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16. ABSTRACT

Foreword

The information in these lecture notes are for a one week air quality training course entitled "Advanced Air Quality Analysis". This course is given to the Transportation Districts (Environmental and Transportation Planners and Engineers) for the purpose of providing information on how to conduct a regional air quality study. This involves the designing and collection of an air quality database, the analyses of such data, and uses of air quality models.

The students should have a working knowledge of material presented in the following air quality training manuals developed by personnel at the Transportation Laboratory:

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 Projects.
7. A Method of Analyzing and Reporting Highway Impact on Air Quality.
8. Impacts of Transportation Systems on the Air Environment.

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November 2005, Division of Research and Innovation

AIR QUALITY TRAINING MANUAL

Advanced Air Quality Analysis

75-55

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION AND RESEARCH
TRANSPORTATION LABORATORY

Lecture Notes for Training Course:

ADVANCED AIR QUALITY ANALYSIS

July 1975

Study made by ....Environmental Improvement Branch

Under the Supervision of ....Earl C. Shirley, P. E.

Prepared by ....Andrew J. Ranzieri, P. E.

ACKNOWLEDGEMENT

These lecture notes have been assembled by Andrew J. Ranzieri under the general supervision of Earl C. Shirley, Chief of the Environmental Improvement Branch. Various people have been involved in the writing of the sections. Acknowledgements are given to the following:

1) Transportation Laboratory, Air Quality Section, for their efforts in developing sections 1-10 and sections 12 and 13.

   Andrew J. Ranzieri
   Gerald R. Bemis
   Michael D. Batham
   Kenneth O. Pinkerman
   Paul Allen
   Charles E. Ward
   Jim Racin
   Donald Ames
   Richard Peter

2) University of California at Davis, Atmospheric Sciences; Section 8, Dr. Leonard O. Myrup

3) Division of Transportation Planning, Sacramento, Section 11, Leonard Sietz

4) District 07, Transportation Planning, Section 11, Jerry E. Bennett

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7. A Method of Analyzing and Reporting Highway Impact on Air Quality.
8. Impacts of Transportation Systems on the Air Environment.

These lecture notes reflect the changes and involvement of Caltrans in evaluating the interrelationship of land use, transportation and air quality planning. The methods discussed in these notes are directed towards the evaluation of these concerns. These lecture notes are to be used as a supplement to the lectures. They are not intended to be complete or self-sufficient.

ADVANCED AIR QUALITY ANALYSIS

Table of Contents

TRANSPORTATION LABORATORY

COURSE AGENDA FOR
ADVANCE AIR QUALITY ANALYSIS

Day & time	Subject	Speaker
Day 1		
8:00 a.m.	Registration - opening session	G. A. Hill
8:10	Introduction to Air Quality Modeling and Sensitivity Analysis	A. J. Ranzieri
9:15	CALINE2-- Line Source Dispersion Model	C. E. Ward
10:00	Break	
10:15	CALINE2 (continued)	
11:15	Temporal & Spatial Distribution of Air Quality along Freeways	A. J. Ranzieri
12:00	Lunch	
1:45	CALINE2 -- Model verification	C. E. Ward
2:25	Break	
2:40	Regional Air Quality Models	A. J. Ranzieri
3:00	Sensitivity Analysis of APRAC-1A	A. J. Ranzieri
4:00	Sensitivity Analysis of DIFKIN	P. D. Allen
4:45	Adjourn	
Day 2		
7:30	Sensitivity Analysis of SAI	A. J. Ranzieri
8:00	Issues to be resolved before using Regional Air Quality Models	A. J. Ranzieri
8:30	Land Use and its Effects on Turbulence	A. J. Ranzieri
9:30	Break	
9:45	A consistent scheme for calculating diffusivities	A. J. Ranzieri
11:00	Examples of calculating diffusivities	A. J. Ranzieri

COURSE AGENDA (continued)

Day & time	Subject	Speaker
Day 2 (continued)		
11:45	Group Problem	
12:00	Lunch	
1:30	Problem Solution	
1:45	Designing Regional Air Quality Monitoring for Air Quality Model Inputs	A. J. Ranzieri
2:45	Break	
3:00	Example of Regional Air Quality Surveys for Urban Areas	A. J. Ranzieri
3:45	Quality Assurance Control for Regional Meteorological and Air Quality Monitoring	K. O. Pinkerman
5:00	Adjourn	
Day 3		
7:30	Emissions Inventory	M. D. Batham
9:00	Energy Requirements for Transportation Systems	M. D. Batham
9:30	Break	
9:45	Overview of Transportation Simulation Modeling	C. C. Whitmarsh
10:30	Vehicular Emissions for Photochemical Oxidant Models	L. Seitz
12:00	Lunch	
1:00	Modifications to Transportation Simulation Modeling	J. Bennett
2:00	Construction Pollution	R. R. Peter
2:30	Break	
2:45	Air Pollution Effects on Vegetation	N. Williams
5:00	Adjourn	

COURSE AGENDA (continued)

Day & time	Subject	Speaker
Day 4		
7:30 a.m.	Air Quality Reviews ARB Land Use Planning	Bill Locket
8:15	EPA Region 9	Ed Marra
9:30	Break	
9:50	FHWA Region 9	Betty Jenkus
	Caltrans Environmental Planning Branch	Jim Gordon
10:30	Group Discussion	
11:00	Closing	A. J. Ranzieri
11:30	Adjourn	

Certificates will be awarded to those students who satisfactorily complete all course assignments and who attend all scheduled presentations.

SECTION 1

AIR QUALITY MODELING

I. Purpose of Air Quality Modeling

A. Assess the impact of highways or multi-model transportation systems on air quality.

B. Evaluate the impact of transportation control plans

C. Provide a systematic procedure to evaluate the interrelationship of land use, transportation and air quality planning.

D. Provide information on where to locate air monitoring stations.

E. Select sites for future sources of air contaminants such as freeways, power plants, etc.

F. Estimate air quality for areas in which pollutant measurements are unavailable.

G. Establish criteria for emission control legislation.

H. Provide a method to forecast areas where NAAQS and alert levels may be exceeded.

I. Comply with Federal and State legislation concerning environmental impact assessment.

J. Provide air quality predictions for compliance with indirect source regulations, where applicable.

MATHEMATICAL MODELING SCALES

Phenomena	Microscale	Mesoscale
Pollutant	Primary gaseous and particulate pollutants.	
		Products of photochemical reactions.
Space Scale	Mixing cell to ~ 200 m highway corridor	0.2 KM to 100 KM (City, air basin)
Time Scale	1 - 60 minutes	1 hour to 1 day
Primary Transport Process	Prevailing (geostrophic) wind.	
	Turbulence	Diurnal wind systems, sea & land.
Source of Transport Energy	Surface roughness, wind shear, connection	Horizontal temperature contrast, topography.
Primary Parameters	Wind speed, surface roughness.	
	Turner Stability Classes	Latitude, stability (inversion ht.)
Typical Model	Line Source	Urban or regional.

FIGURE 1-1

II. Definition of Air Quality Model

A mathematical representation of the physical transport, mixing process, and chemical reactions that occur in the atmosphere after the release of a pollutant.

III. Mathematical Scales of Motion

A. Microscale

B. Mesoscale or Regional

C. See Figure 1-1

IV. Predictive Capabilities

A. Microscale - predict above baseline levels

B. Mesoscale or Regional - predict above initial concentrations

C. See Figure 1-2 through 1-5

V. Modeling Characteristics

Air Quality Models should include:

A. High Spatial Resolution

1. Microscale

A. Lane width
b. Roadway width
c. Geometry of highway section
d. Choice of receptor location
e. Choice of wind direction

2. Mesoscale

a. Choice of receptor location

B. Time Resolution

1. Microscale and Mesoscale

a. Changes in traffic densities
b. Changes in meteorology

(1) U and Ø
(2) Stability - surface and elevated

C. Consider Local Mixing Effects

1. Microscale

a. Mixing cell
b. Aerodynamic effects of fills
c. Aerodynamic effects of cuts
d. Aerodynamic effects of viaducts
e. Surface roughness characteristics

2. Mesoscale

a. Surface roughness characteristics
b. Mixing process below elevated inversion

D. Capability of Arbitrary Wind Direction

1. Mesoscale and Microscale

a. Normal
b. Oblique
c. Parallel

E. Inclusion of Chemical Reactions

1. Microscale

a. $NO+O_3 \longrightarrow NO_2+O_3$

2. Mesoscale

a. Photochemical Reactions

F. Computational Efficiency

1. Microscale and Mesoscale

a. Computer time
b. Logistics of input data

G. Models should be rational in the development of the physical and mathematical equations.

VI. Level of Analysis for Air Quality Modeling

A. Microscale - see Figure 1-6

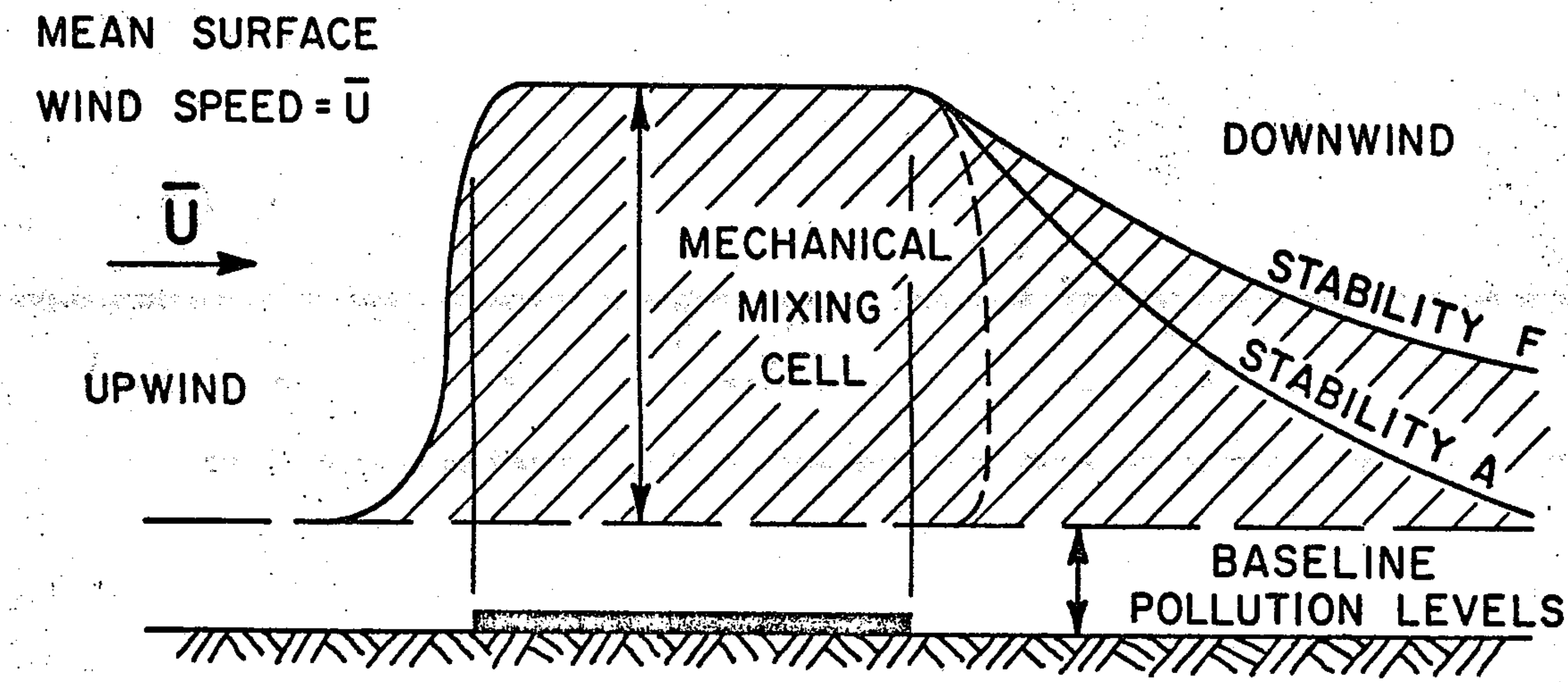
1. Box or Empirical - mixing cell
2. Gaussian - Downwind transport and diffusion
3. Conservation of Mass - mixing cells, downwind transport and diffusion

B. Mesoscale or Regional - see Figure 1-7

1. Pollutant Burden - Rollback (CO, NO_2, O_3)
2. SRI APRAC-1A - Gaussian Model for CO only
3. Conservation of Mass - Photochemical models

C. Real World - Combinations of empirical and physical analyses

WINDS NOT PARALLEL TO HIGHWAY ALIGNMENT

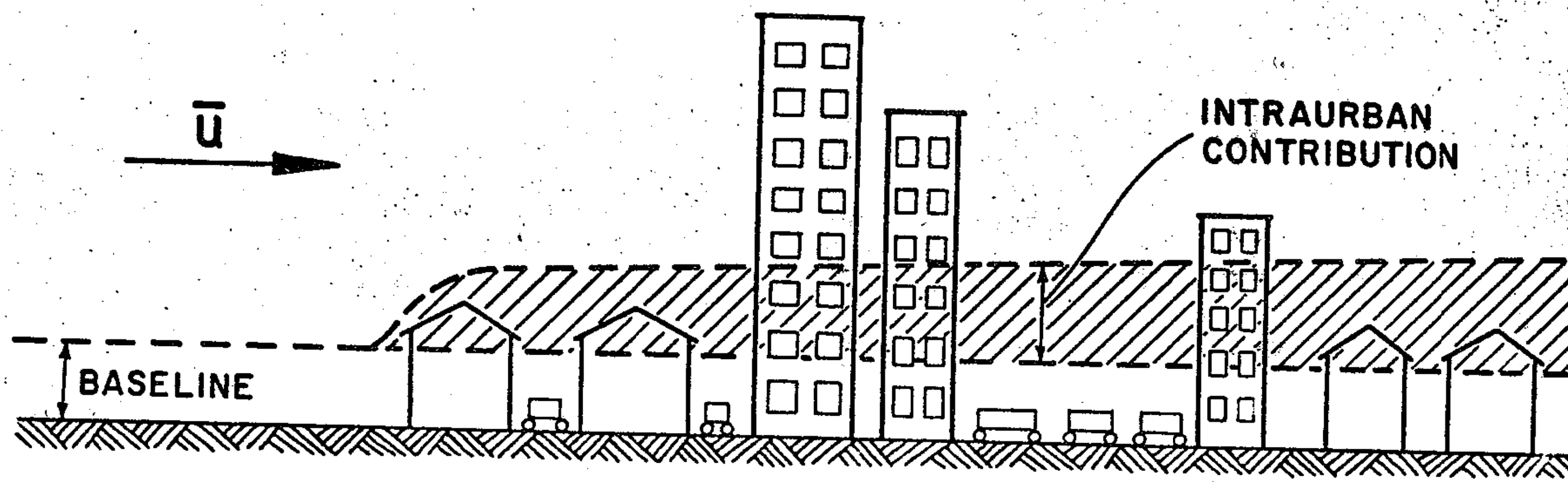


MODEL ESTIMATES ONLY SHADED AREA.

TOTAL POLLUTANT CONCENTRATION = BASELINE POLLUTANT LEVELS + POLLUTANTS GENERATED FROM HWYS.

FIGURE 1-2

MESOSCALE OR REGIONAL



TOTAL CONCENTRATION URBAN AREA =
BASELINE + INTRAURBAN CONTRIBUTION

FIGURE 1-3

MICROSCALE ANALYSIS

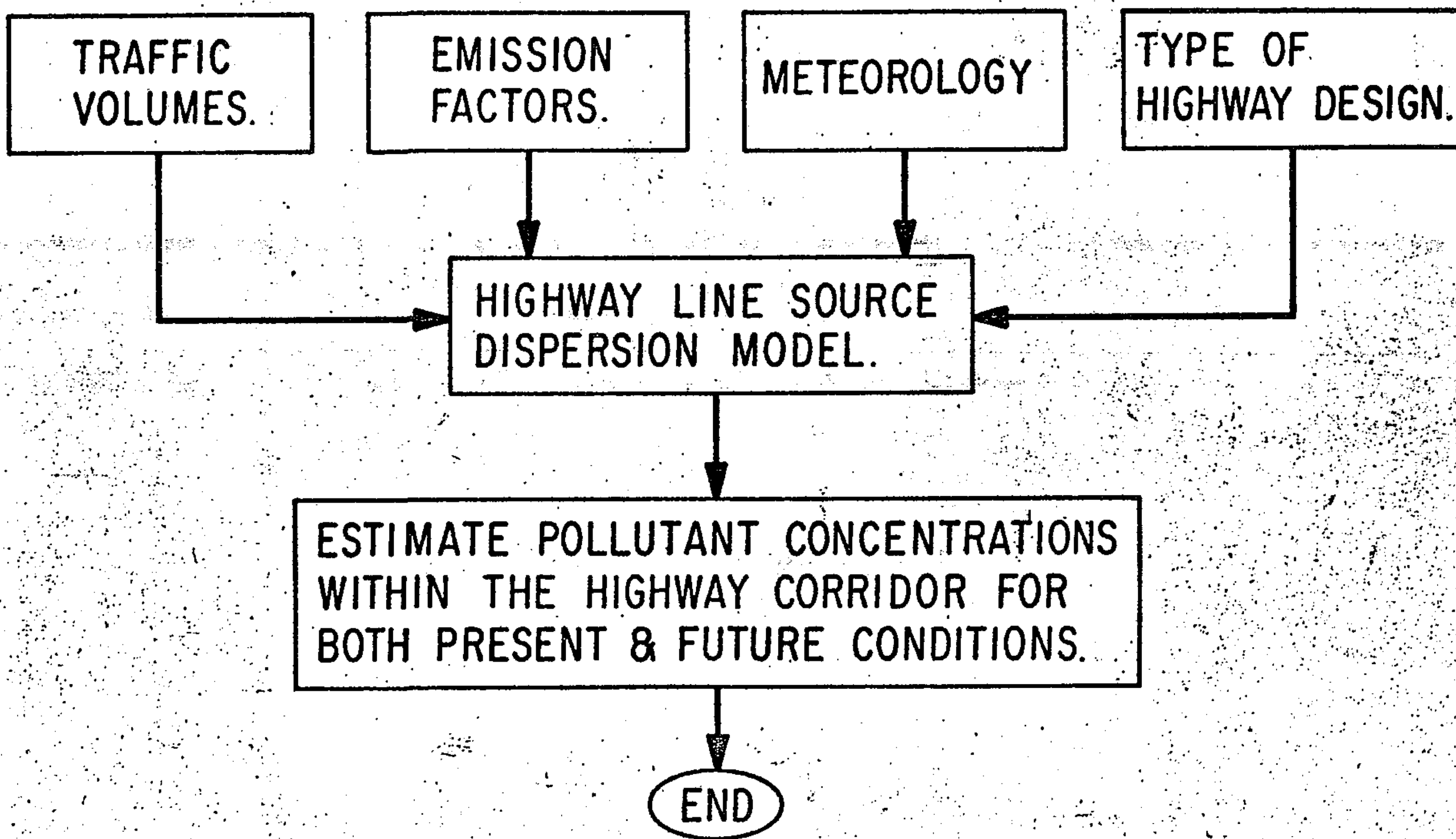


FIGURE 1-4

REGIONAL ANALYSIS

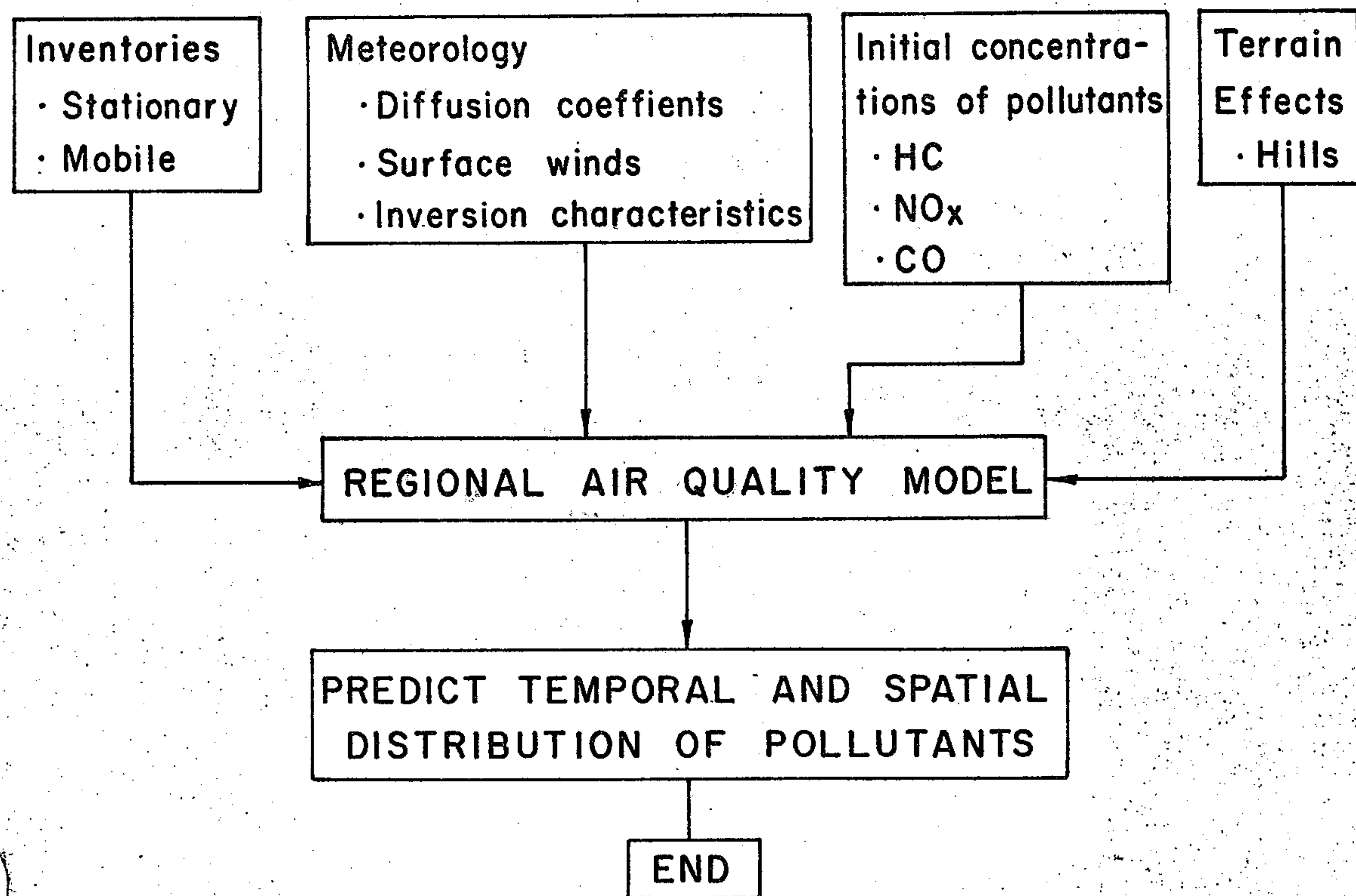


FIGURE 1-5

LEVELS OF ANALYSIS MICROSCALE

- BOX OR EMPIRCAL - MIXING CELL.
- GAUSSIAN - DOWNWIND TRANSPORT & DIFFUSION.
- DECOM - MIXING CELL, DOWNWIND TRANSPORT & DIFFUSION.
- STATISTICAL - MIXING CELL & DOWNWIND.
- COMBINATIONS OF EMPIRCAL AND PHYSICAL ANALYSIS

FIGURE 1-6

LEVELS OF ANALYSIS
FOR REGIONAL AIR QUALITY MODELING

- POLLUTANT BURDEN - ROLLBACK (CO, NO_2, O_3).
- SRI APRAC-IA – CO ONLY
- DECOM – PHOTOCHEMICAL (CO, NO_2, O_3)

FIGURE 1-7

VII. Types of Air Quality Models

A. Box Models

<u>Assumptions</u>

1. Pollutant concentrations are homogeneous through the region of interest.

2. The source is distributed uniformly.

3. The emitted pollutants are instantaneously and uniformly mixed.

4. A uniform wind characterizes the transport.

5. A constant height through which mixing is vigorous is typical of time averaged meteorology.

$$C = \frac{nEl}{WH\bar{u}}$$

where C = concentration in mass per unit volume
n = vehicles per hour
E = emission factor in gram per unit length as a function of route speed
l = length of box section
w = width of box section
h = height of box section
$\bar{u}$ = wind speed

B. Gaussian Plume Model

This model was originally developed to describe the concentration distribution of an inert pollutant downwind from a point source (industrial stack).

It has subsequently been extended for applications to line and area sources by imposing the principle super-position. In the usual applications of this model the assumptions are:

1. Only inert pollutants are considered.

2. Wind shear is neglected.

3. Measures of plume spread are assumed constant and are based on experimental studies, usually carried out over rural areas. They are a function of atmospheric stability class.

4. Pollutants are distributed normally in both the crosswind and vertical directions.

5. Conservation of Mass - no loss of pollutants.

General Equation: See Figures 1-8

Application of Gaussian Models: Flat open areas free of terrain effects that may alter the surface winds.

C. Equation of Conservation of Mass

The approach can include:

1. Temporal variations in meteorological conditions.

2. All types of highway designs, depressed sections, interchanges.

3. Irregularities in terrain features.

4. The effects of land use in construction of the wind flow field and in the turbulent diffusivities.

5. Wind patterns of any type.

6. Variations in atmospheric stability. These are treated through the choice of vertical turbulent diffusivity.

General Equation: See Figure 1- 9

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} + w\frac{\partial c}{\partial z} = \frac{\partial}{\partial x}\left[K_x\frac{\partial c}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_y\frac{\partial c}{\partial y}\right] + \frac{\partial}{\partial z}\left[K_z\frac{\partial c}{\partial z}\right] + R_i + S_i$$

where c_i = time-averaged concentration of species i

u,v,w = time-averaged wind components in the x,y, and z direction respectively

K_x,K_y,K_z = turbulent eddy diffusivities

S_i = volumetric rate of emission of species i

R_i = chemical reactions

Limitations:

The computational requirements for the solution of these equations can be substantial, both with respect to computing time and computer storage.

The following should be considered when using this approach:

1. Will it predict ground level concentrations with acceptable accuracy compared with more simplified approaches?

2. Assuming that the model is of acceptable accuracy, can it be operated at a reasonable cost, given the computing time and computer storage requirements associated with such an effort?

D. Statistical Multiple Regression Analysis

This approach is based on the statistical analysis of observed data. It includes the following:

1. Establishes and evaluates the distribution of pollutants near a source.

2. Isolates and assesses the significance of parameters influencing the concentrations, transport and diffusion of pollutants.

3. Evaluates the observed dependencies based on known physical and newly postulated principles.

4. Parameterizes the dependencies.

Limitations:

Generally these regression models are applicable for limited types of highway designs and meteorological conditions, or given regional areas.

E. Combinations of above approaches

1. Empirical and physical concepts are included.

VIII. Applications of Microscale and Regional Air Quality Models

A. Transportation Alternatives

1. No build
2. Spatial
3. Modal
4. Temporal
5. Design

B. Forecast Years

1. Present or Baseline year
2. ETC
3. ETC+10 years
4. ETC+20 years

C. Meteorology - Typical and Bad Day

1. Summer - O_3
2. Winter - CO, HC, NO_x

GENERAL GAUSSIAN EQUATION

$$\frac{C(X,Y,Z)\,\bar{U}}{Q} = \frac{1}{2\pi\sigma_Y\sigma_Z}\left[\mathrm{EXP}-\frac{1}{2}\left(\frac{Y}{\sigma_Y}\right)^2\right]\left[\mathrm{EXP}-\frac{1}{2}\left(\frac{Z+H}{\sigma_Z}\right)^2+\mathrm{EXP}-\frac{1}{2}\left(\frac{Z-H}{\sigma_Z}\right)^2\right]$$

C = CONCENTRATION

$\bar{U}$ = WIND SPEED

σ_Y, σ_Z = TURBULENCE PARAMETERS

Z = RECEPTOR HEIGHT

H = EFFECTIVE STACK HEIGHT

Y = RECEPTOR LOCATION FROM ℄ OF PLUME

FIGURE 1-8

DECOM

$$\underbrace{\frac{\delta c}{\delta t}}_{\text{RATE OF CHANGE OF CONCENTRATION}} + \underbrace{u\frac{\delta c}{\delta x} + v\frac{\delta c}{\delta y} + W\frac{\delta c}{\delta z}}_{\text{WIND FLOW FIELD ADVECTION TERM}} = \underbrace{\frac{\delta}{\delta x}\left[K_x\frac{\delta c}{\delta x}\right] + \frac{\delta}{\delta y}\left[K_y\frac{\delta c}{\delta y}\right] + \frac{\delta}{\delta z}\left[K_z\frac{\delta c}{\delta z}\right]}_{\text{DIFFUSION TERM}} + \underbrace{Si}_{\text{SOURCE}} + \underbrace{Ri}_{\text{CHEMICAL REACTION}}$$

u, v, & W = x, y, & z WIND SPEEDS

$K_x, K_y,$ & K_z = DIFFUSIVITY COEFFICIENTS

BOUNDARY CONDITION:

$$\left.\begin{array}{l} \dfrac{\delta c}{\delta t} = 0 \\ v = W = 0 \end{array}\right\} \text{GAUSSION SOLUTION (STEADY STATE)}$$

FIGURE 1-9

SECTION 2

SENSITIVITY ANALYSIS OF EXISTING AIR QUALITY MODELS

I. Definition: Sensitivity analysis can be defined as the fractional variation of the predictive concentration as a function of the fractional changes in the model input parameters. The sensitivity study itself serves as a vehicle for examining the responses of the model by varying the input parameters within a range of physical reality. The goal is to assess the influence of each parameter insofar as predicted air quality is concerned.

II. Development of Air Quality Models

A. Trial and error appraoch

B. Primative model first developed

III. Results Evaluated (Primative Model)

A. Purpose - identify sources of errors or inadequacies in the primative model

1. Observations or measurements vs model predictions - cause and effect relationships

2. Theoretical assessment - to affirm that all parameters have been included to simulate urban air pollution, transport, etc.

IV. Sensitivity Analysis

A. Objectives

1. To assess the importance of a given input parameter in the model so that decisions can be made as whether this parameter should be retained in the model.

2. To determine the necessity of including the temporal or spatial variation of a physical parameter once its importance has been established.

3. To estimate the required accuracy of a given parameter so that appropriate arrangements can be made to meet those requirements.

4. To enhance the knowledge of the role played by each parameter so that an explanation can be offered in those cases for which model predictions differ from observational data.

B. See Figure 2-1

V. Evaluation and Model Development

A. More effective evaluation if sensitivity analysis is made in terms of:

1. input data requirements
2. accuracy of inputs
3. cost effectiveness

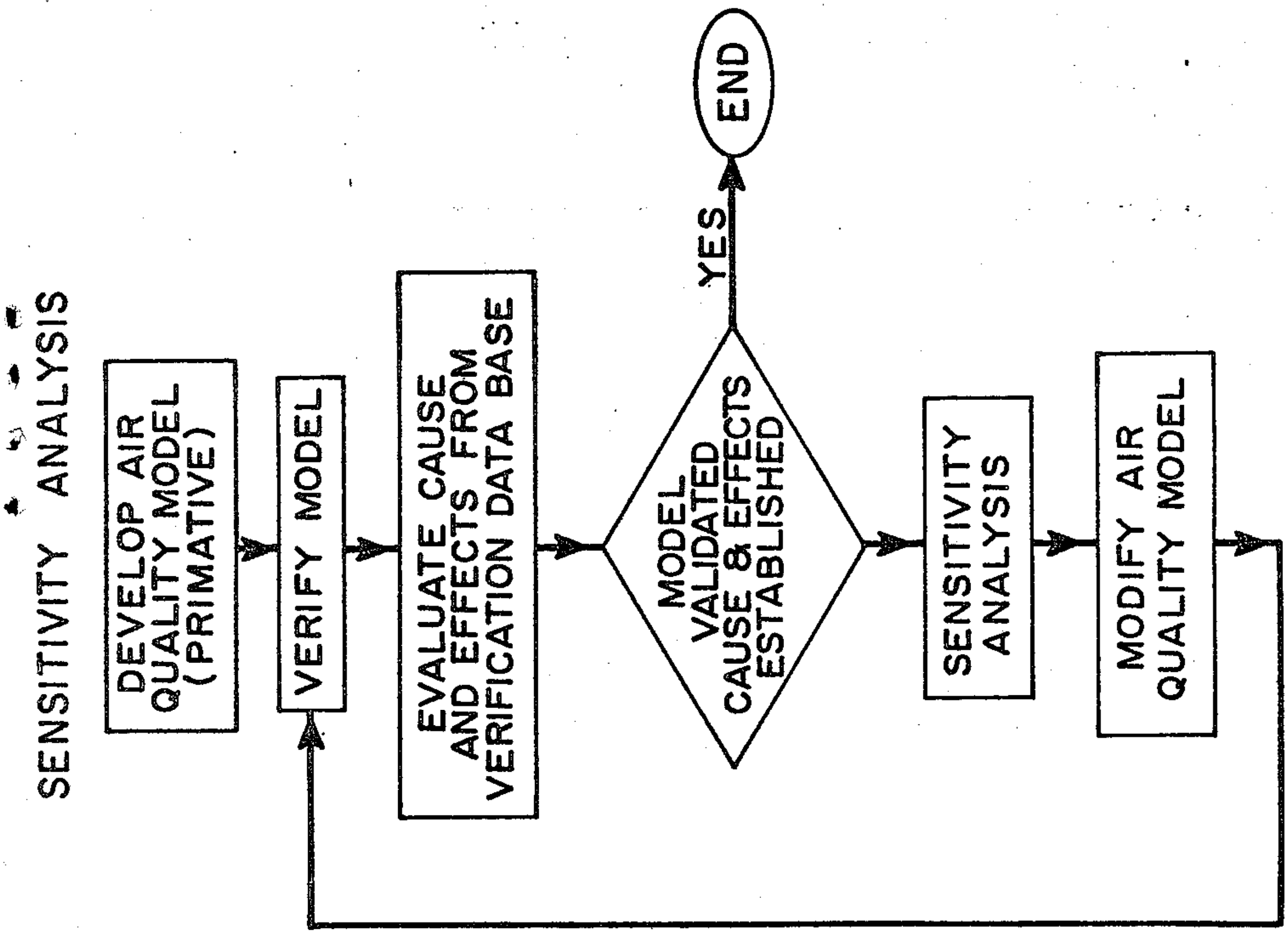

SENSITIVITY ANALYSIS
DEVELOP AIR QUALITY MODEL (PRIMATIVE)
VERIFY MODEL
EVALUATE CAUSE AND EFFECTS FROM VERIFICATION DATA BASE
MODEL VALIDATED CAUSE & EFFECTS ESTABLISHED
YES
END
SENSITIVITY ANALYSIS
MODIFY AIR QUALITY MODEL

FIGURE 2-1

VI. Important Considerations for Transportation Planners and Engineers Using Existing Air Quality Models

A. Accuracy of air quality estimates are strong function of the quality of input data

B. Inevitable uncertainties and inaccuracies in information available

1. Traffic
2. Emission factors
3. $\bar{u}$, ϕ
4. Stability
5. Inversion heights
6. Solar radiation intensity

C. Air quality calculations are subject to a range of uncertainty which should be specified if possible.

D. Example: Instrumental accuracy and site characteristics suggest an uncertainty of $\pm$ 2 mph, what uncertainty will this introduce into the output calculation of air pollution concentrations?

VII. Important to know the effects in output values caused by changes in inputs

A. Small change in input ⟶ large change in output.

1. Model is sensitive to that input.

2. Must provide accurate value of input to avoid large errors in outputs.

B. Large changes in inputs ⟶ little effect on outputs.

1. Don't need high input accuracy to achieve high output accuracy for that particular variable.

VIII. Combination of Parameter Values

A. Model outputs could be possible totally independent to the changes in one or more inputs.

IX. Sensitivity Analysis for Microscale Models

A. Input parameters to consider:

1. What are the effects of traffic volume inputs on the predictions?

2. What are the effects of emission factors inputs on the predictions?

3. What are the effects of wind speed inputs on the predictions?

4. What are the effects of wind direction inputs on the predictions?

5. What are the effects of atmospheric stability input on the predictions?

6. What are the effects of highway design input on predictions?

7. What are the effects of receptor location input on predictions?

8. What are the effects of numerical stability input on predictions?

9. Combination of above parameters

X. Sensitivity Analysis of Regional Models

A. Input parameters to consider:

1. What effects do the time distribution of traffic volumes have on the predicted concentrations?

2. What effects do the area source or grid size have on predicted concentrations?

3. What effect does the inversion height have on predicted concentrations?

4. What effects do the wind shear or mean surface winds have on the predicted concentrations? What about exposure of sensors for existing wind data?

5. What effects do the surface roughness heights have on predicted concentrations?

6. What effects do the diffusivity coefficients have on the predicted concentrations?

7. What effect does the UV radiation intensity have on predicted concentrations (clear day compared to hazy day).

8. What effect do the emission factors for CO, HC, NO_x have on predicted concentrations?

9. What effect does the number of wind stations have in determining wind trajectories?

10. What are the effects of the reaction rates for the formation of photochemical smog?

11. What are the effects of numerical stability on the predicted concentrations?

XI. Proper Sensitivity Analysis Can Determine:

A. Data requirements
B. Accuracy of input required
C. Cost effectiveness of collecting inputs
D. Applications

XII. Sensivity Analysis does not:

A. Indicate that the theoretical approach used is valid.
B. Indicate whether or not a model is verified with field data.

SECTION 3

CALIFORNIA LINE SOURCE DIFFUSION MODEL (CALINE2)

I. Model Characteristics

A. Relates

1. Traffic volumes
2. Emission Factors
3. Meteorology
4. Type of Highway Design

B. Predict concentrations for gaseous pollutants

1. CO - inert, stable gas O.K.
2. HC - provide a health standard and separate the reactive hydrocarbons.
3. NO_2 - no predictions because of the reaction

a. $NO + O_3 \longrightarrow NO_2 + O_2$
b. % of NO_x is NO_2

4. Does not consider particulates
5. Predicts above baseline levels - See Figure 3-1

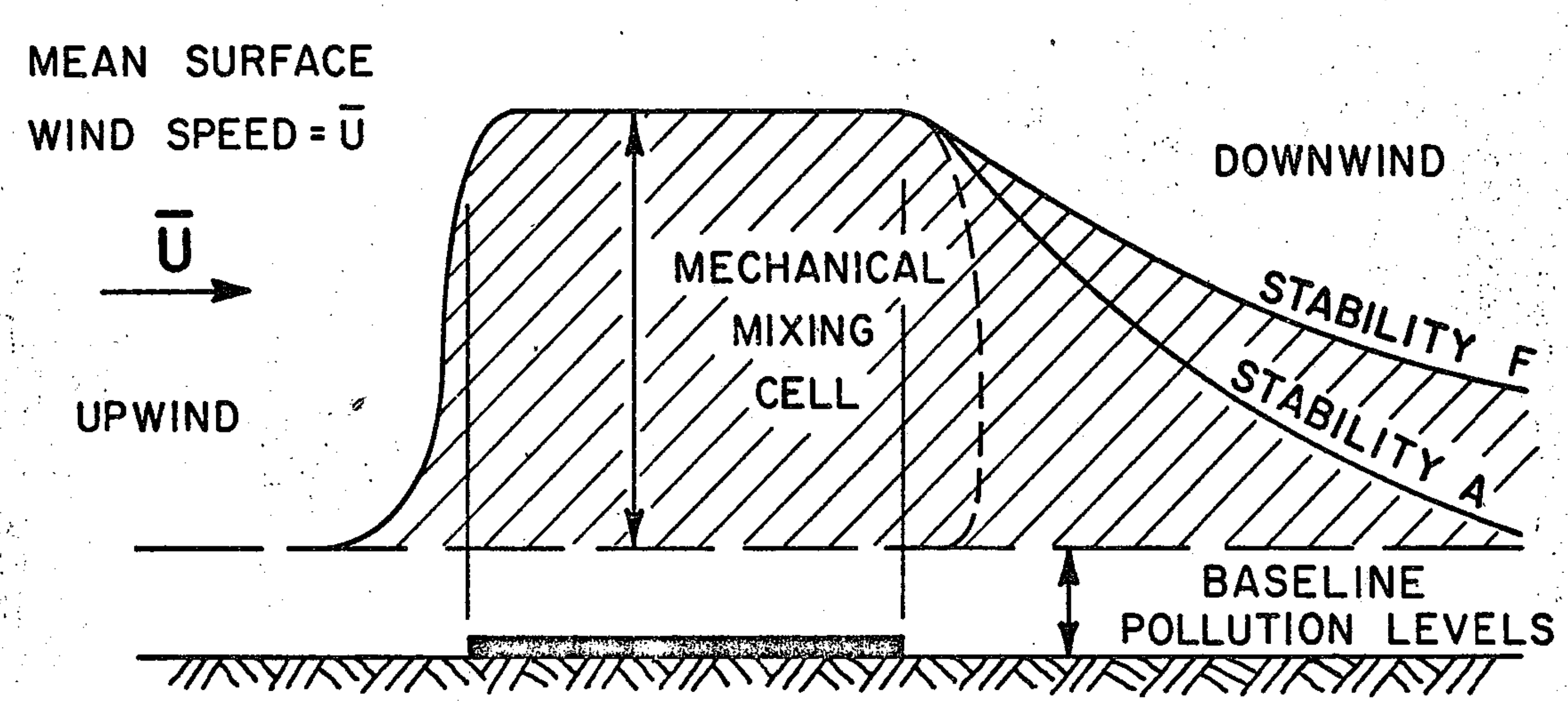
II. Modeling Approach

A. Box - mechanical mixing cell

B. Gaussian - downwind transport and diffusion

C. See Figure 3-2

WINDS NOT PARALLEL TO HIGHWAY ALIGNMENT



MODEL ESTIMATES ONLY SHADED AREA.

TOTAL POLLUTANT CONCENTRATION = BASELINE POLLUTANT LEVELS + POLLUTANTS GENERATED FROM HWYS.

[Fig]URE 3-1

CALINE LINE SOURCE MODEL

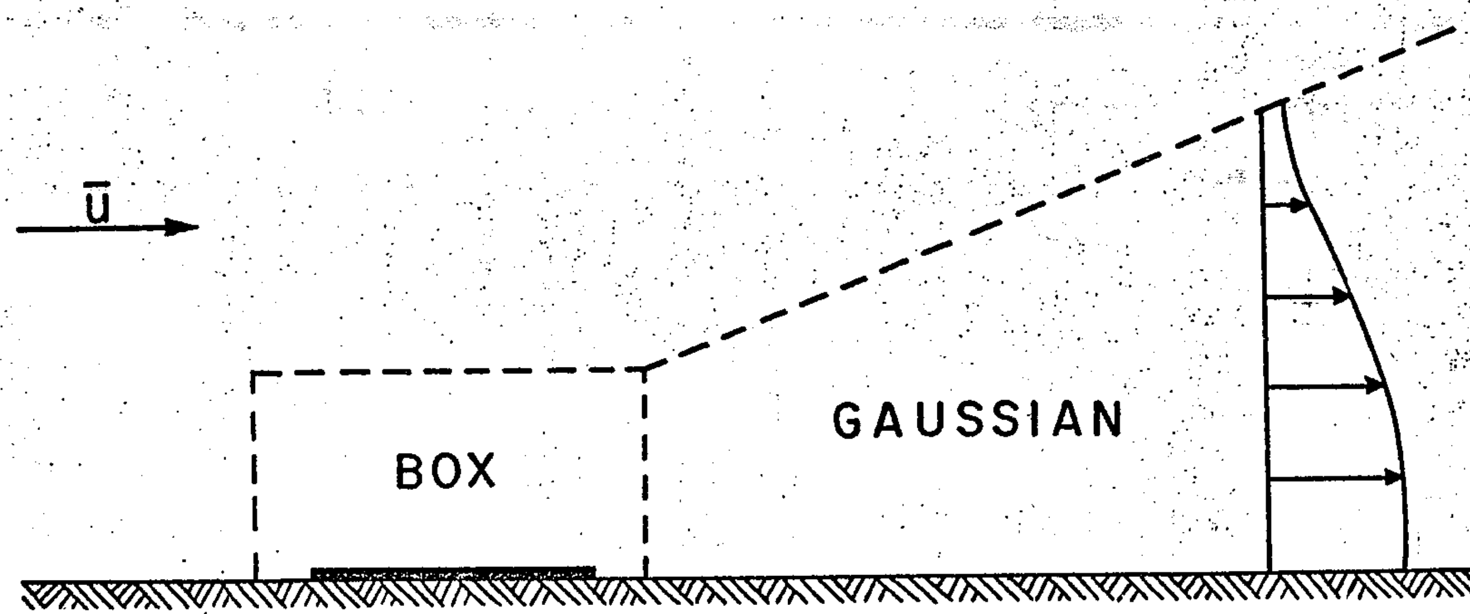


FIGURE 3-2

III. CALINE2 Model

A. Assumptions

1. Normal distribution of pollutants in the horizontal and vertical directions.

2. Continuous emission source from vehicles on highway for time period analyzed.

3. Stability of the atmosphere is based on studies made by Pasquill and Turner.

4. The concentration within the mechanical mixing cell is independent of stability class. (The mechanical mixing cell is defined as the initial dispersion of pollutants caused by the motion (turbulence) of the moving vehicles.)

