)	(6) At-Grade CO ppm	(7) Elevated CO ppm (5) x (6)
50	22.5	0.77	1.8	0.428	2.9 - 5.1	1.2 - 2.2
1000		0.90	1.6	0.563	2.6 - 4.5	1.5 - 2.5
500		0.83	1.2	0.692	1.9 - 3.3	1.3 - 2.3
1000	22.5	0.78	1.0	0.780	1.6 - 2.8	1.2 - 2.2

Note that by having a highway on a 25 foot high fill that there is theoretically a significant difference in the ground level concentrations.

In all of the examples presented, the pollutant concentrations were estimated downwind from the highway line source. The estimates were for the peak morning traffic hours. The analysis included the most probable and worst meteorological conditions based on historical data. These estimates of ground level concentrations for the morning hours are not indicative of levels which may occur throughout the day. The other time periods of the day may have (1) different wind directions and speed, (2) a change in surface stability, (3) a change in traffic volume, and (4) change in emission factors caused by a change in average route speed. It should also be stressed that the worst meteorological conditions for the A.M. may not be the worst for the P.M. estimates.

If a daily time history of pollutant concentration is required, the historical meteorological data must be analyzed for different time periods through the day. Additional traffic volumes and average route speed must be known. Figure 5 might represent diurnal variation of pollutant concentration of CO based on meteorology, traffic volumes and speed for a typical summer and winter day. Figure 5 might be characteristic of the pollutant concentrations as given by terrain and topography in Example 1.

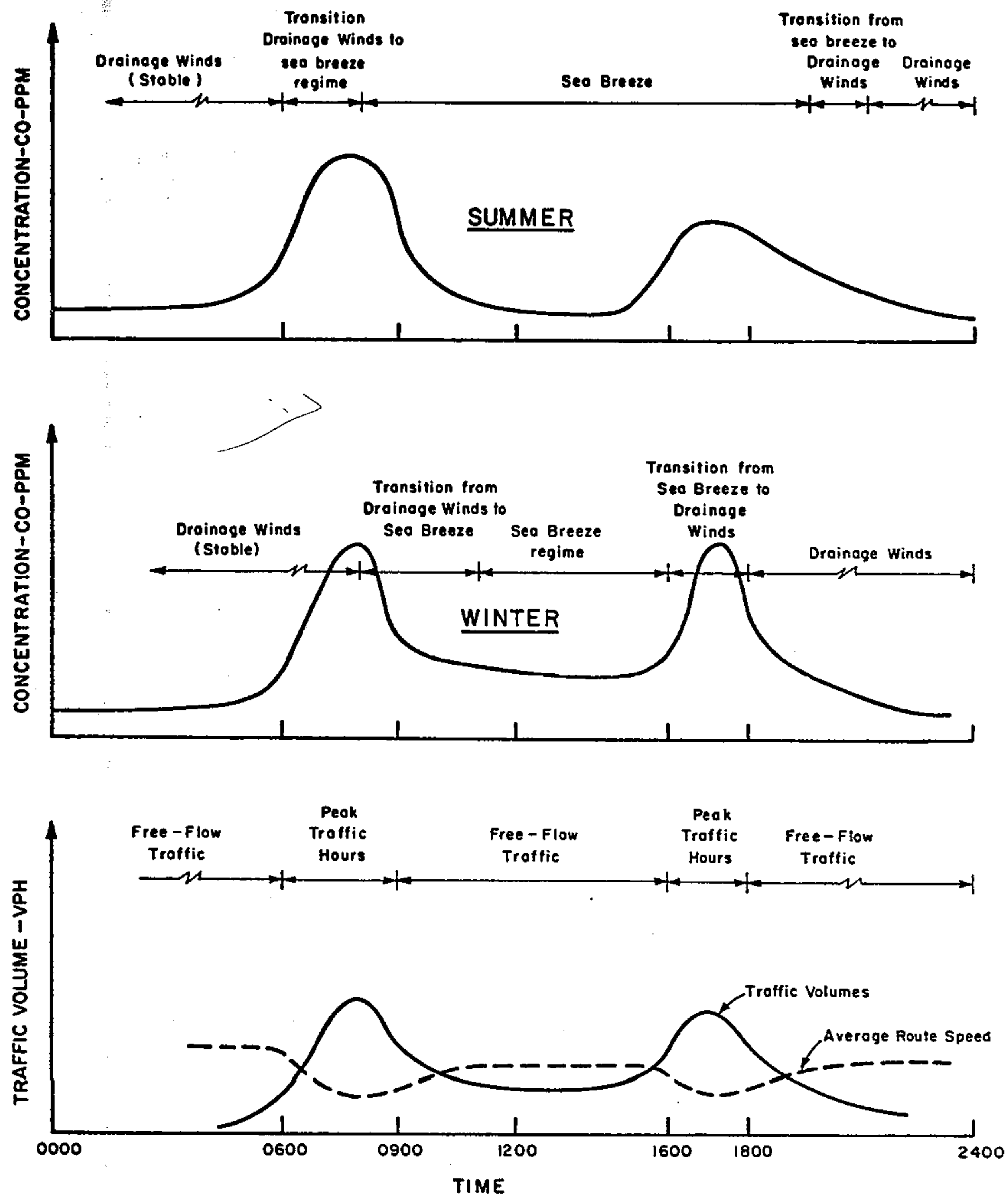


FIGURE 5 TYPICAL DIURNAL VARIATION OF GROUND LEVEL CONCENTRATIONS OF CO FOR SUMMER AND WINTER DAY FOR EXAMPLE PROBLEM # 1

Critical Year of Pollutant Concentrations Within Highway Corridor

The pollutant concentrations within the highway corridor are a function of (1) traffic volumes, (2) emission factors, (3) meteorological conditions and (4) type of highway design. Once the meteorological parameters have been analyzed and the type of design established, the pollutant concentrations are a function of traffic volumes and emission factors. During the period between the estimated date of completion (ETC) of a highway project and twenty years (ETC+20) thereafter, the traffic volumes tend to increase while emission factors decrease. Depending on the magnitude of the traffic volume increase and the magnitude of the emission factor decrease, it may be possible to estimate the critical year of maximum pollutant concentrations on and within the highway corridor. Beyond this point in time the number of vehicles with emission control devices becomes significant in terms of reduction of the primary pollutant emissions from vehicles. Under these conditions the ground level pollutant concentrations should decrease.