5. The vertical height of the mechanical mixing cell is assumed to be 4 meters. The horizontal width of the cell is assumed to extend from edge of pavement to edge of pavement for medians less than or equal to 30 feet.

6. A uniform wind field exists.

7. No aerodynamic effects on air passing over structures, etc.

B. Difficulties of Gaussian Models

1. Original development of turbulent parameters σ_y and σ_z

   a. Flat open area in Kansas and gently rolling hills in England, representative for flat open areas only.

   b. σ_y and σ_z

      (1) σ_y and σ_z a function of horizontal distance from source

      (2) Original σ_y and σ_z valid only for 0.1 kilometer (328 feet) horizontal distance from source and greater

   c. Project smoke - smoke candles

      (1) Purpose:

         (a) Determine general dispersion characteristics from line source

         (b) Examine the mechanical mixing cell

         (c) Obtain rough estimate of σ's near source

      (2) Project conducted on airport runway under neutral atmospheric stability and with surrounding terrain flat and open.

      (3) 4 meters found as upper limit of mechanical mixing cell

2. Modification of σ_z to incorporate results from project smoke

   a. See Figure 3-3

3. Wind Speed - height to measure $\bar{U}$ because of the wind shear and ground turbulence

   a. See Figure 3-4 - exposure for air flow around building

   b. Standard h = 10 meters or equivalent. Also method to estimate surface stability uses $\bar{U}$ at 10 m.

C. Model Inputs

1. Traffic volumes - vehicles/hour (VPH)

2. Emission Factors - Function of route speed and percent heavy duty vehicles

3. Meteorology

   a. Atmospheric stability class
   b. Wind speed
   c. Wind angle to highway alignment

4. Type of Highway Design

   a. Pavement height above or below grade
   b. Width of roadway, including all lanes, median and shoulders

VERTICAL DISPERSION PARAMETERS

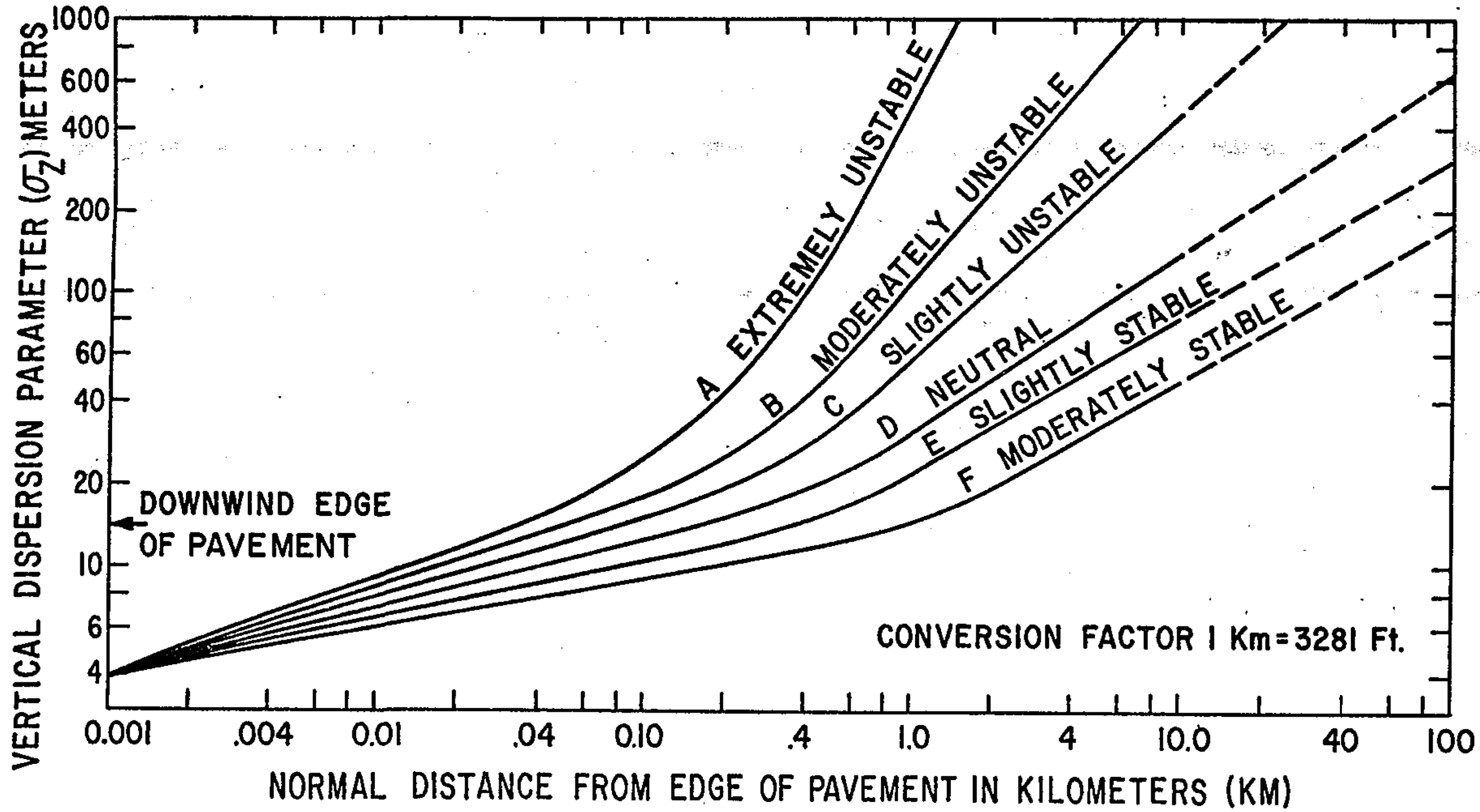
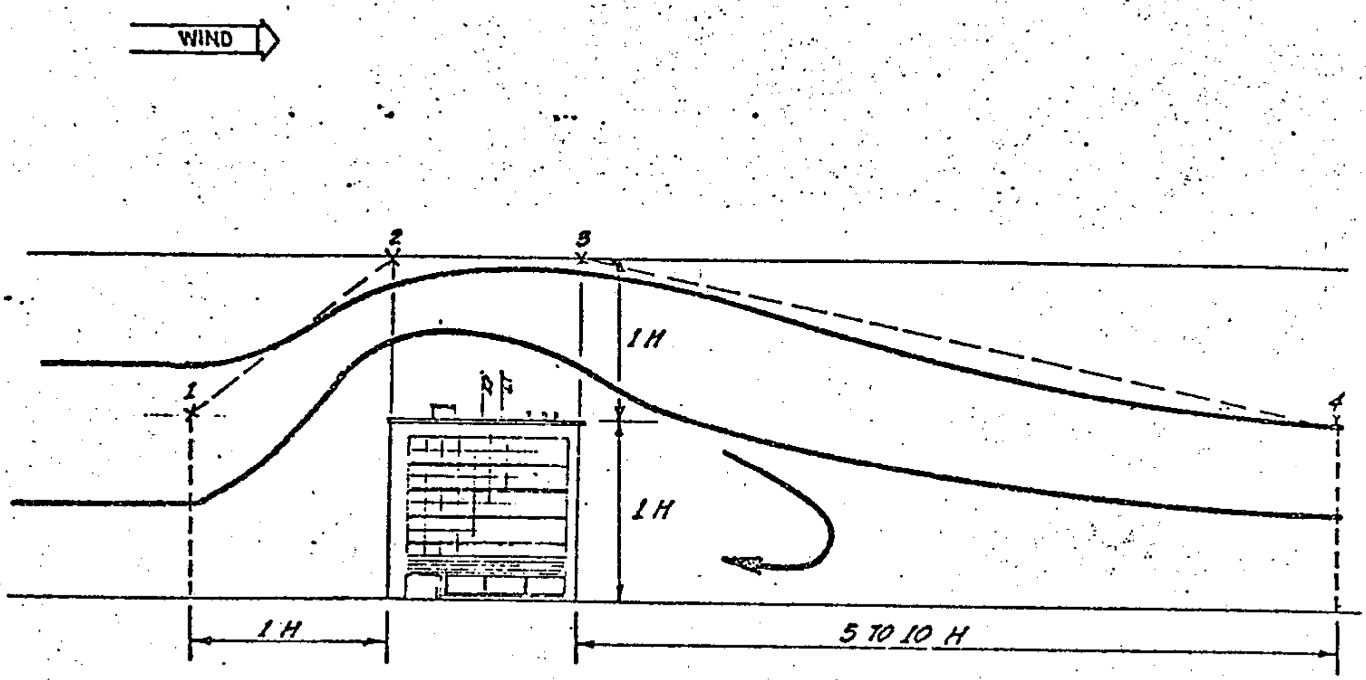
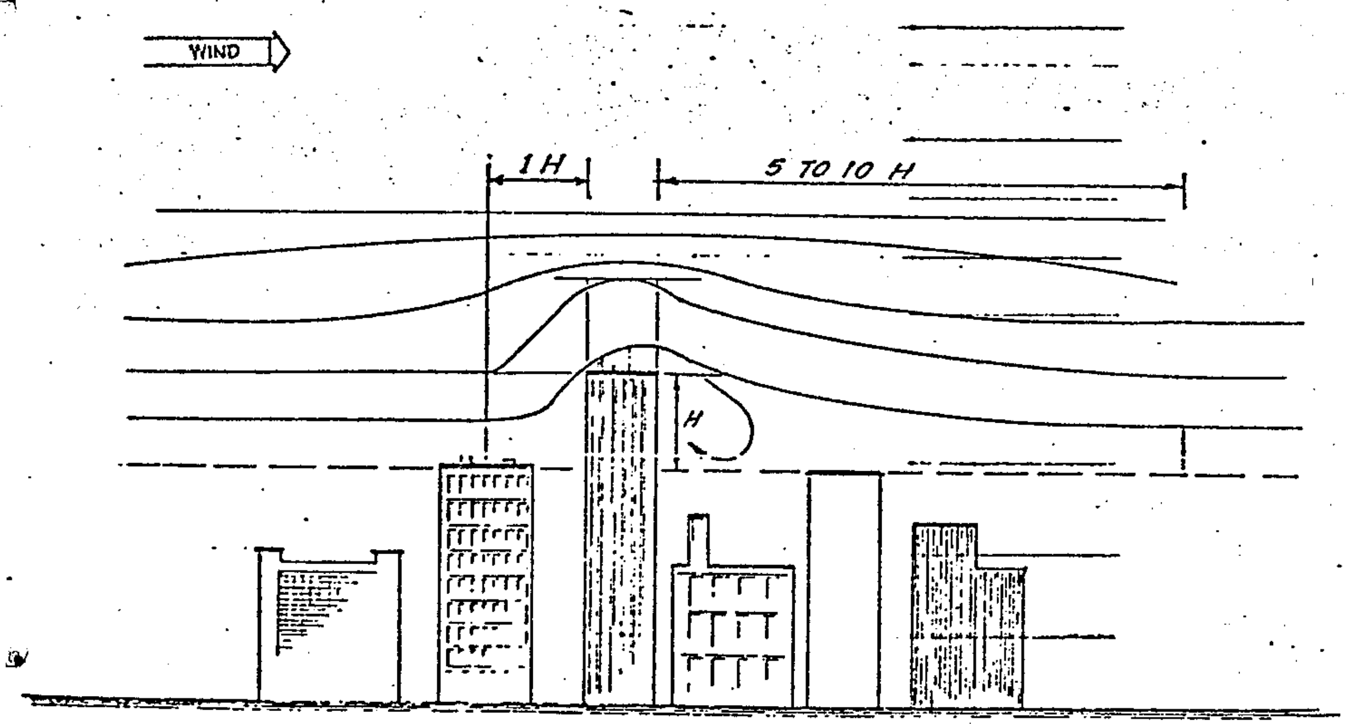


FIGURE 3-3



PROPER EXPOSURE OF WIND SYSTEMS
NEAR CUBICAL BUILDINGS



PROPER EXPOSURE OF WIND SYSTEMS
IN BUILT-UP AREAS

 FIGURE 3-4

5. Receptor location

a. Distance perpendicular to highway
b. Height above grade

D. General Flow Chart of Model

1. See Figure 3-5

E. Outputs - estimates of <u>one hour</u> CO concentrations, above background levels

1. Estimated CO concentration in PPM or ug/m^3 at receptor

2. Estimated CO concentration in PPM or ug/m^3 in highway mixing cell.

IV. Limitations of CALINE2 Model

A. Aerodynamic effect of air flow for cut and fill sections.

B. Different surface roughness heights not considered in using σ's

C. Cannot handle zero wind speed (typical of all Gaussian Models - use 1 m/sec

D. Topographic effects of converging or diverging wind flow fields.

V. Advantages of CALINE2 Model

A. Simplicity

FLOW CHART FOR CALINE MODEL

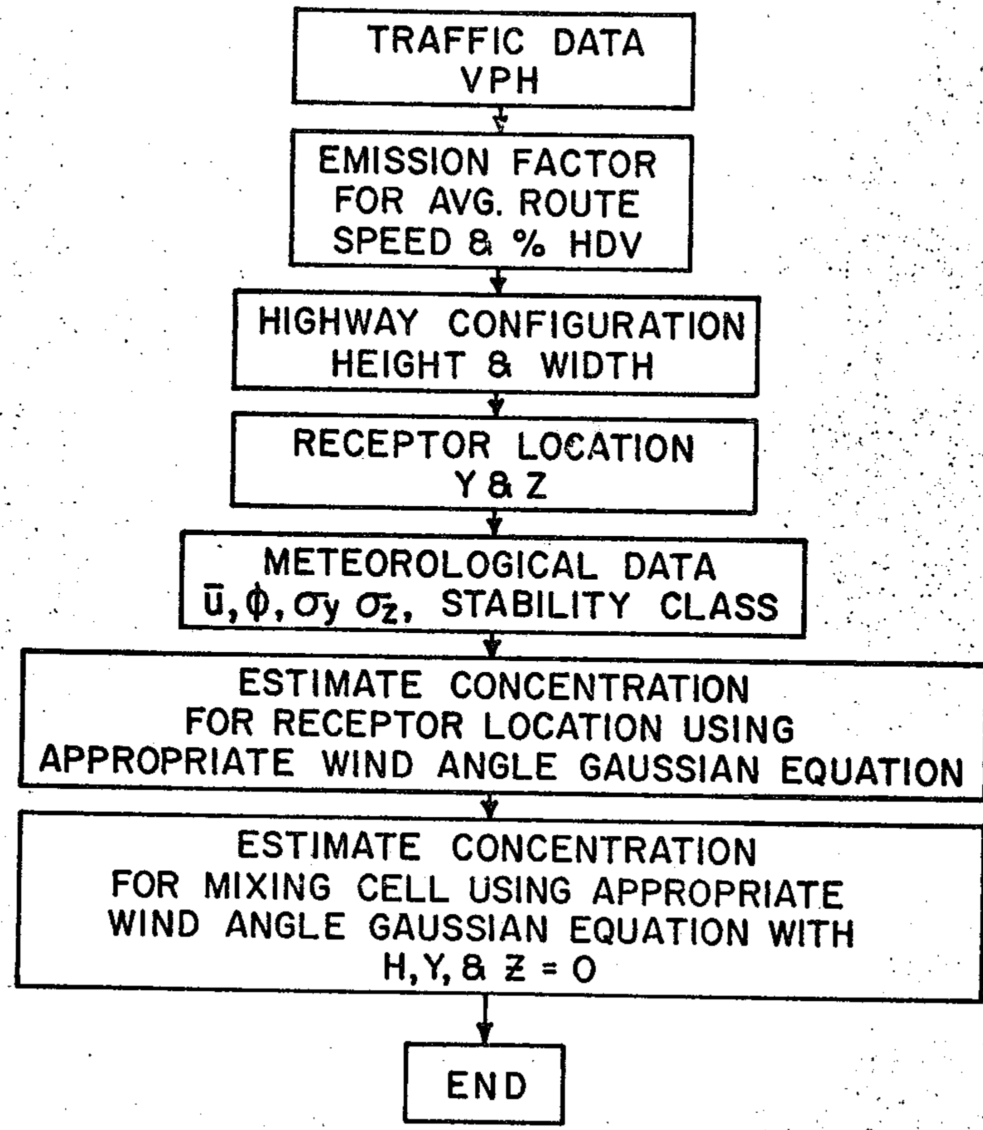


FIGURE 3-5

B. Practical model in terms of "real life". Can be used by Transportation Planners and Engineers.

C. Provides a basic foundation to understanding the fundamentals of transport and diffusion so that more advanced models can be used with confidence.

D. Computational efficiency

E. Presently performs as well as the more rigorous mathematical approaches.

VI. Review of Older Line Source Model Format

A. Gaussian Dispersion Theory combined with fixed box, as discussed previously.

B. Separated into two sub-models

1. Crosswind sub-model

a. Winds crossing the highway from normal (90°) to 12.5°

b. Uses only vertical dispersion parameter, since infinite line source has uniform horizontal (parallel to highway) distribution for crosswind

c. If other than 90°, factor of $1/\sin\phi$ is used

2. Parallel wind sub-model

a. Winds from parallel (0°) to 12.5° - assumes 0°

b. Sums up contributions from number of square area sources, since assumes that parallel wind causes concentrations to build up downwind.

3. 12.5° arbitrarily chosen as limiting condition for choosing sub-model.

C. Constant coefficients in original Gaussian Equations removed to cause overprediction or "safety factor".

D. Calibration coefficients (K)

1. Originally 4.24 to agree with New York field study data.

2. Later divided by 4.24 to nullify, since data from Los Angeles indicated original uncalibrated model predicted closer to field samples.

3. FHWA requested other agencies to modify uncalibrated model predictions by 0.8 to agree with their investigatory data.

E. Empirical ratios developed to compensate for depressed highway sections.

1. Creates imaginary mixing cell at level of top of depressed section, See Figure 3-6.

2. See Air Quality Manual Modification Number 1 at the end of this section.

CO REDUCTION FACTOR SCHEMATIC FOR DEPRESSED HIGHWAY SECTIONS

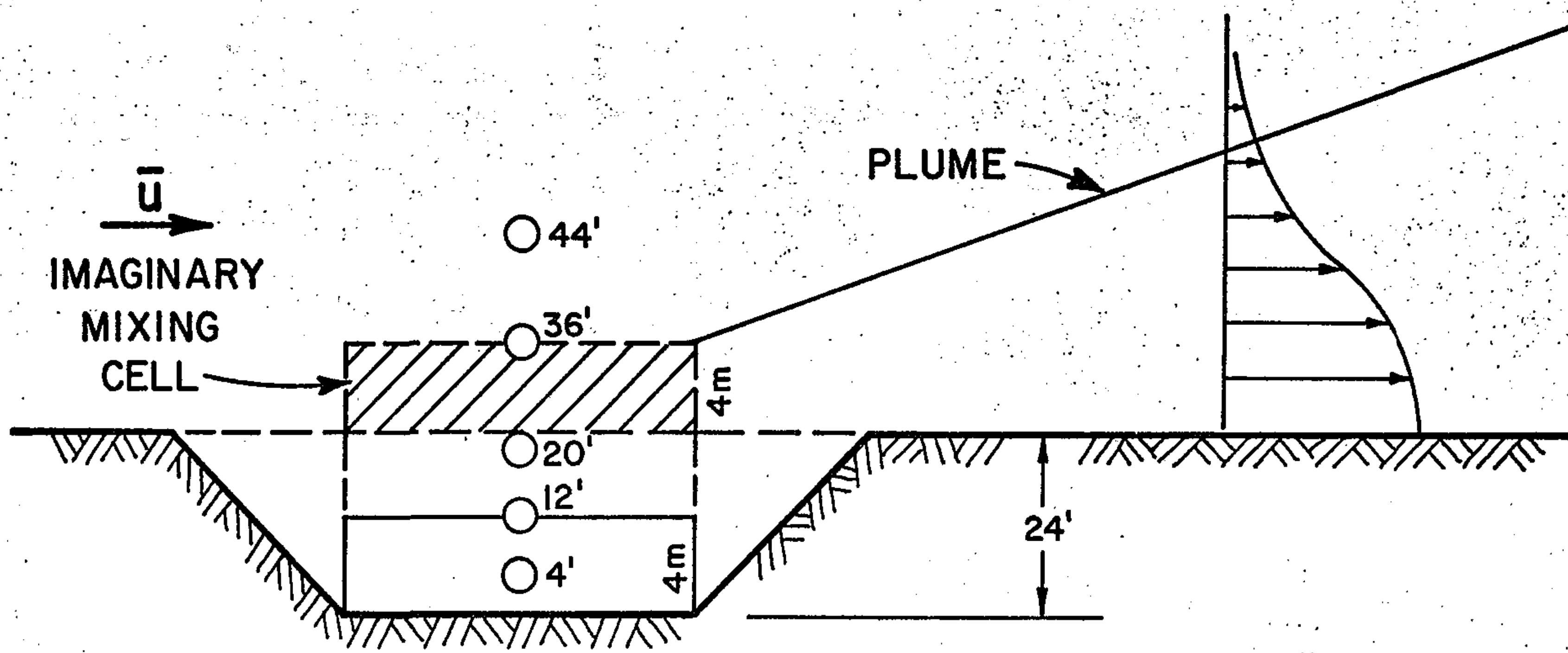


FIGURE 3-6

VII. Model Modifications - Development of CALINE2

A. Basic dispersion equations have been returned to original form, as discussed in Turner's "Workbook of Atmospheric Dispersion Estimates".

1. See Figure 3-7 and Figure 3-5
2. Pure crosswind (90°) - infinite line source
3. Pure parallel wind (0°) - summation of area sources.

4. Concentrations for wind angles between 0° and 90° are calculated using weighted sum of crosswind and parallel wind equations.

5. Mixing Cell - solution of applicable equation (s) for highway height, receptor height, and receptor distance set equal to 0.

6. Constant coefficient of $2/\sqrt{2\pi}$ (for Z and H = 0) in crosswind equation approximately equals 0.8, therefore incorporate FHWA suggestion.

7. Calibration coefficients (K's) excluded.

8. Provides solid theoretical basis for other modifications.

B. Units of Model

1. C = pollutant concentration

BASIC CALINE2 MODEL EQUATIONS

1. GAUSSIAN - CROSSWIND (LINE SOURCE), $\phi = 90°$

$$C_1 = \frac{(Fact)\ Q_1}{\sigma_z \bar{u} \sqrt{2\pi}} \left[EXP\left(-\frac{1}{2}\left(\frac{Z+H}{\sigma_z}\right)^2\right) + EXP\left(-\frac{1}{2}\left(\frac{Z-H}{\sigma_{z_i}}\right)^2\right) \right]$$

2. GAUSSIAN - PARALLEL WIND (POINT SOURCE), $\phi = 0°$

$$C_2 = \sum_{i=1}^{n} \frac{(Fact)\ Q_2}{\sigma_{y_i} \sigma_{z_i} \bar{u} 2\pi} \left\{ \left[EXP\left(-\frac{1}{2}\left(\frac{Y}{\sigma_{y_i}}\right)^2\right) \right] \left[EXP\left(-\frac{1}{2}\left(\frac{Z+H}{\sigma_{z_i}}\right)^2\right) + EXP\left(-\frac{1}{2}\left(\frac{Z-H}{\sigma_{z_i}}\right)^2\right) \right] \right\}$$

WHERE n = INTEGER OF $\frac{\text{HIGHWAY DISTANCE PARALLEL TO WIND}}{W}$

3. GAUSSIAN - CROSSWIND, $0° < \phi < 90°$

$$C_3 = C_1 \ SIN^2 \phi + C_2 \ COS^2 \phi$$

4. BOX

$H, Y, Z = 0$

SOLVE FOR APPROPRIATE C USING ONE OF THE ABOVE EQUATIONS

FIGURE 3-7

2. Fact = conversion factor, to express C in appropriate units, e.g., to express C in PPM of CO,

$$\text{Fact} = \frac{0.0245}{\text{CO molecular wgt}} \times \frac{10^6 \text{ ug}}{\text{gm}} = 875$$

3. Q = source strength, in gm/m-sec or gm-m/m-sec.
   a. $Q_1 = (\text{fact}_2) \times \text{EF} \times \text{VPH}$
   b. $Q_2 = (\text{fact}_2) \times \text{EF} \times \text{VPH} \times \text{W}$
   c. $\text{Fact}_2 = 1.726 \times 10^{-7}$ mile-hr/m-sec

4. EF = average speed-corrected emission factor, in gms/mile

5. VPH = traffic volume, in vehicles/hour
6. W = highway width including all lanes, shoulders, and medians, in meters.
7. H = height of highway above or below grade, in meters
8. Z = height of receptor above grade, in meters

9. Y = perpendicular distance of receptor from edge of highway, in meters

10. $\bar{U}$ = average wind speed, in meters/sec
11. ϕ = average angle of wind to highway
12. σ_y = horizontal dispersion coefficient, in meters
13. σ_z = vertical dispersion coefficient, in meters

C. Empirical ratios for depressed sections are retained.

D. Parallel wind

1. Summation of area sources (See Figure 3-8)

   a. Highway divided into square area sources, with side length equal to the highway width.

SCHEMATIC SHOWING GENERAL GAUSSIAN DISPERSION OF POLLUTANTS FROM FIRST VIRTUAL POINT SOURCE UNDER PARALLEL WIND CONDITIONS

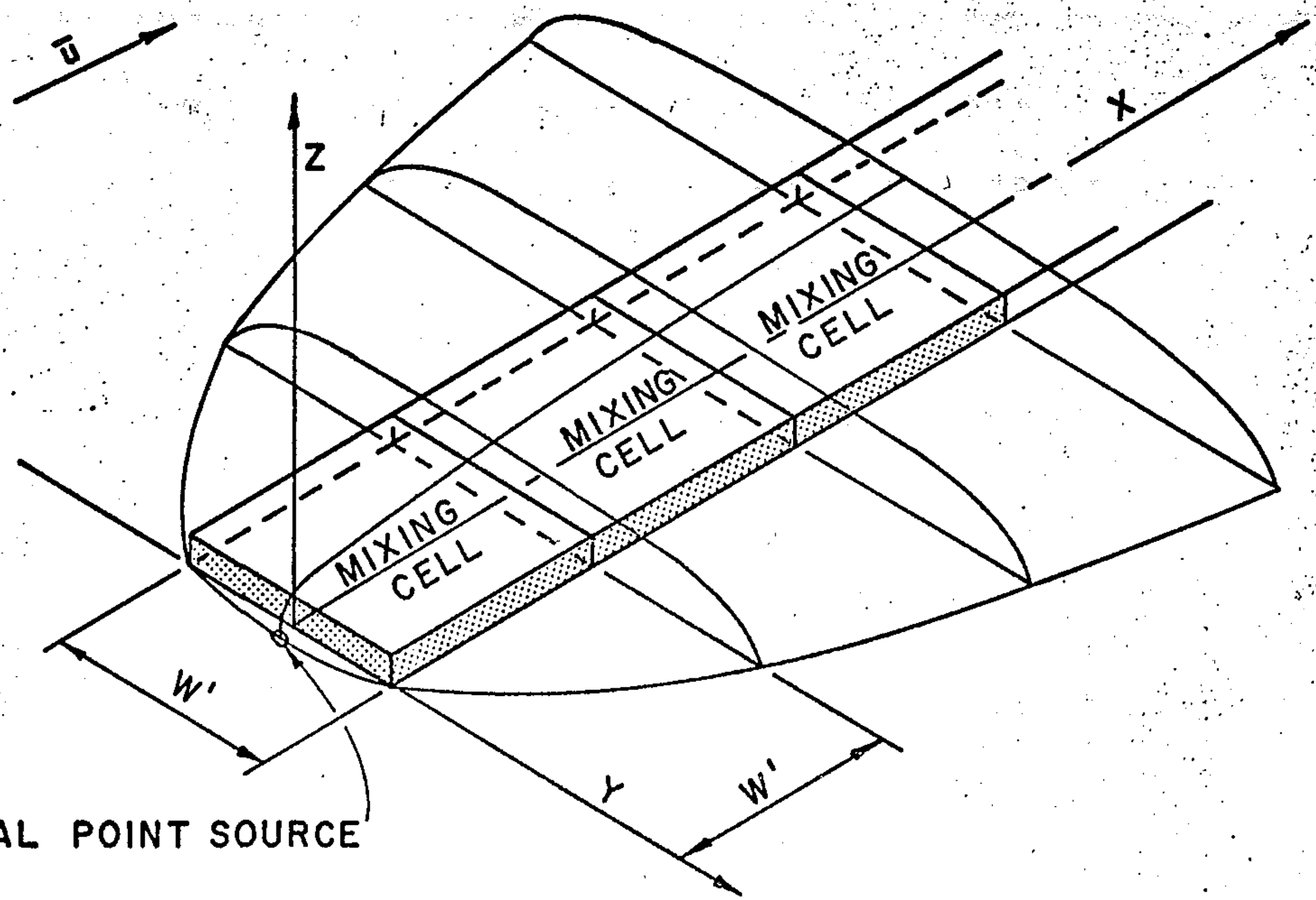


FIGURE 3-8

b. Area sources converted to equal number of point sources

(1) A distance back from the area source is calculated to locate a point source with equal source strength which will yield the initial horizontal dispersion (σ_y) at the upwind edge of the area source.

(2) This distance to the virtual point source is dependant on stability class and highway width.

(3) The dispersion at the upwind edge of the area source is assumed to be equal to the plume width ($4.3 * \sigma_y$), therefore an estimate for σ_y is = width/4.3.

(4) The downwind distance corresponding to such a σ_y is found from the appropriate stability class horizontal dispersion parameter curve.

2. Concentration in parallel wind cell (area source) required to be equal to crosswind mixing cell concentration.

a. Comparison of equations indicated that a factor approximately equal to the virtual point source distance was required to make the equations equal, in magnitude and units.

b. Physical interpretation: The virtual point source distance is the distance the "Y" axis is moved towards the highway centerline to artificially force the concentration at the highway edge to equal the mixing cell concentration.

3. Horizontal dispersion parameter (σy) curves (See Figure 3-9).

   a. Extrapolated to distance corresponding to highway width (= virtual point source distance)

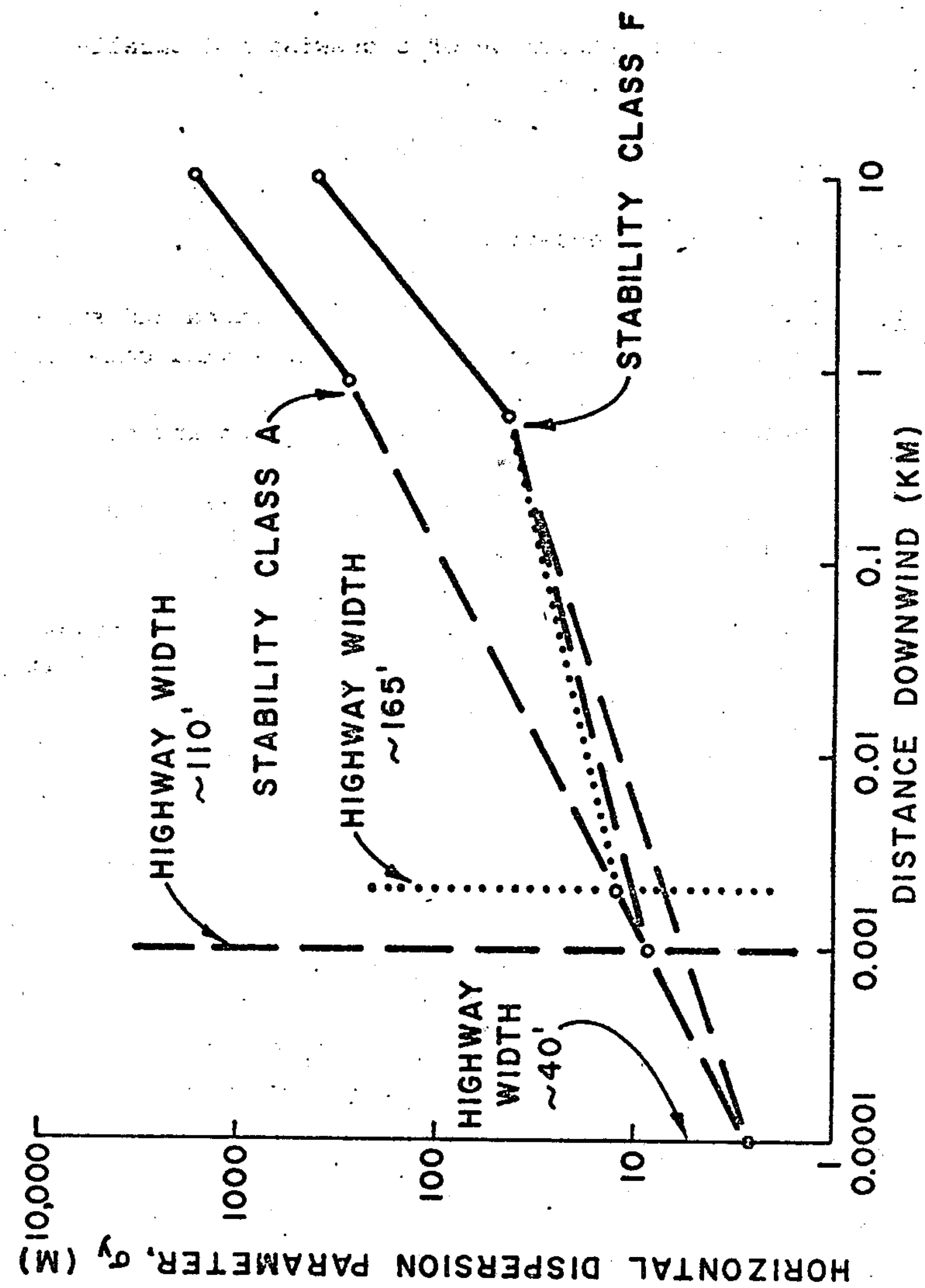
   b. σy at this point approximately equals the highway width divided by 4.3.

   c. Curves for all stability classes start at this point.

   d. Only first linear segment approximation of the curve is changed.

   e. Vertical dispersion parameter (σz) independent of highway width.

4. Scaling factor obtained from sensitivity analysis (See Figure 3-8) yields pollutant concentration corresponding to essentially "infinite" parallel wind highway segment, from the concentration calculated for a short (1/2 mile) parallel wind highway segment.



MODIFICATION OF σ_y FOR VARIATIONS IN HIGHWAY WIDTH

FIGURE 3-9

a. Fewer area sources or integration steps so that computer time is minimal.

b. Allows comparison of crosswind and parallel wind results.

D. Crosswind

1. 90° is "pure" equation

2. 0° $<$ wind angle $<$ 90° requires calculation and sum of "pure" corsswind and "pure" parallel wind components.

3. Influence of each component depends on angle.

4. Now have continuous function between 0° and 90° no discontinuity at 12.5°.

5. Eliminates 1/sin ϕ factor which allowed wind speed component to become smaller than the model's limit for wind speed.

VIII. Sensitivity Analysis

A. Variation in Predicted CO levels due to variation of input parameter.

B. Base case

1. Arbitrarily chosen as "typical" day
2. 6-lane highway - approximately 120' wide
3. Average usage - 6000 vehicles/hour
4. Neutral conditions - stability class "D", wind speed 3 mph
5. Completely parallel (0°) or crosswind (90°) wind angle
6. Emission factor of 25 gms/mile

7. At-grade highway
8. Mixing Cell Receptor
9. Parallel wind highway length of 1/2 mile

C. Vehicle/hour, See Figure 3-10
D. Emission factor, See Figure 3-11
E. Wind Speed, See Figure 3-12
F. Wind Angle, See Figures 3-13 and 3-14
G. Stability Class, See Figure 3-15
H. Pavement Height, See Figure 3-16
I. Highway width, See Figure 3-17
J. Highway length with parallel wind, See Figure 3-18
K. Horizontal and vertical dispersion parameters, See Figure 3-19

IX. Model Validation

A. Spatial distribution of pollutants

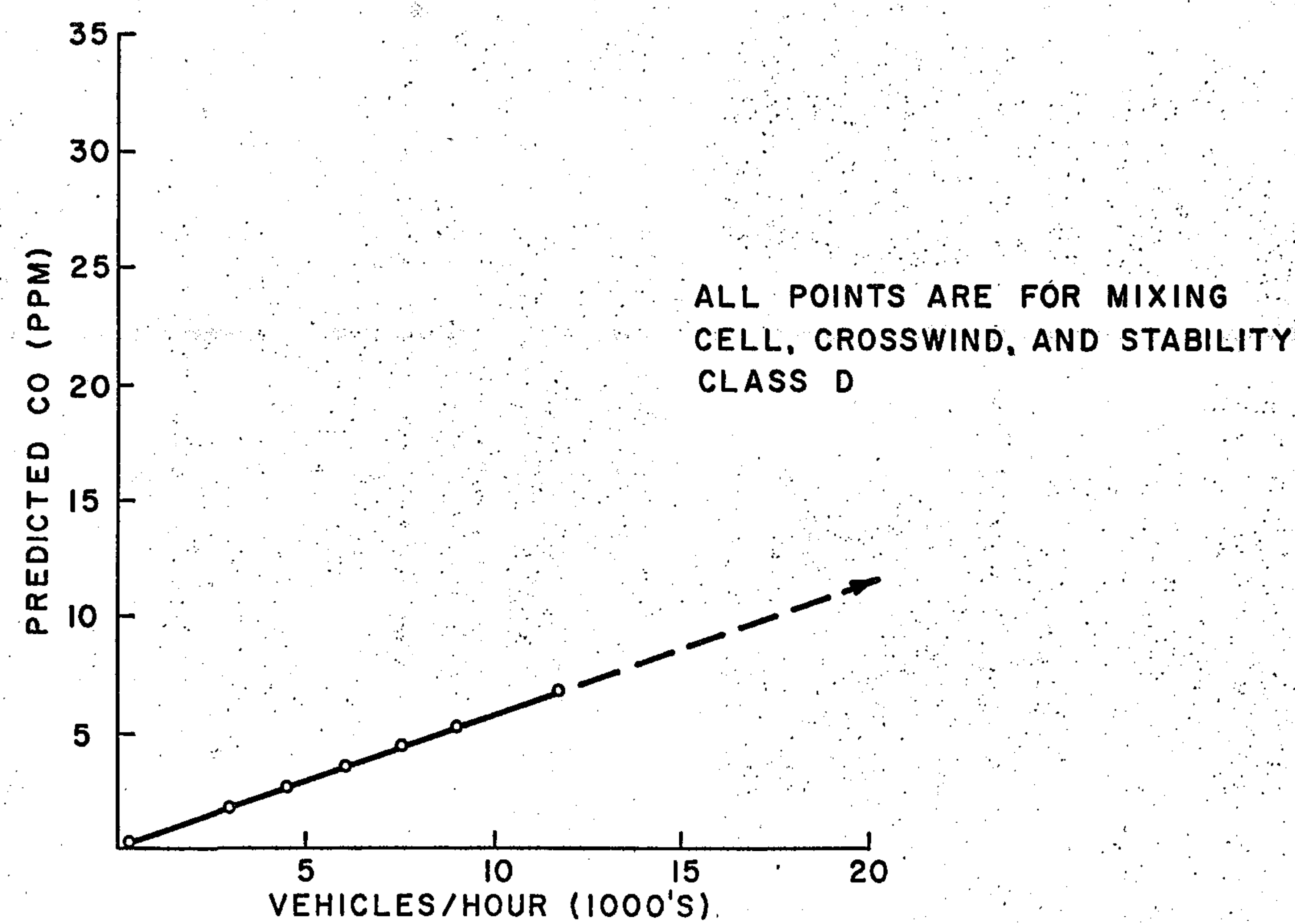
1. CO, Figures 3-20 through 3-29
2. Particulates, Figure 3- 34
3. NO_x, Figures 3-31 and 3-32
4. HC, Figure 3-33

B. Model validation flow chart, Figure 3-34A

C. Validation of CALINE2 by sample site (with comparisons to older model's regressions), See Figures 3-35 through 3- 53

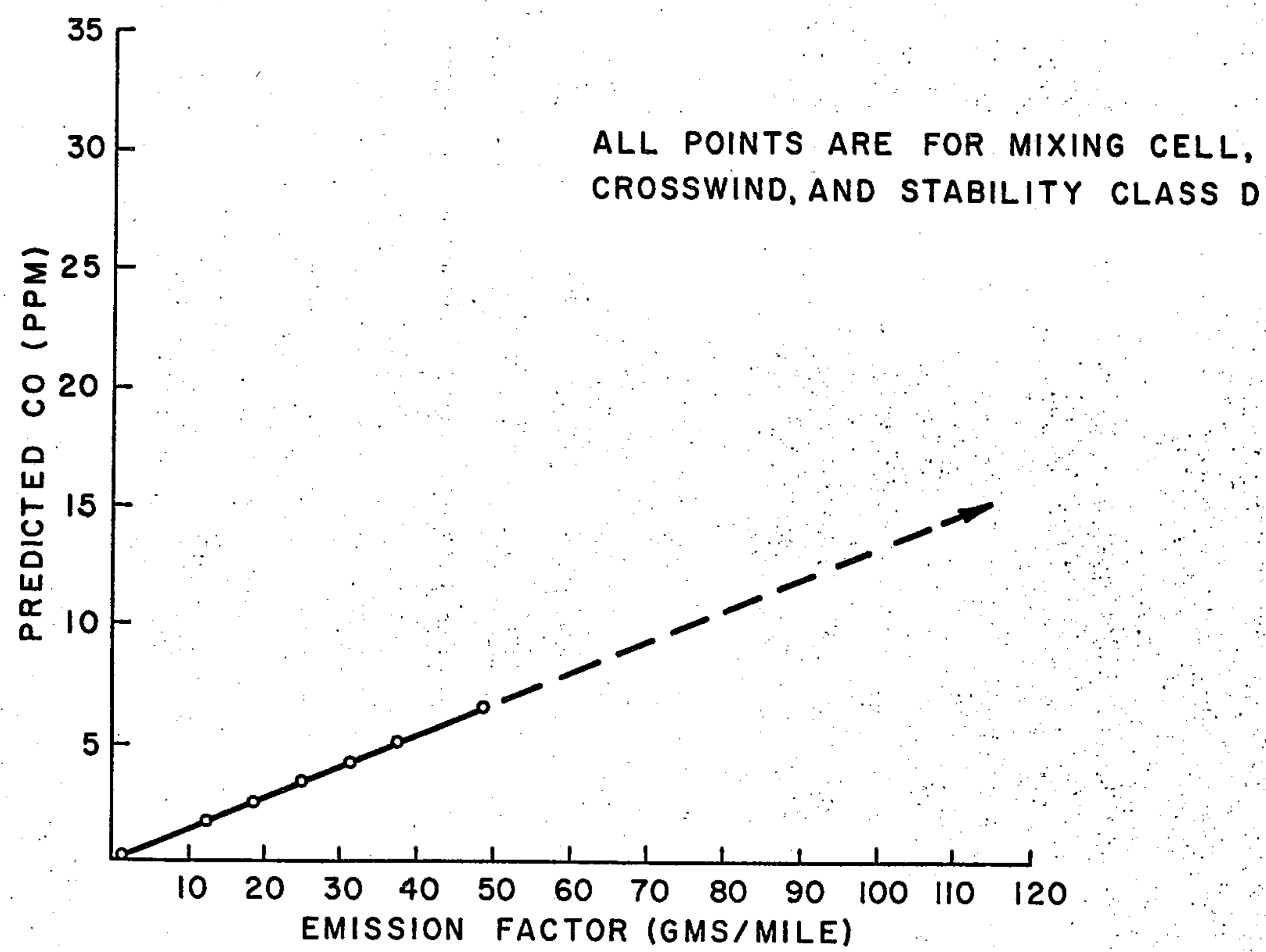
D. Validation of AeroVironment Model, Figures 3- 54 through 3- 57