Equations (4) and (9) give the expression of source strength as a function of traffic volume and emission factor for cross-winds and winds parallel to the highway alignment respectively. Both traffic volumes and emission factors are a function of time (year).

It is necessary to maximize the product of the traffic volume and emission factors for the estimated 20 year project life. To maximize the product of the traffic volume and emission factor results in the most critical year which the ground level concentrations will be the highest. These estimates of the maximum ground level concentrations can be made by using the critical year traffic volume and emission factors in the mathematical model.

In some cases it may not be possible for a critical year to occur. This can result if (1) the rate of traffic increase is greater than the rate of the emission factor decrease or (2) the rate of traffic volume increase is less than the rate of emission factor decrease. The critical year concept along with the two other possibilities are illustrated in Figures 6, 7 and 8.

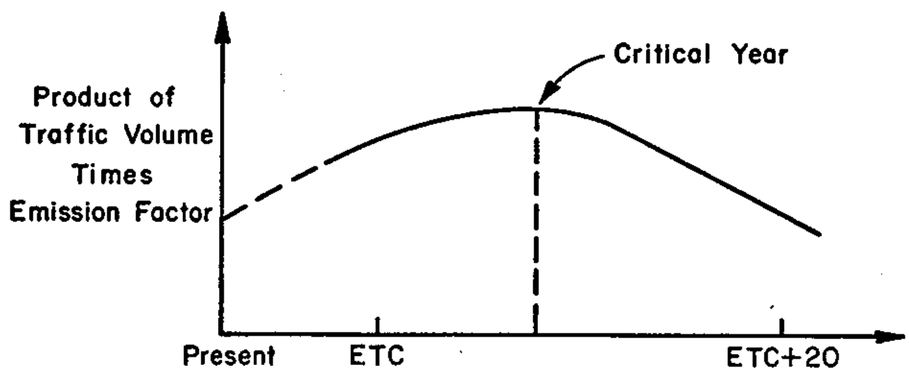


Fig. 6 CRITICAL YEAR OF POLLUTANT CONCENTRATION WITHIN HIGHWAY CORRIDOR

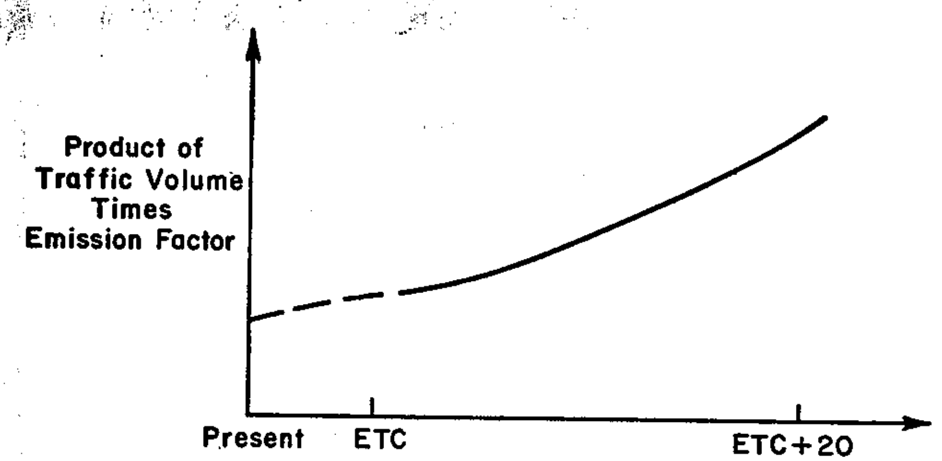


Fig. 7 TRAFFIC VOLUME INCREASE GREATER THAN RATE OF EMISSION FACTOR DECREASE

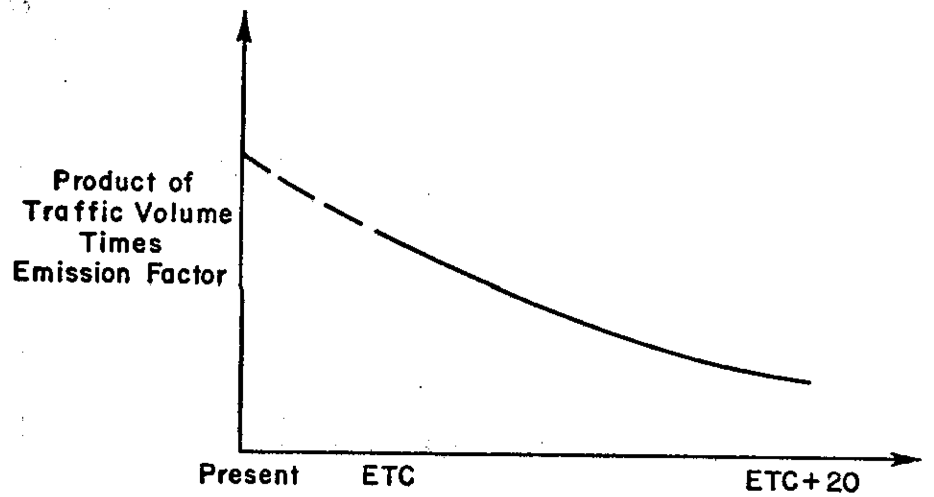


Fig. 8 TRAFFIC VOLUME INCREASE LESS THAN RATE OF EMISSION FACTOR DECREASE

In Figure 7 (where the rate of traffic volume increase is greater than the rate of emission factor decrease) one would expect the most critical year to be ETC+20.