E. Validation of S^3 Model, Figures 3- 58 through 3- 61



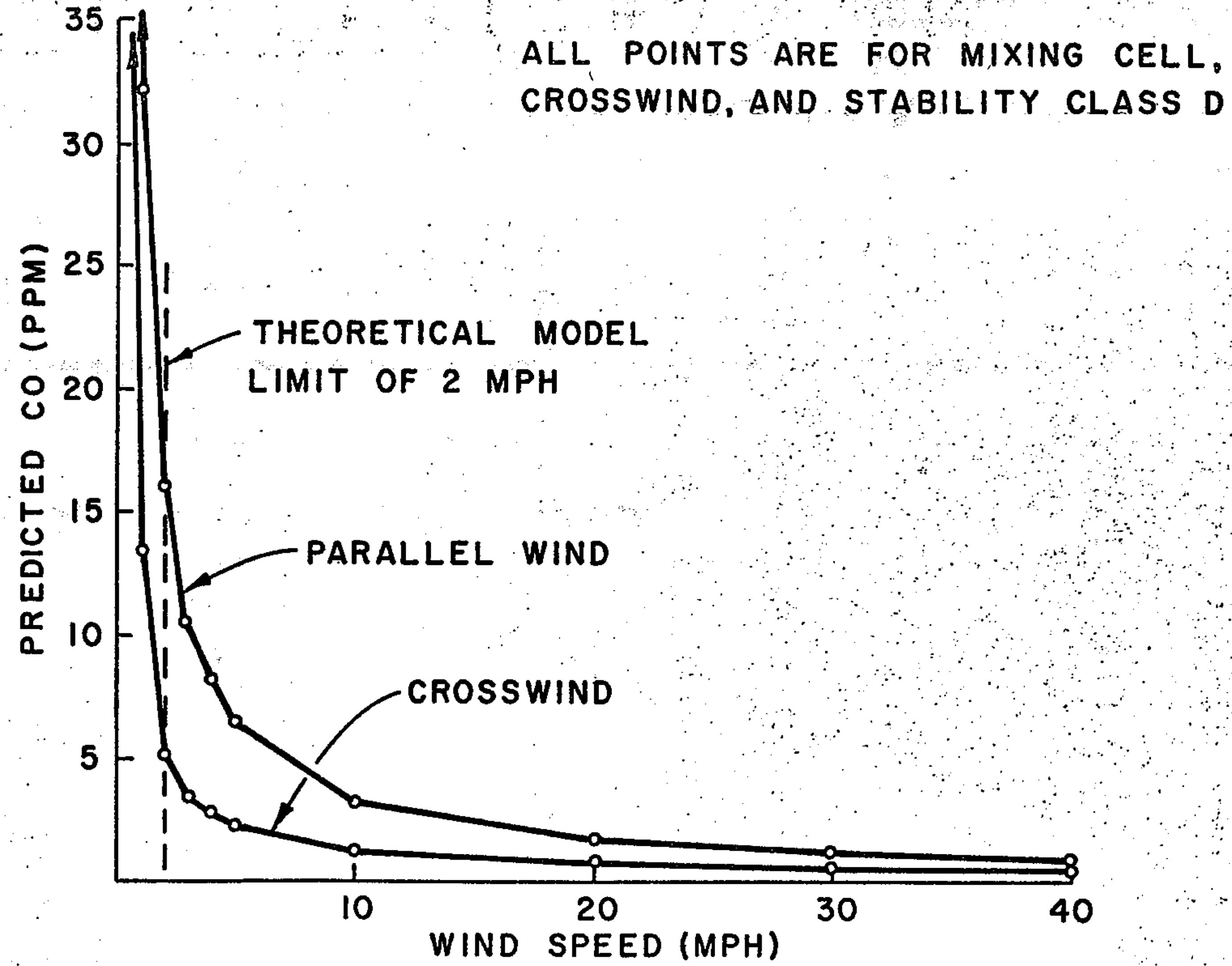
CALINE 2 SENSITIVITY TO VEHICLES PER HOUR

FIGURE 3-10



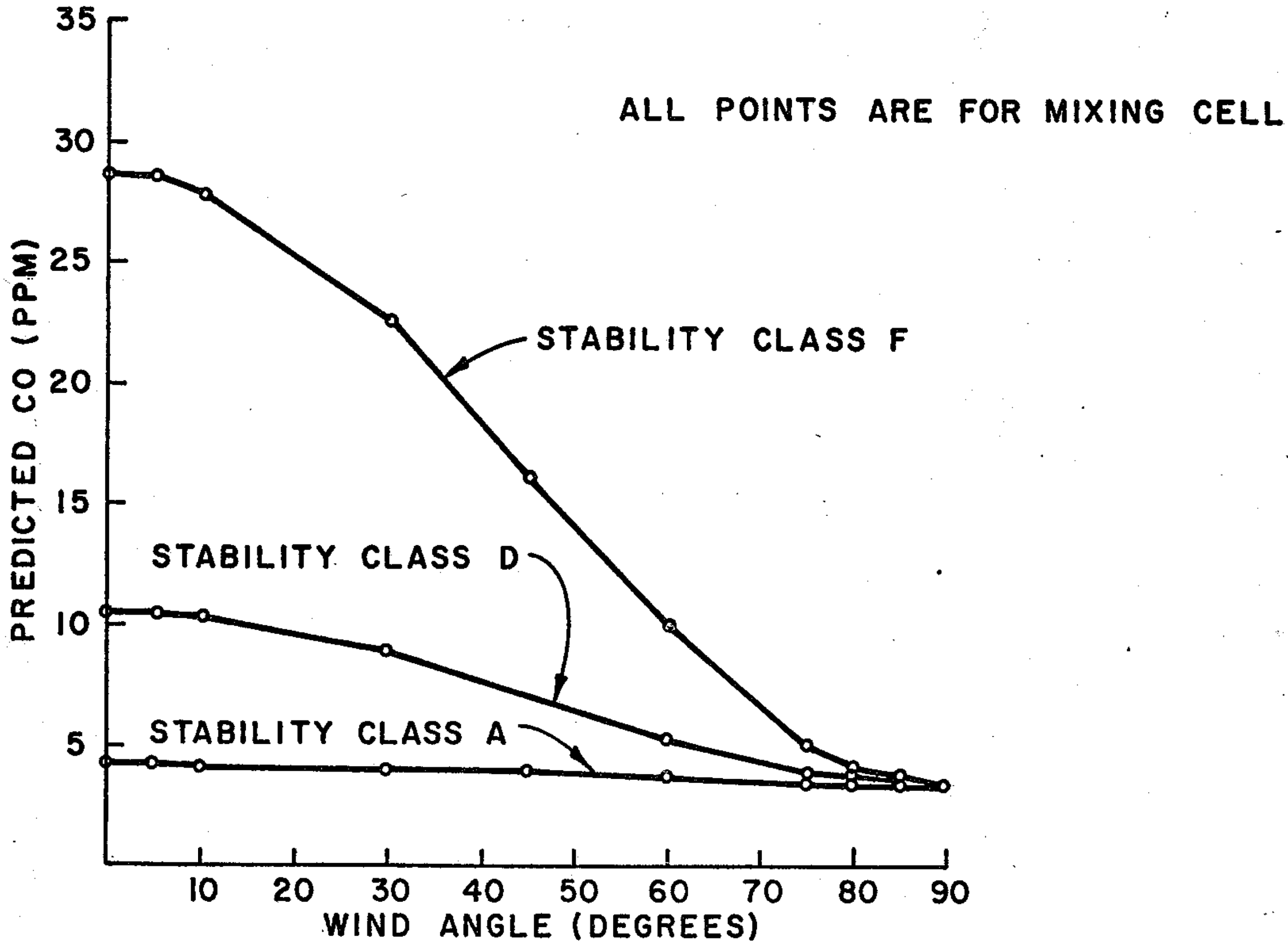
CALINE 2 SENSITIVITY TO EMISSION FACTOR

FIGURE 3-11



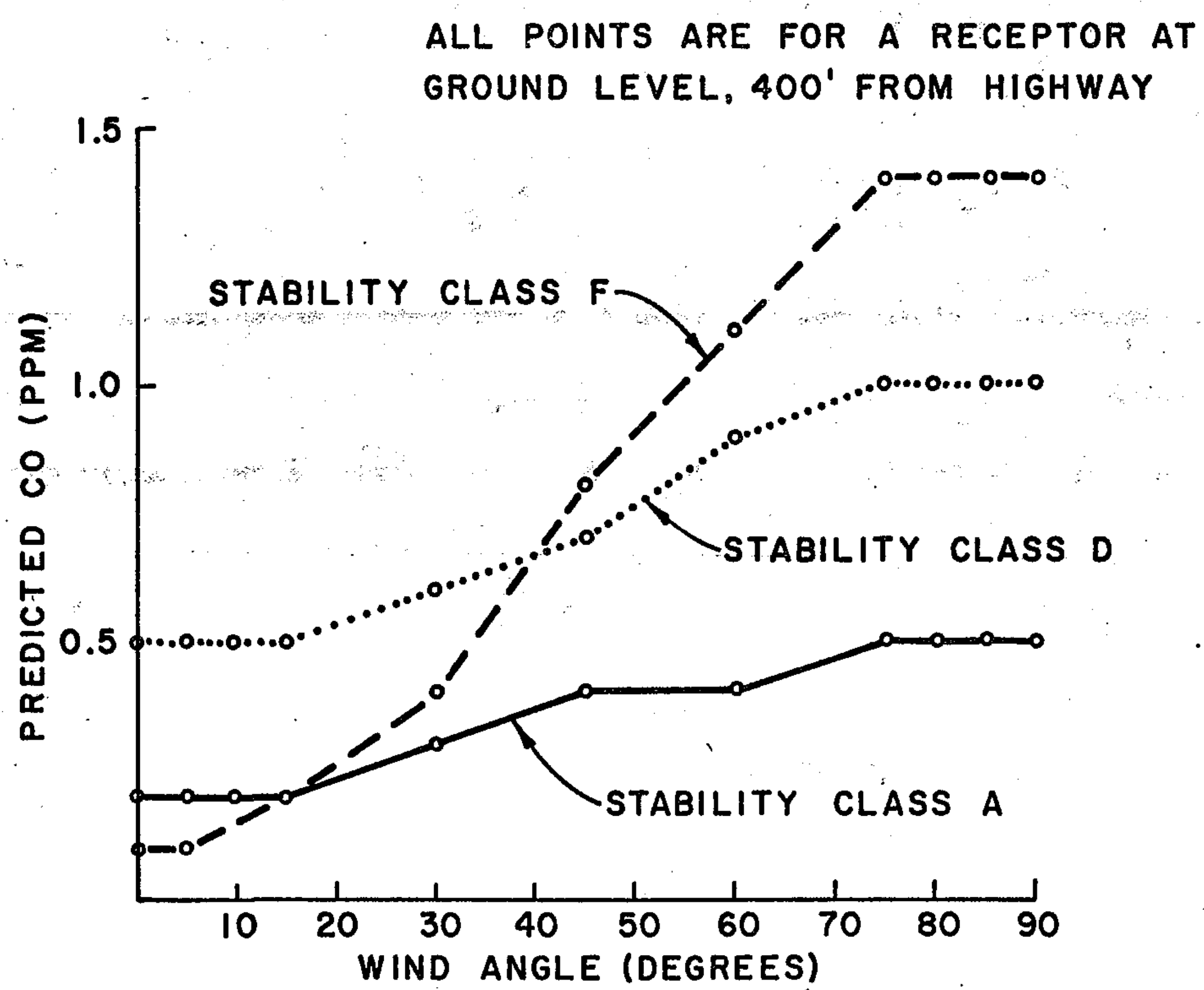
CALINE 2 SENSITIVITY TO WIND SPEED

FIGURE 3-12



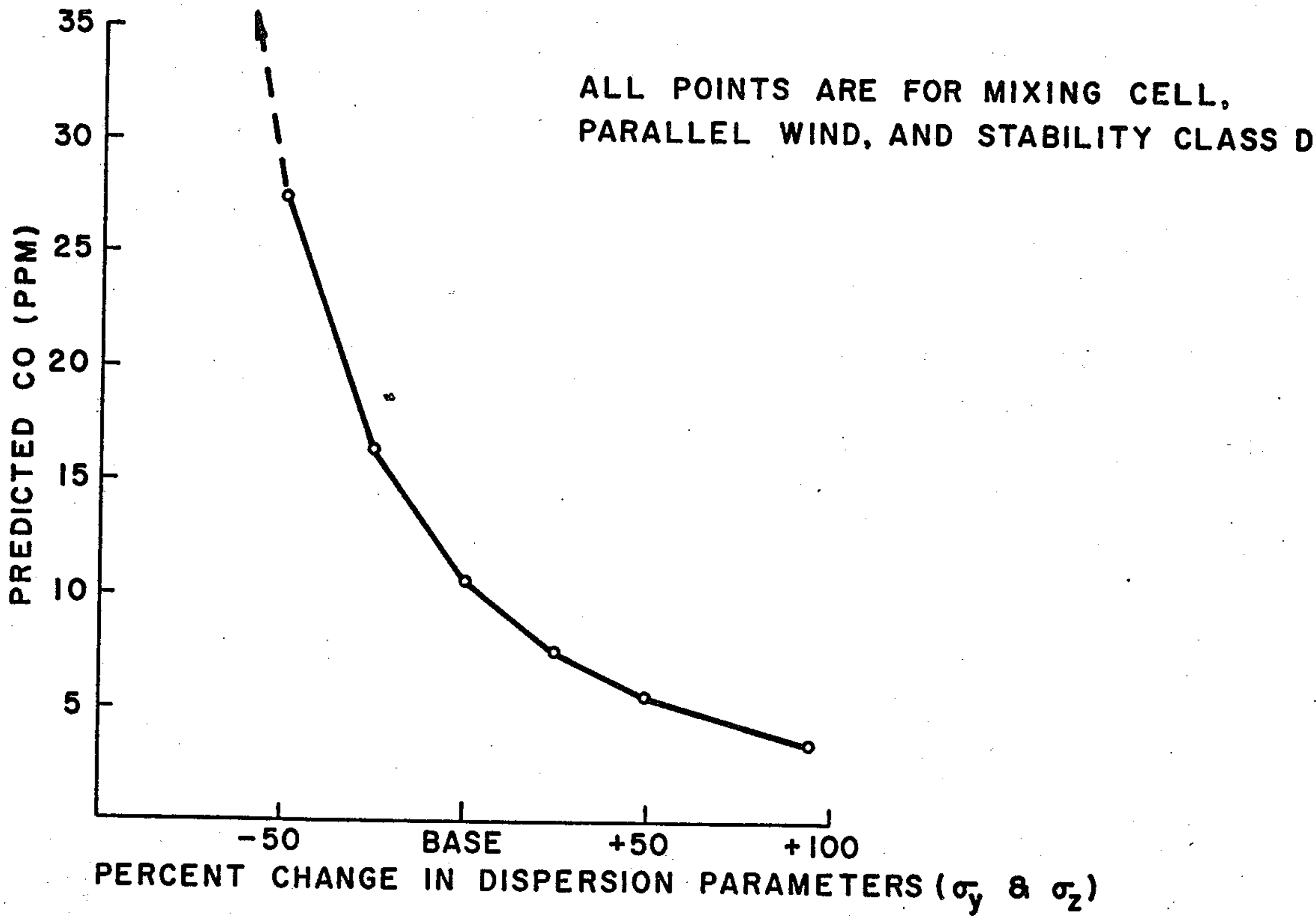
CALINE 2 SENSITIVITY TO WIND ANGLE

FIGURE 3-13



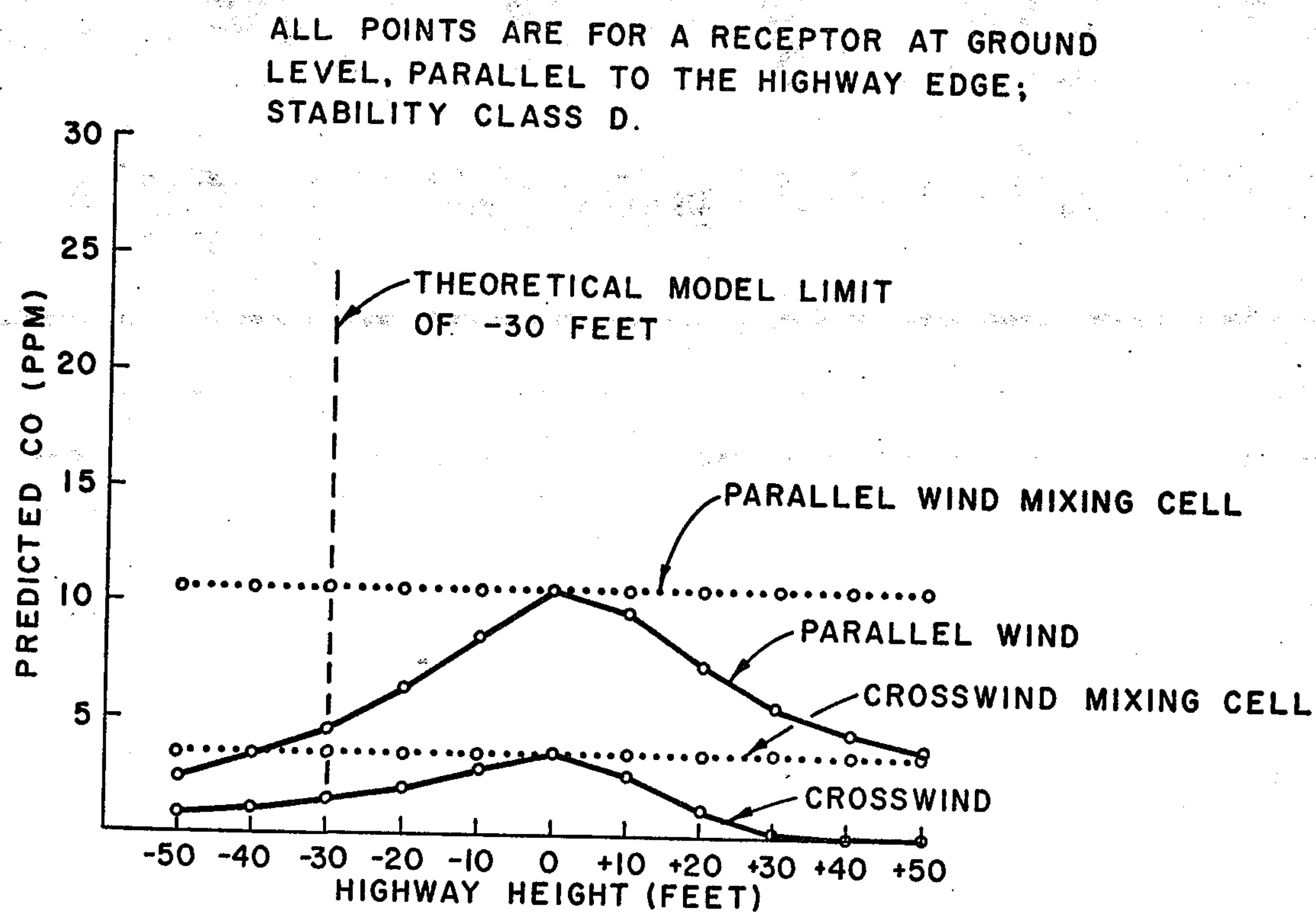
CALINE 2 SENSITIVITY TO WIND ANGLE

FIGURE 3-14



CALINE 2 SENSITIVITY TO DISPERSION PARAMETERS

FIGURE 3-15



CALINE 2 SENSITIVITY TO HIGHWAY HEIGHT

FIGURE 3-16

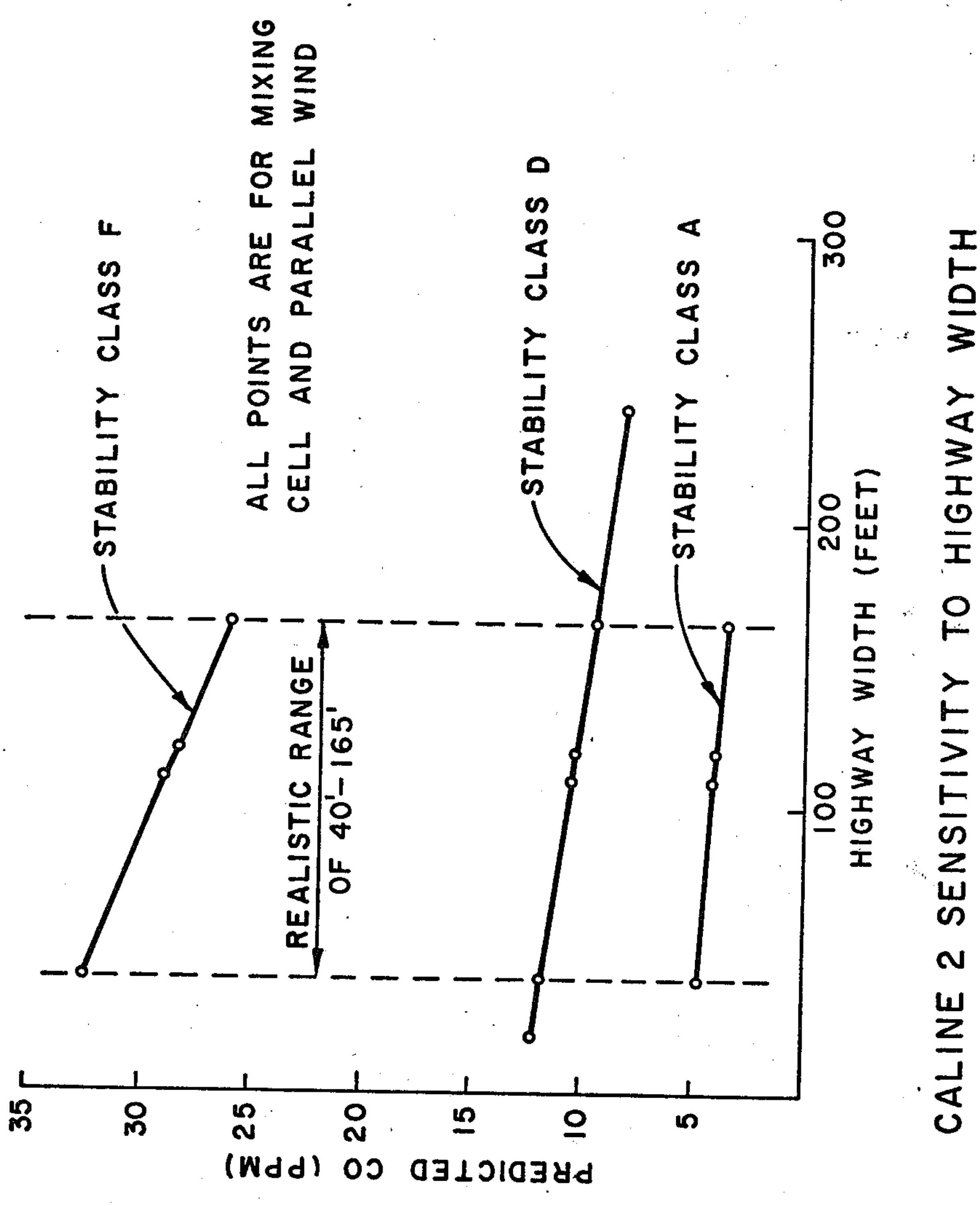


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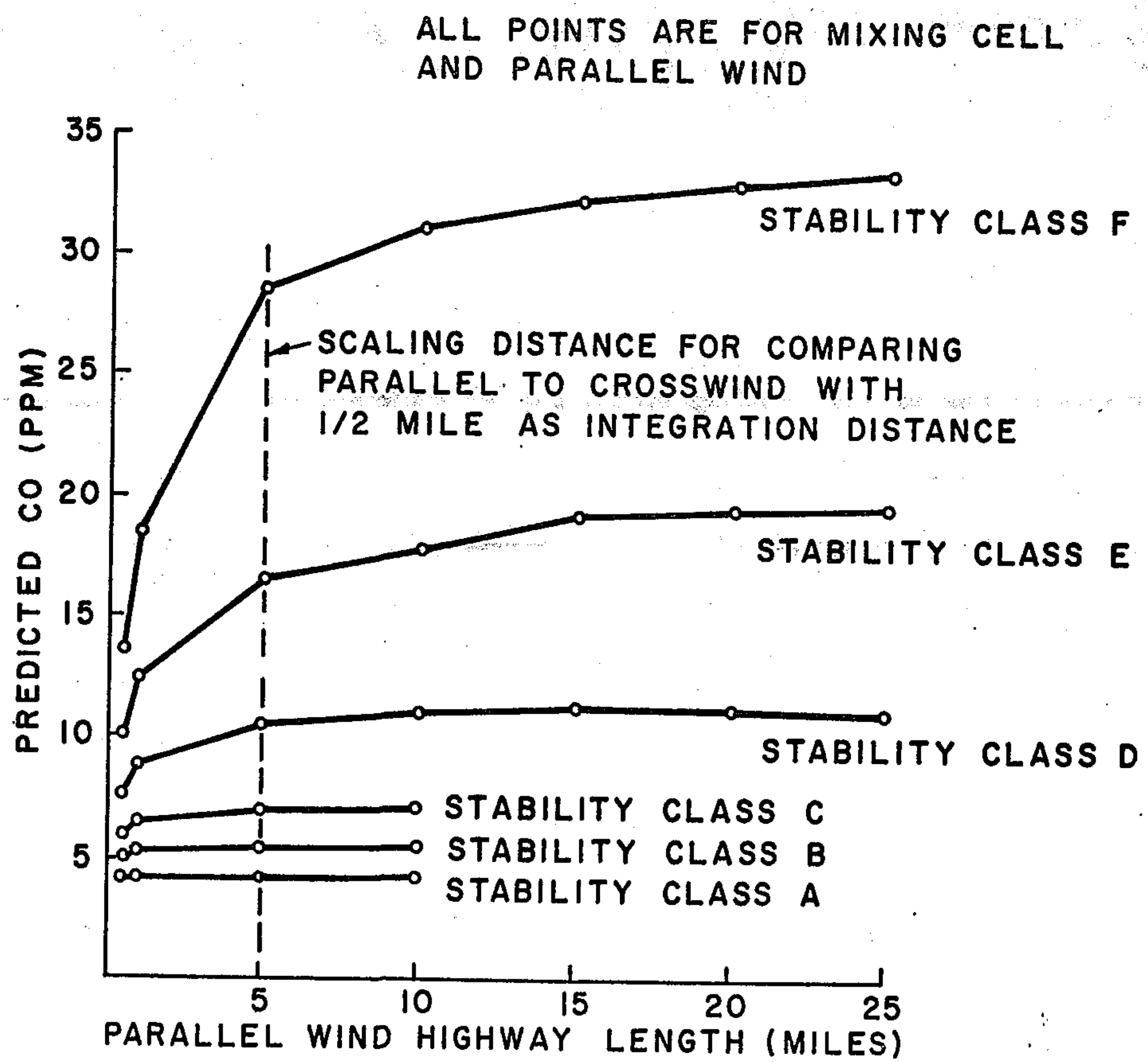
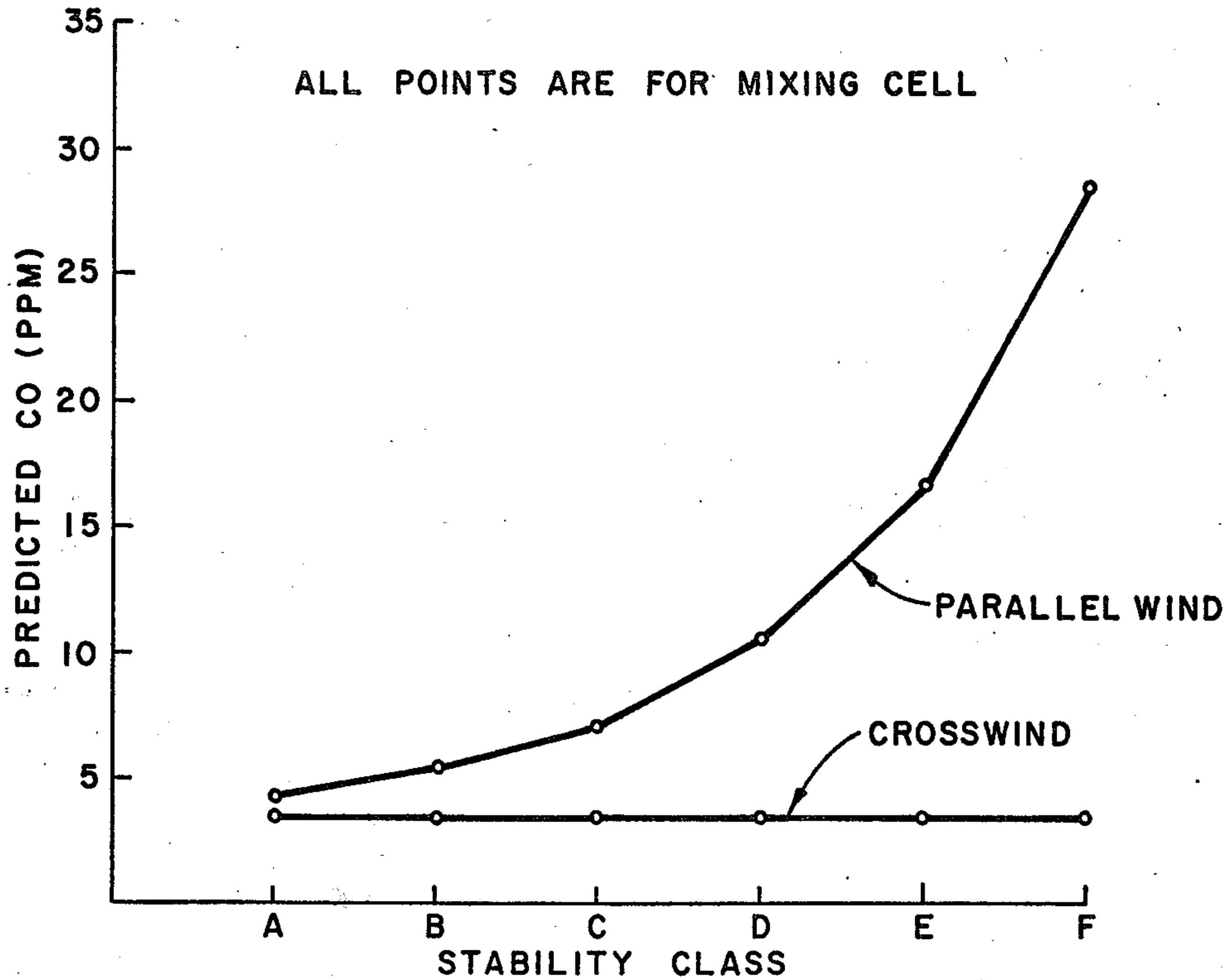
FIGURE 3-17



CALINE 2 SENSITIVITY TO
HIGHWAY LENGTH PARALLEL TO WIND

FIGURE 3-18



CALINE 2 SENSITIVITY TO STABILITY CLASS

FIGURE 3-19

COMPARISON OF EARLIER AND PRESENT VERSIONS OF THE CALIFORNIA LINE SOURCE DISPERSION MODEL

CAL%DISP (Earlier Model)	CALINE2 (Present Model)
1. General Gaussian Assumptions and Limitations are common to both models.	
2. Calibration Coefficients a) multiplication by 4.24 to agree with early N.Y. CO data, b) divide (a) by 4.24 to agree with early L.A. CO data c) multiplication of original by 0.8 to agree with FHWA CO data.	2. Calibration Coefficients none have been developed
3. Empirical ratios for depressed sections Empirical ratio applied to non-mixing cell receptors to artificially lower their concentrations (imaginary mixing cell)	3. Empirical ratios for depressed sections Same as earlier model
4. Dispersion parameters a) σ_y curves extrapolated to width of runway (110') used for "Project Smoke"; 1/30.5 used to adjust for different widths b) σ_z curves extrapolated to height of mixing cell (4 meters) as determined from "project smoke"	4. Dispersion parameters a) σ_y curves dynamically extrapolated to width of project being considered. b) Same as earlier model
5. Crosswind equation a) $12.5° < \phi \leq 90°$ b) Multiply predicted concentration by $1/\mathrm{SIN}\,\phi$ c) Constants contained in original Gaussian equations left out to cause overprediction	5. Crosswind equation a) $\phi = 90°$ b) If $0° < \phi < 90°$, modify predicted concentrations in following fashion: $C_3 = C_1 \mathrm{SIN}^2\phi + C_2 \mathrm{COS}^2\phi$ (see item 6 for C_2) c) Equation reincludes constants containe[d] in original Gaussian equations.

CAL%DISP (Earlier Model)	CALINE2 (present model)
d) Equation: $$C_1=\frac{4.24\,Q_1\,F_{act}}{K\sigma_z\bar{u}\,\sin\varphi}\left[\exp\left(-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right)+\exp\left(-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right)\right]$$ (Note: symbols explained in class text)	d) Equation: $$C_1=\frac{F_{act}\,Q_1}{\sigma_z\bar{u}\sqrt{2\pi}}\left[\exp\left(-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right)+\exp\left(-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right)\right]$$
6. Parallel wind equation	6. Parallel wind equation
a) $0° \leq \phi \leq 12.5°$	a) $\phi = 0°$
b) Summation of virtual point sources which have been extrapolated from area sources	b) Same as earlier model, except using new dispersion parameters of item 4
c) Number of area sources is function of length of project parallel to wind	c) Scaling factor used to make "infinite" line source so C_2 can be compared with and added to C_1 as in item 5b
d) Constants contained in original Gaussian equations left out to cause overprediction	d) Equation reincludes constants contained in original Gaussian equations.
e) Equation: $$C_2=\sum_{i=1}^{n}\frac{4.24\,Q_2\,F_{act}}{K\sigma_{y_i}\sigma_{z_i}\bar{u}}\left\{\left[\exp\left(-\frac{1}{2}\left(\frac{y}{\sigma_{y_i}}\right)^2\right)\right]\times\left[\exp\left(-\frac{1}{2}\left(\frac{z+H}{\sigma_{z_i}}\right)^2\right)+\exp\left(-\frac{1}{2}\left(\frac{z-H}{\sigma_{z_i}}\right)^2\right)\right]\right\}$$	e) Equation: $$C_2=\sum_{i=1}^{n}\frac{F_{act}\,Q_2}{\sigma_{y_i}\sigma_{z_i}\bar{u}\,2\pi}\left\{\left[\exp\left(-\frac{1}{2}\left(\frac{y}{\sigma_{y_i}}\right)^2\right)\right]\times\left[\exp\left(-\frac{1}{2}\left(\frac{z+H}{\sigma_{z_i}}\right)^2\right)+\exp\left(-\frac{1}{2}\left(\frac{z-H}{\sigma_{z_i}}\right)^2\right)\right]\right\}$$
7. Mixing Cell equation	7. Mixing Cell equation
a) H = Z = D=O	a) Same as earlier model
b) Depressed section ratio not used	b) " " " "
c) Crosswind mixing cell not required to be equal to one cell of parallel wind segment.	c) Crosswind mixing cell required to be equal to one cell of parallel wind segment.

8. Worst Case Comparsion – See Figure 19A & B

[illegible]

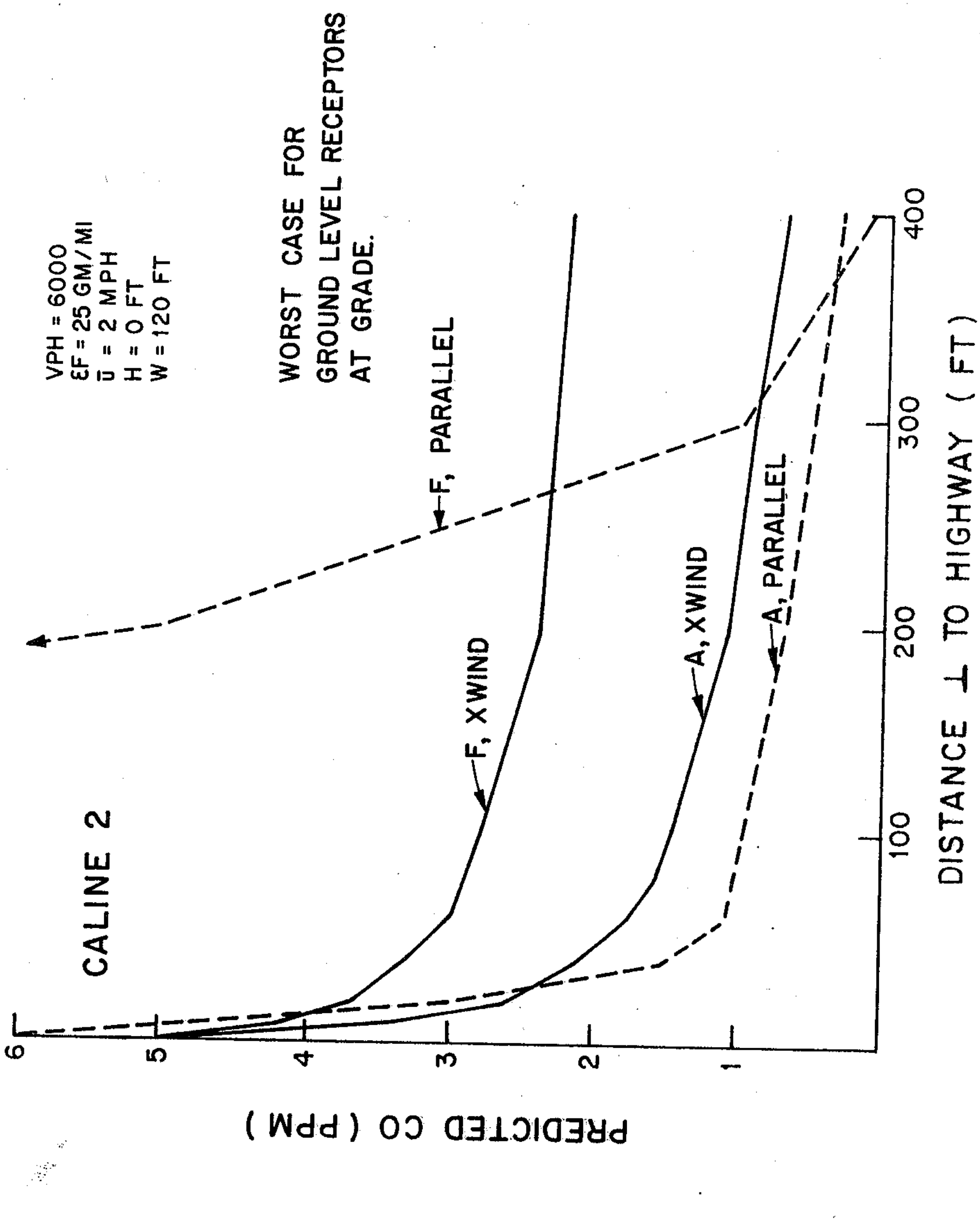
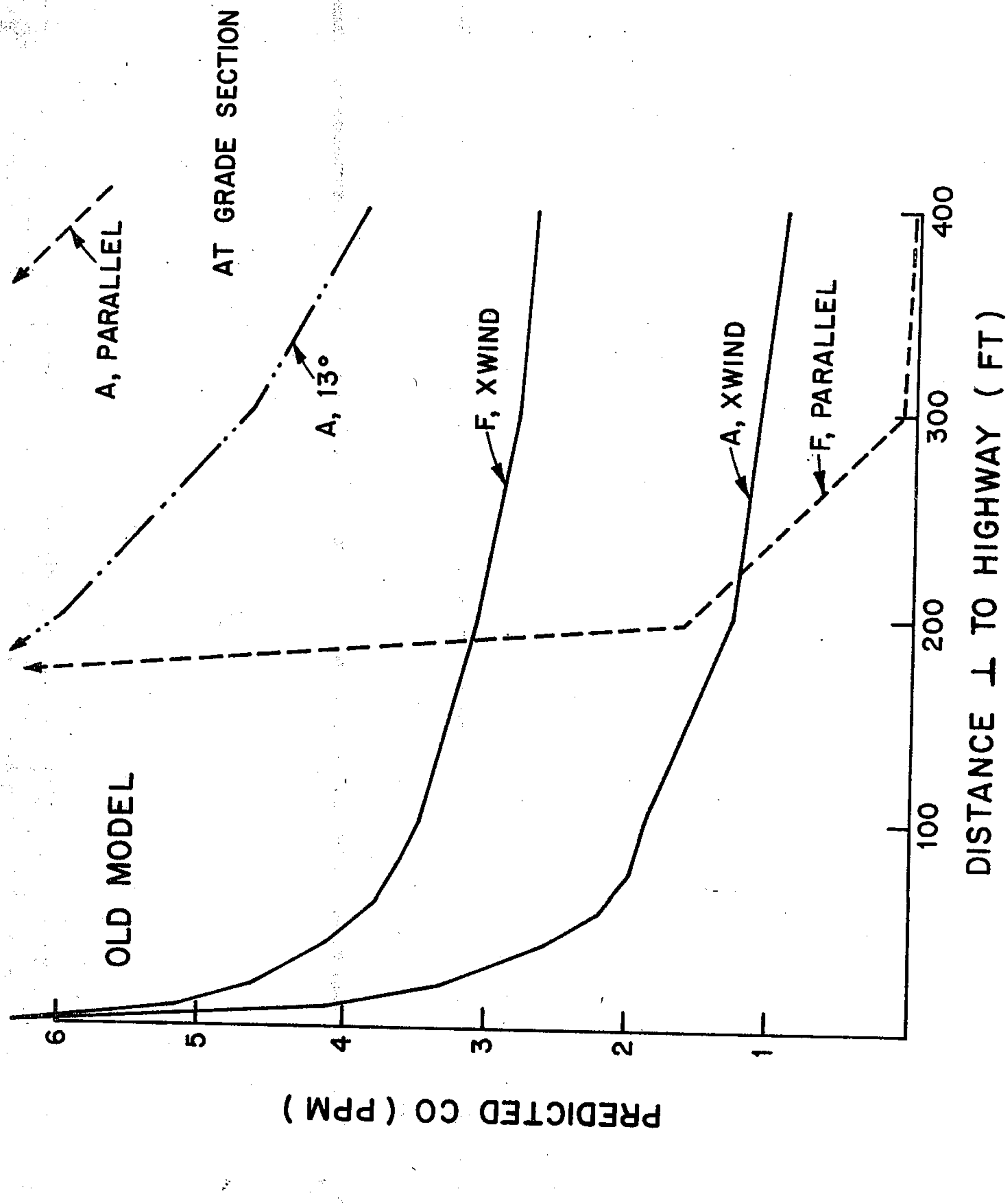

CALINE 2
VPH = 6000
εF = 25 GM/MI
ū = 2 MPH
H = 0 FT
W = 120 FT
WORST CASE FOR
GROUND LEVEL RECEPTORS
AT GRADE.
F, PARALLEL
F, XWIND
A, XWIND
A, PARALLEL
PREDICTED CO (PPM)
6
5
4
3
2
1
100
200
300
400
DISTANCE ⊥ TO HIGHWAY (FT)

FIGURE 3-19A



OLD MODEL
AT GRADE SECTION
A, PARALLEL
A, 13°
F, XWIND
A, XWIND
F, PARALLEL
PREDICTED CO (PPM)
1
2
3
4
5
6
100
200
300
400
DISTANCE ⊥ TO HIGHWAY (FT)

FIGURE 3-19B

AIR QUALITY MANUAL MODIFICATION

Prepared by
Andrew Ranzieri and Gerald Bemis
Transportation Laboratory

Modification No. 1 - Revision to Line Source Dispersion Model for Depressed Sections

A major revision to the line source model [1] used to estimate microscale concentrations is described. This revision affects concentrations downwind from depressed sections for both cross and parallel wind conditions.

This revision constitutes an interim improvement in our method of analysis, based upon data from actual carbon monoxide measurements made in conjunction with our Federally-funded research project in Los Angeles. This modification affects all depressed sections (depth limited to 30 feet or less).

From our studies in the Los Angeles area, we have derived a mathematical relationship using regression techniques relating height above pavement to carbon monoxide concentrations as a function of surface stabilities for depressed sections only. The relationship was derived from heights above the pavement of four feet to 44 feet. These CO concentrations were measured in the median on the Santa Monica Freeway at the 4th Avenue Pedestrian Overcrossing and on the Harbor Fryeway at the 146th Avenue Pedestrian Overcrossing.

Different relationships were derived for stability A, B, and C-D combined. Not enough data were gathered for stability E and F due to meteorological conditions. Until further data are obtained, it will be assumed that the relationship derived for stability C-D can be used for stability E or F.

In order to incorporate this change in our microscale modeling analysis, we have developed a "CO Reduction Factor." This transposes the mixing cell concentration, on the highway within the depressed section, into an imaginary mixing cell at the same height as the surrounding terrain. The at-grade dispersion equation is then used to calculate concentrations downwind from the depressed section.

(1) Air Quality Manual CA-HWY-MR657082S-4-72-12 "Mathematical Approach to Estimating Highway Impact on Air Quality"

The "CO Reduction Factor" was derived from the CO concentrations measured at 4 feet, 12 feet, 20 feet, 36 feet or 44 feet, divided by the CO concentration at 4 feet. The CO Reduction Factor for 4 feet is 1.0 and the CO Reduction Factor for any height above 4 feet is less than 1.0. The following is the derived CO Reduction Factor:

$$\text{CO Reduction Factor} = 10^{RF}$$

where for Stability A,

$$RF=[-.18164-.01448(h)+1.439\text{x}10^{-5}(VPH)+7.9\text{x}10^{-4}(\emptyset)]$$

for Stability B,

$$RF=[.21754-.01431(h)-7.2\text{x}10^{-4}(\emptyset)-2.252\text{x}10^{-2}(\bar{U})]$$

and for Stability C thru F

$$RF=[.02019-.01382(h)+4.98\text{x}10^{-6}(VPH)-5.73\text{x}10^{-3}(\bar{U})]$$

In the above equations, h = the positive vertical distance between the roadway and the surrounding terrain in feet. The other parameters are the same as defined in the Air Quality Manual titled "Mathematical Approach to Estimating Highway Impact on Air Quality."

In almost all cases, the carbon monoxide concentration decreases with height. This decrease is gradual in the bottom 12 feet, reinforcing the concept that a uniform mixing cell concentration exists. There were, however, a few cases where aerodynamic eddies caused some increase of CO concentrations with height. These cases were excluded from the analysis and will be subject to future research.

In the latest subroutine (described below), the modified procedure for calculating carbon monoxide concentrations for <u>depressed sections</u> is as follows:

1) Calculate the mixing cell concentration in the same manner as before.

2) If, and only if, <u>a depressed section</u> is being analyzed, an equivalent at-grade mixing cell is created by multiplying the mixing cell concentration by the CO Reduction Factor.

Assumptions of the method (excluding previous assumptions in the air quality manuals):

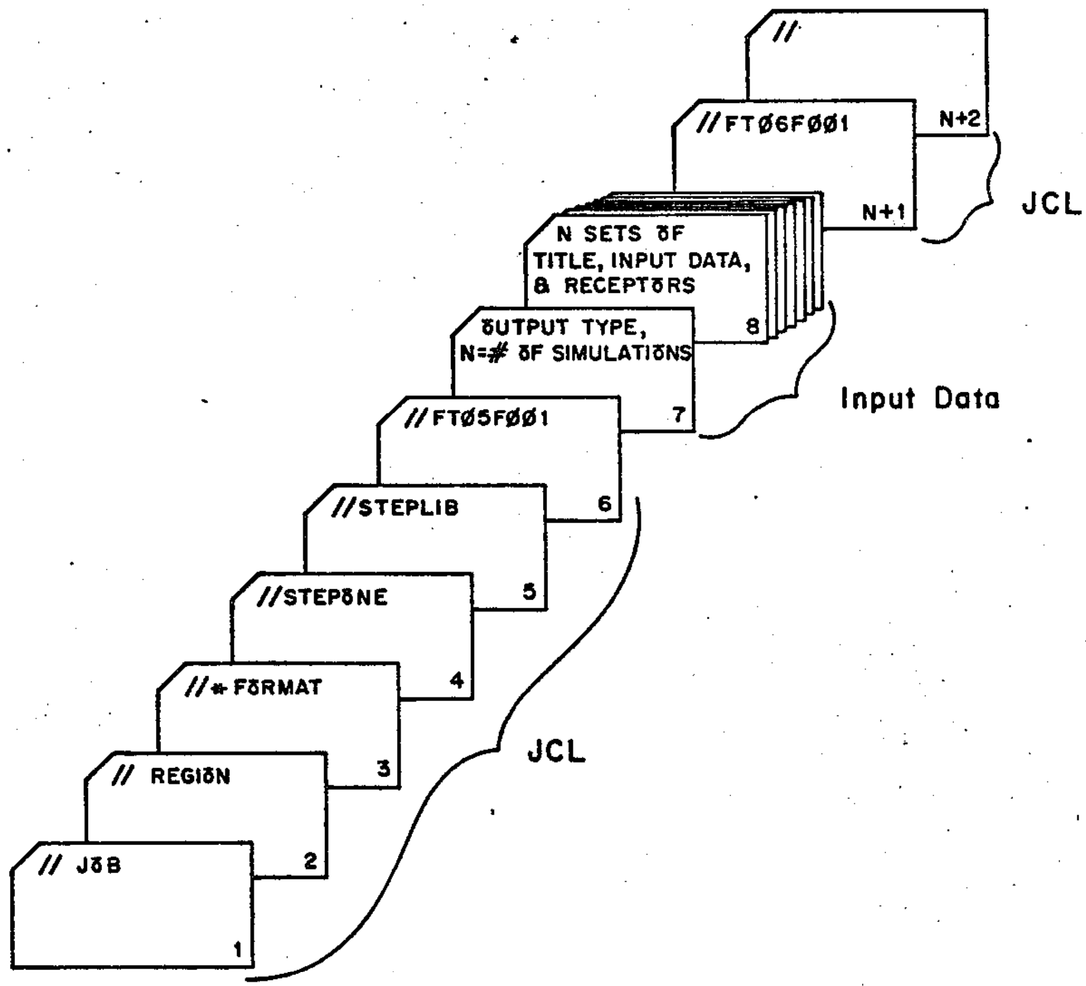
1) The mixing cell heights for the depressed section and the equivalent at-grade section are the same.

2) The CO reduction factor determined for stability C-D will be used for stabilities E and F until future data are available for these stability conditions.

3) Aerodynamic eddies are not included in this analysis and will be subject to further research and validation (the largest allowable CO reduction factor is 1.0).

The following are the input deck and sheets for accessing the FORTRAN program containing CALINE2. Included is an example run of the program.

INPUT DECK FOR CALINE2



JCL CARDS

card sequence number (columns 73–80)

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          (1)        (2)                  (3)(4)     (5)     (6)     (7)       (8)              (9)
//ENVLIN[ ]  JŌB (T[ ]I00P,TR3N,T[ ][  ],[     |     |     |          ]),[          ],      1
//           REGIŌN=I00K,CLASS=A                                                              2
                                        (10)               (11)         (12)
//*FŌRMAT    PR,DDNAME=,FŌRMS=DC[  ],CARRIAGE=[ ],DEST=[      ]                               3
//STEPŌNE    EXEC PGM=CALINE2                                                                 4
//STEPLIB    DD DSN=TRANSLIB,DISP=SHR                                                         5
//FT05F001   DD *                                                                             6
                                                                                              7
                                        INPUT DATA CARDS                                      ↓
                                                                                              N
//FT06F001   DD SYSŌUT=A                                                                    N+1
//                                                                                          N+2
```

DAS-C5 90-062

(1) - DATA ITEM, SEE NŌTES

Ø - INDICATES A NUMERIC ZERŌ

Ō - INDICATES AN ALPHABETIC "O"

NOTES FOR JCL(JOB CONTROL LANGUAGE)CARDS

Card Sequence Number	Item	Item Description
1	1	Optional job identifier, can be left blank
	2	District identification character.*
	3	District identification character.*
	4	MSP code.*
	5	Source code for your job.
	6	Charge code for your job.
	7	Expenditure authorization code for your job.
	8	Special Designation code for your job, may be left blank if you have none.

Note that items 5-8 are not to be separated by commas. Don't forget the ")," after item 8 and if item 8 is left blank or does not require the entire 9-character field, move the ")," to the left so that there are no blanks.

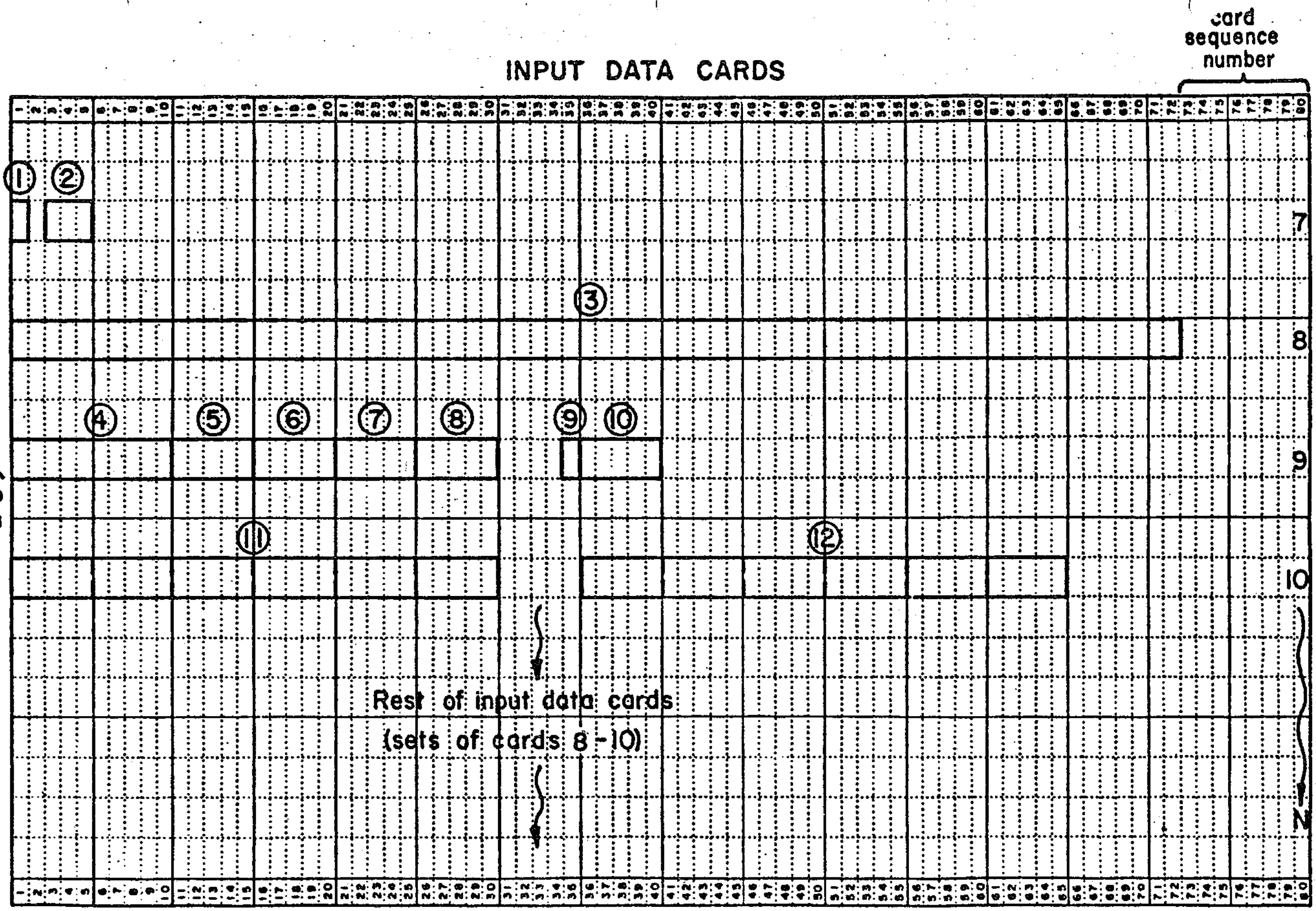
	9	User name, can be any form of your name which will fit in 8 characters or less. If less than 8 characters, move the "," to the left so there are no blanks.
3	10	Output form code, "021" if the output is to come out at your district's remote printer (unless your standard form is different from 14"x8 1/2"). If you desire your output to be printed on 14"x11", route your output to Teale Data Center, and request "061". If you want to put your output directly in a report, or have it in an easily-xeroxable form, route it to Teale, and request "075". See items 11 and 12 for the last two options.
	11	Carriage control code, tells the printer where to expect to page, according to the type of output form requested. For "021" in item 10, this code should be "A". For either "061" or "075", it should be "D".
	12	Destination code, tells the computer where the output is to be printed. Usually of the form "RMT --" where the blanks are replaced by your printer destination code.* This routes the output back to you. If you want it to be printed on the high-speed printers in Sacramento at the Teale Data Center, which is usually the case when your remote printer has a large backlog, or when you request other than standard forms (see items 10 & 11), encode "TDC" and ignore the two remaining blanks. The output will automatically be sent through the State mail or courier system to your EDP section or to the remote printer site, and can be picked up there.

* Contact your EDP (Electronic Data Processing) section for the codes assigned to your District or job.

Cards N+1 and N+2 are to be placed after the end of your input data cards. Don't forget them.

NOTE: The sequence numbers in the last 8 columns of each card are only that; they are for your convenience and for use as reference here, and may or may not be included on your card since the computer will ignore them.

INPUT DATA CARDS



DAS-CS 90-062

(1) - DATA ITEM, SEE NOTES

NOTES FOR INPUT DATA CARDS

Card Sequence Number	Item	Item Description *
7	1	Form of output 1 = pollutant concentration in parts per million (PPM) 2 = pollutant concentration in micrograms per cubic meter
	2	Number of separate simulation runs
8	3	Title for simulation run. If you want the title centered on the output, center it on the card.
9	4	Vehicles per hour
	5	Average, speed-corrected, heavy-duty-vehicle-weighted emission factor, in grams/mile
	6	Average wind speed, in miles/hour (cannot be less than 2 mph)
	7	Angle of wind to highway, in degrees (must be in the range 0-90°, inclusive)
	8	Pavement height, in feet (cannot be less than -30') note that heights above or below grade (for fill or depressed sections) should be used only when those sections are 1 mile in length or longer, otherwise consider the section to be at-grade, or at the average pavement height of the bounding sections.
	9	Atmospheric stability class, in numeric format (1-6 = A-F)
	10	Highway width, including all lanes, median, and shoulders, in feet (medians should be 30' or less, otherwise simulate each side separately and add concentrations at the receptor site)
10	11	Six receptor distances perpendicular to highway, to nearest foot within each 5-character field. Enter -99 for each distance not desired. (distances cannot be negative, nor greater than 1500', which is the limit of the microscale)

* All inputs are in integer format which, for FORTRAN, means they will have to be right justified within the field.

Card Sequence Number	Item	Item Description *
10 (cont.)	12	Six receptor heights above grade, to nearest foot within each 5-character field. Enter -99 for each distance not desired. Items 11 and 12 will be used together to create a receptor matrix, i.e., each distance will be used in turn with each of the heights. The entire matrix will be output for each simulation run. The matrix can be as small as 1 x 1 (only 1 receptor), and as large as 6 x 6 (36 receptors).

You will need as many sets of cards 2, 3, and 4 as you have separate simulation runs.

*All inputs are in integer format which, for FORTRAN, means they will have to be right justified within the field.

EXAMPLE
JCL CARDS