In Figure 8, one would expect the ground level concentrations to be highest when the facility first goes into operation. Beyond that year, the ground level concentrations, as estimated by the mathematical model, are reduced.

The analysis of the critical year concept is based on the peak hourly traffic volumes for the twenty year project life. The following information and assumptions are required for the analysis:

1) Peak hourly volume estimates for ETC and ETC+20.

2) Average route speeds for the peak hourly traffic.

3) Assume the incremental increase in traffic volume is linear from ETC to ETC+20.

4) Emission factors for carbon monoxide as a function of average route speed are obtained from reference [4].

In preparing a quantitative air quality impact report it is recommended that pollutant concentrations within the highway corridor be estimated for the following conditions:

1) ETC

2) Most critical year if it exists.

3) ETC+20

The following example will illustrate the critical year concept.

EXAMPLE NO. 4

CRITICAL YEAR WITHIN HIGHWAY CORRIDOR

Given:

An existing (8 mile long) 4 lane highway is to be widened to 8 lanes by 1976. The following traffic information was estimated by Urban Planning Section to assess the impact of the widening on peak traffic volumes:

1972 Traffic

Peak hour traffic	5000 vehicles
Speed (mph)	40
HDV (%)	10

1976 Traffic	Existing Freeway	Widened Freeway
Peak hour traffic	6000	6000
Speed (mph)	34	57
HDV (%)	10	10

1992 Traffic*

Peak hour traffic	10,000
Speed (mph)	50
HDV (%)	10

Find:

Estimate the (1) critical year of the maximum CO concentration within the highway corridor and (2) estimate yearly fluctuation of CO in tons per day per peak hourly volume.

Solution:

Assumptions

1. The speed on the existing highway in 1976 of 34 mph will change to 57 mph immediately after widening of project.

2. A straight line increase in the peak hourly traffic from 1972 through 1992.

*Normally the traffic volumes should be estimated for the time of completion and twenty years thereafter although in this example the Urban Planning Section could only make an estimate for 1992 based on available information.

Based on the procedures for estimating future traffic*, the completion of the wider highway in 1976 will have no effect on the traffic volumes. It will only affect the route speed with the widening of the highway. However, the speed was assumed to vary linearly for two periods: 1972 to 1976 (existing highway facilities) and for the 1976 through 1992 (widened highway). Estimates of the speed for the existing highway facilities will vary from 40 mph in 1972 to 34 mph in 1976 while the speed for the widened highway varies from 57 mph when opened in 1976 to 50 mph in 1992.

The following tabular format is used to estimate the critical year for CO along with the yearly fluctuations of the CO load. The emission factors used are based on the California Air Resources Board 7 mode test cycle as being most representative for highway use. To estimate the peak hourly tonnage the following equation was used:

$$\text{Tons} = (\text{Peak Hour DVM})\ (\text{EF})\ 1.10 \times 10^{-6}$$

Where DVM = daily vehicle miles for the peak traffic period.

EF = emission factor in grams per mile

1.10×10^{-6} = conversion factor from grams to tons.

YEAR	TRAFFIC	PROJECT LENGTH MILES	PEAK HOUR VEHICLE MILES	SPEED	HDV	E.F.	TONS
1972	5000	8	40,000	40	10%	33	14.5
1974	5500	8	44,000	38	10%	29	14.1
1976	6000	8	48,000	36	10%	25	13.2
1976	6000	8	48,000	58	10%	18	9.5
1978	6500	8	52,000	57	10%	15.5	8.9
1980	7000	8	56,000	56	10%	13.5	8.3
1982	7500	8	60,000	55	10%	11.5	7.6
1984	8000	8	64,000	54	10%	8.8	6.2
1986	8500	8	68,000	53	10%	7	5.2
1988	9000	8	72,000	52	10%	7	5.6
1990	9500	8	76,000	51	10%	7	5.9
1992	10,000	8	80,000	50	10%	7	6.2

Figure 9 is a plot of the results. The critical year is estimated to be in 1972. Note the abrupt change in CO load when the new facilities are in operation in 1976. This results from a higher route speed which reduces the CO pollutant load.

*This applies only for this project as estimated by the Division of Highways Advanced Urban Planning Department.