```
                                                                        card sequence number
          ①       ②             ③④    ⑤     ⑥     ⑦     ⑧              ⑨
//ENVLINE2  JŌB (TM100P,TR3N,TFPKA,19701197017625646ARBAGE   ),CHUKWARD,   1
//          REGIŌN=100K,CLASS=A                                             2
                                ⑩          ⑪        ⑫
//*FŌRMAT   PR,DDNAME=,FŌRMS=DC075,CARRIAGE=D,DEST=TDC                      3
//STEPŌNE   EXEC PGM=CALINE2                                                4
//STEPLIB   DD DSN=TRANSLIB,DISP=SHR                                        5
//FT05F001  DD *                                                            6
                                                                            7
                         INPUT DATA CARDS
                                                                            N
//FT06F001  DD SYSŌUT=A                                                     N+1
//                                                                          N+2
```

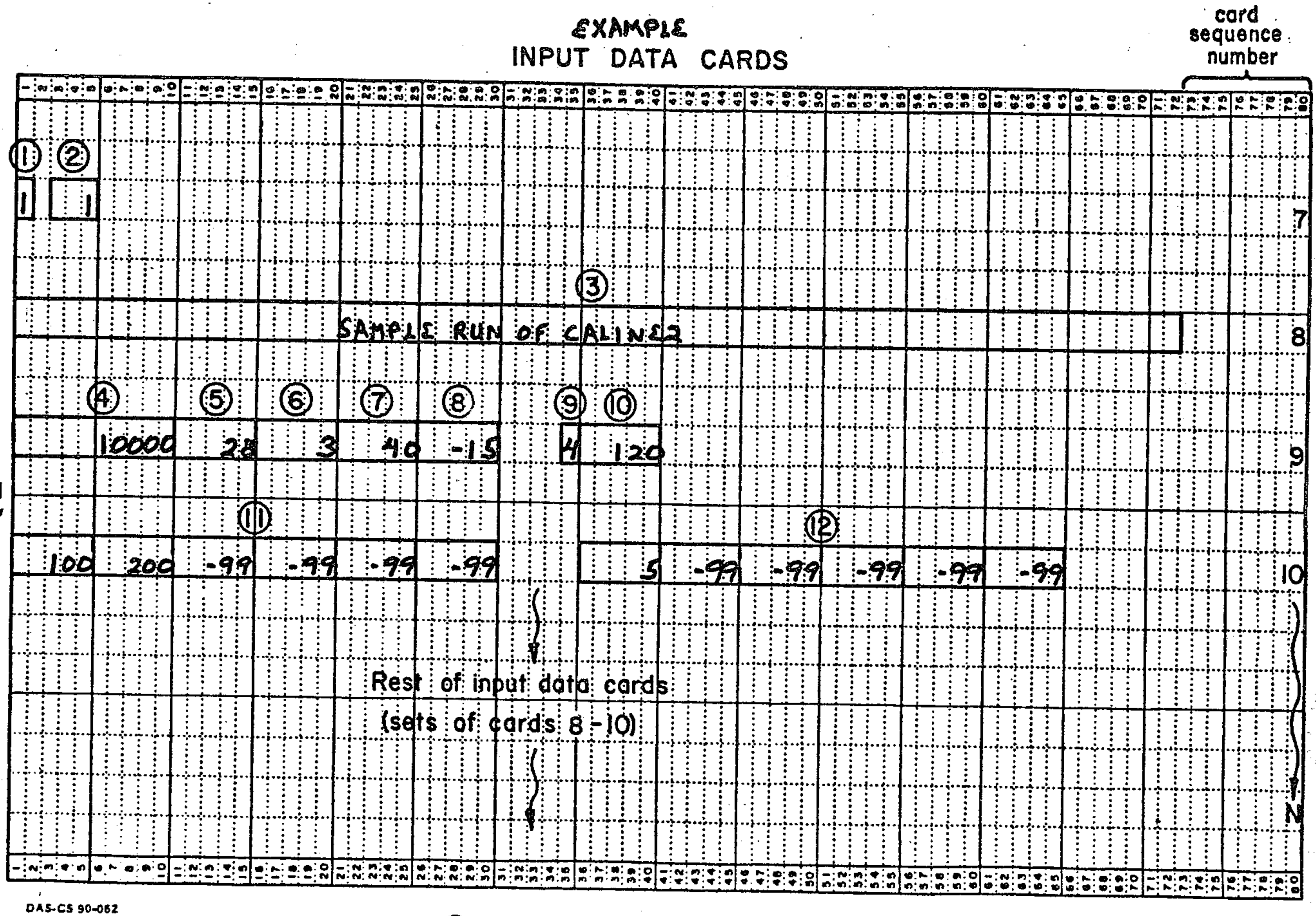
DAS-CS 90-062

① - DATA ITEM, SEE NŌTES

Ø - INDICATES A NUMERIC ZERŌ

Ō - INDICATES AN ALPHABETIC "O"

EXAMPLE
INPUT DATA CARDS



① - DATA ITEM, SEE NOTES

CALINE2: CALIFORNIA LINE SOURCE DISPERSION MODEL, REVISED JANUARY, 1975

SAMPLE RUN OF CALINE2

PREDICTED CO CONCENTRATION (PPM)

VARIABLES			RECEPTOR HEIGHT (Z FEET)	DISTANCE PERPENDICULAR TO HIGHWAY (D FEET) 100	200
VPH=	10000				
EF=	28	GMS/MI			
U=	3	MPH	5	4.0	2.4
PHI=	40	DEGREES			
H=	-15	FEET			
CLAS=	4	(D)			
W=	120	FEET			

MIXING CELL CONCENTRATION = 14.1 PPM

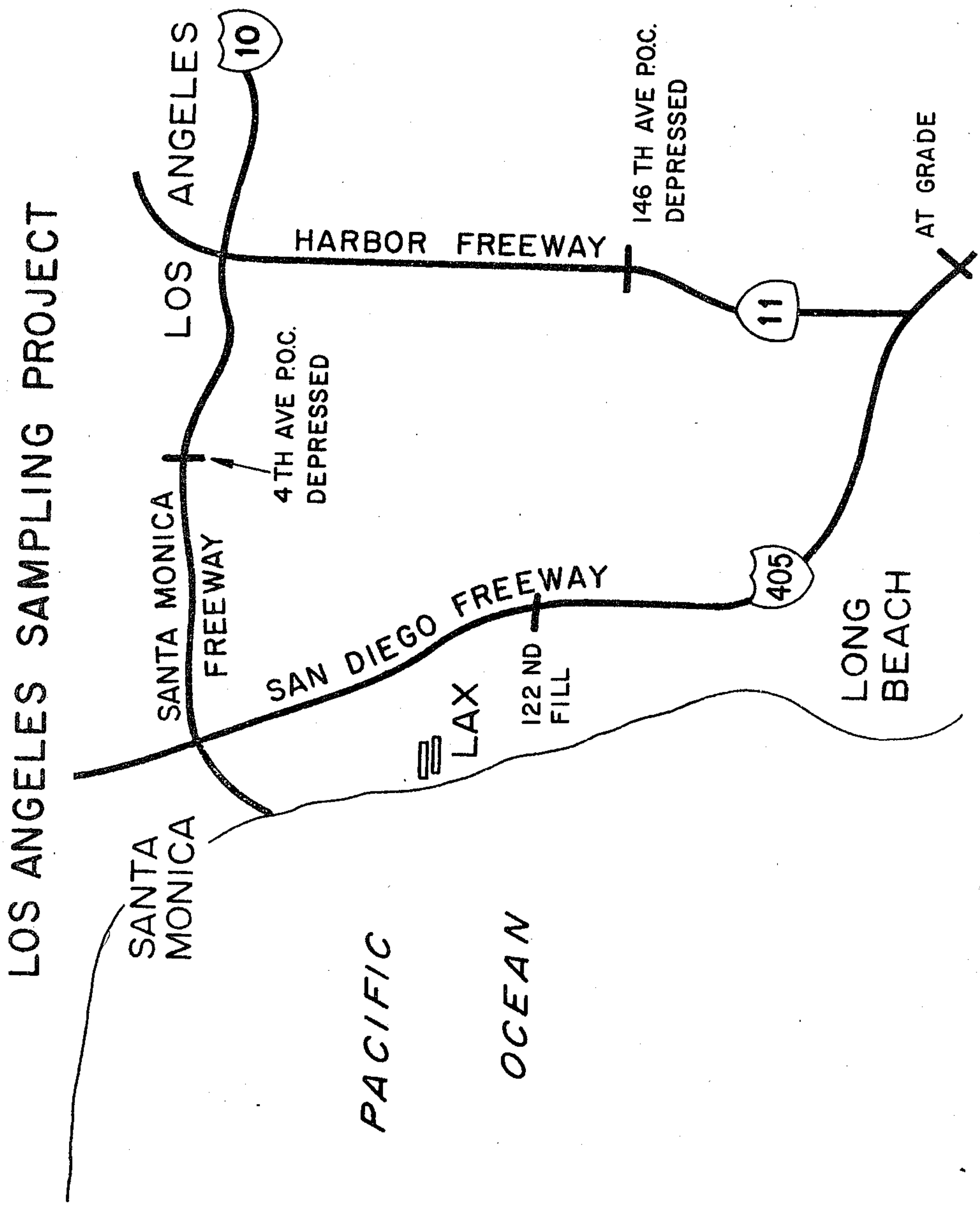

LOS ANGELES SAMPLING PROJECT
LOS ANGELES
10
HARBOR FREEWAY
146 TH AVE P.O.C.
DEPRESSED
11
AT GRADE
4 TH AVE P.O.C.
DEPRESSED
SANTA MONICA
FREEWAY
SAN DIEGO FREEWAY
405
122 ND
FILL
LAX
LONG
BEACH
SANTA
MONICA
PACIFIC
OCEAN

FIGURE 3-20

IN-SECTION STUDY

Purpose:

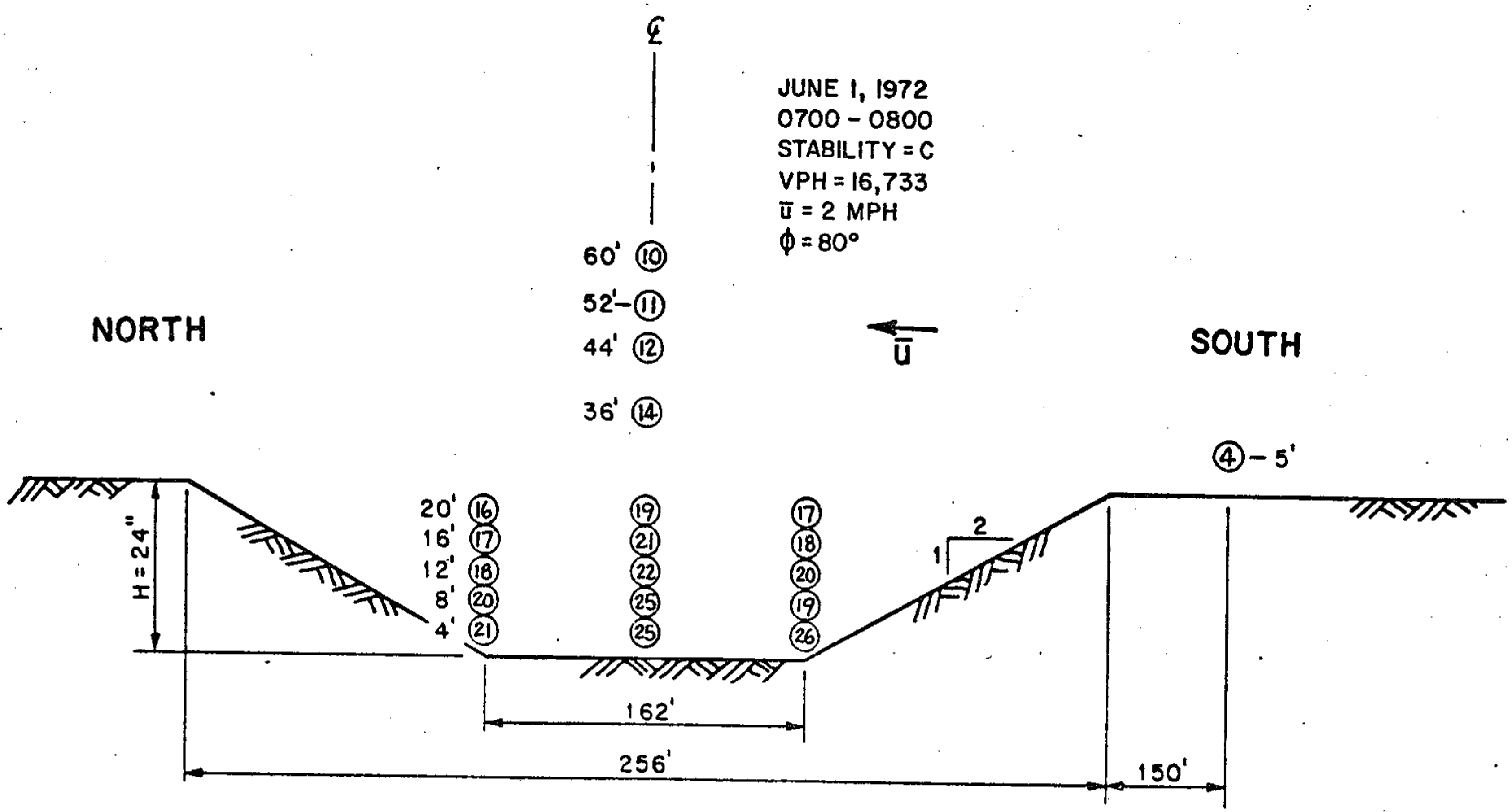
1. Evaluate CO concentration that drivers are exposed to.

2. Analyze the spatial distribution of the mixing cell concentrations.

3. Analyze vertical CO gradients over the median.

4. Evaluate the effects of Depressed Sections on horizontal dispersion of pollutants.

5. Evaluate land use effects on pollutant dispersion.



SURFACE ROUGHNESS CHARACTERISTICS
RESIDENTIAL AREA, 2-STORY HOUSES

CROSSWIND CO CONCENTRATIONS SANTA MONICA FREEWAY
AT 4TH AVE P.O.C. IN-SECTION STUDY

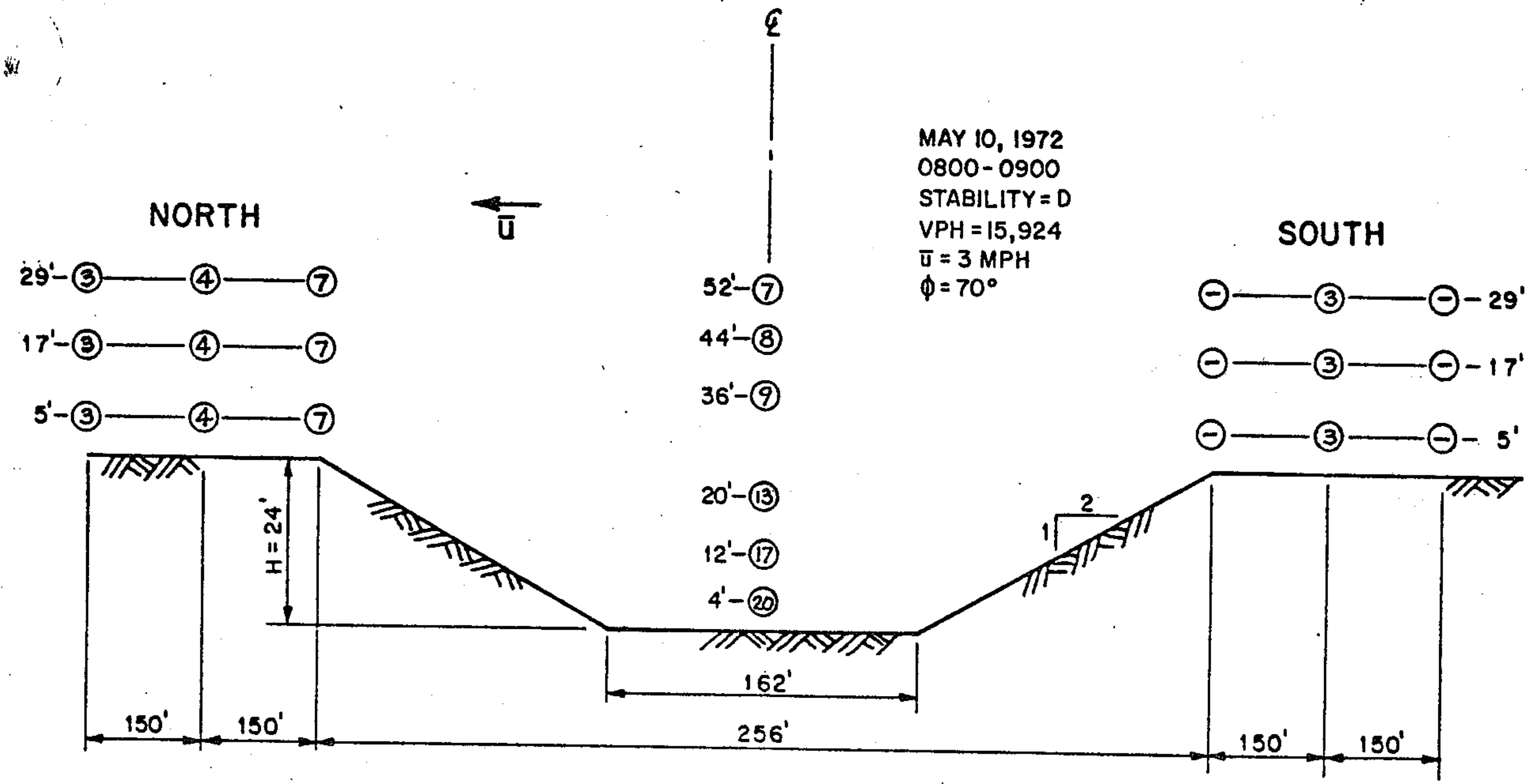
FIGURE 3-21

DOWNWIND DISPERSION STUDY

Purpose:

1. Determine the vertical distribution of CO.

2. Determine where downwind ambient CO concentrations are reached.



SURFACE ROUGHNESS CHARACTERISTICS
RESIDENTIAL AREA, 2-STORY HOUSES

CROSSWIND CO CONCENTRATIONS, SANTA MONICA FREEWAY
AT 4TH AVE P.O.C. DOWNWIND STUDY

FIGURE 3-22

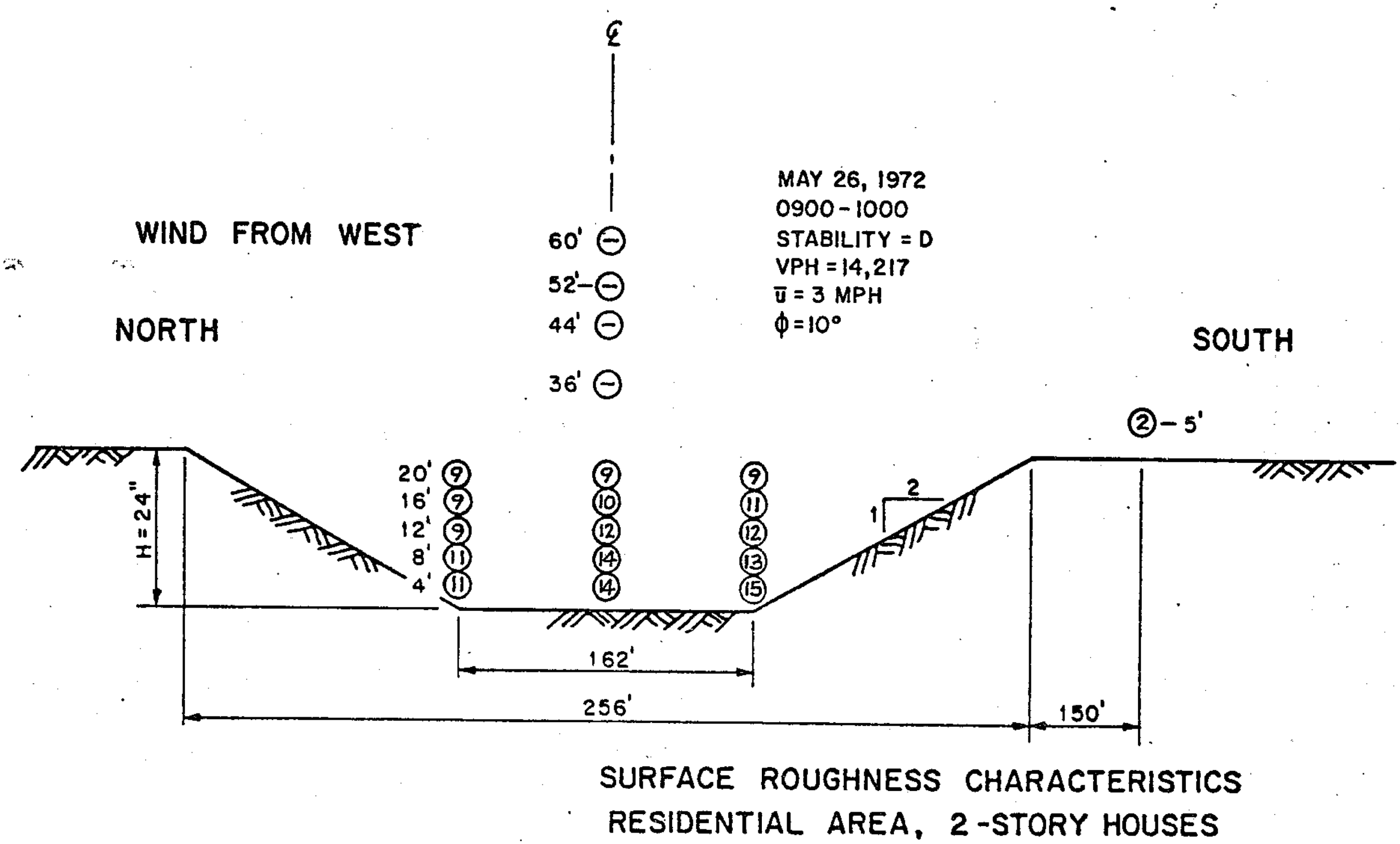
IN-SECTION FOR PARALLEL WINDS

Purpose:

1. Buildup of CO concentrations on roadway.

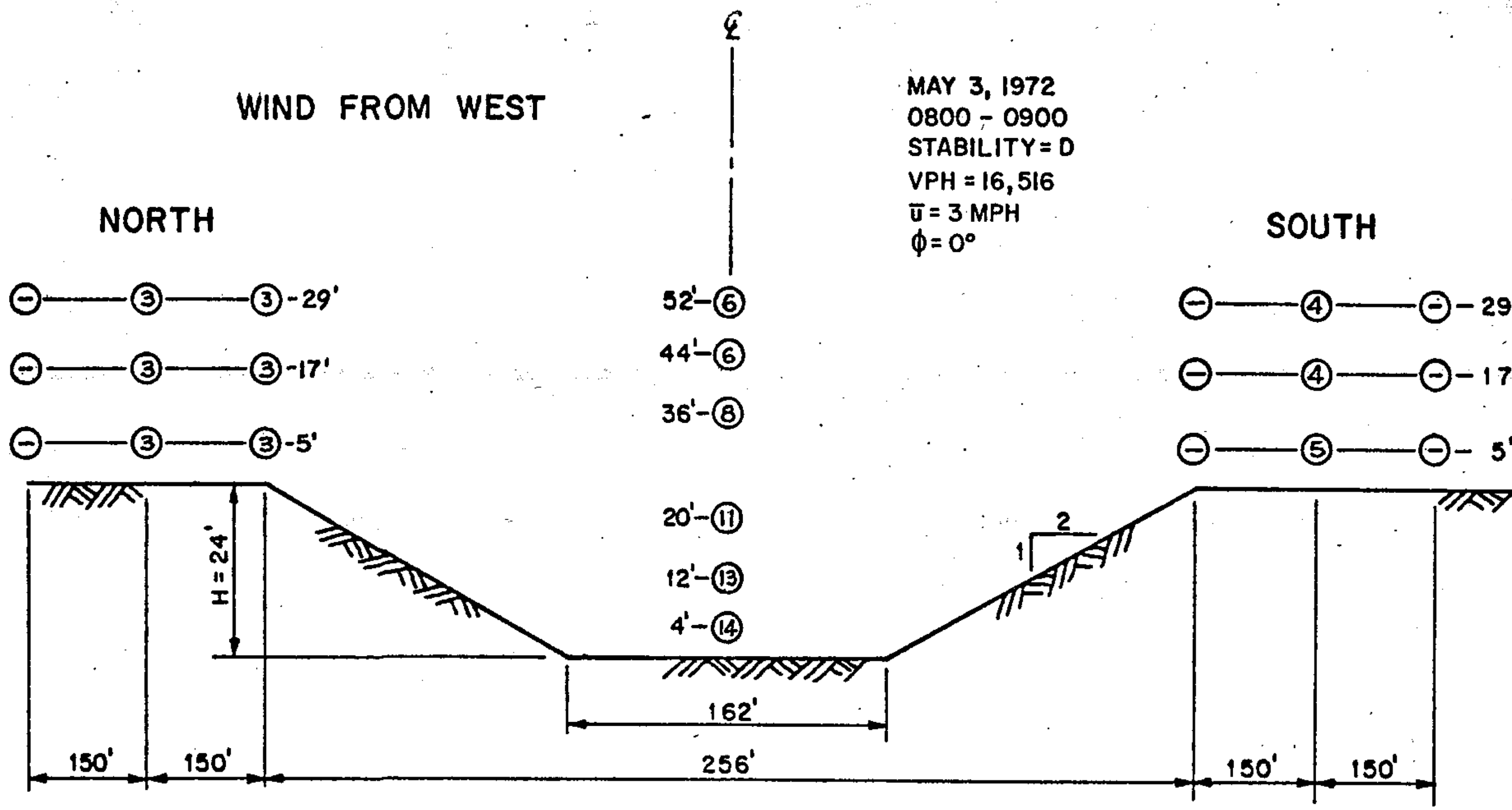
2. Effects of depressed section on pollution buildup.

3. Vertical distribution of CO for parallel wind buildup.



PARALLEL WIND CO CONCENTRATIONS, SANTA MONICA FREEWAY
AT 4TH AVE P.O.C. IN-SECTION STUDY

FIGURE 3-23



SURFACE ROUGHNESS CHARACTERISTICS
RESIDENTIAL AREA, 2-STORY HOUSES

PARALLEL WIND CO CONCENTRATIONS, SANTA MONICA FREEWAY
AT 4TH AVE P.O.C. HORIZONTAL STUDY

FIGURE 3-24

DEPRESSED SECTION CROSSWINDS

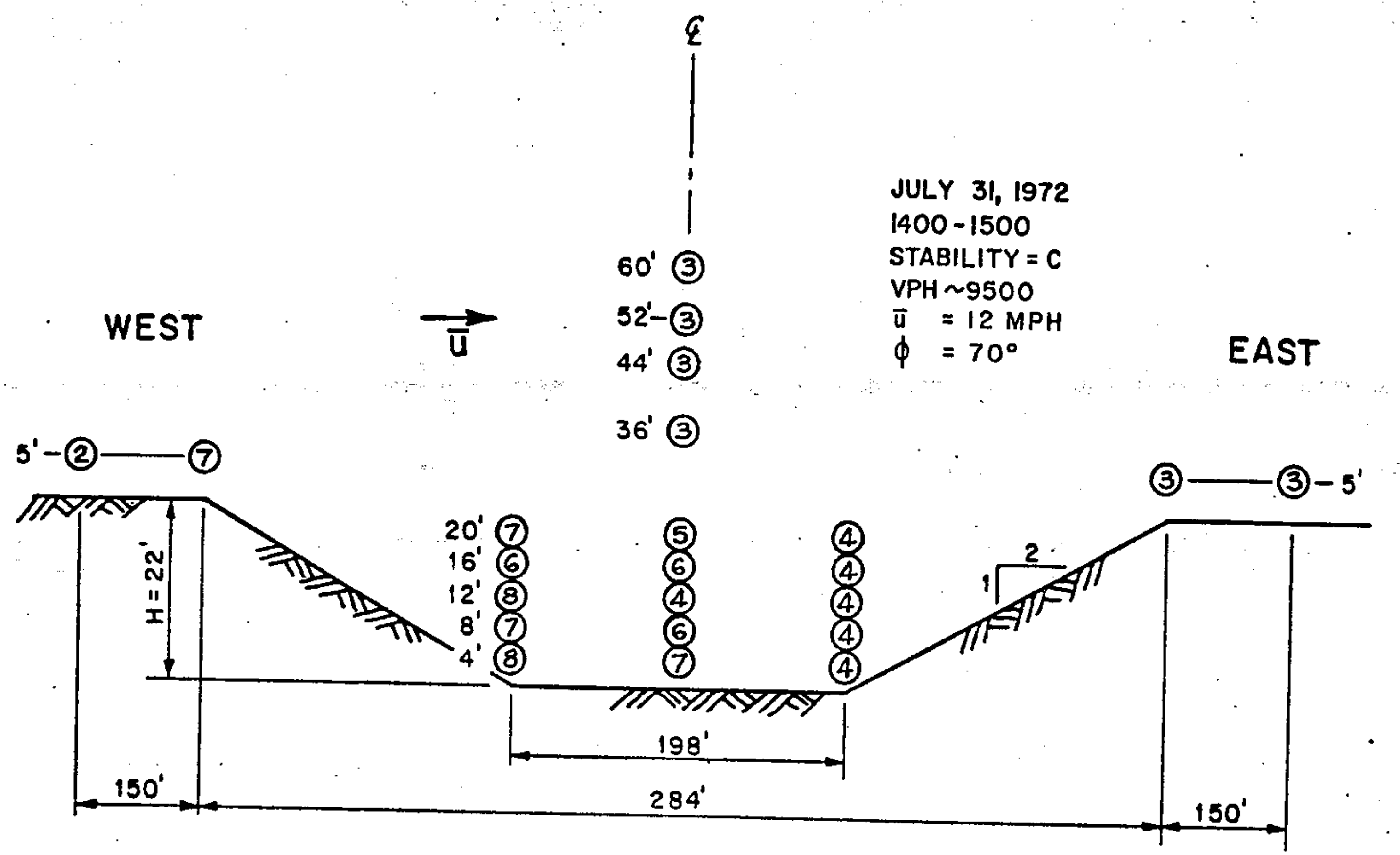
Purpose:

1. Evaluate areodynamic eddies in the section in terms of horizontal gradients.

2. Evaluate vertical CO gradients within section and downwind.

3. Evaluate downwind dispersion and to point where ambient levels are reached.

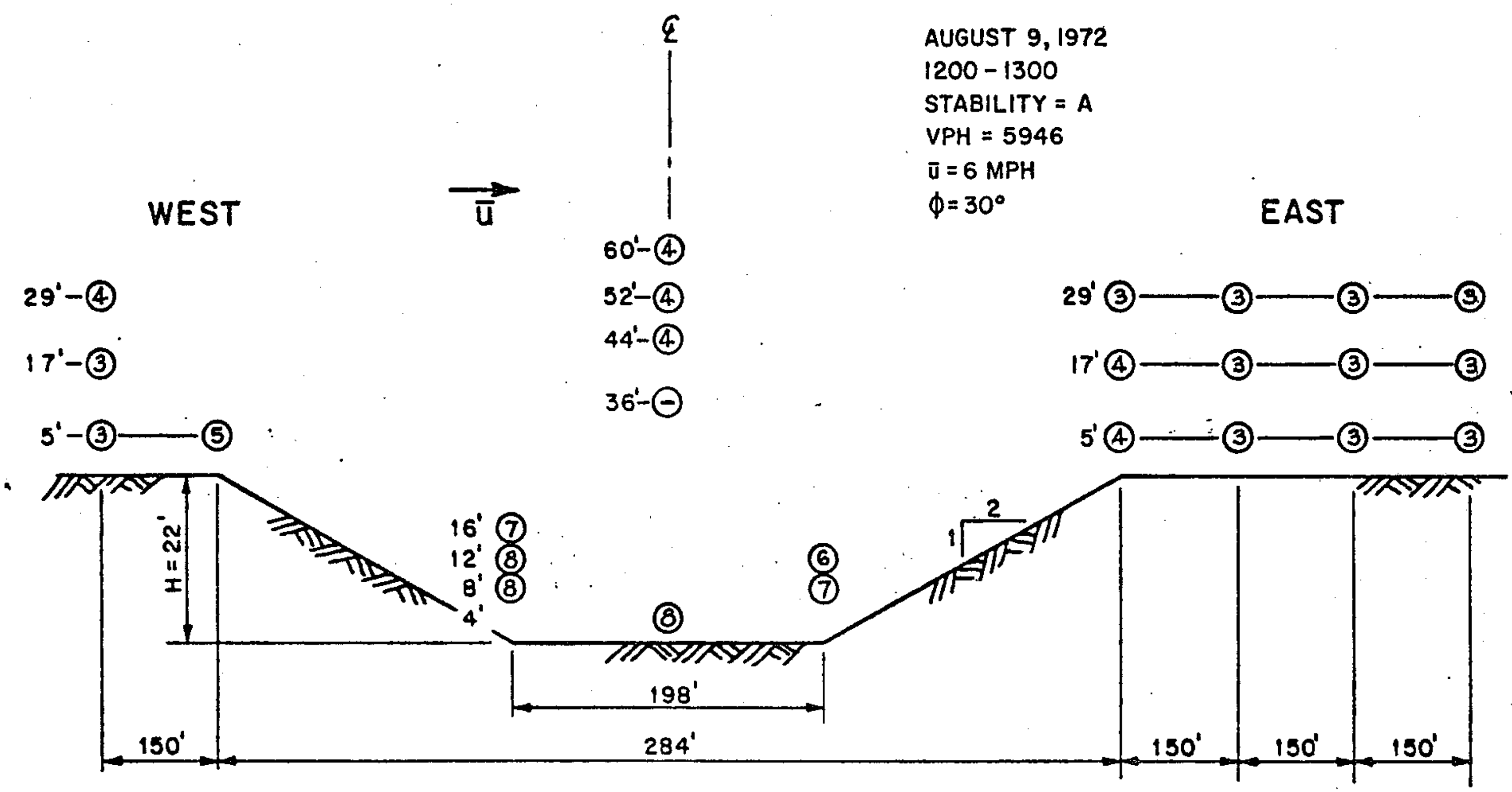
4. Compare land use effects on pollutant dispersion.



SURFACE ROUGHNESS CHARACTERISTICS
RESIDENTIAL AREA, 1-STORY HOUSES

CROSSWIND CO CONCENTRATIONS, AERODYNAMIC EDDIES, HARBOR FREEWAY
AT 146TH AVE IN-SECTION STUDY

FIGURE 3-25



SURFACE ROUGHNESS CHARACTERISTICS
RESIDENTIAL AREA, 1-STORY HOUSES

CROSSWIND CO CONCENTRATIONS HARBOR FREEWAY
AT146TH AVE HORIZONTAL STUDY

FIGURE 3-26

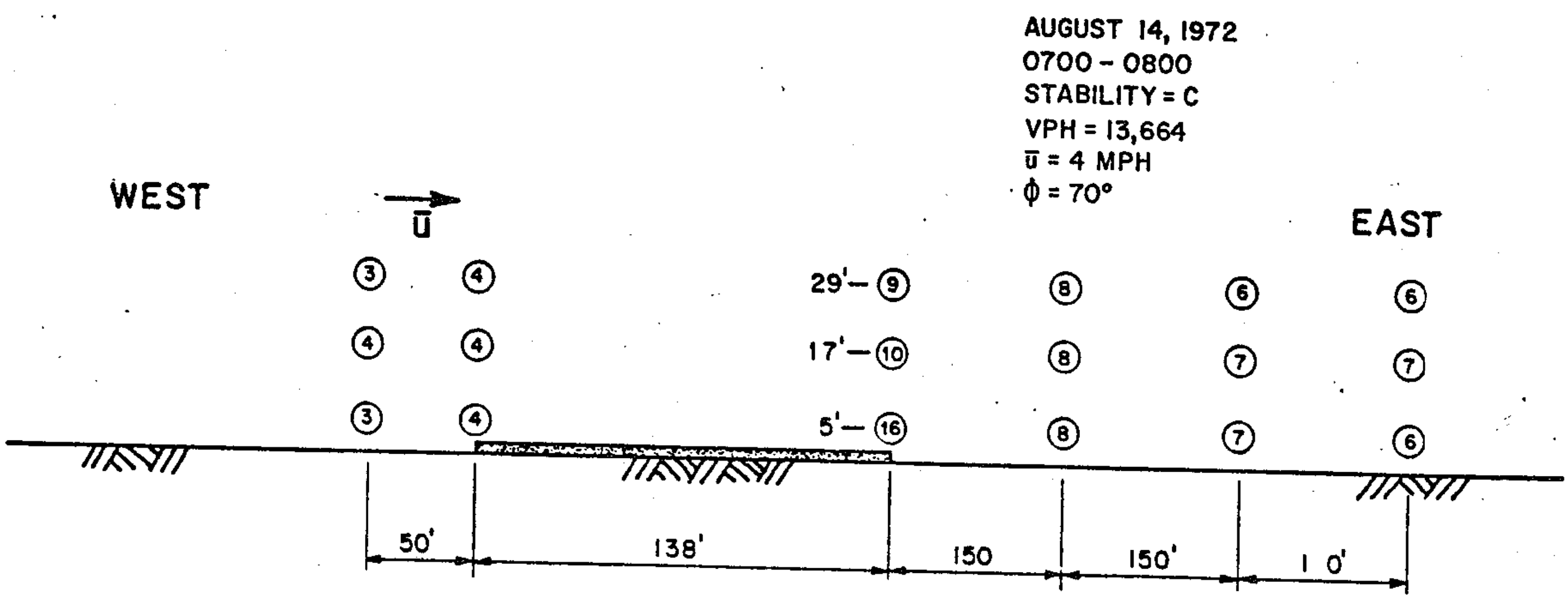