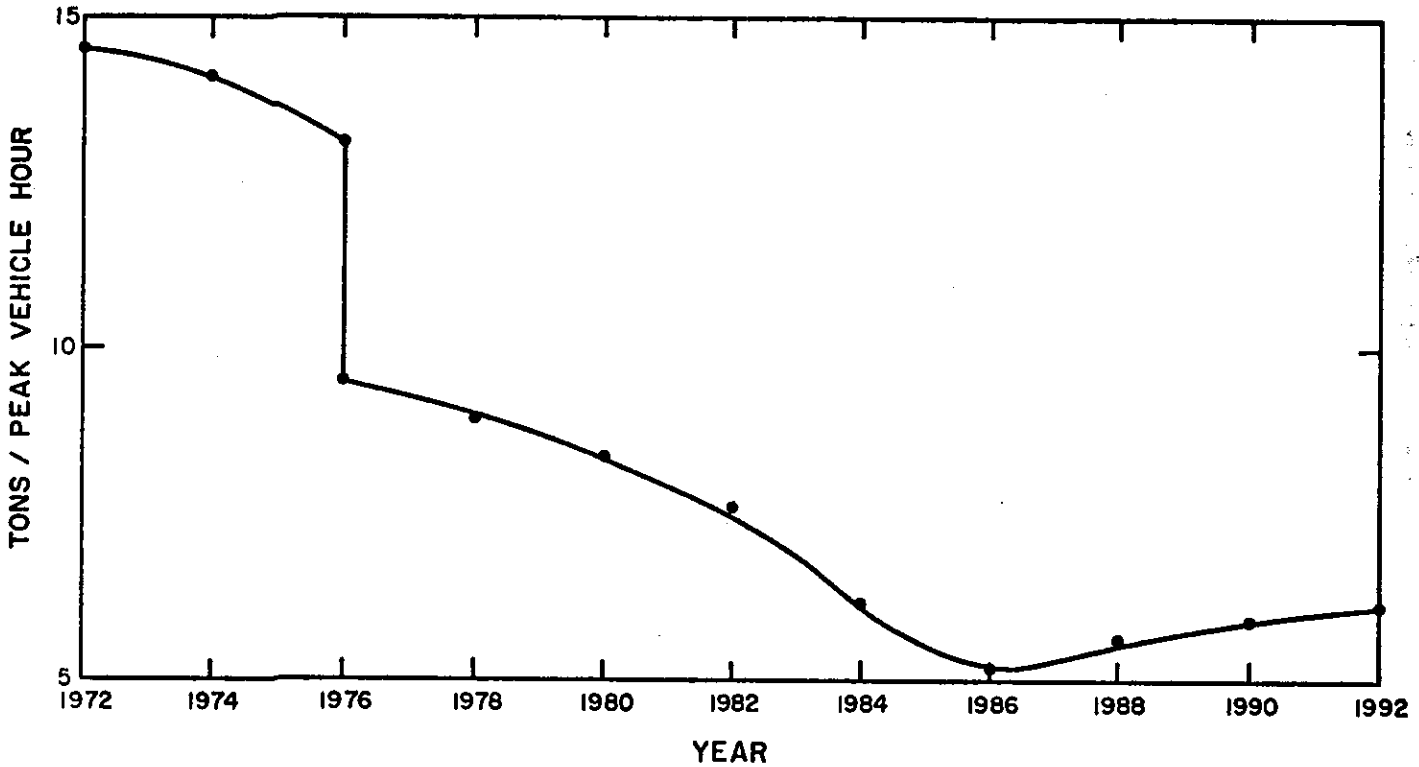


Fig. 9 YEARLY FLUCTUATION OF ESTIMATED TOTAL CO LOAD EMITTED DURING PEAK HOUR TRAFFIC

MESOSCALE ANALYSIS*

In addition to its effect on nearby receptors a highway may have a significant effect on overall air quality. This effect results from a change in pollutant burden on the air basin. The change in pollutant burden is a function of rate of change in traffic volumes and speeds throughout the network and in emission factors. The rate of change of the emission factor is a function of the vehicle model year and vehicle operation. In pre-1975 vehicles the emission factors for CO and HC are expected to reduce with higher average route speeds while factors for NO_x increase. A freeway with its better operating mode will result in less CO and HC at the expense of an increase in NO_x. Both HC and NO_x are involved in the photochemical reaction to form smog. Photochemical modeling has not reached the point where the effects of HC reduction and NO_x increase can be estimated. Total pollutant burdens for CO and HC should be analyzed, however, with and without the proposed improvement. No estimate will be made for NO_x because of insufficient data available on the emission factor vs. average route speed [4].

To make a comparison with and without a new highway means assessing pollutant loads for the existing transportation facilities (freeways and local streets) and comparing the result to the pollutant load with a new highway. The comparison must be made over the life of the facility. This will indicate the comparative increase or decrease in pollutant burden caused through changes in the traffic network.

Critical Year for Mesoscale Analysis

Calculation of pollutant burden for the mesoscale analysis depends on (1) traffic volumes, (2) daily vehicle miles traveled, (3) vehicle mix and (4) emission factors. In the planning and design of a highway the traffic volumes generally increase with time because of future development and growth. As traffic volumes increase during the project life, the emission factors are reduced due to improvements in emission controls. It may be possible, depending on the rate of traffic increase and rate of decrease of emission factors, to estimate a critical year for maximum pollutant burden as was previously done in the corridor

*In this manual a mesoscale analysis encompasses the area where the existing traffic network will change due to the new facility.

analysis. In some cases a critical year may not occur within the design life of the project. This is caused by (1) rate of traffic increase greater than rate of emission factors decrease or (2) rate of traffic increase less than the rate of emission factor decrease. The critical year concept is illustrated in Figures 10, 11 and 12.

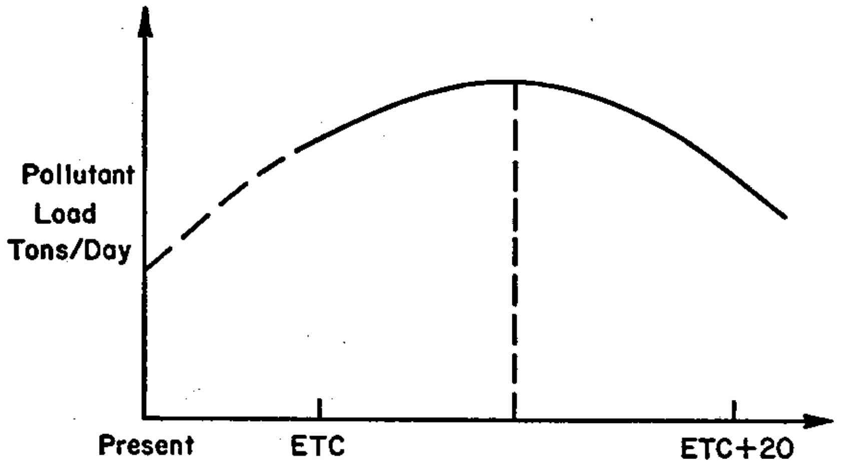


Fig. 10 CRITICAL YEAR OF POLLUTANT LOAD FOR MESOSCALE ANALYSIS

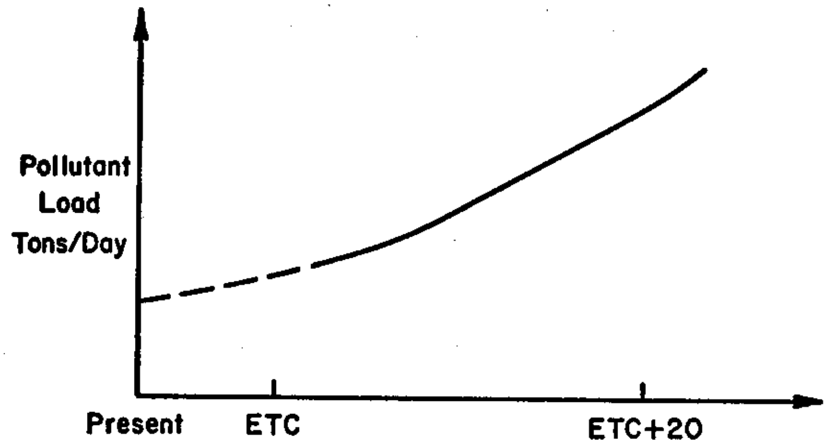


Fig. 11 TRAFFIC INCREASE GREATER THAN EMISSION FACTOR DECREASE FOR MESOSCALE ANALYSIS

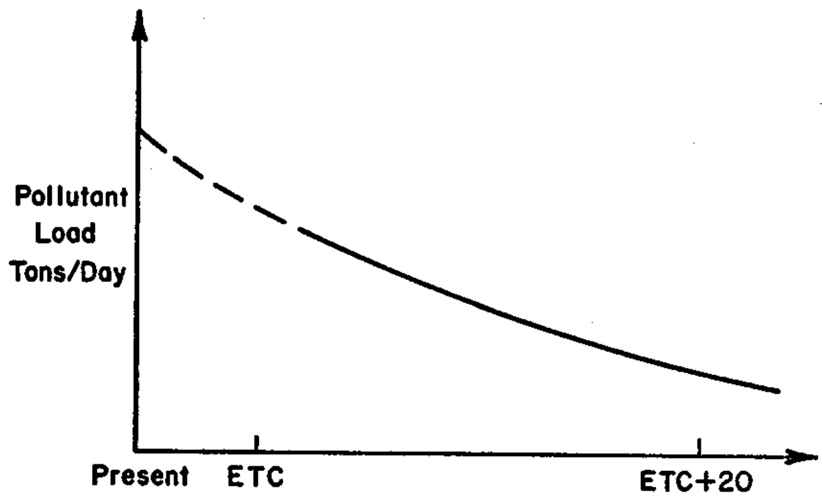


Fig. 12 TRAFFIC INCREASE LESS THAN EMISSION FACTOR DECREASE FOR MESOSCALE ANALYSIS

Figure 10 indicates that with the construction of a new highway the pollutant load will increase beyond ETC until a maximum is reached. Assuming that historical meteorological conditions remain the same, more adverse air pollution days will be experienced until the critical year is reached.

Figure 11 indicates that the air quality from ETC to ETC+20 years will continually be degraded if a new highway is constructed. Figure 12 indicates that the construction of a highway will improve the air quality from ETC to ETC+20 years. In this case the number of vehicles using transportation facilities that have emission control devices offsets the traffic increase. Fewer adverse air pollution days can be expected in future years.

The mesoscale analysis of the impact of a highway on the air environment with and without the new facilities requires future traffic estimates and emission factors. The following information and assumptions are required for the mesoscale analysis:

1. Daily vehicle miles traveled for freeway and local streets.

2. Average daily route speeds for freeways and local streets.

3. Assume the incremental increase in daily vehicle miles traveled is linear from ETC to ETC+20 years.

4. Emission factors for CO and HC as a function of average route speed.

To plot tons per day as the ordinate in Figures 10, 11 and 12 use the following equation:

$$\text{Tons per day} = \text{E.F.} \times \text{DVM} \times 1.10 \times 10^{-6} \qquad (17)$$

Where E.F. = emission factor in gms/mi.

DVM = daily vehicle miles

The following example will illustrate the critical year concept for the mesoscale analysis.

EXAMPLE NO. 5

MESOSCALE ANALYSIS FOR CRITICAL YEAR

Given:

A new freeway is to be built in an urban area. The estimated time of completion of the project is 1975. The following traffic information is for a twenty year life with and without the construction of the new highway.