AT-GRADE SECTION

Purpose:

1. Compare mixing cell concentrations with depressed sections.

2. Evaluate horizontal and vertical CO distributions.

3. Evaluate land use on pollutant dispersion.



SURFACE ROUGHNESS CHARACTERISTICS
FLAT, OPEN FIELD

CROSSWIND CO CONCENTRATIONS SAN DIEGO FREEWAY
AT WEIGH STATION, AUGUST HORIZONTAL STUDY

FIGURE 3-27

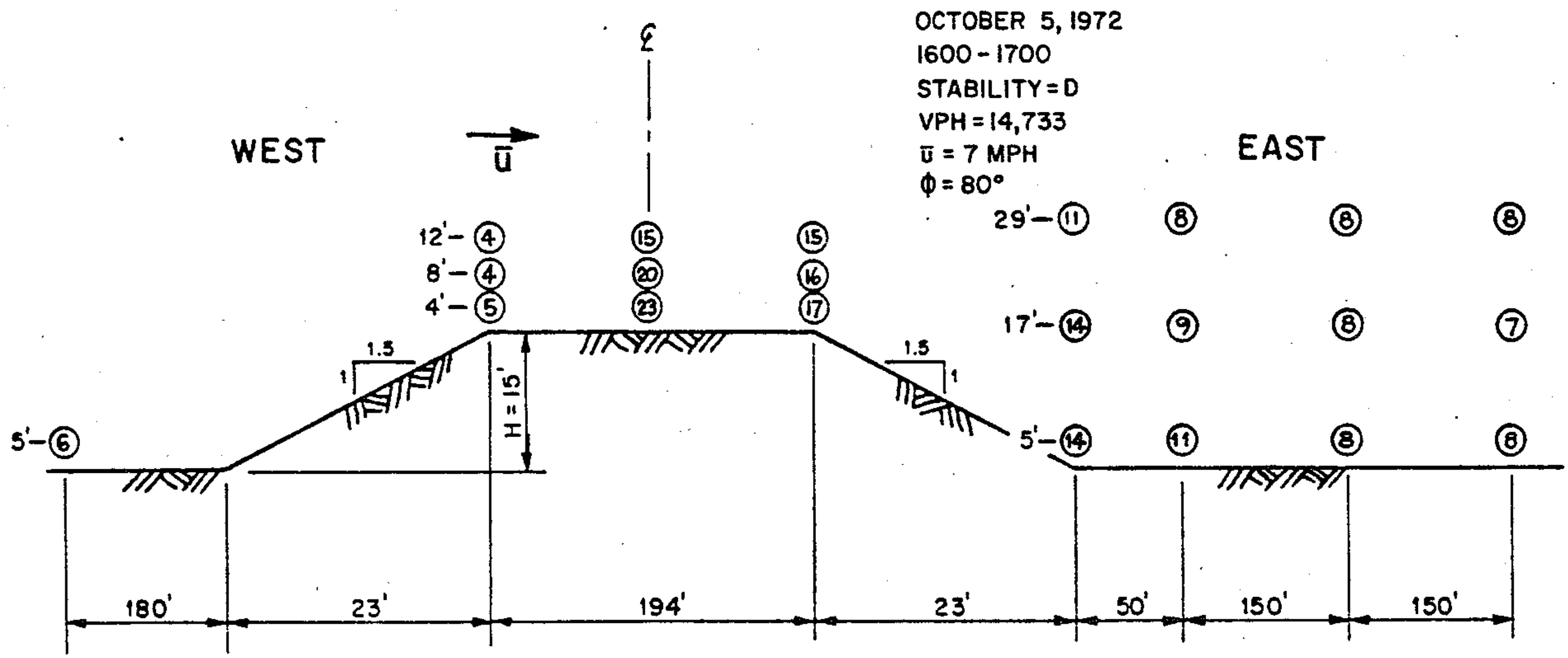
ELEVATED SECTION

Purpose:

1. Study aerodynamic effects downwind of fill on pollutant dispersion.

2. Compare elevated source of releases with at-grade and depressed sections on downwind dispersion.

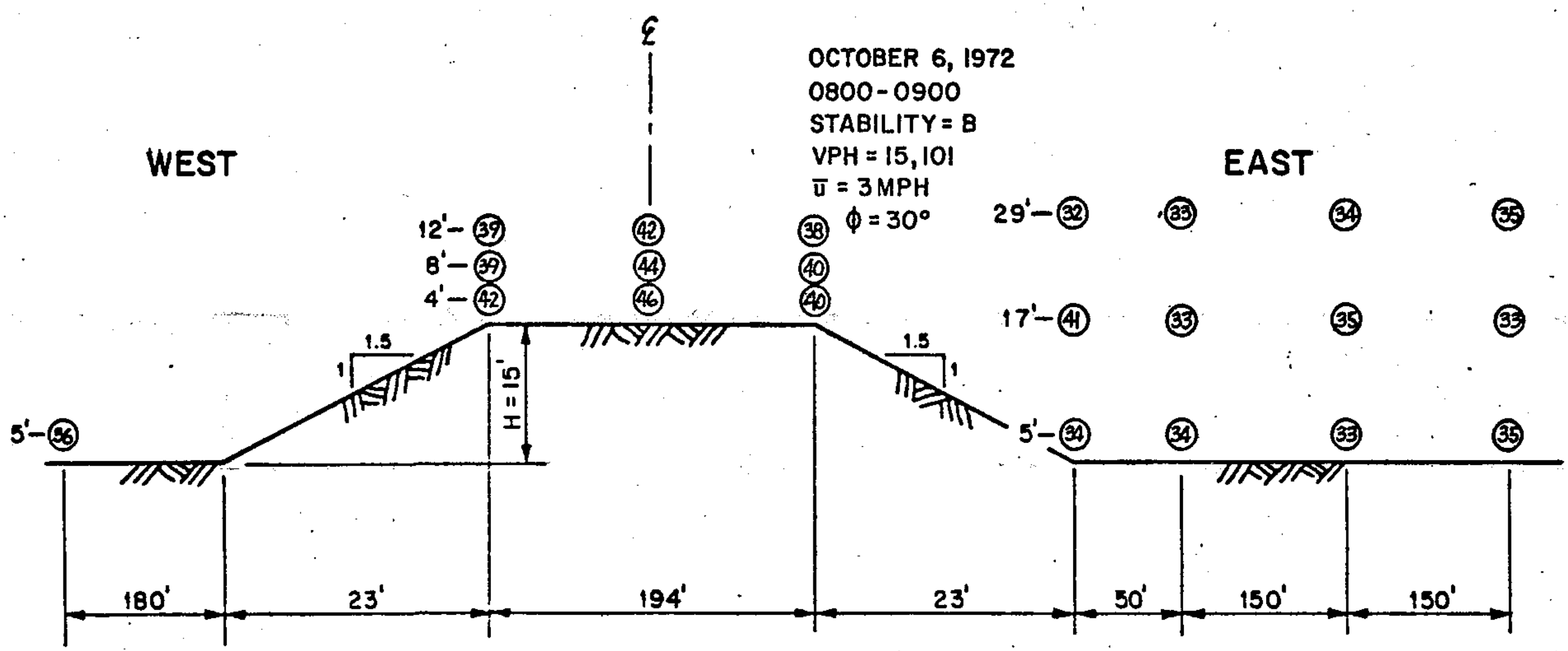
3. Evaluate the horizontal and vertical dispersion of pollutants.



SURFACE ROUGHNESS CHARACTERISTICS
FLAT, OPEN FIELD

CROSSWIND CO CONCENTRATIONS, SAN DIEGO FREEWAY
AT 122ND AVE HORIZONTAL STUDY

FIGURE 3-28



SURFACE ROUGHNESS CHARACTERISTICS
FLAT, OPEN FIELD

CROSSWIND CO CONCENTRATIONS, SAN DIEGO FREEWAY
AT 122ND AVE HORIZONTAL STUDY

FIGURE 3-29

DATA FROM RESEARCH VAN

Pollutants Monitored:

1) CO
2) THC & CH_4
3) NO_x, NO, NO_2
4) O_3
5) H_2S
6) SO_2

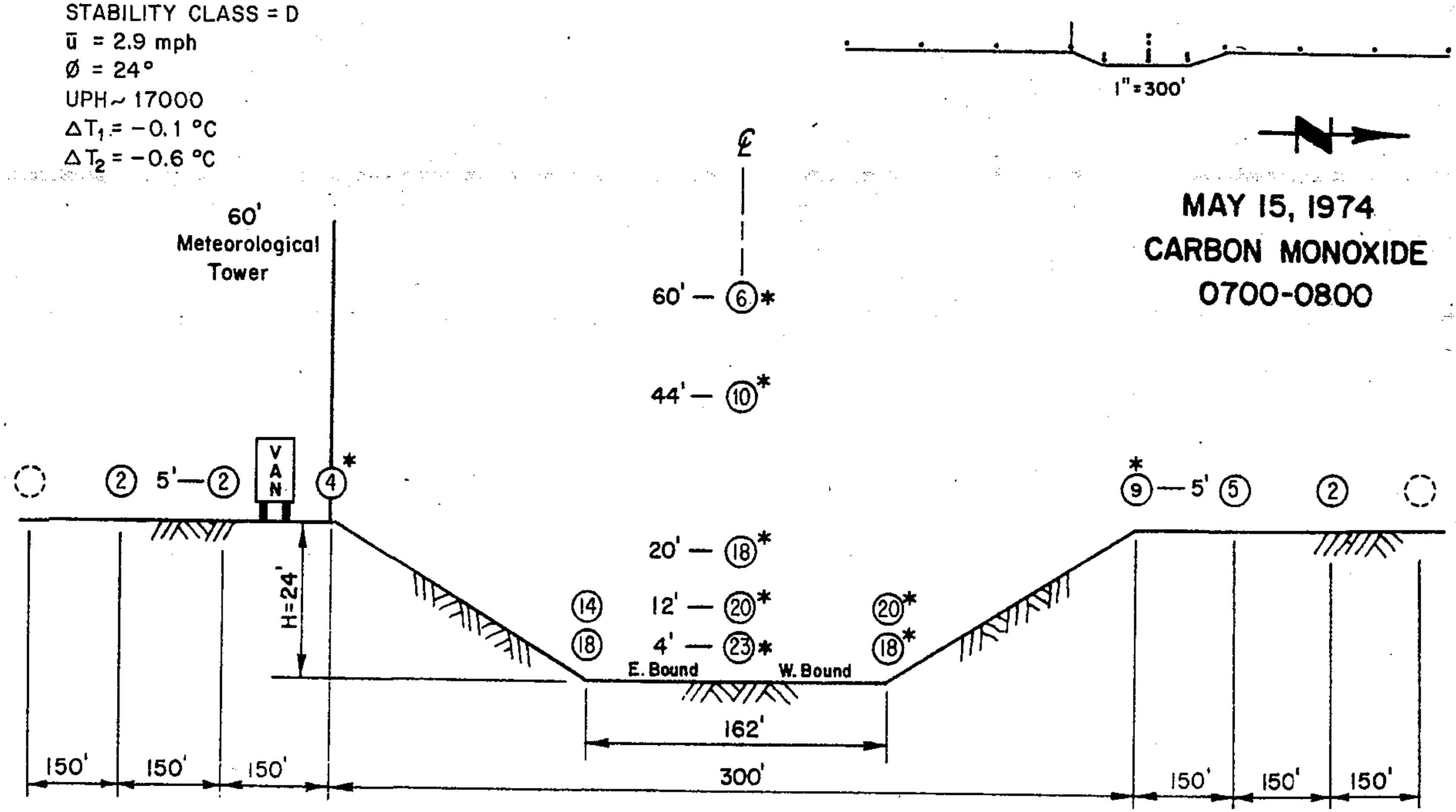
Meteorological Variables Monitored:

1) turbulence
2) surface lapse rates
3) wind shear
4) UV
5) humidity
6) wind speed and direction

PROBE LOCATIONS
SANTA MONICA FWY @ 4 th AVE. P.O.C.

STABILITY CLASS = D
$\bar{u}$ = 2.9 mph
ϕ = 24°
UPH ~ 17000
ΔT_1 = −0.1 °C
ΔT_2 = −0.6 °C

MAY 15, 1974
CARBON MONOXIDE
0700-0800



* Probes for bag box

FIGURE 3-29A

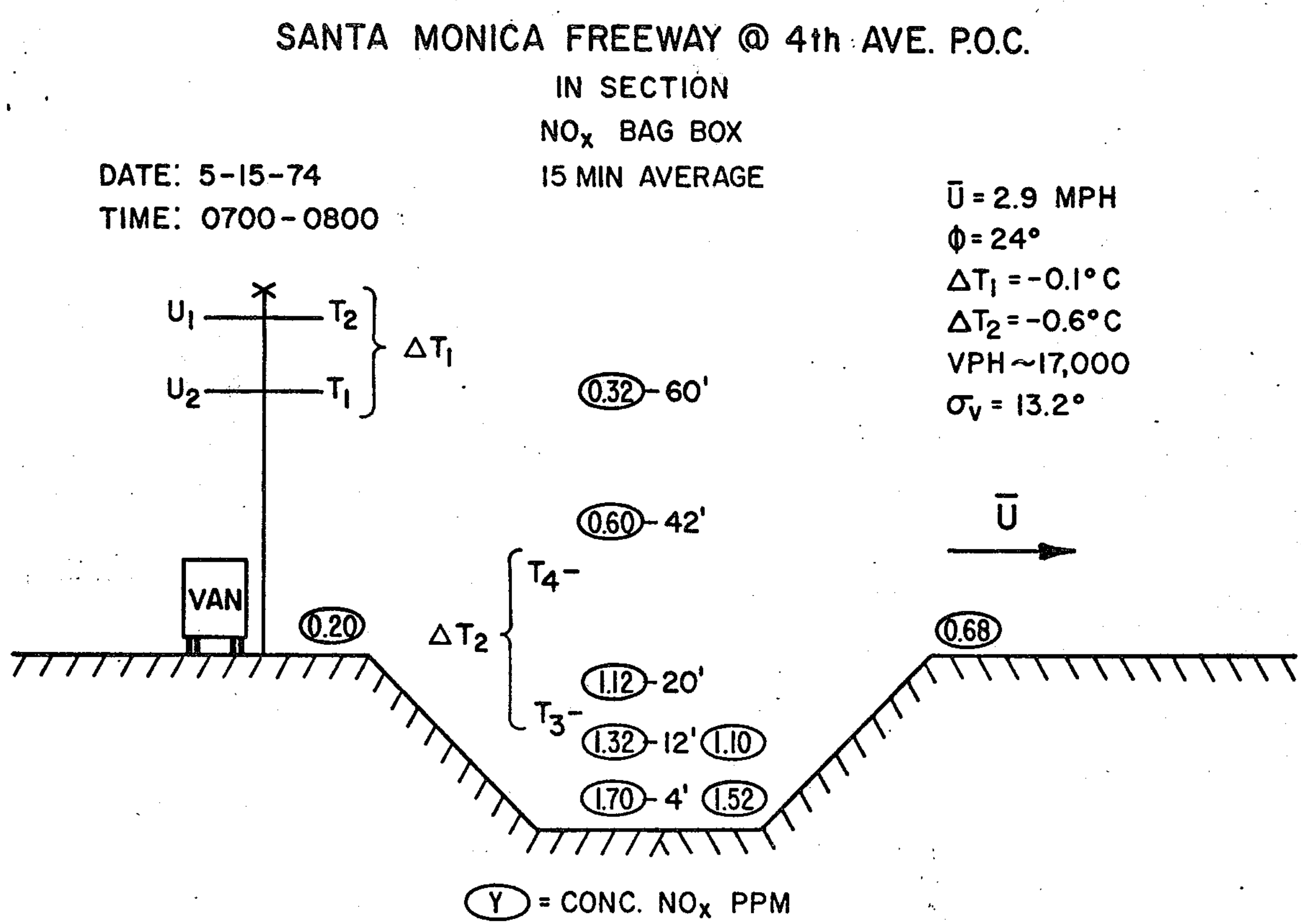

SANTA MONICA FREEWAY @ 4th AVE. P.O.C.
IN SECTION
NOx BAG BOX
15 MIN AVERAGE
DATE: 5-15-74
TIME: 0700-0800
Ū = 2.9 MPH
ϕ = 24°
ΔT1 = -0.1° C
ΔT2 = -0.6° C
VPH ~ 17,000
σv = 13.2°
U1
U2
T2
T1
ΔT1
Ū
VAN
0.20
0.32 - 60'
0.60 - 42'
T4
ΔT2
T3
1.12 - 20'
1.32 - 12' 1.10
1.70 - 4' 1.52
0.68
Y = CONC. NOx PPM

FIGURE 3-30

SANTA MONICA FREEWAY @ 4th AVE. P.O.C.

IN SECTION

NO_2/NO-BAG BOX

15 MIN AVERAGE

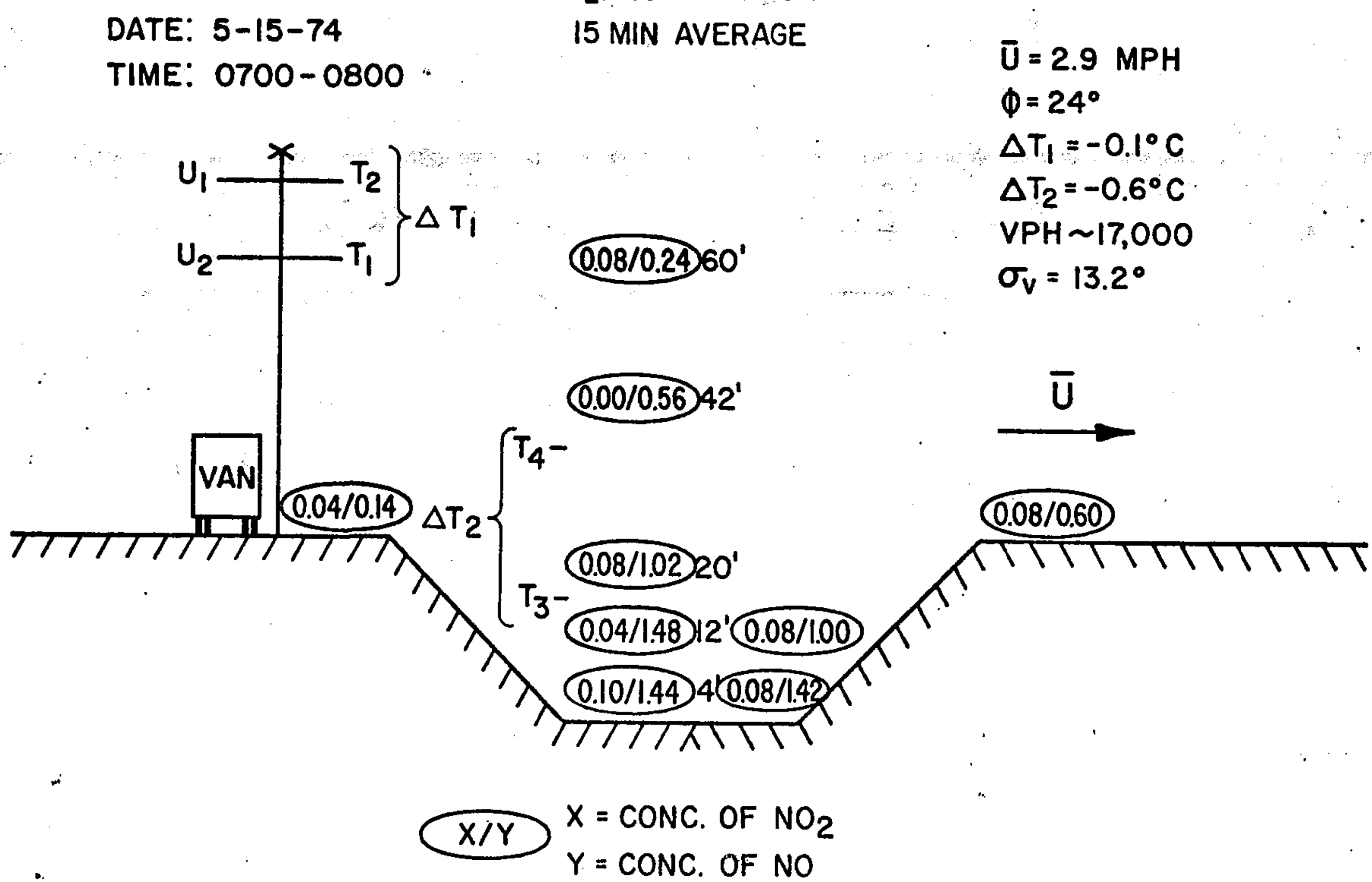


FIGURE 3-31

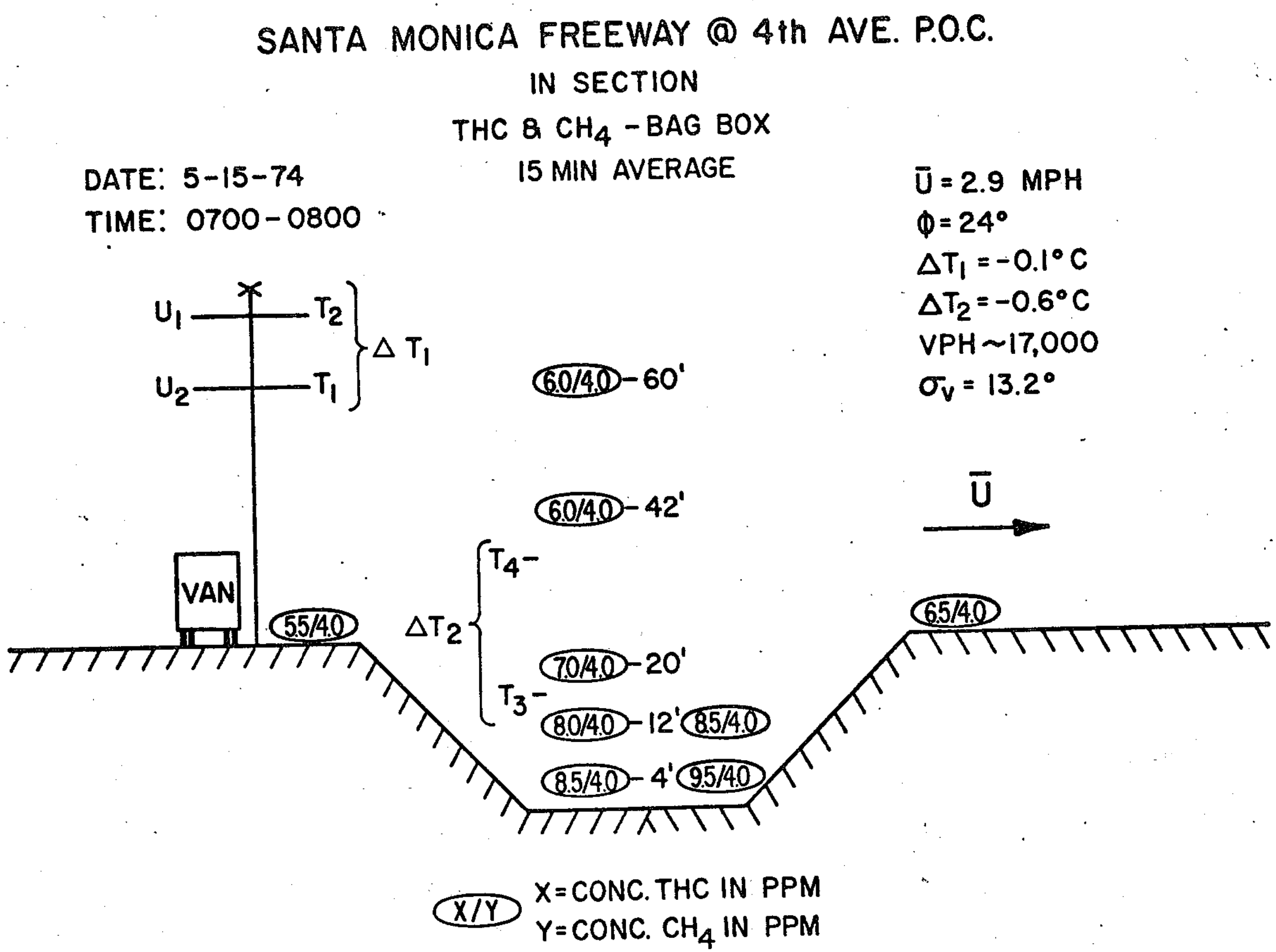
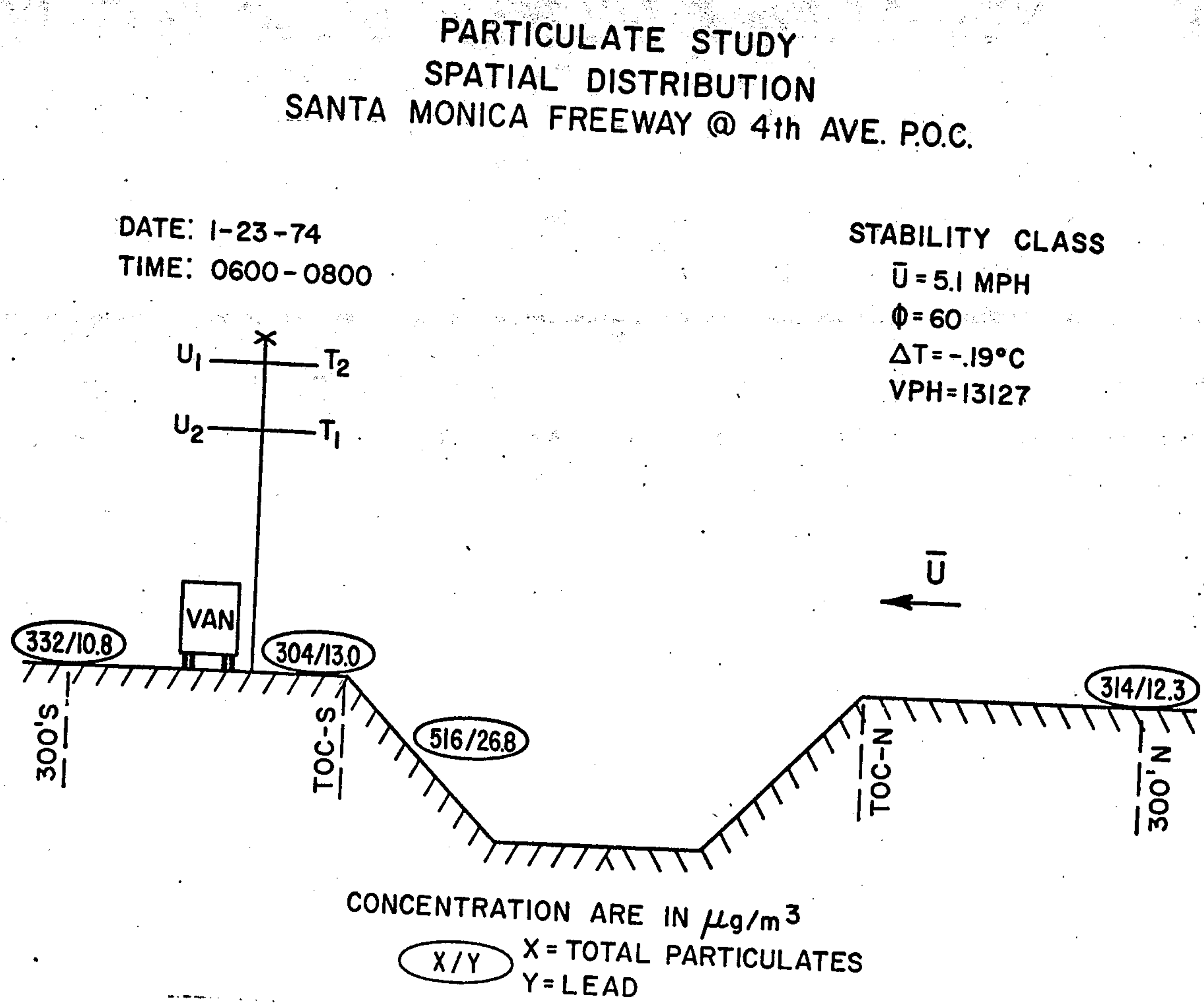

SANTA MONICA FREEWAY @ 4th AVE. P.O.C.
IN SECTION
THC & CH_4 - BAG BOX
15 MIN AVERAGE
DATE: 5-15-74
TIME: 0700-0800
$\bar{U}$ = 2.9 MPH
ϕ = 24°
ΔT_1 = -0.1° C
ΔT_2 = -0.6° C
VPH ~ 17,000
σ_v = 13.2°
U_1
U_2
T_2
T_1
ΔT_1
T_4
T_3
ΔT_2
VAN
5.5/4.0
6.0/4.0 - 60'
6.0/4.0 - 42'
7.0/4.0 - 20'
8.0/4.0 - 12' 8.5/4.0
8.5/4.0 - 4' 9.5/4.0
6.5/4.0
$\bar{U}$
X/Y
X = CONC. THC IN PPM
Y = CONC. CH_4 IN PPM

FIGURE 3-33



PARTICULATE STUDY
SPATIAL DISTRIBUTION
SANTA MONICA FREEWAY @ 4th AVE. P.O.C.
DATE: 1-23-74
TIME: 0600-0800
STABILITY CLASS
Ū = 5.1 MPH
ϕ = 60
ΔT = -.19°C
VPH = 13127
U1
T2
U2
T1
VAN
Ū
332/10.8
304/13.0
516/26.8
314/12.3
300'S
TOC-S
TOC-N
300'N
CONCENTRATION ARE IN μg/m3
X/Y
X = TOTAL PARTICULATES
Y = LEAD

FIGURE 3-34

MODEL VALIDATION

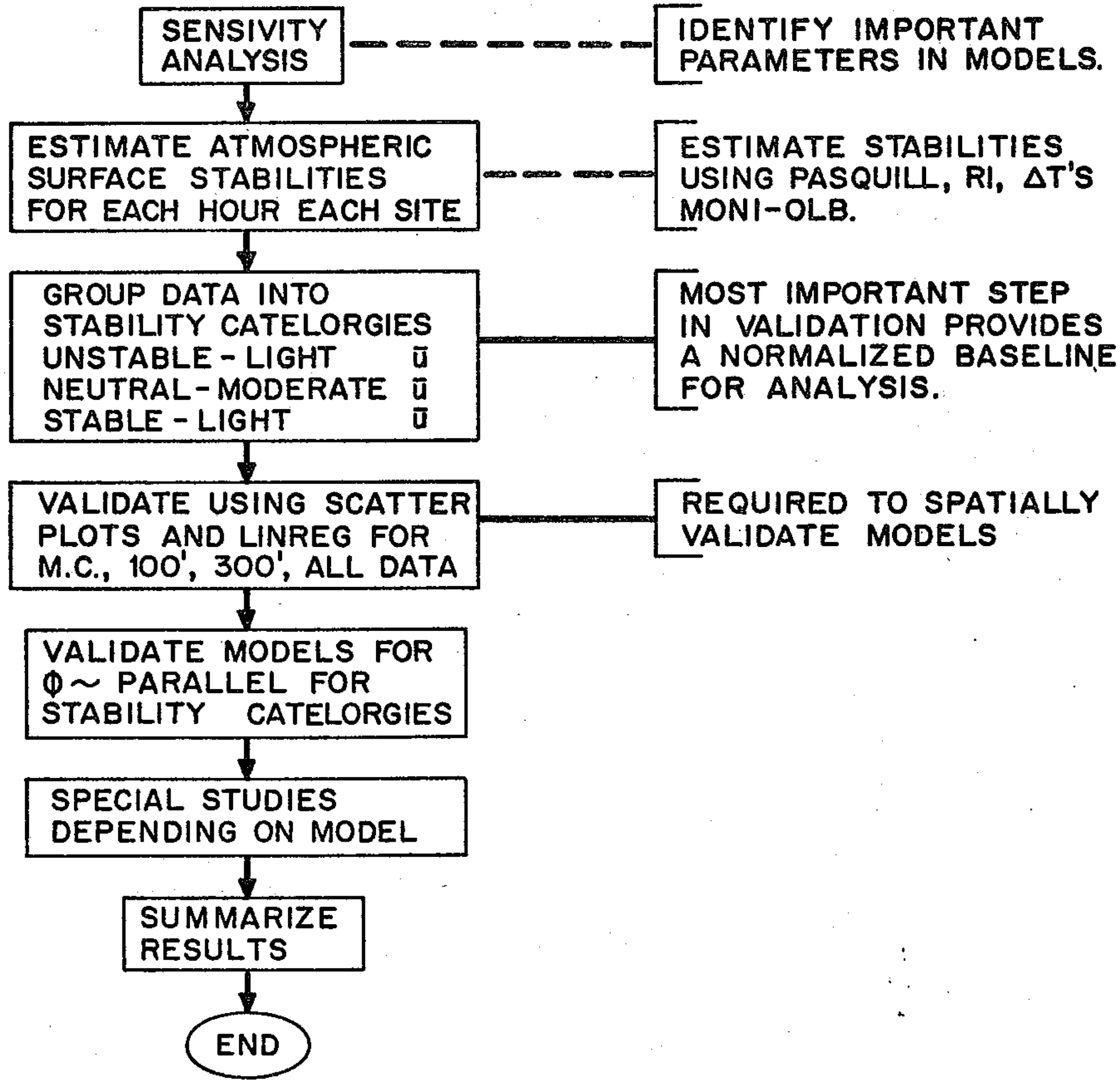
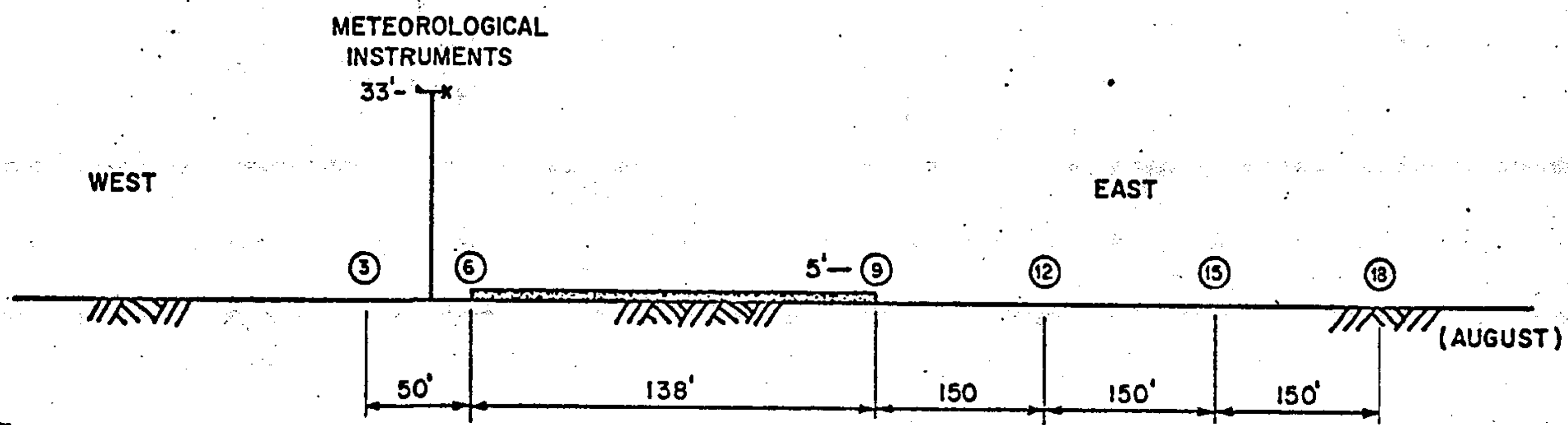


FIGURE 34A



① DENOTES PROBE NUMBER

PROBE LOCATION SAN DIEGO FREEWAY
AT WEIGH STATION, HORIZONTAL STUDY

FIGURE 3-35

AT-GRADE SITE, CROSSWIND
MIXING CELL POINTS

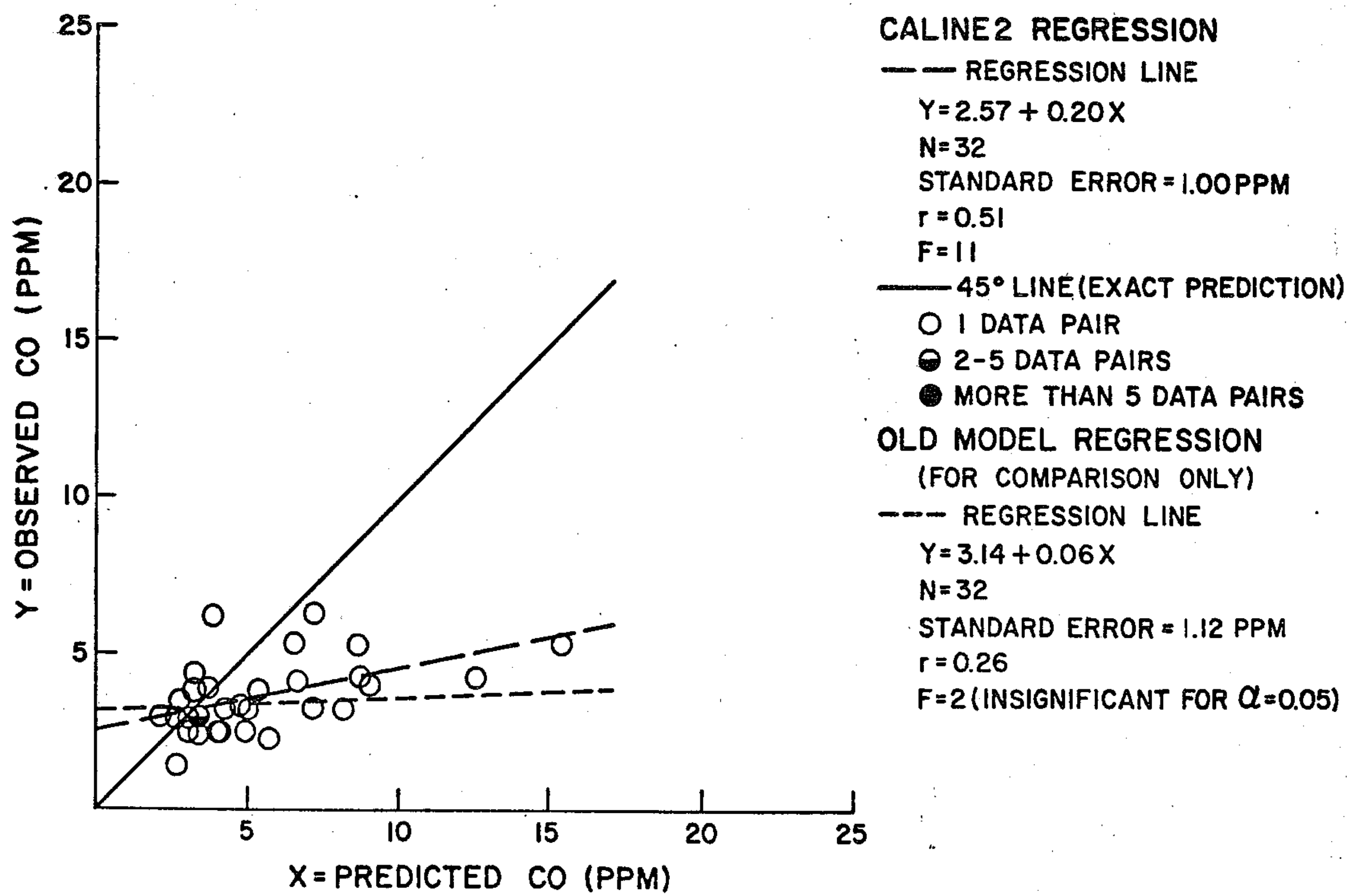


FIGURE 3-36

AT-GRADE SITE, CROSSWIND

OFF-HIGHWAY GROUND-LEVEL POINTS

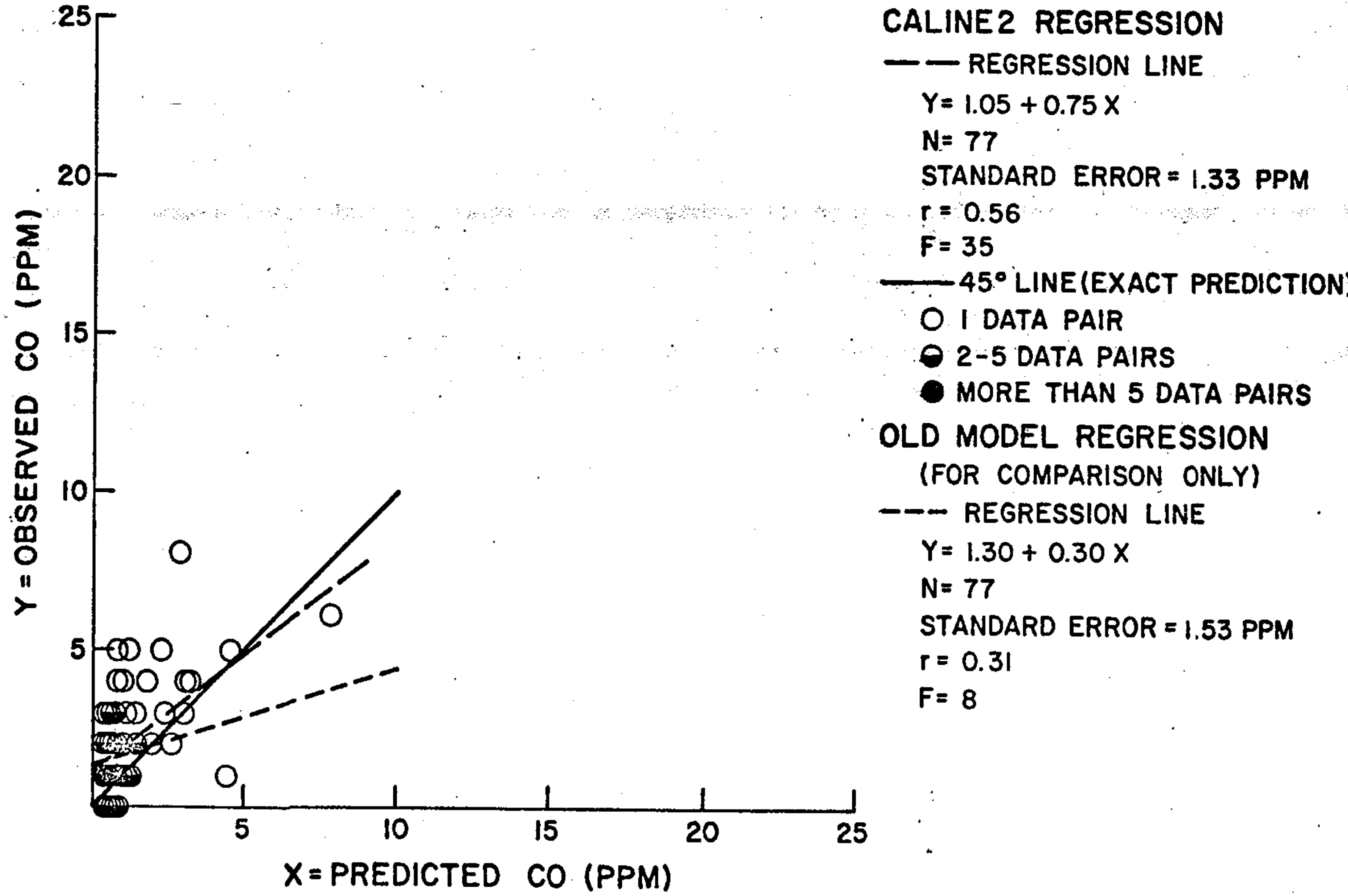


FIGURE 3-37

AT-GRADE SITE, CROSSWIND

OFF-HIGHWAY GROUND-LEVEL & MIXING CELL POINTS

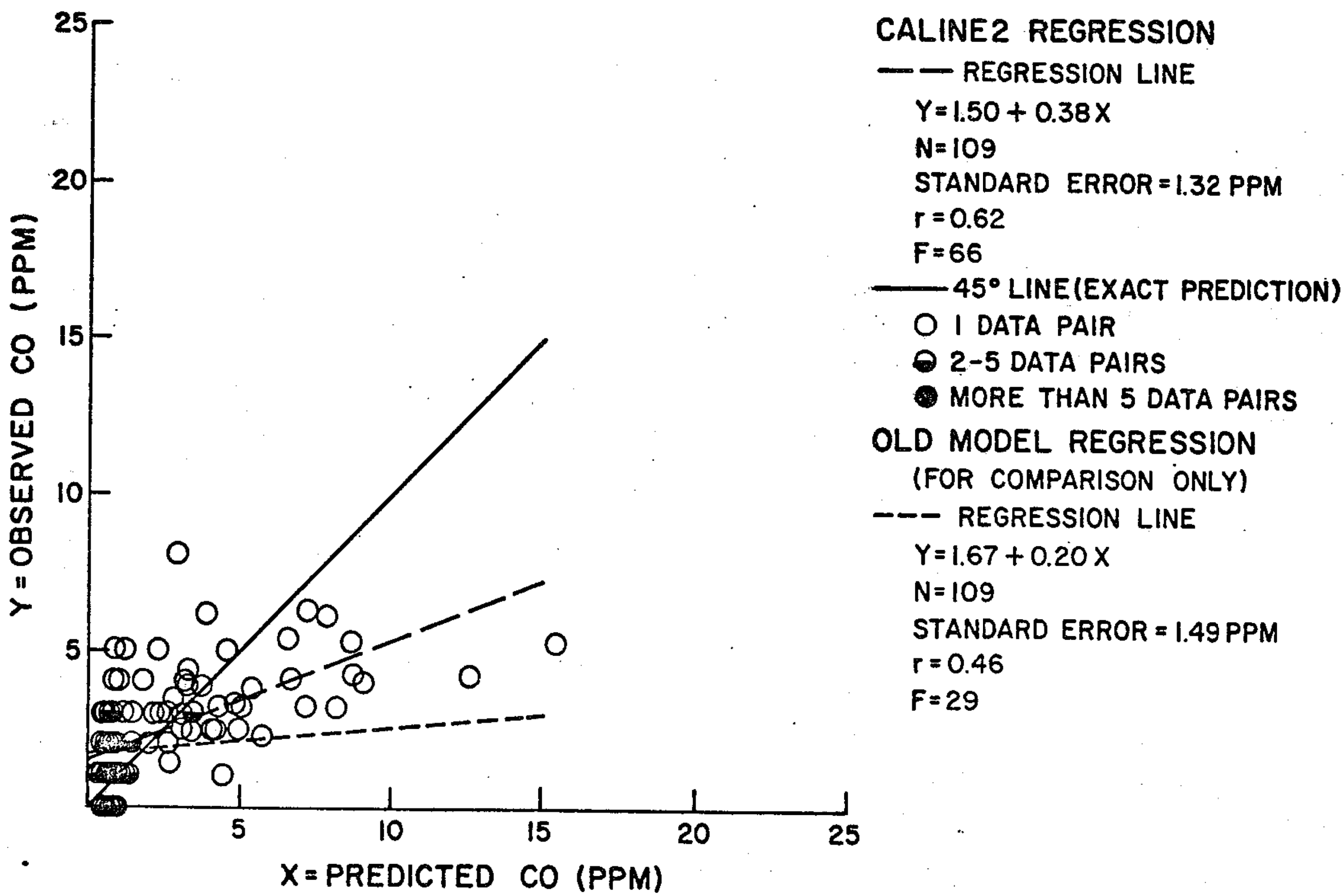


FIGURE 3-38

AT-GRADE SITE, PARALLEL WIND

MIXING CELL POINTS

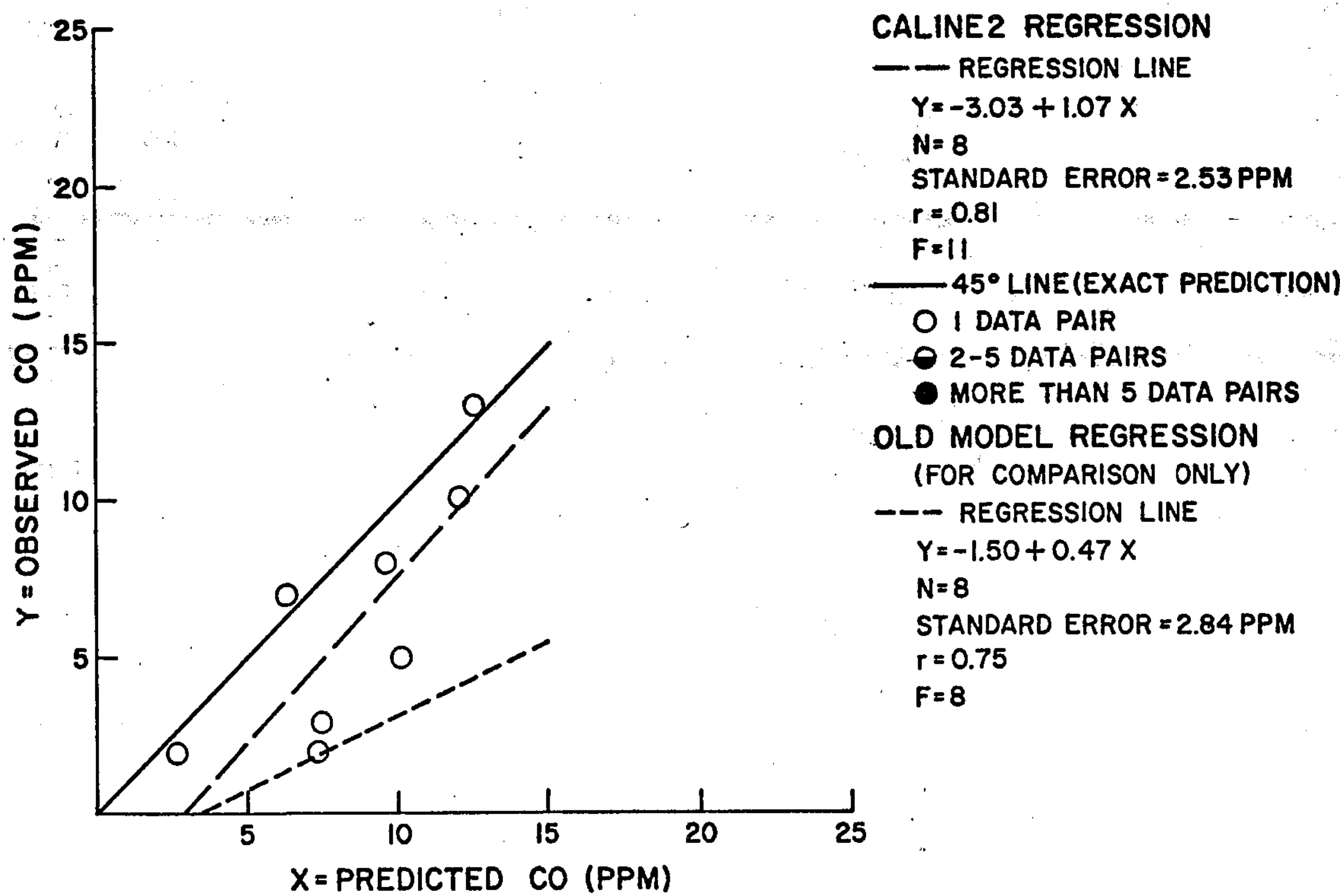
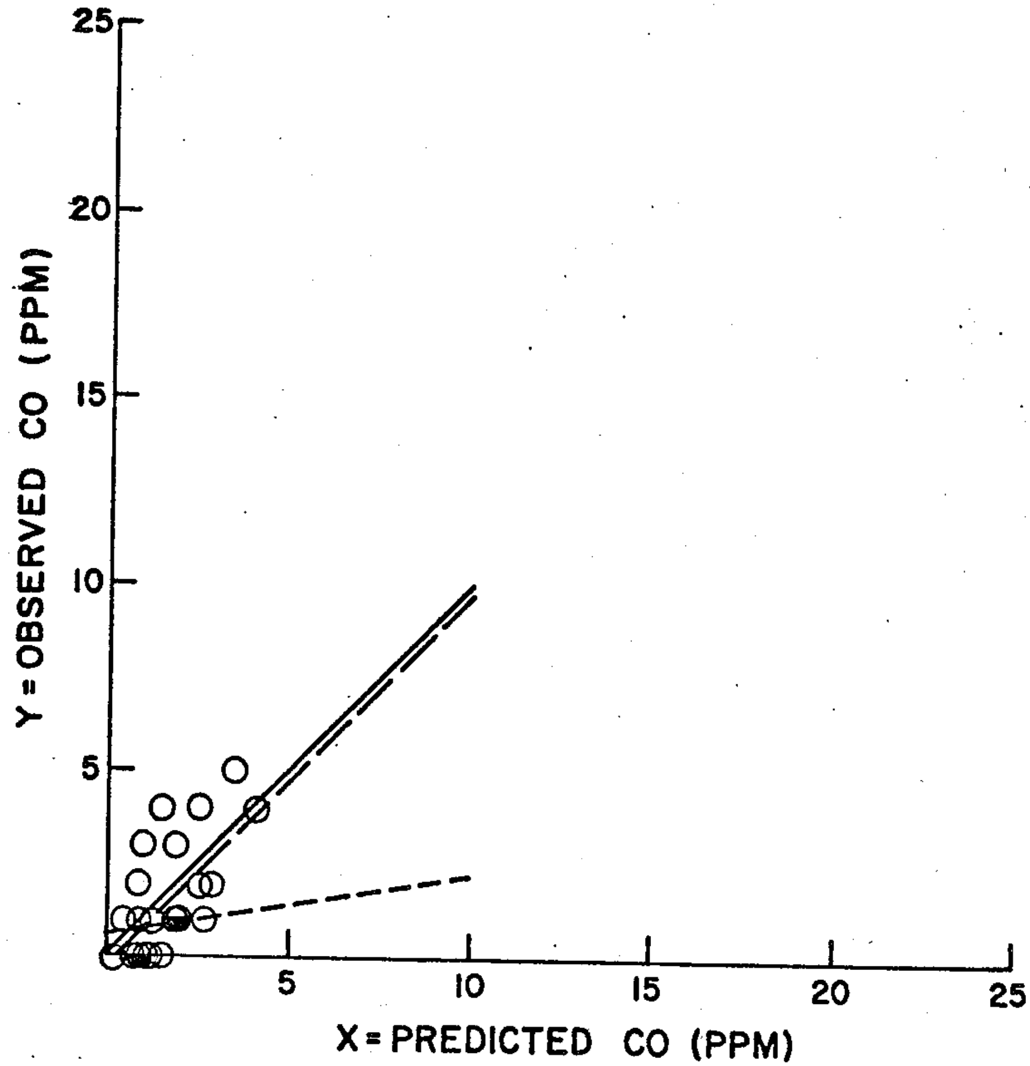


FIGURE 3-39

AT-GRADE SITE, PARALLEL WIND
OFF-HIGHWAY GROUND-LEVEL POINTS



CALINE2 REGRESSION
— — REGRESSION LINE
Y = −0.16 + 1.00X
N = 24
STANDARD ERROR = 1.21 PPM
r = 0.64
F = 15
——— 45° LINE (EXACT PREDICTION)
○ 1 DATA PAIR
◒ 2–5 DATA PAIRS
● MORE THAN 5 DATA PAIRS
OLD MODEL REGRESSION
(FOR COMPARISON ONLY)
- - - REGRESSION LINE
Y = 0.57 + 0.17X
N = 24
STANDARD ERROR = 1.37 PPM
r = 0.49
F = 7

FIGURE 3-40

AT-GRADE SITE, PARALLEL WIND
OFF-HIGHWAY GROUND-LEVEL & MIXING CELL POINTS

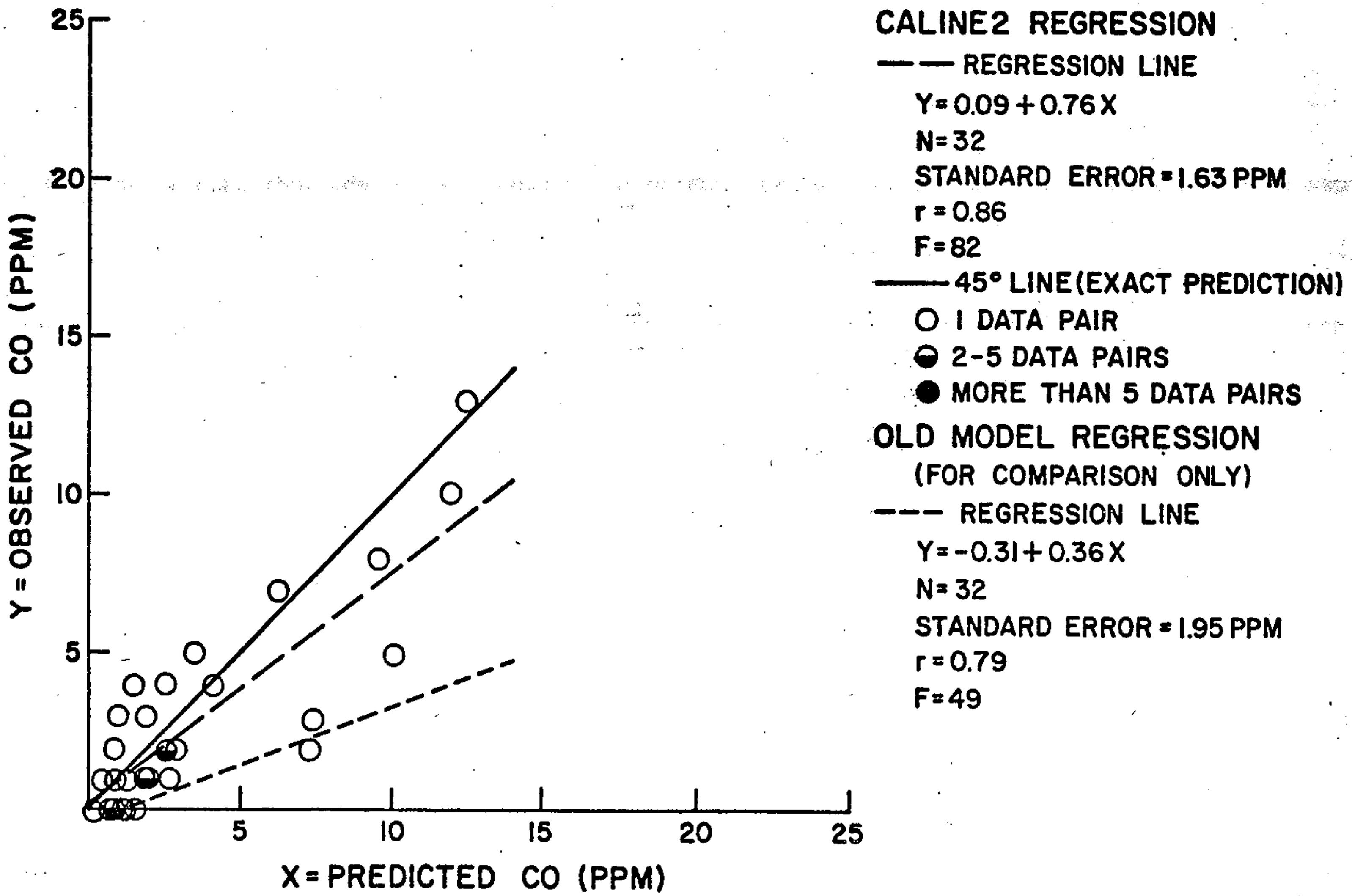
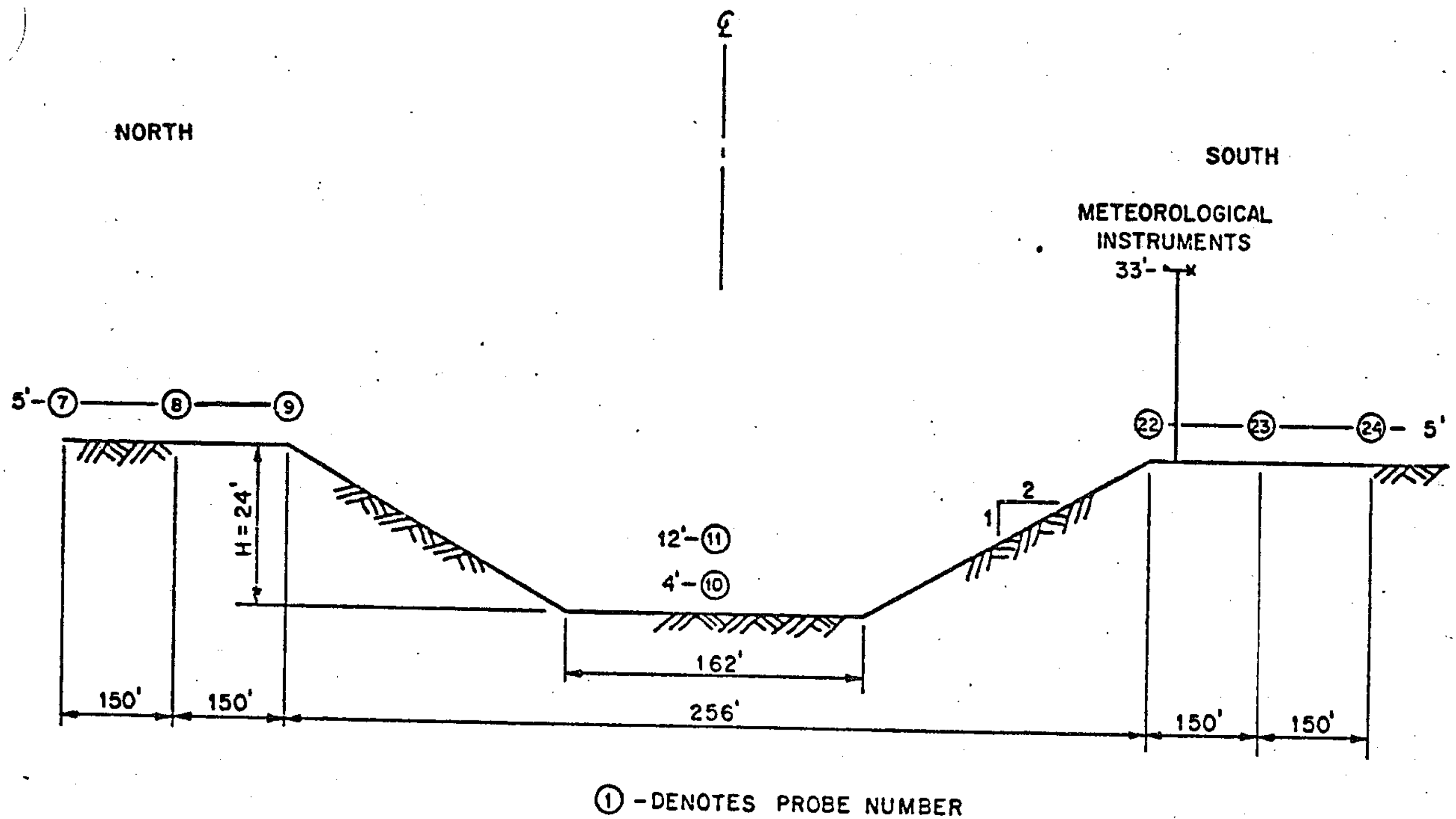
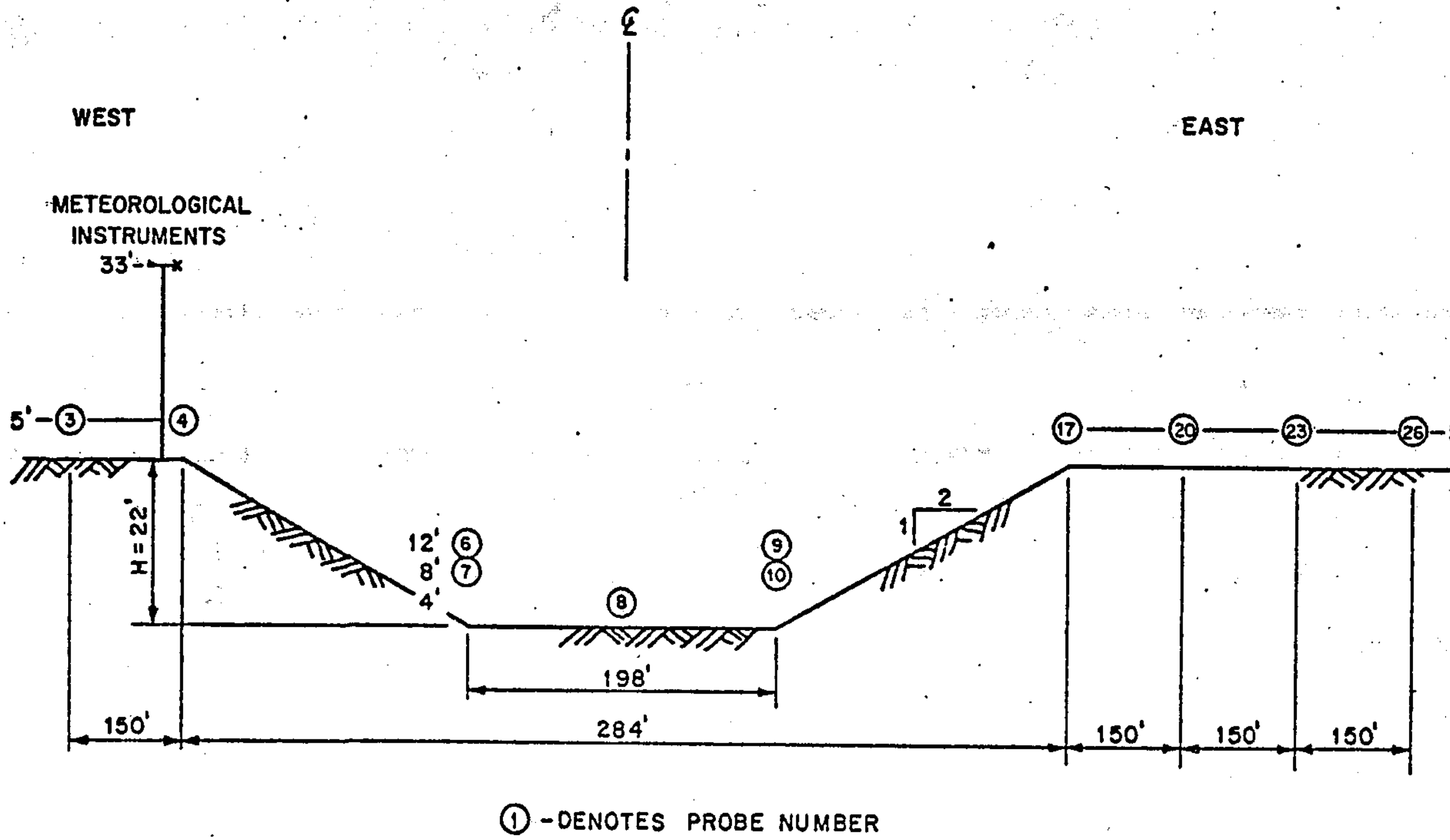