Existing Highway Facilities

1975 Traffic	Freeways	Local Streets
Daily vehicle miles	810,000	680,000
Average route speed (mph)	45	25
HDV	10%	5%

1995 Traffic		
Daily vehicle miles	1,840,000	2,000,000
Average route speed (mph)	35	25
HDV	10%	5%

Construction of New Freeway

1975 Traffic	Freeways	Local Streets
Daily vehicle miles	1,200,000	420,000
Average route speed (mph)	50	30
HDV	10%	5%

1995 Traffic		
Daily vehicle miles	2,800,000	970,000
Average route speed (mph)	45	25
HDV	10%	5%

Find:

Estimate the critical year of the CO burden in tons per day within the study area with and without the construction of the new freeway. Determine if the construction of the new freeway will reduce the total CO pollutant burden for the twenty year period.

Solution:

Assumptions:

1. A linear increase in daily vehicle miles traveled on freeways and local streets from 1975 through 1995 with and without the construction of the freeway.

2. A linear decrease in route speed on freeways and local streets from 1975 through 1995 with and without the construction of the freeway.

Tons per day = DVM x EF x 1.10×10^{-6}

Where DVM = daily vehicle miles
EF = emission factor in grams per miles for highways or city streets.

1.10×10^{-6} = conversion factor from grams to tons

The following tabular formats are used to estimate the CO pollutant burden for freeways and local streets within the study area. The emission factors for freeways are based on the California Air Resources Board 7 mode test cycle as being most representative for highway use while the emission factors for local streets are based on the 1972 Federal Test Procedure.

WITH NEW FREEWAY

Freeways

Year	Freeway DVM	Speed	HDV	EF	Tons
1975	1,200,000	50	10%	22	29.1
1980	1,600,000	49	10%	14	24.7
1985	2,000,000	47	10%	7.8	17.2
1990	2,400,000	46	10%	7	18.5
1995	2,800,000	45	10%	7	21.6

Local Streets

Year	Freeway DVM	Speed	HDV	EF	Tons
1975	420,000	30	5%	35	16.2
1980	557,500	29	5%	16.5	10.1
1985	695,000	27	5%	7.5	5.7
1990	832,500	26	5%	7	6.4
1995	970,000	25	5%	7	7.5

WITHOUT NEW FREEWAY

Freeways

Year	Freeway DVM	Speed	HDV	EF	Tons
1975	810,000	45	10%	23	20.5
1980	1,067,500	42	10%	14.5	17.0
1985	1,325,000	40	10%	7.8	11.4
1990	1,582,500	38	10%	7	12.2
1995	1,840,000	35	10%	7	14.2

Local Streets

Year	Freeway DVM	Speed	HDV	EF	Tons
1975	680,000	25	5%	40	30.0
1980	1,010,000	25	5%	17.5	19.5
1985	1,340,000	25	5%	7.8	11.5
1990	1,670,000	25	5%	7	12.9
1995	2,000,000	25	5%	7	15.4

TOTAL WITH NEW FREEWAYS

	Freeway	Local Streets	Total
1975	29.1	16.2	45.3
1980	24.7	10.1	34.8
1985	17.2	5.7	22.9
1990	18.5	6.4	24.9
1995	21.6	7.5	29.1

TOTAL WITHOUT NEW FREEWAYS

	Freeway	Local Streets	Total
1975	20.5	30.0	50.5
1980	17.0	19.5	36.5
1985	11.4	11.5	22.9
1990	12.2	12.9	25.1
1995	14.2	15.4	29.6

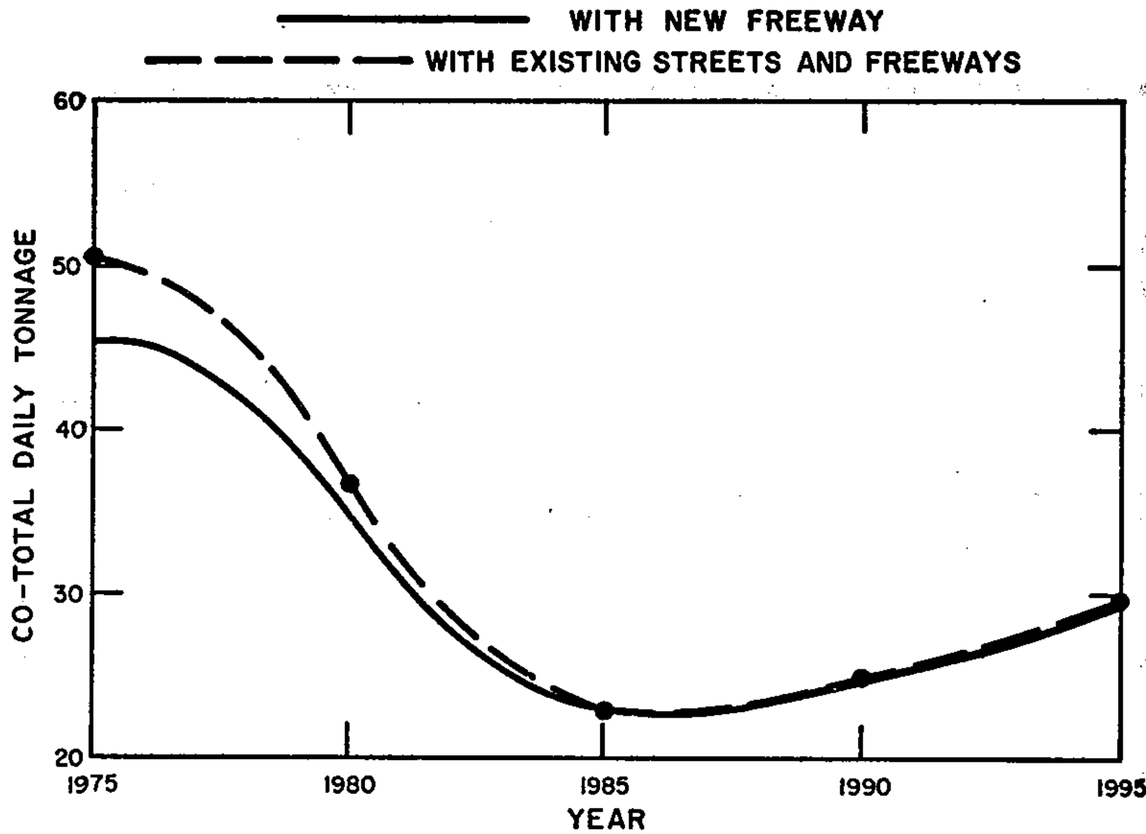


Fig. 13 YEARLY FLUCTUATION OF ESTIMATED TOTAL DAILY CO POLLUTANT LOAD

Figure 13 is a plot of the total daily CO pollutant burden vs. year. The results indicate that both with and dwithout the construction of the freeway that 1975 is the critical year for the total CO burden emitted within the study area. However, with the construction of the freeway higher average route speed are obtained thus reducing the emissions of CO as compared to existing highway facilities. From 1975 to 1985 the construction of the freeway will reduce the total pollutant burden indicated by the area between the two curves in Figure 13. After 1985 there is no significant difference in the toral CO pollutant burden with or without the construction of the freeway.

SUMMARY

The mathematical analysis of the impact of a highway on the environment requires two analyses: (1) corridor analysis and (2) mesoscale analysis. In the corridor analysis, special consideration is given to estimating the CO pollutant concentrations from the highway to the point downwind where ambient levels are again approached. The mesoscale analysis emphasizes the "air basin concept". This analysis evaluates the effects of the proposed highway on general community air quality. Consideration is limited, at the present, to two primary gaseous pollutants emitted from motor vehicles namely CO and HC.

At the present time the California Division of Highways has concentrated most of its efforts in developing and validating a mathematical model for the highway corridor region. More extensive work with actual field measurement of pollutant concentrations will be made in the future to develop and statistically validate regional models to supplement the present mesoscale analysis.

Figures 14 and 15 are generalized flow charts for the corridor and mesoscale analysis along with the required inputs.