FIGURE 3-41



PROBE LOCATIONS, SANTA MONICA FREEWAY
AT 4TH AVE P.O.C. HORIZONTAL STUDY

FIGURE 3-42



PROBE LOCATIONS, HARBOR FREEWAY
AT 46TH AVE HORIZONTAL STUDY

FIGURE 3-43

CUT SITES, CROSSWIND
MIXING CELL POINTS

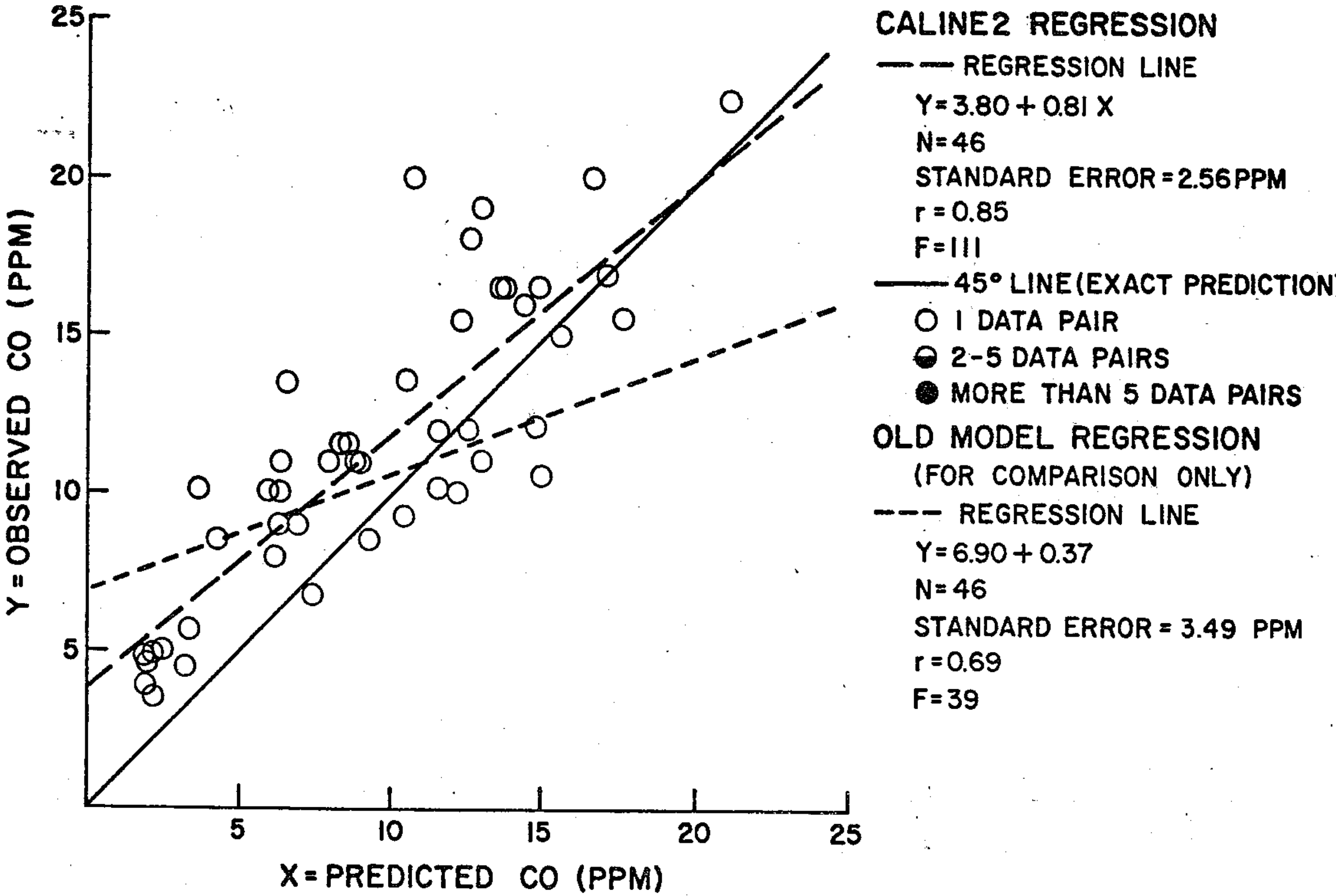


FIGURE 3-44

CUT SITES, CROSSWIND
OFF-HIGHWAY GROUND-LEVEL POINTS

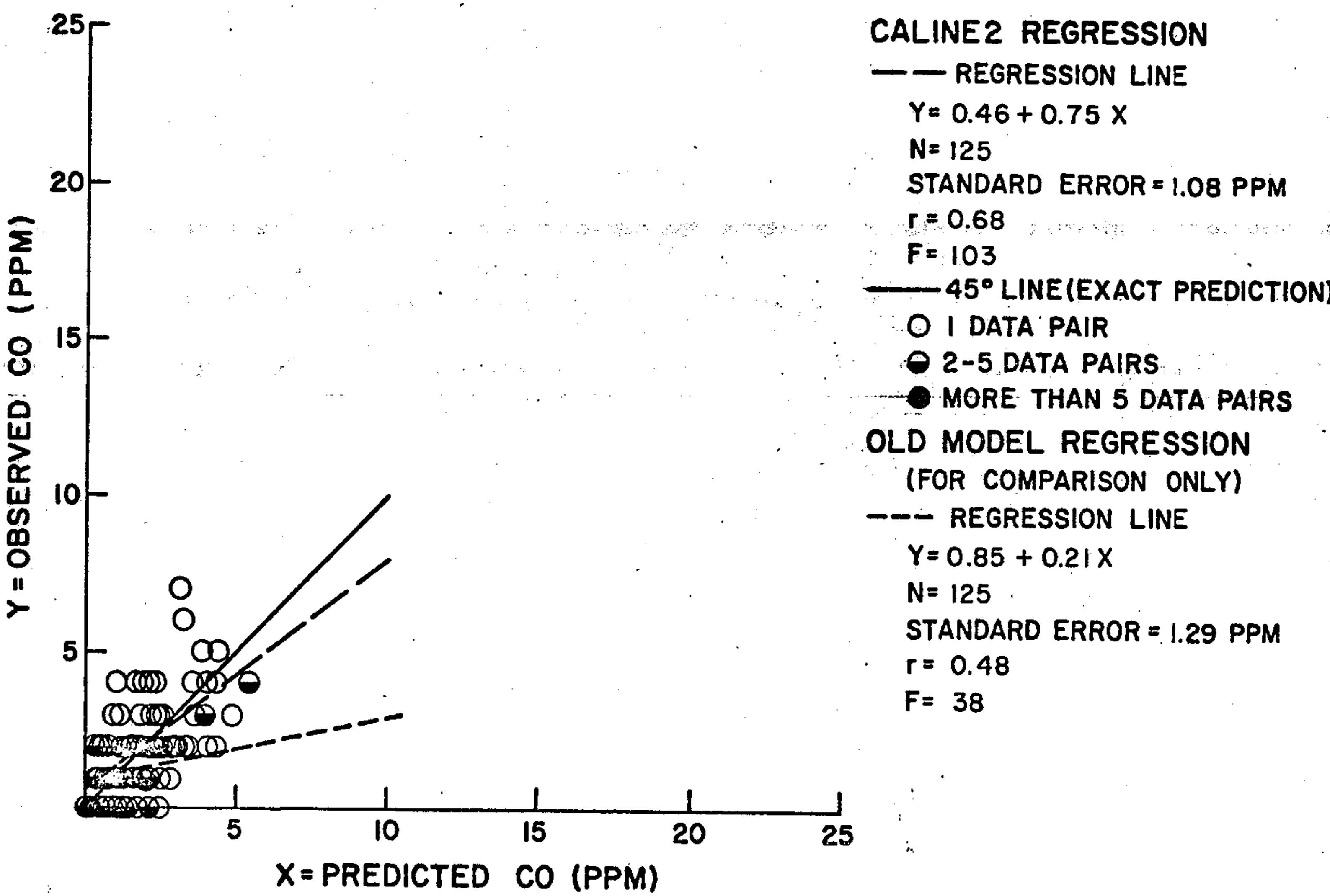


FIGURE 3-45

CUT SITES, CROSSWIND

OFF-HIGHWAY GROUND-LEVEL & MIXING CELL POINTS

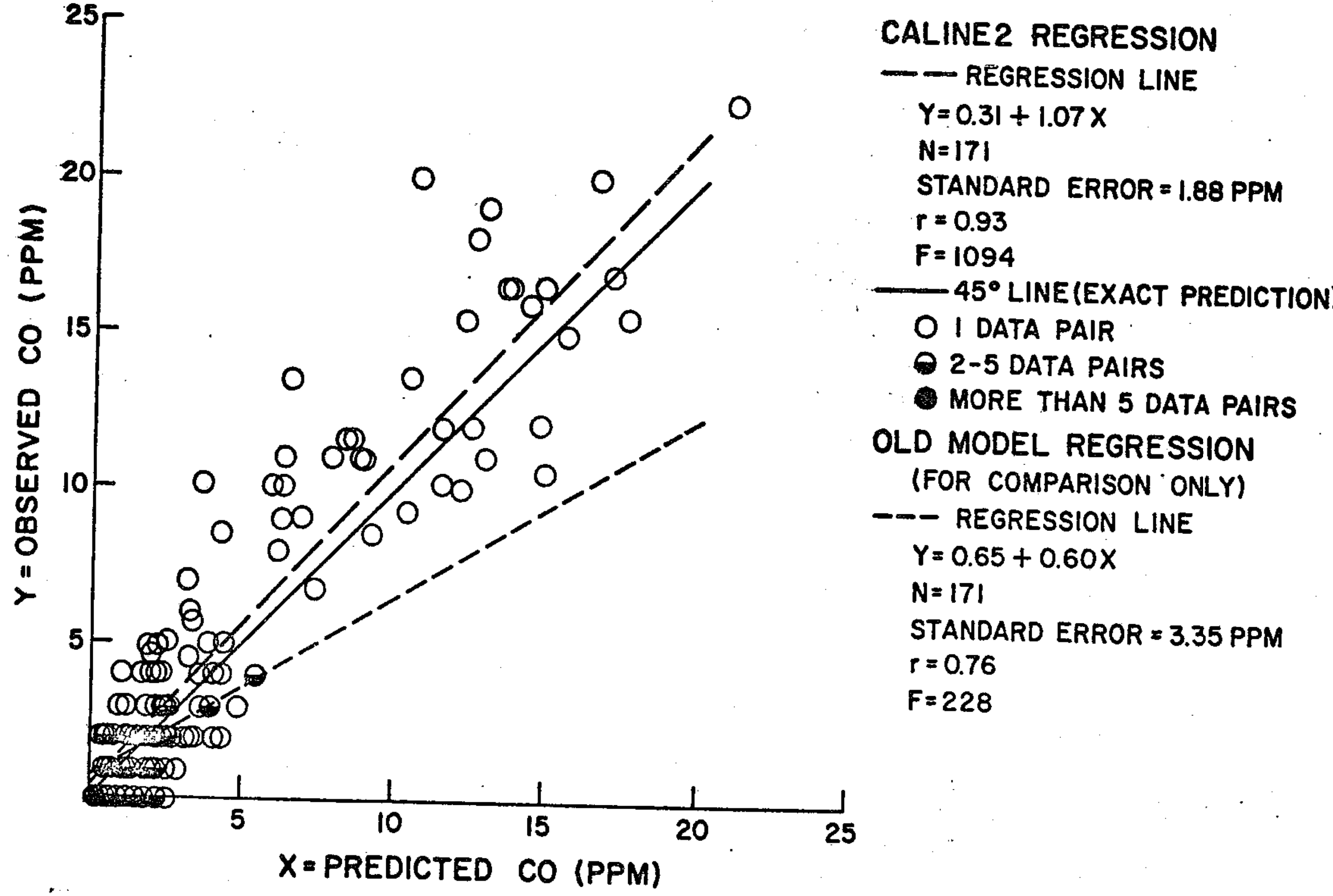


FIGURE 3-46

CUT SITES, PARALLEL WIND

MIXING CELL POINTS

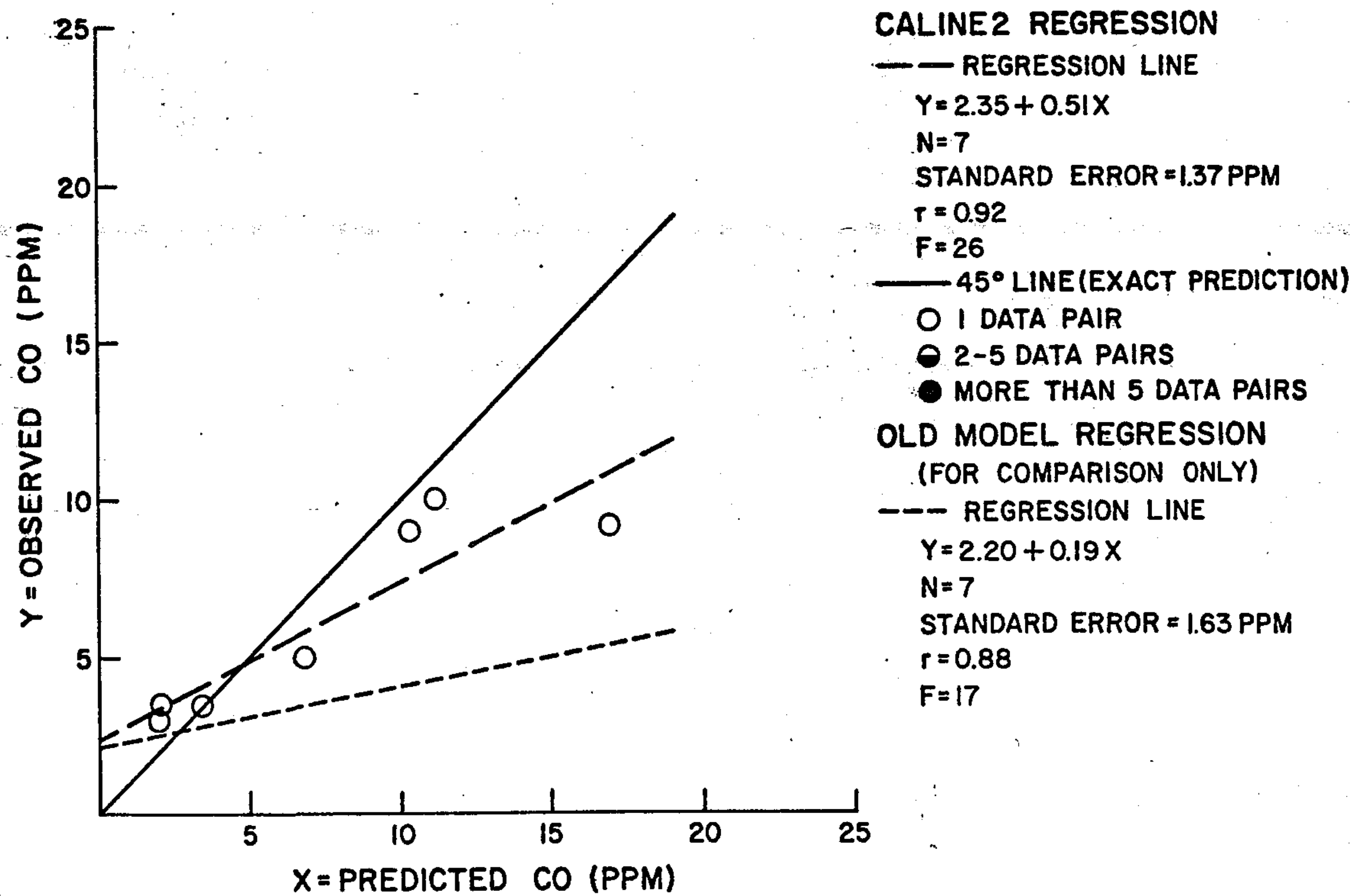


FIGURE 3-47

CUT SITES, PARALLEL WIND

OFF-HIGHWAY GROUND-LEVEL POINTS

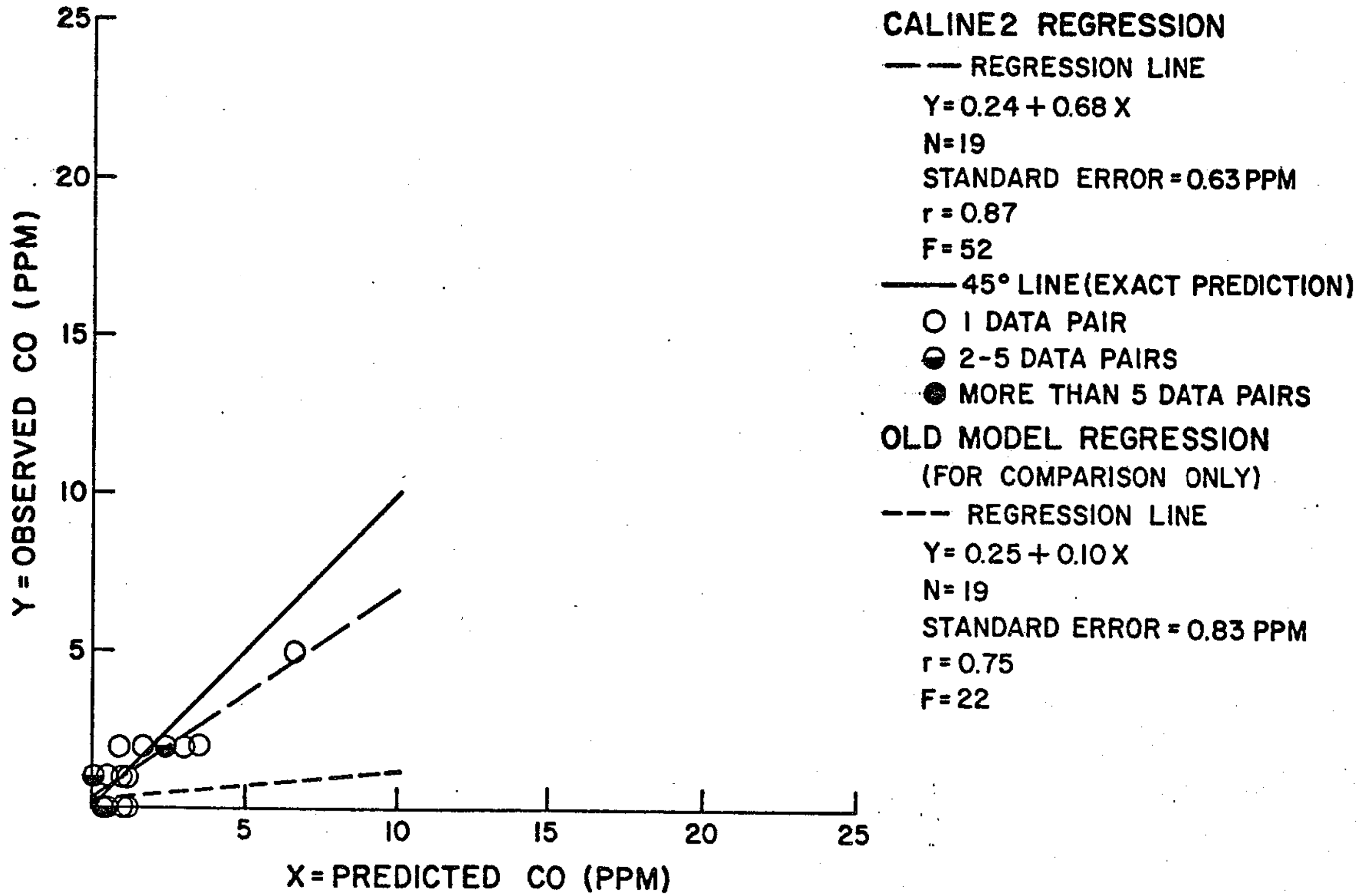


FIGURE 3-48

CUT SITES, PARALLEL WIND

OFF-HIGHWAY GROUND-LEVEL & MIXING CELL POINTS

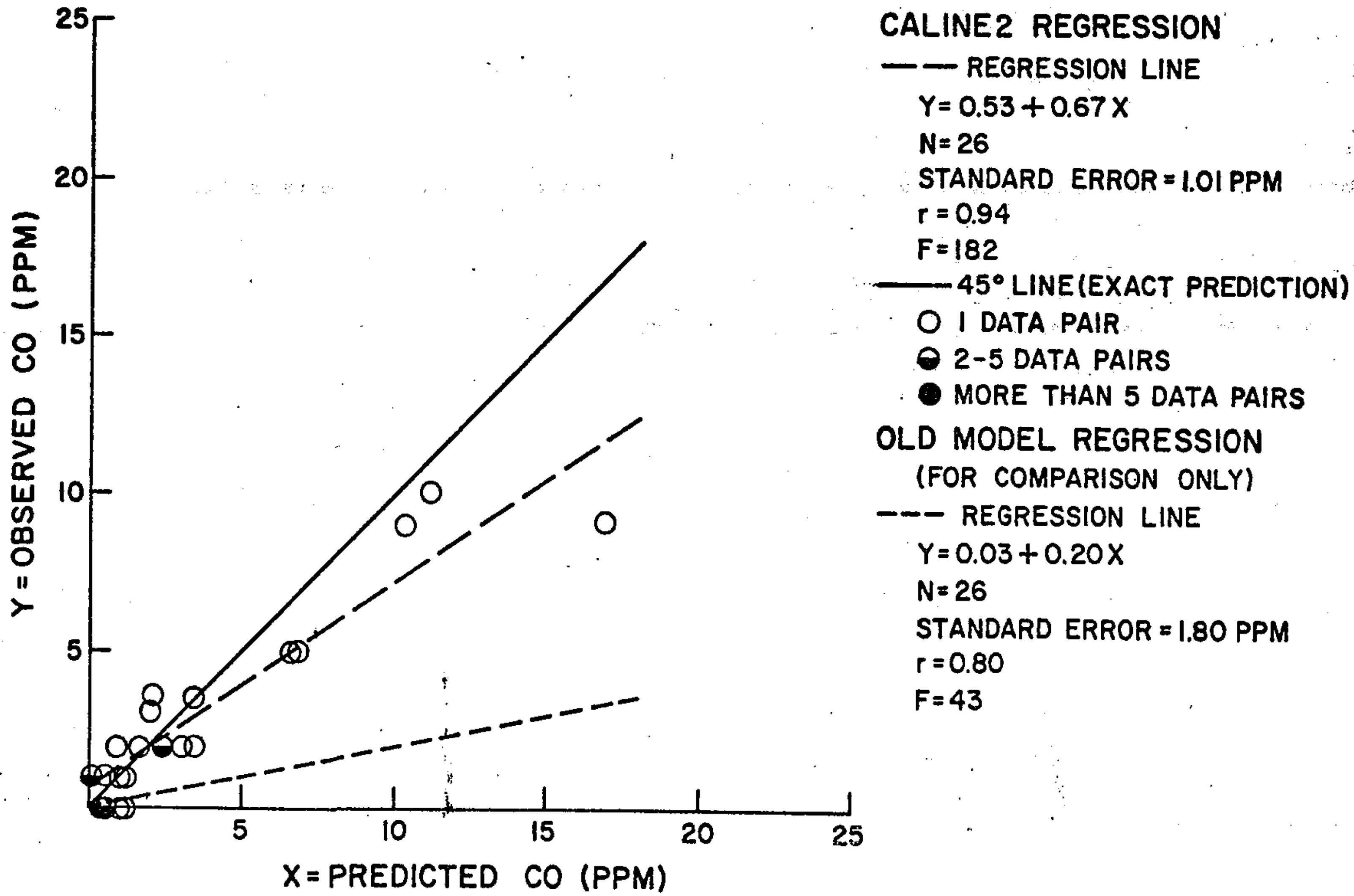
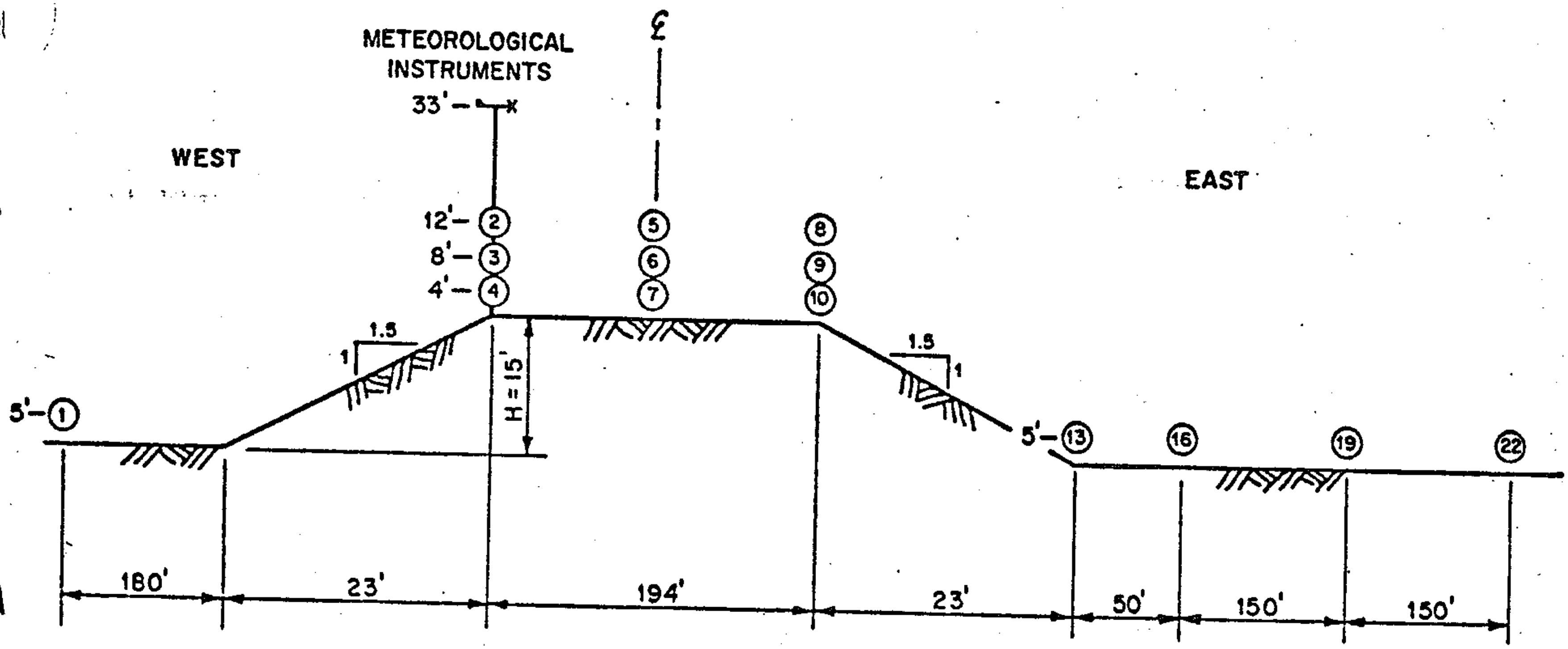


FIGURE 3-49



1 — DENOTES PROBE NUMBER

PROBE LOCATIONS SAN DIEGO FREEWAY
AT 122ND AVE HORIZONTAL STUDY

FIGURE 3-50

FILL SITE, CROSSWIND
MIXING CELL POINTS

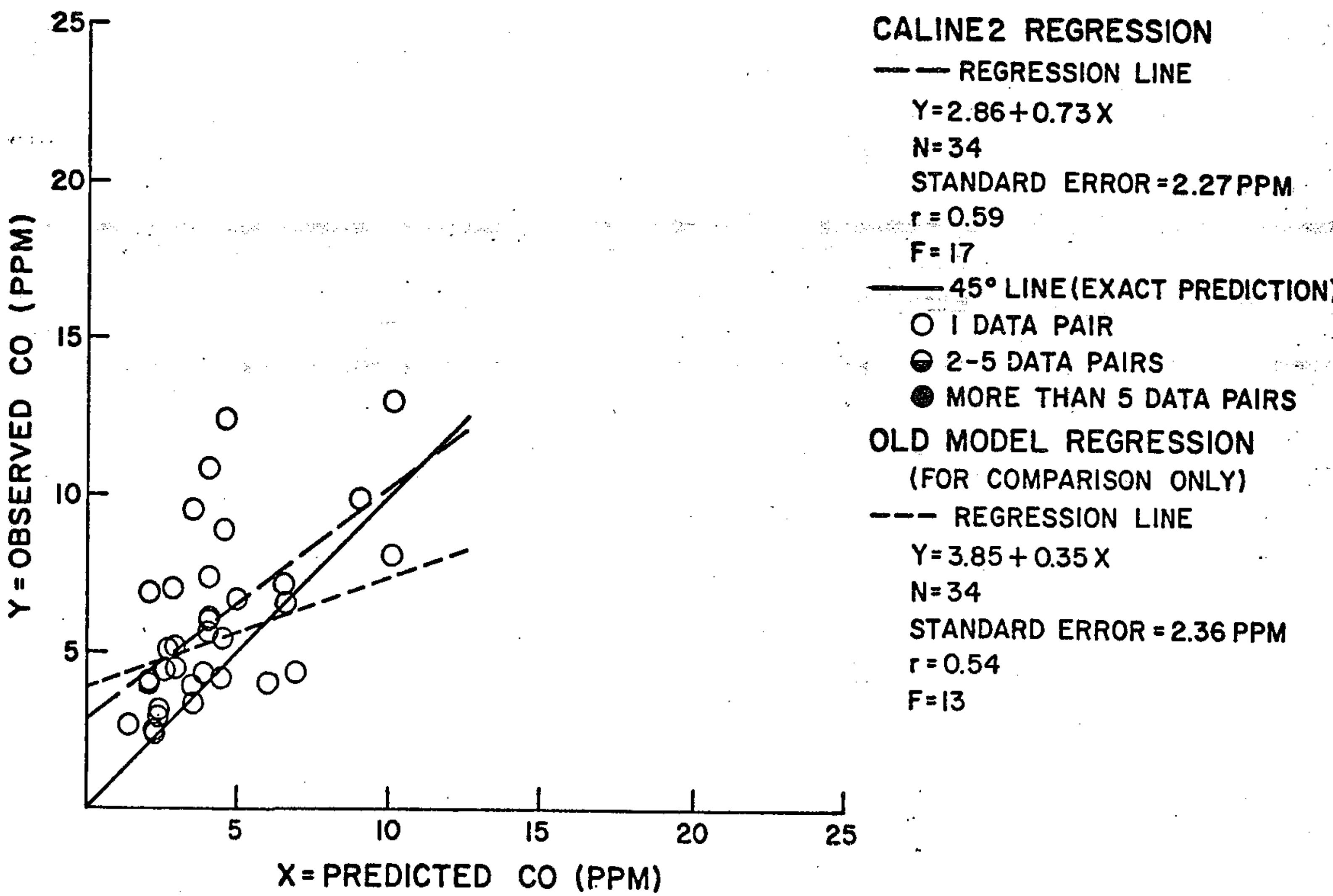


FIGURE 3-51

FILL SITE, CROSSWIND

OFF-HIGHWAY GROUND-LEVEL POINTS

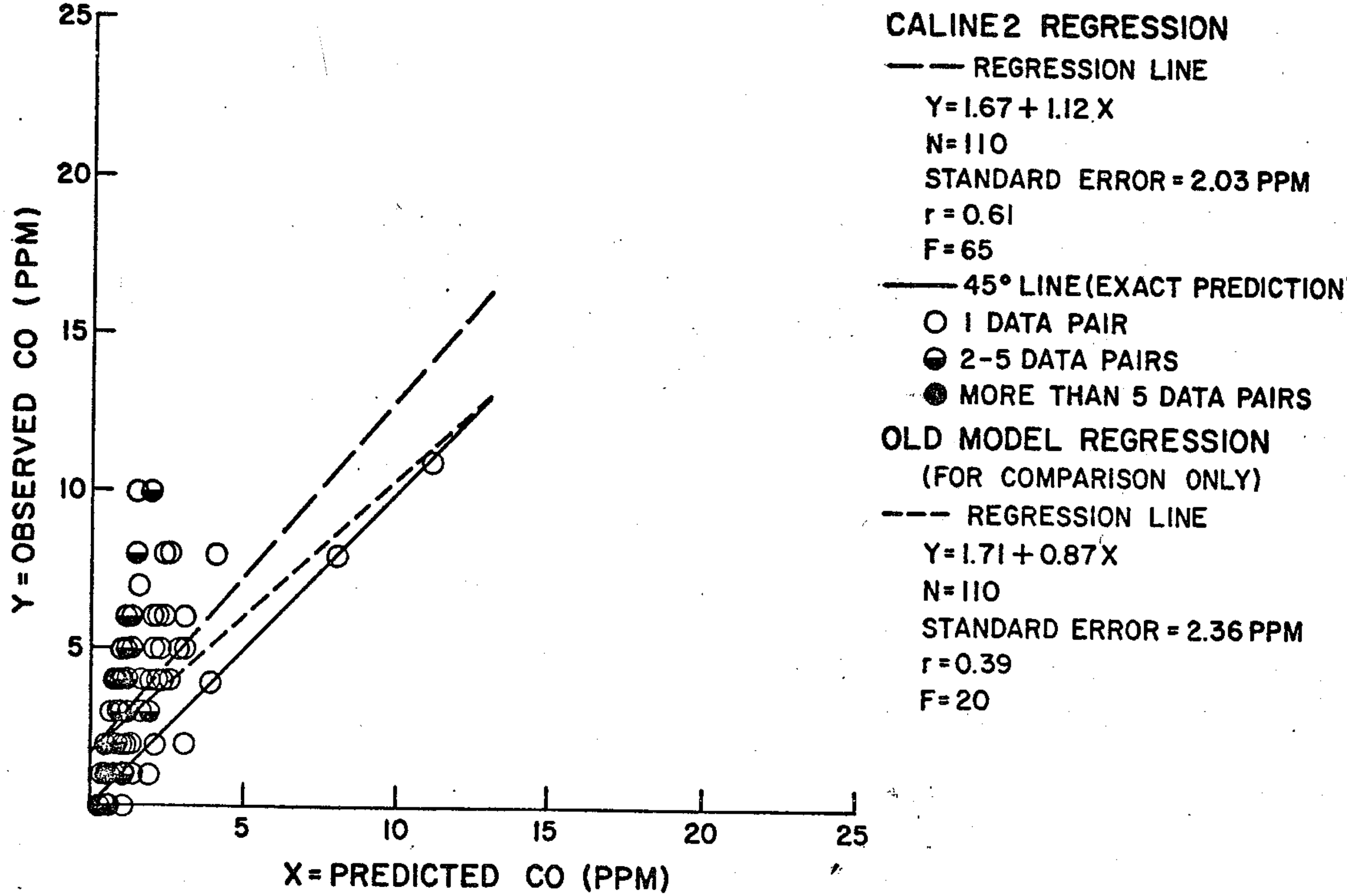


FIGURE 3-52

FILL SITE, CROSSWIND
OFF-HIGHWAY GROUND-LEVEL & MIXING CELL POINTS

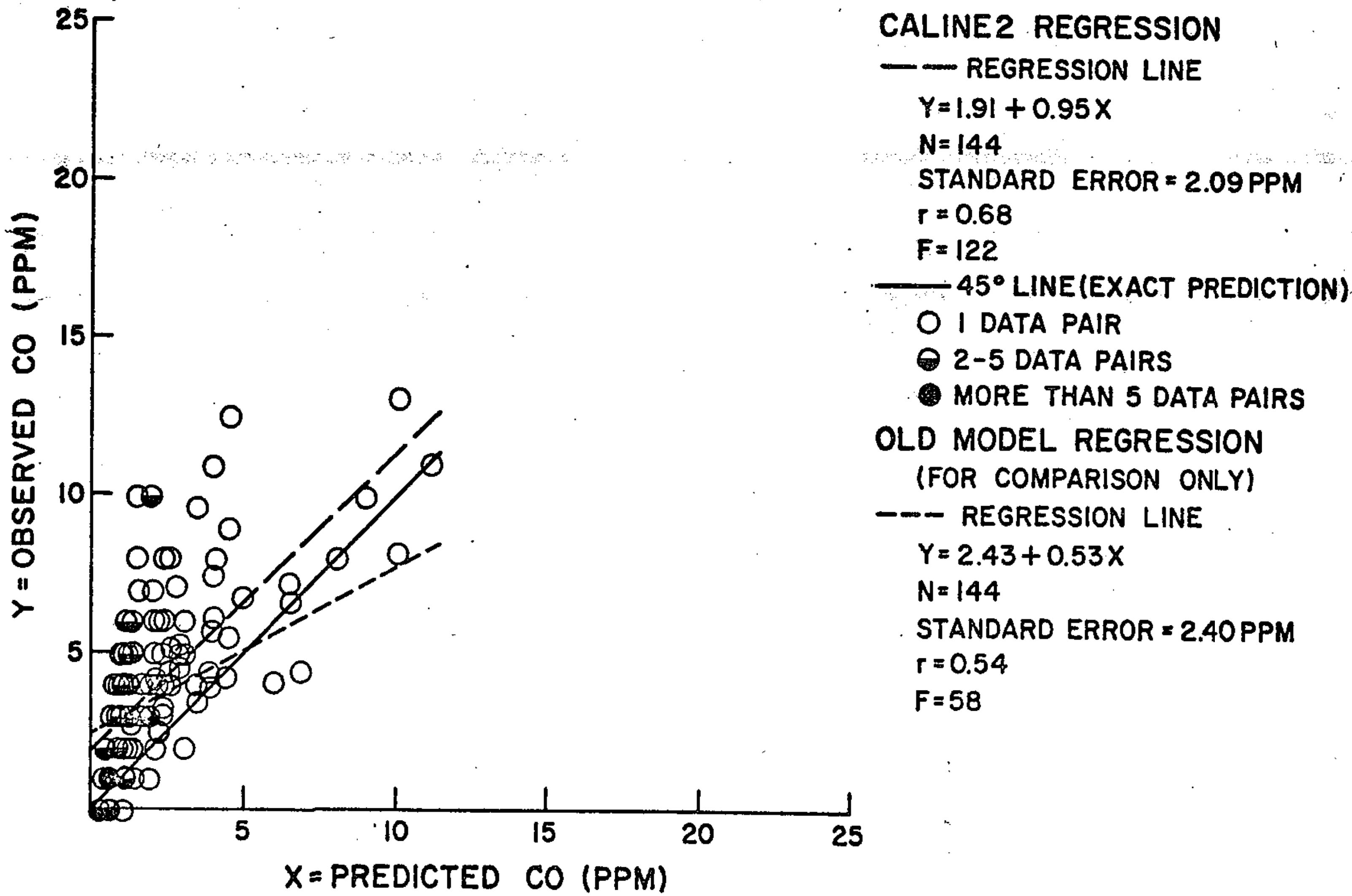


FIGURE 3-53

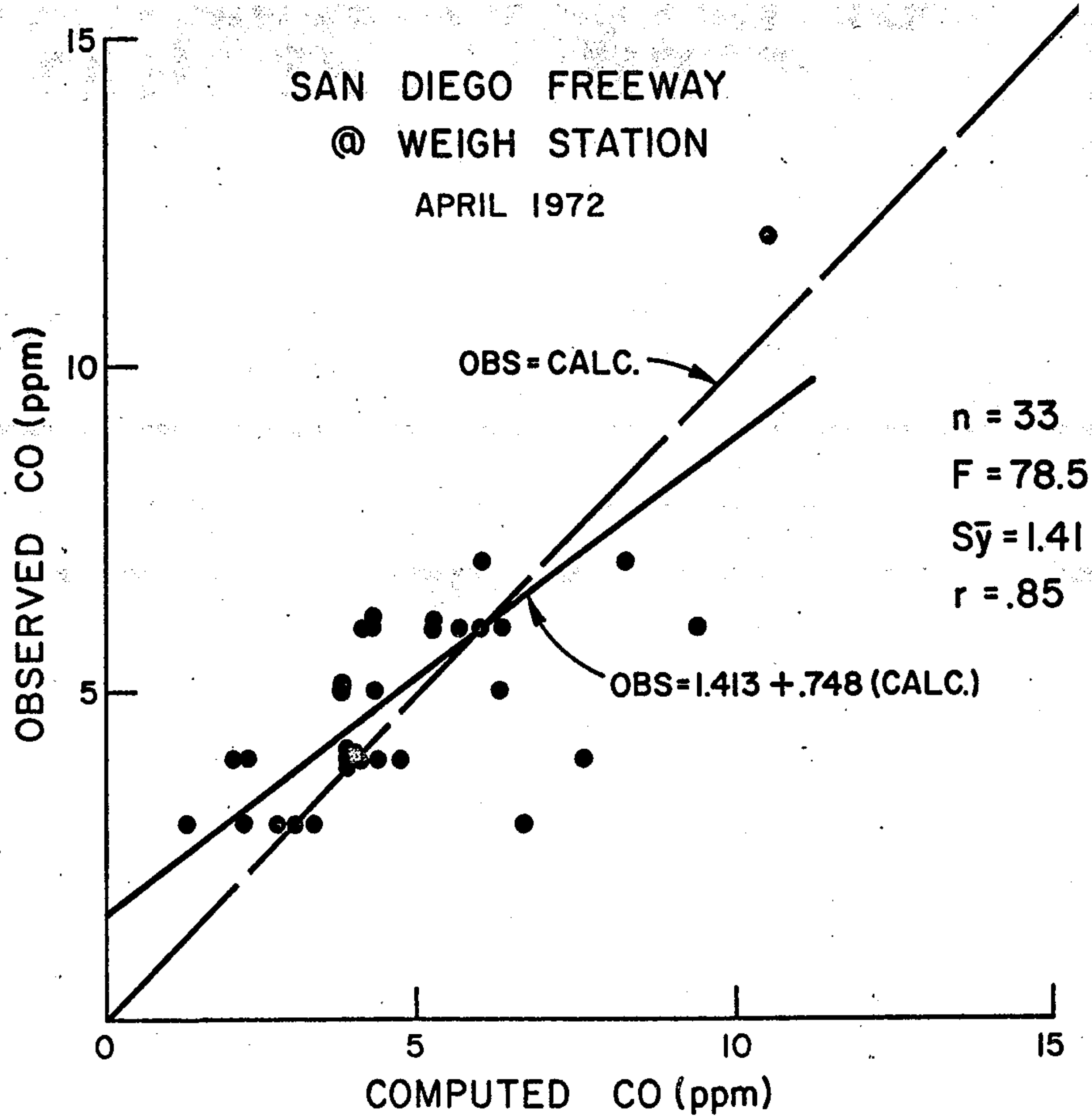
X. AeroVironment Line Source Model: April and August 1972 Validation for Carbon Monoxide

A. Inputs to Model Include:

1. $\bar{U}$
2. Ø
3. Radiation Flux (set to zero)
4. Reference Roughness (.1m)
5. Actual Roughness (.5m)
6. Ratio of Vertical to Horizontal Dispersion Speeds (.32)
7. VPH
8. EF (set to 15 grams/mile ≈ 50 mph)
9. Ambient Level
10. Coordinates of Plane perpendicular to Road Segment

B. Variables Unusual to Most Line Source Models

1. Roughness
2. Ratio of Dispersion Speeds
3. Radiation Flux (very sensitive)



AEROV VS SITE DATA AT 100' FROM EDGE RDWY. FOR CO.

FIGURE 3-54

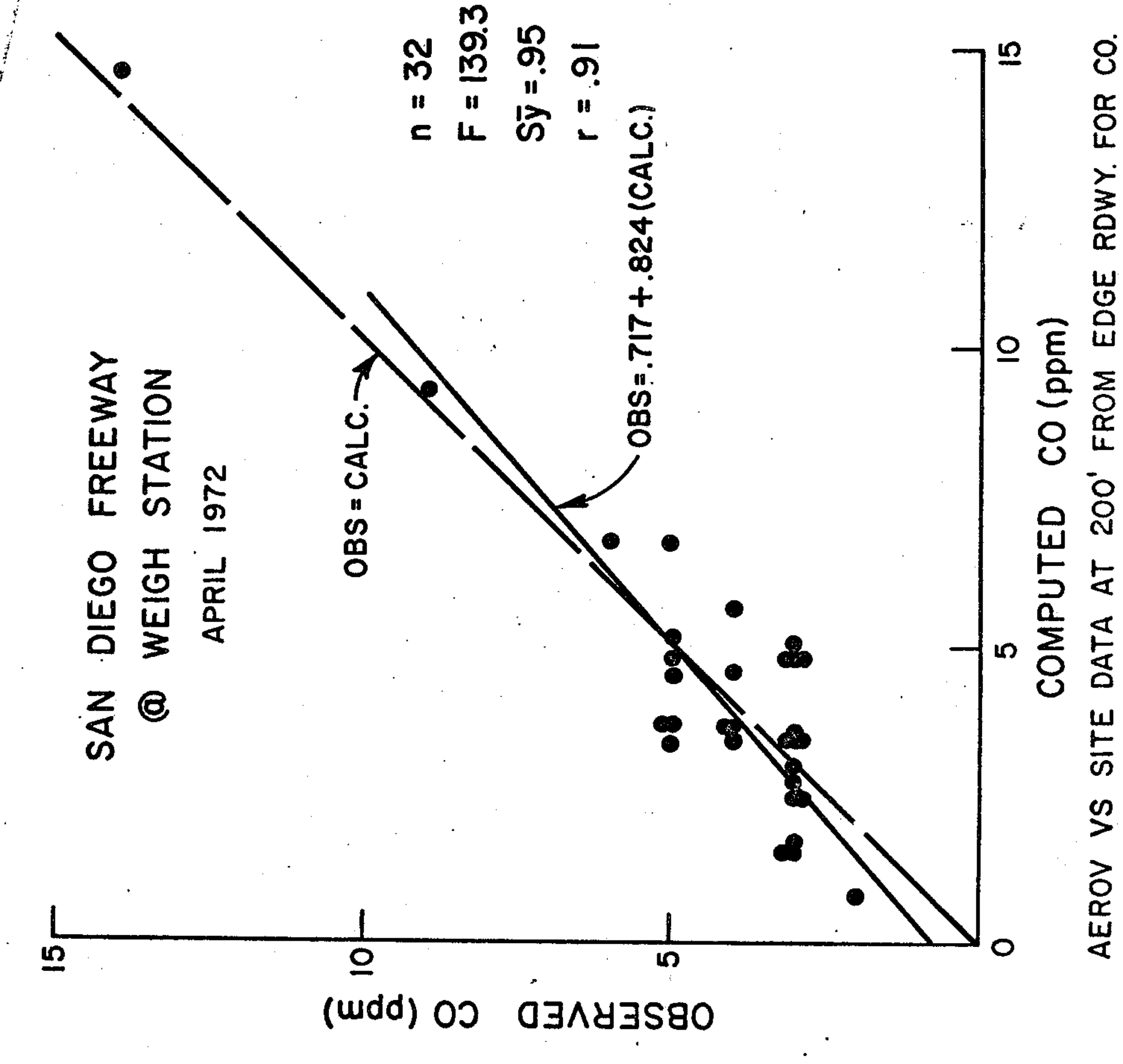

SAN DIEGO FREEWAY
@ WEIGH STATION
APRIL 1972
n = 32
F = 139.3
$S_{\bar{y}}$ = .95
r = .91
OBS = CALC.
OBS = .717 + .824 (CALC.)
OBSERVED CO (ppm)
COMPUTED CO (ppm)
AEROV VS SITE DATA AT 200' FROM EDGE RDWY. FOR CO.
0
5
10
15

FIGURE 3-55

AERO VIRONMENT LINE SOURCE MODEL VS SITE DATA AT 150 FT FROM ROADWAY AUGUST 1972

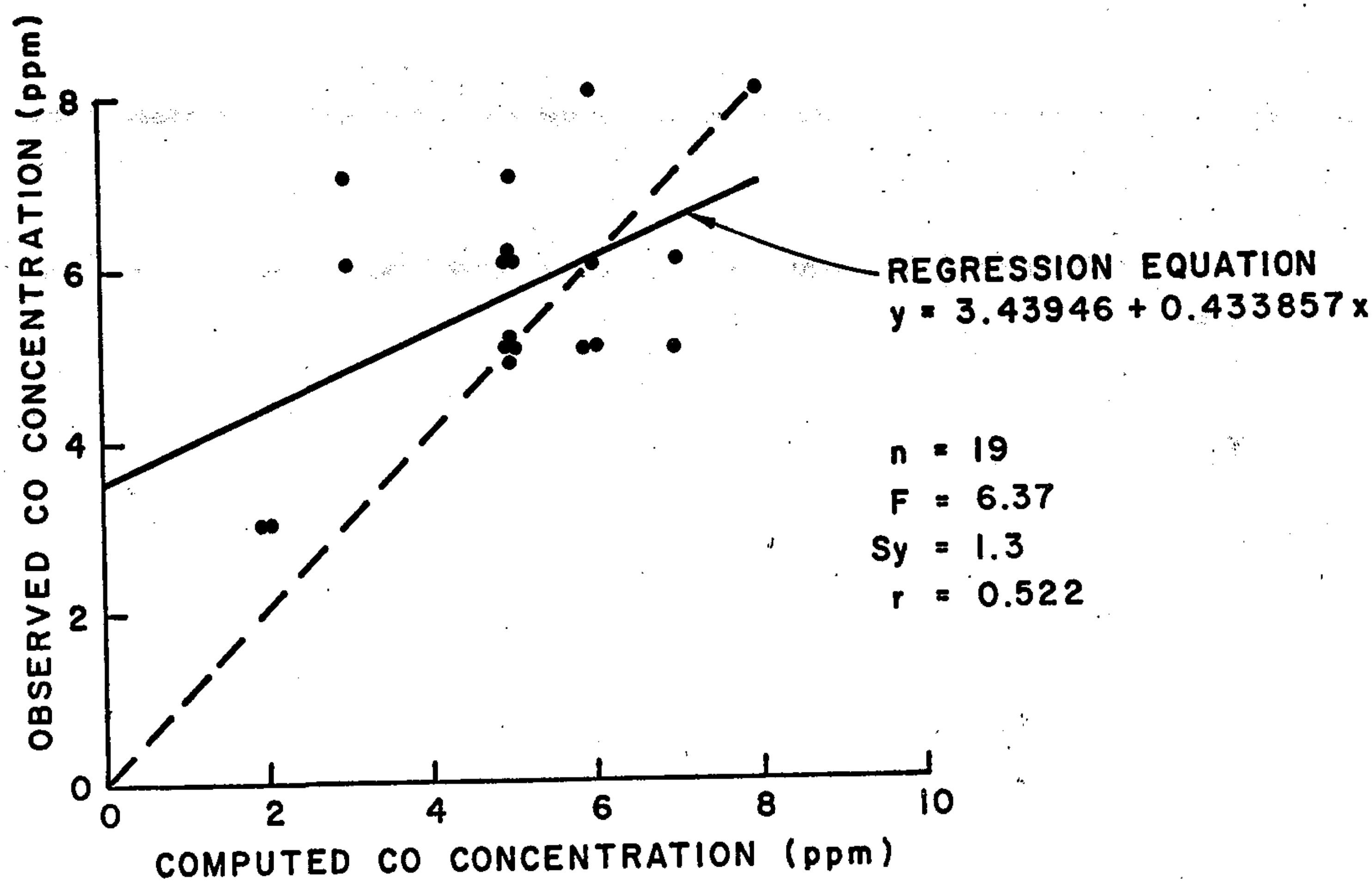


FIGURE 3-56

AERO VIRONMENT LINE SOURCE MODEL
VS SITE DATA AT 300 FT FROM ROADWAY
AUGUST 1972

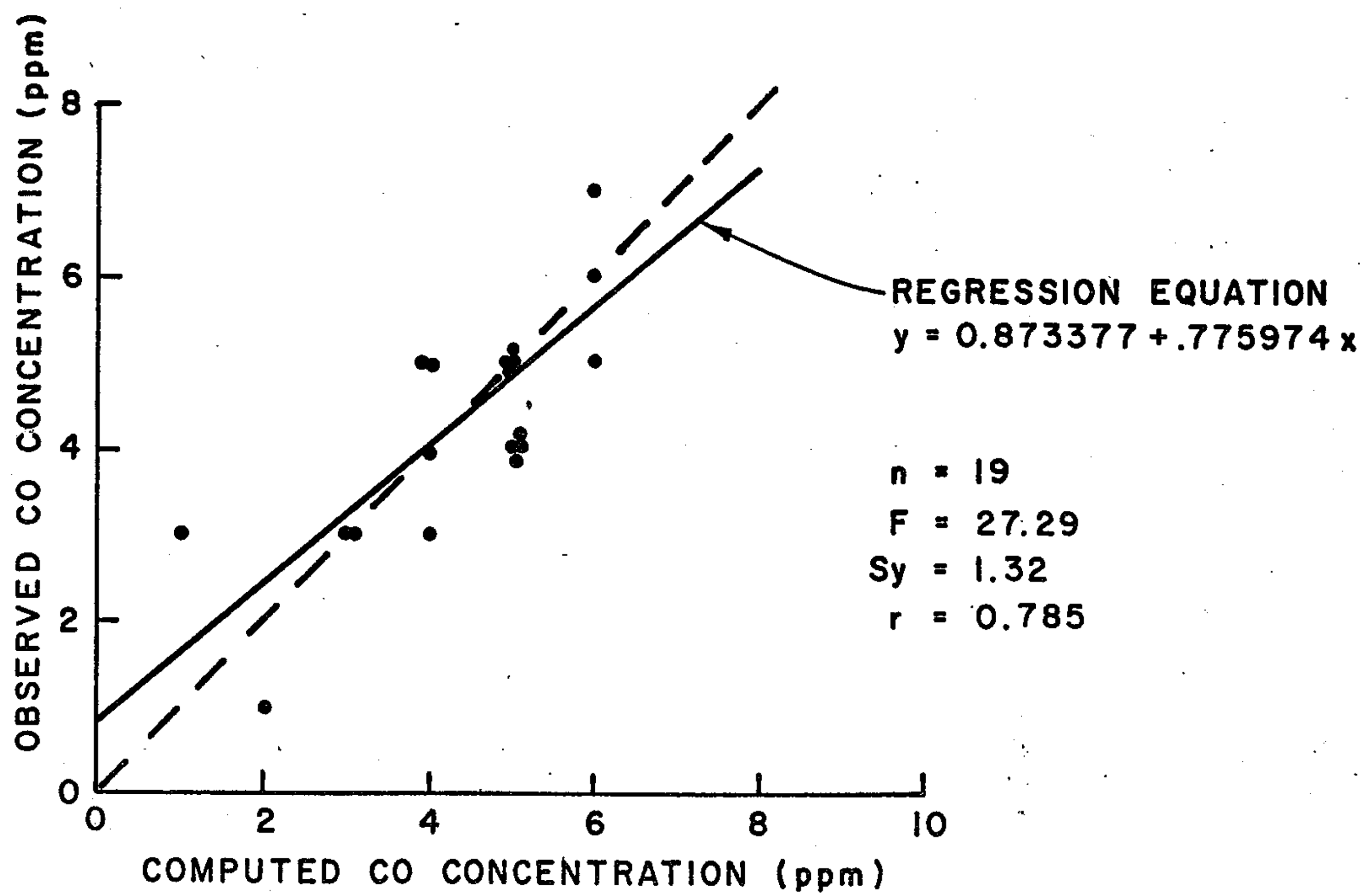


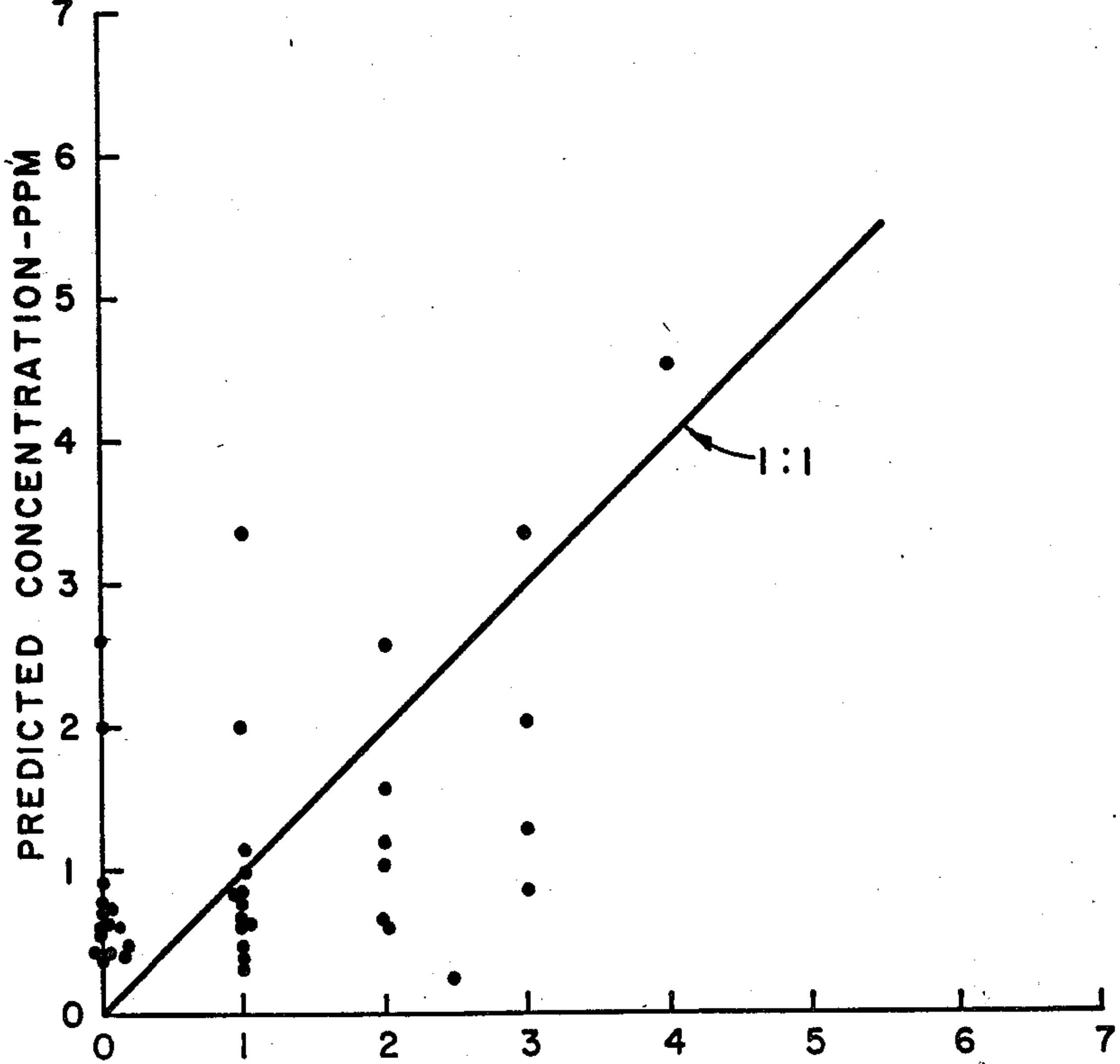
FIGURE 3-57

XI. SYSTEM SCIENCE AND SOFTWARE, S^3

A. Inputs

1. Grid height and length
2. Roadway height and width
3. Stability Class
4. Wind profile
5. Diffusivities
6. Terrain features
7. Windspeed and direction
8. Emission factors
9. Vehicles per hour

OFF-ROADWAY MEASUREMENTS VERSUS PREDICTIONS– AT-GRADE SECTION



SOURCE: S^3 REPORT

FIGURE 3-58

OFF-ROADWAY MEASUREMENTS VERSUS PREDICTIONS—
(INCLUDING ROAD EDGE PTS.) AT-GRADE SECTION

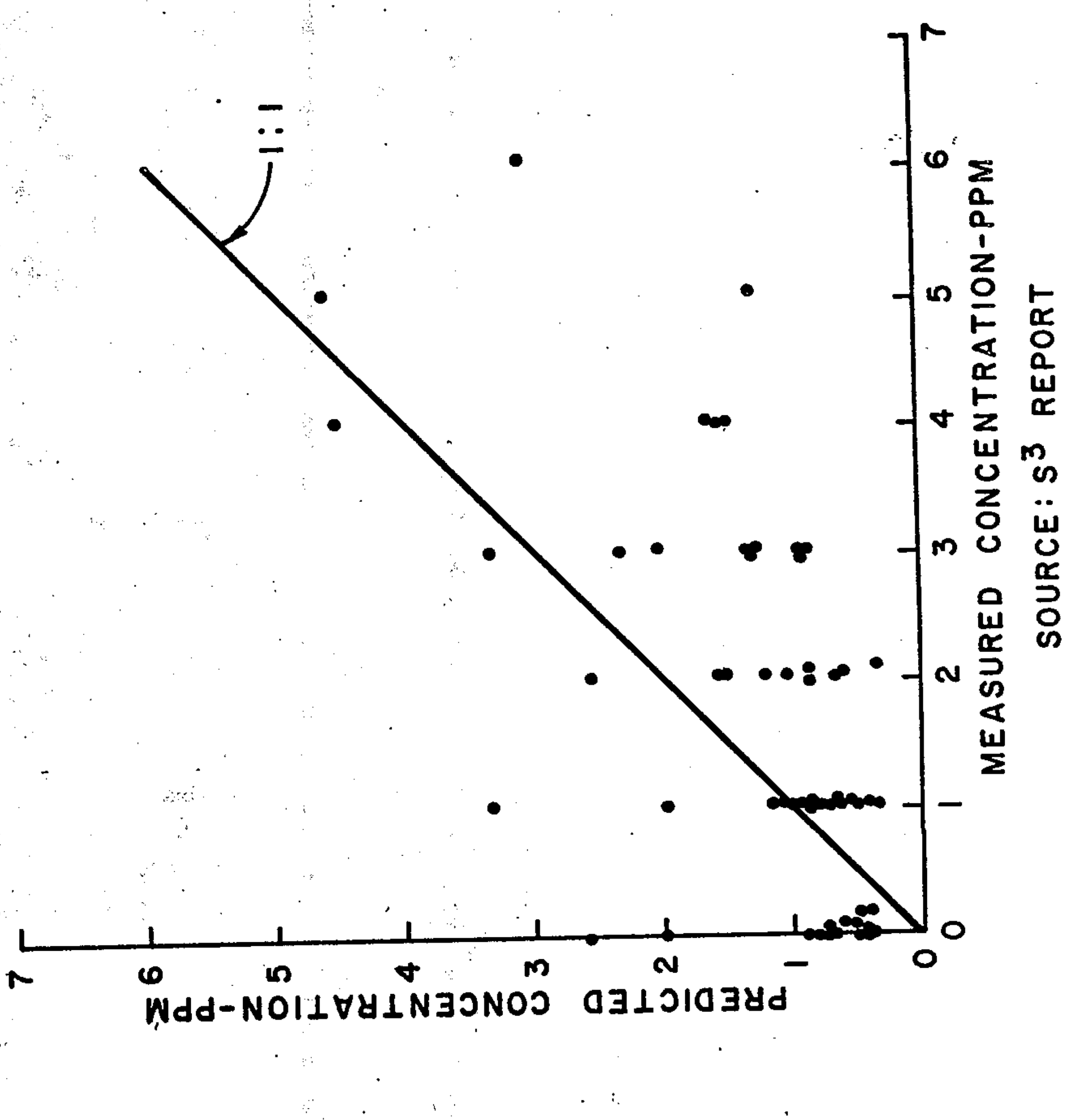
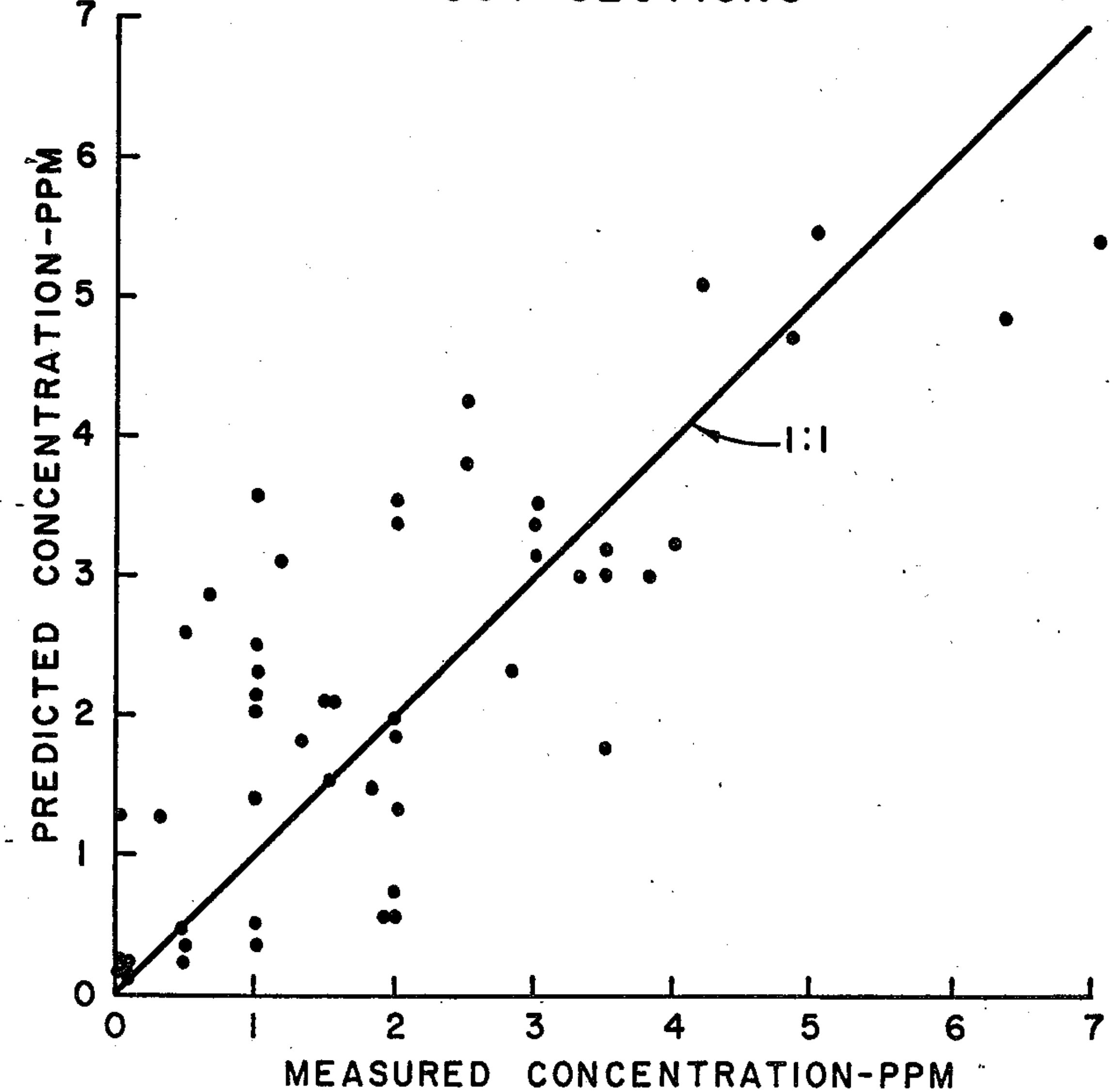


FIGURE 3-59

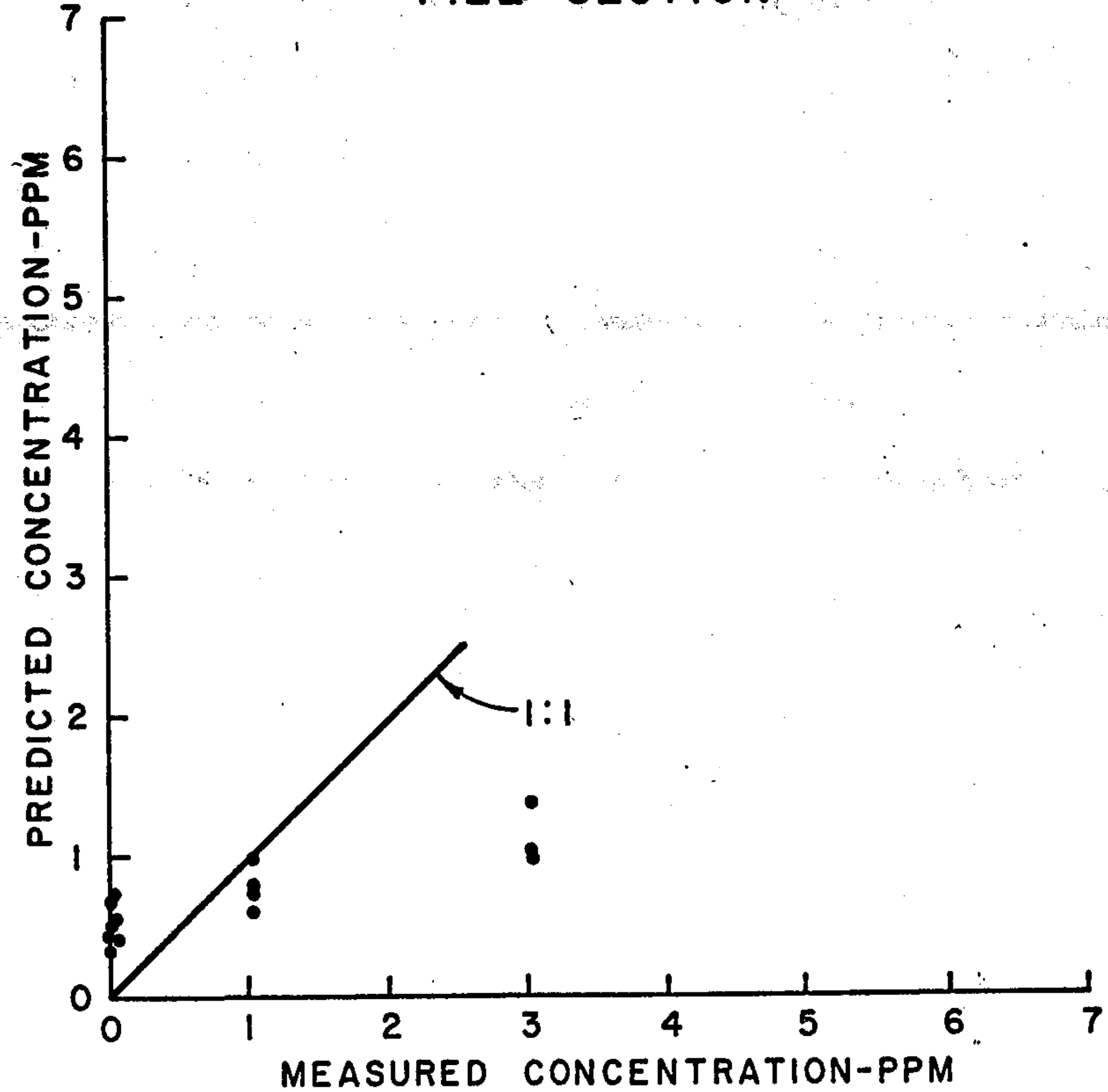
OFF-ROADWAY MEASUREMENTS VERSUS PREDICTIONS— CUT SECTIONS



SOURCE: S^3 REPORT

FIGURE 3-60

OFF-ROADWAY MEASUREMENTS VERSUS PREDICTIONS—FILL SECTION



SOURCE: S^3 REPORT

FIGURE 3-61

SECTION 4

REGIONAL AIR QUALITY MODELING

I. Uses of Regional Air Quality Models

A. Assess the impact of transportation systems on regional air quality.

B. Identify "hot spots" and locations of air monitoring stations for system planning.

C. Evaluate transportation control strageties.

D. Evaluate the interrelationship of land use, transportation and air quality planning.

II. Federal Regulations Requiring Regional Analysis

A. Clear Air Act of 1970
B. Federal Aid Highway Act
C. EPA Indirect Source Regulations
D. See Figure 4-1

III. Levels of Analyses for Regional Air Quality Modeling

A. Pollutant burden - Rollback (CO, NO_2, O_3)
B. Conservation of Mass - Photochemical (CO, NO_2, O_3)
C. Models predict above baseline levels - Figure 4-2

IV. Pollutant Burden Transportation System - Figure 4-3