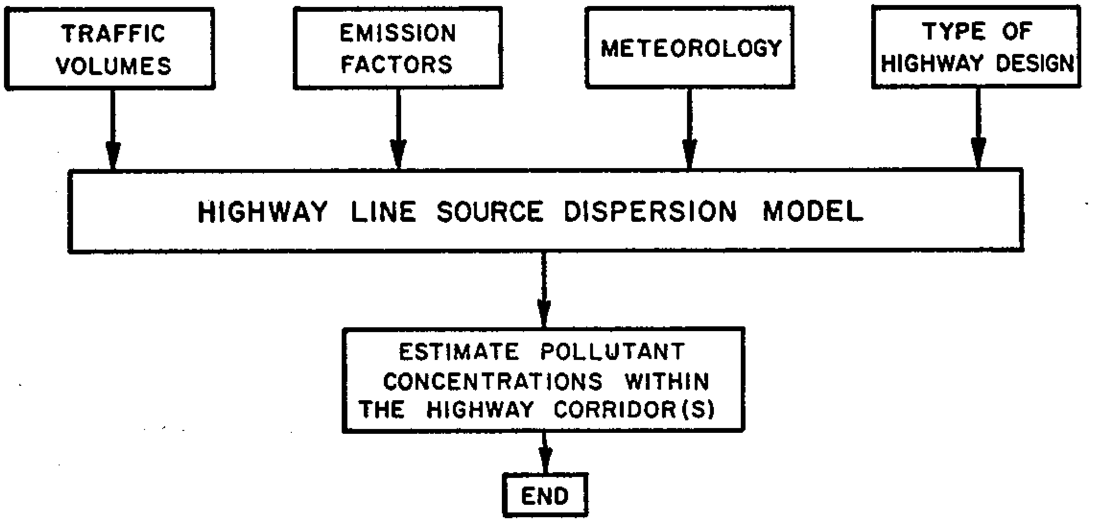


Fig. 14 FLOW CHART FOR CORRIDOR ANALYSIS

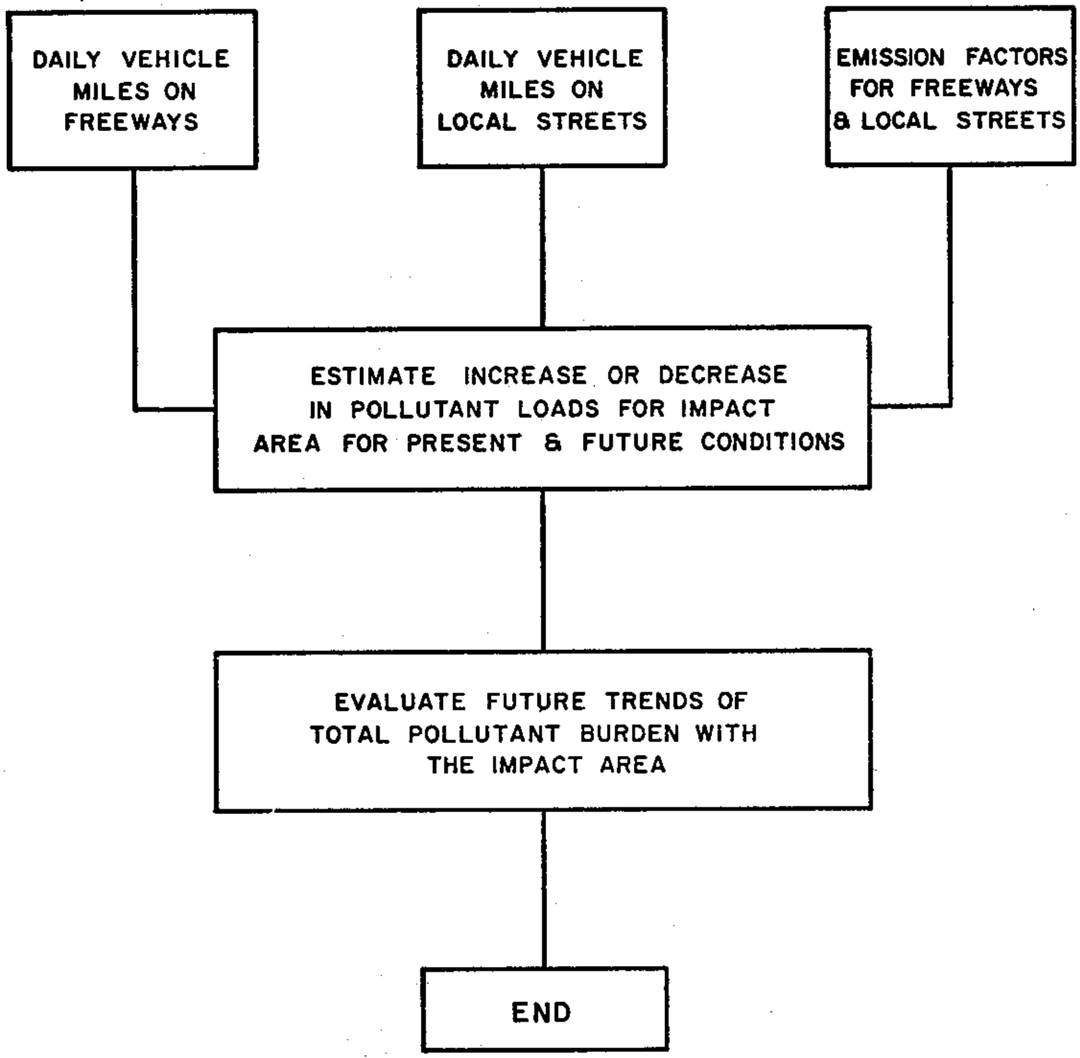


Fig. 15 FLOW CHART FOR MESOSCALE ANALYSIS

SENSITIVITY ANALYSIS

One important consideration which should be emphasized is that the usefulness and accuracy of the air quality estimates to be made with the California Division of Highways approach (mesoscale and microscale analyses) are a strong function of the quality of the input data. Since there are inevitable uncertainties and inaccuracies in the information available, the air quality calculations which one can make will be subject to a range of uncertainty. For instance, if instrumental accuracy and site characteristics suggest an uncertainity in the mean wind speed of ±2 mph, what uncertainty will this introduce into the calculation of air pollution concentration? This is a very typical problem when obtaining meteorological data from an existing station with marginal proper exposure of the wind system [5].

Figure 16 illustrates a sensitivity analysis for the microscale region using the highway line source dispersion model with nonparallel wind conditions. The variables in the upper chart are surface stability, wind direction and speed. Traffic volumes and emission factors are constant. It is apparent that as the wind direction (ø) approaches zero (parallel wind conditions) the ground level concentrations increase significantly. For example, for Stability F with traffic and emission factor constant, and with a wind direction change from $\phi = 90°$ to $\phi = 22.5°$ the downwind concentrations change by a factor of about 2.6. Similar results are shown for Stability Class A. For Stabilities A, D and F the wind speeds were doubled. This results in reducing the ground level concentrations in the downwind direction by a factor of 2. From the above calculations it should be stressed the importance of obtaining wind data from instruments with proper exposure [5]. Also included in the upper chart of Figure 16 is the effect of estimating the surface stability. With $\phi = 22.5°$ with $\bar{u} = 4$ mph and for Stabilities A, D and F, the downwind concentrations at a distance of 100 feet are estimated to be 1.9, 2.6 and 3.6 ppm respectively. The variables in the lower part of Figure 16 are year, speed and traffic volumes. The emission factor for CO and HC used in the model are independent of route speed beyond 1985 based on the emission control standards as they exist today. A careful analysis must be made to estimate route speeds up to about 1980. Beyond 1980 emission factors have an insignificant effect on the pollutant concentrations. This is illustrated in the lower chart for 1990 with traffic volumes of 8000vph and route speed of 35 and 60 mph. The pollutant concentration is directly related to traffic volumes. Doubling the traffic volumes will result in doubling the pollutant concentrations as shown in the figure. Care and judgment should be used when estimating future traffic volume to include land use, development and mass transit if applicable.

Figure 17 illustrates a sensitivity analysis for nonparallel wind conditions with surface stability and the type of highway design as the variables. The stability classes are A, D and F. The type of highway designs vary from at grade to elevated to cut sections. For similar meteorological and traffic conditions (Stability F) on elevated highways of 30 feet will reduce ground level concentrations downwind by (1) a factor of about 2 compared to an at grade section up to 300 feet downwind of the highway and (2) a factor of about 2.5 compared to a 20 foot cut section up to 300 feet downwind of the highway. For Stability Class A the differences in ground level concentrations in comparing at grade to elevated to cut sections up to 100 feet downwind of the highway have less significance on the order of about 30%. Beyond 100 feet there appears to be no significant difference.

A similar sensitivity analysis can be made for the mesoscale analysis for the total pollutant burden. For this analysis the variables are daily vehicle miles and average route speeds. The conclusions reached for the microscale sensitivity analysis for traffic volumes and speeds can be applied to the mesoscale analysis.

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