A. Input Variables

1. Vehicle miles traveled on each link

2. Vehicle speed on each link
3. Emission factors for CO, HC, NO_x

B. Outputs - Tons per day

$$TPD = 1.1 \times 10^{-6} \text{ (VMT) (EF)}$$

C. Traffic Requirements

Speed (mph)	VMT	E.F.
10	-	-
20	-	-
30	-	-
40	-	-
50	-	-
60	-	-

D. Critical Year for Regional Transportation Analysis

1. Rate of traffic volume increase equals rate of decrease in emission factors.

2. Rate of traffic increase less than the rate of emission factor decrease.

E. Typical Outputs from Pollutant Burden Transportation Analysis

1. See Figures 4-4 through 4-7

V. Rollback

A. Assumptions - See Figure 4-8

B. Equation Figure 4-8

C. Predictions for O_3

1. $O_3 \propto$ RHC where RHC are emissions from stationary and mobile sources.

D. Example to Predict Future CO

Base year (1970) CO concentration (1 hr) = 50 ppm

Base year (1970) CO emissions (stationary + mobile) = 500 TPD

Future year (1980) CO emissions (stationary + mobile) = 250 TPD

$$C_{max} = 50\left(\frac{250}{500}\right) = 25 \text{ ppm}$$

E. Example to Predict Future O_3

Baseline year (1970) O_3 concentration (1 hr.) = 0.40 ppm

Baseline year (1970) RHC (stationary + mobile) emissions = 700 TPD

Future year (1980) RHC (stationary + mobile) emissions = 300 TPD

F. Limitations of Rollback for Primary and Secondary Pollutants

1. No_4 meteorological inputs

2. Cannot predict temporal or spatial distribution of pollutants

3. Does not include HC, NO_x and ultraviolet radiation for predicting O_3

4. No information on spatial alternatives for transportation plans.

5. Different baseline years give different predictions for air quality

6. It is at best a first order of magnitude estimate

G. Rollback Techniques Using Larsen Model

1. See Figure 4-9

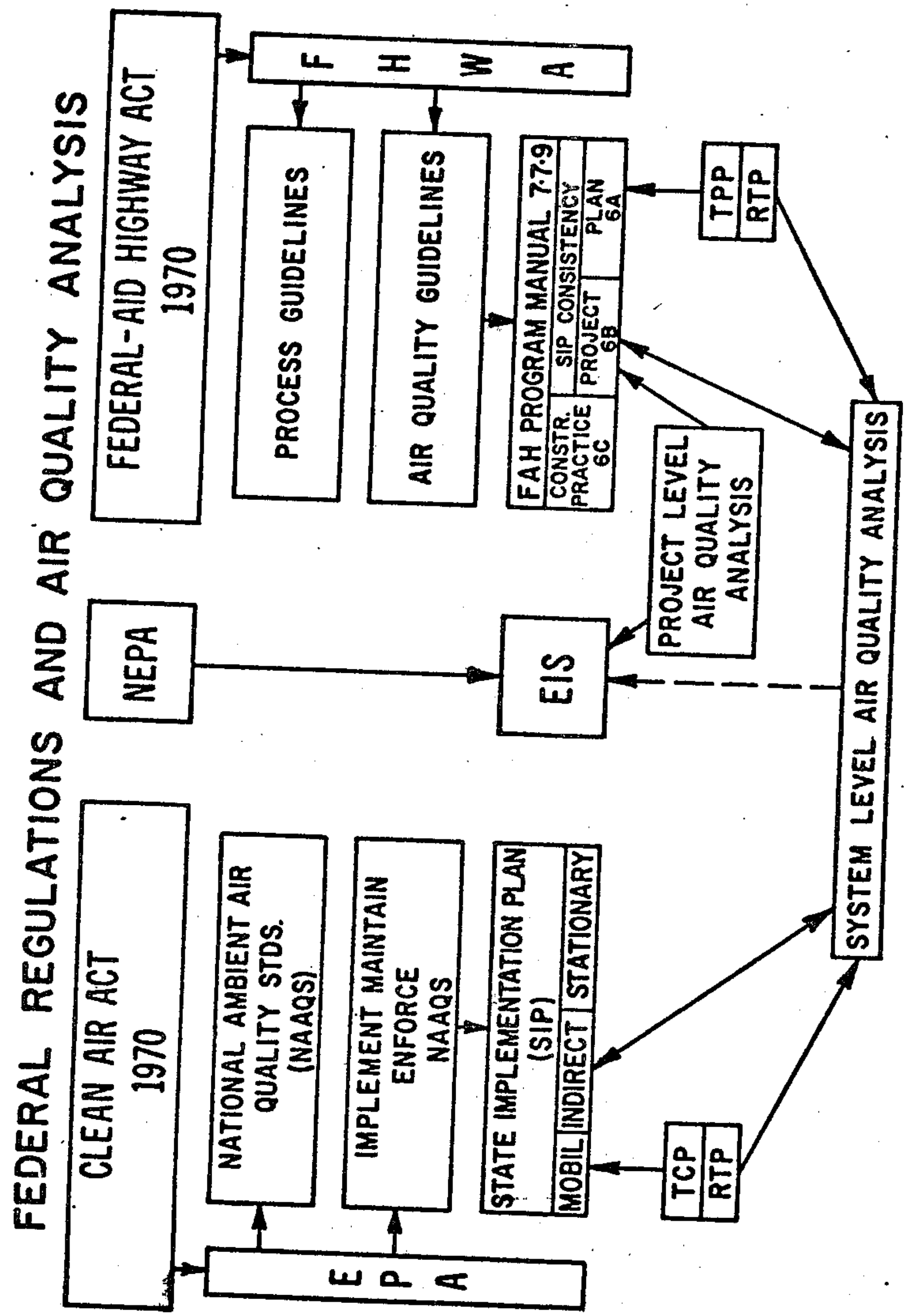
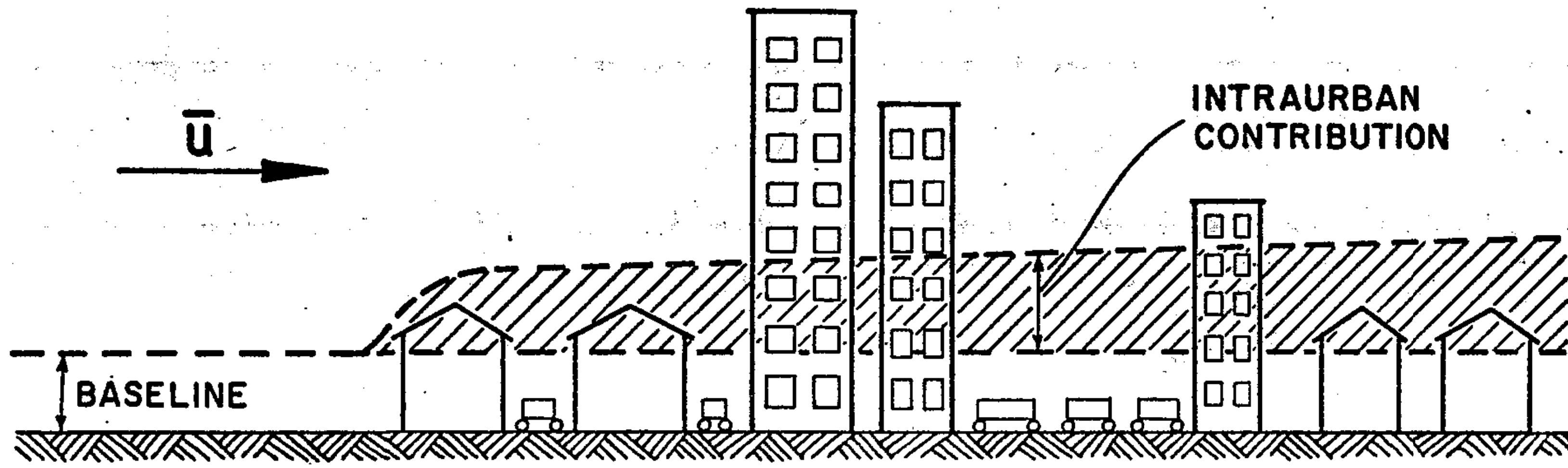

FEDERAL REGULATIONS AND AIR QUALITY ANALYSIS
CLEAN AIR ACT 1970
EPA
NATIONAL AMBIENT AIR QUALITY STDS. (NAAQS)
IMPLEMENT MAINTAIN ENFORCE NAAQS
STATE IMPLEMENTATION PLAN (SIP)
MOBIL
INDIRECT
STATIONARY
TCP
RTP
NEPA
EIS
PROJECT LEVEL AIR QUALITY ANALYSIS
SYSTEM LEVEL AIR QUALITY ANALYSIS
FEDERAL-AID HIGHWAY ACT 1970
FHWA
PROCESS GUIDELINES
AIR QUALITY GUIDELINES
FAH PROGRAM MANUAL 7·7·9
CONSTR. PRACTICE 6C
SIP CONSISTENCY
PROJECT 6B
PLAN 6A
TPP
RTP

FIGURE 4-1

MESOSCALE OR REGIONAL



TOTAL CONCENTRATION URBAN AREA =
BASELINE + INTRAURBAN CONTRIBUTION

FIGURE 4-2

MESOSCALE ANALYSIS

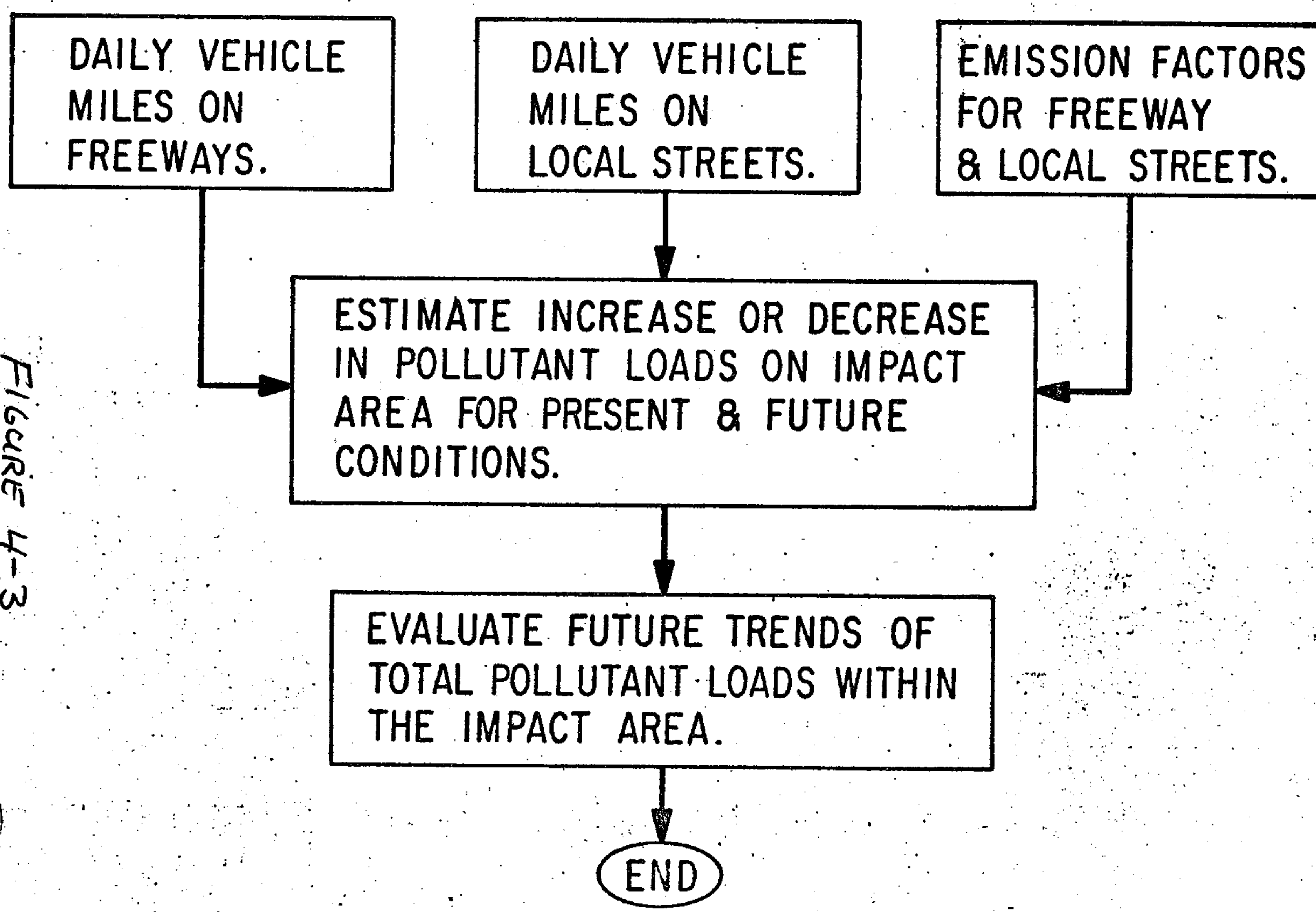


FIGURE 4-3

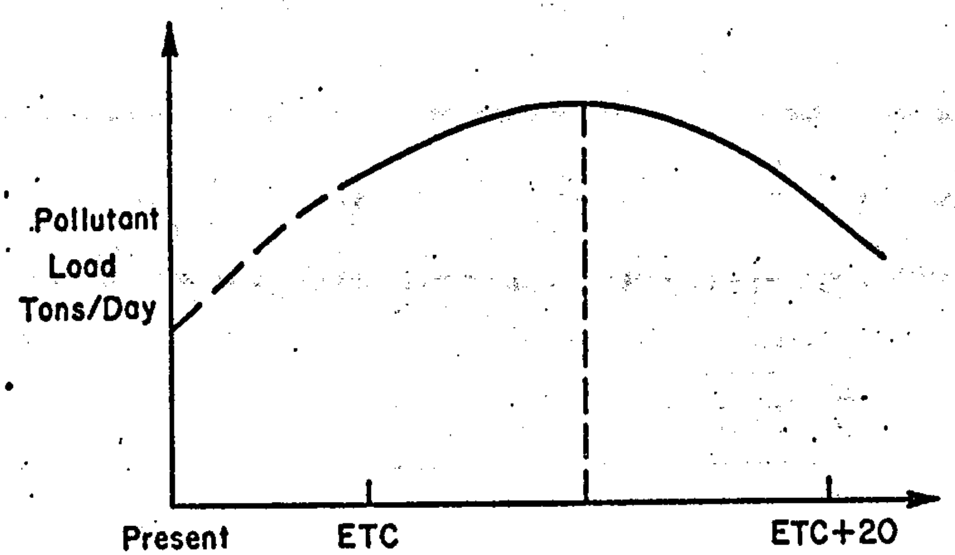
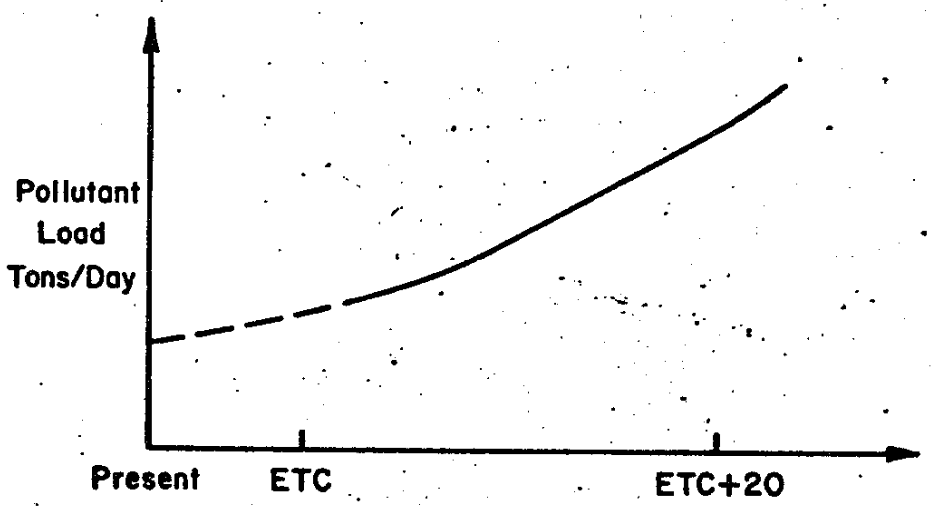


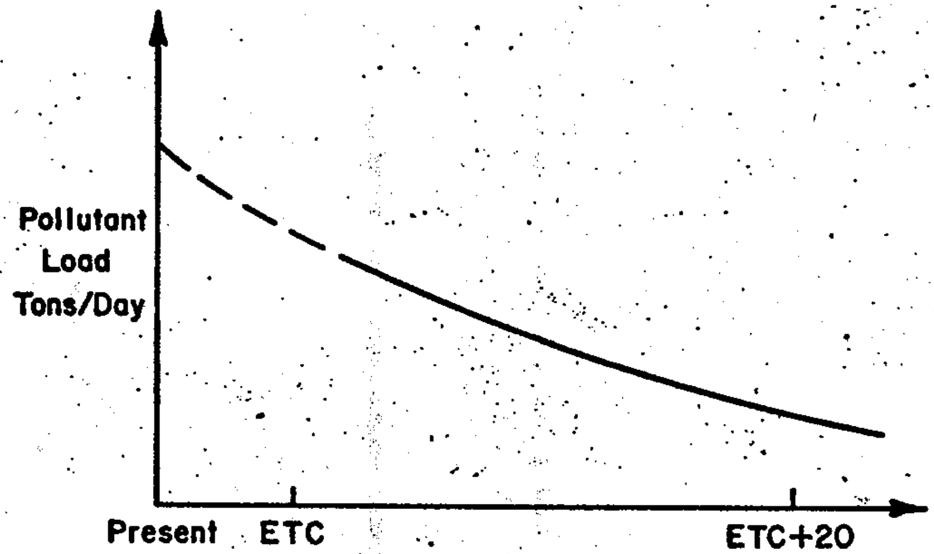
Fig. 10 CRITICAL YEAR OF POLLUTANT LOAD
FOR MESOSCALE ANALYSIS

FIGURE 4-4



TRAFFIC INCREASE GREATER THAN EMISSION FACTOR DECREASE FOR MESOSCALE ANALYSIS

FIGURE 4-5



TRAFFIC INCREASE LESS THAN EMISSION FACTOR DECREASE FOR MESOSCALE ANALYSIS

FIGURE 4-6

ESTIMATED TOTAL TRAFFIC LOAD FOR CARBON MONOXIDE

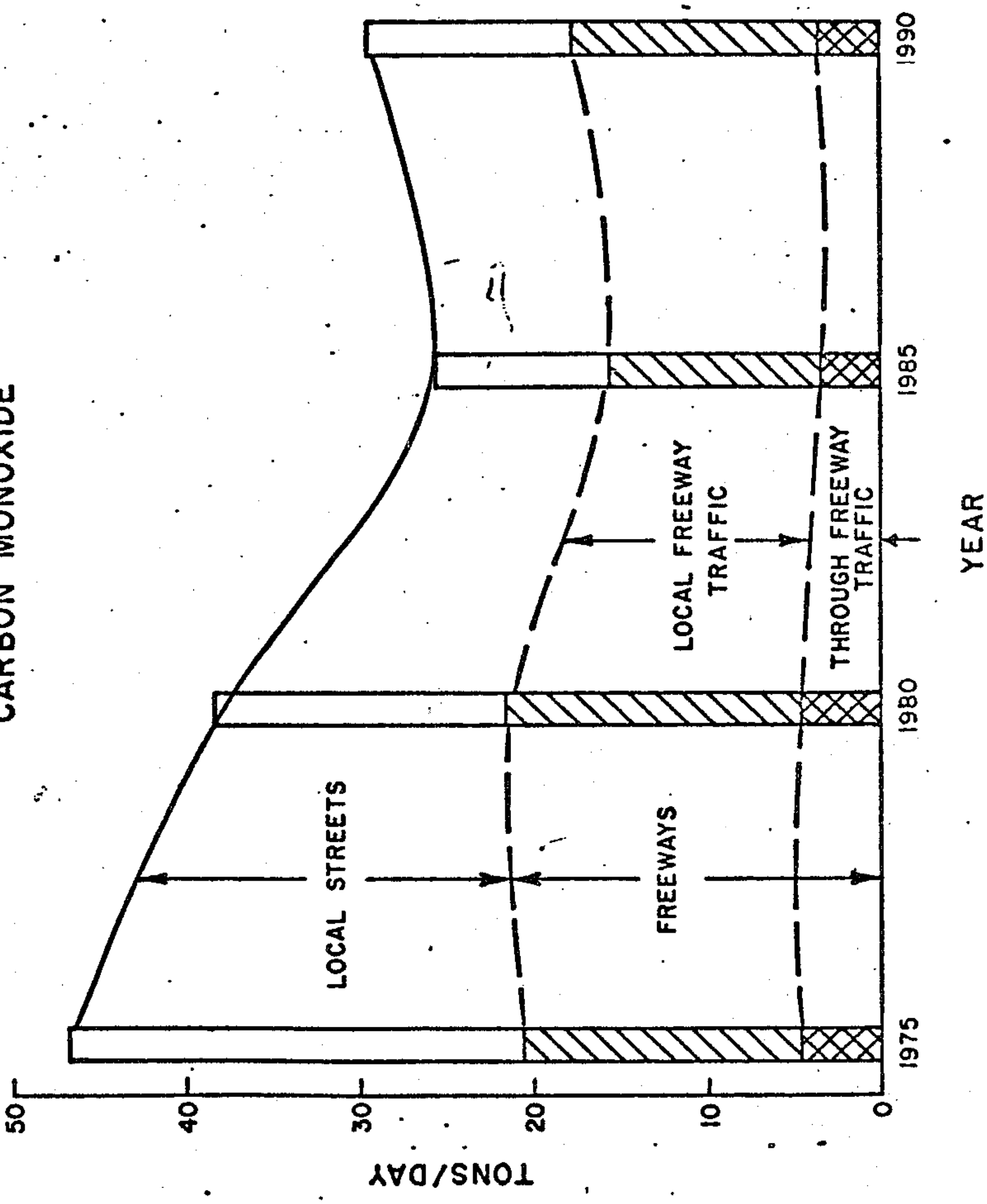


FIGURE 4-7

PROPORTIONAL ROLLBACK MODEL

ASSUMPTIONS:

(1) LINEAR PROPORTIONALITY EXISTS BETWEEN REGIONAL EMISSIONS AND OBSERVED CONCENTRATIONS.

(2) SPATIAL AND TEMPORAL VARIATIONS OF EMISSIONS IN THE ANALYSIS YEAR ARE IDENTICAL TO THAT OF THE BASE YEAR.

(3) EMISSION SOURCES WITHIN THE REGION ARE REDUCED BY THE SAME PERCENTAGE AS A RESULT IN THE CONTROL STRATEGY.

$$C_{max} = \frac{\bar{E}_S}{\bar{E}_B} \times C_{B_{max}}$$

WHERE C_{max} = MAXIMUM FUTURE CONCENTRATION

$\bar{E}_S$ = AVG. DAILY EMISSIONS FORECAST UNDER THE STRATEGY

$\bar{E}_B$ = AVG. DAILY EMISSIONS CALCULATED FOR BASE YEAR (1970)

$C_{B_{max}}$ = MAXIMUM CONCENTRATION OBSERVED AT MONITORING SITE DURING THE BASE YEAR

FIGURE-4-8

ROLLBACK TECHNIQUE

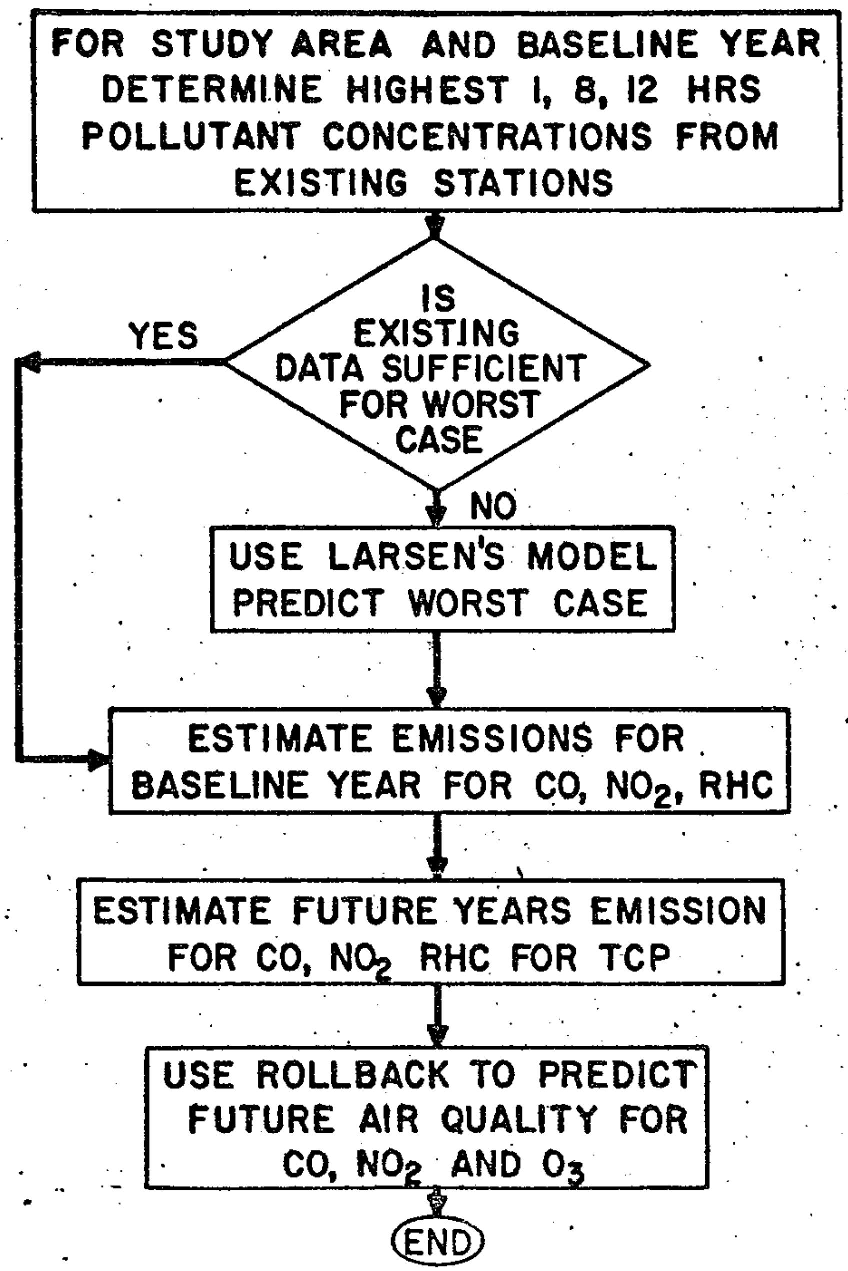


FIGURE 4-9

VI. SRI Regional Model

APRAC-1A*

A. Purpose

1. To estimate the CO concentrations for an urban area from readily available traffic and meteorological data

2. Model includes sources of:

   a. Extraurban diffusion from upwind sources.

   b. Intraurban diffusion from freeways, arterial and feeder street sources.

   c. Local diffusion of emissions within a street canyon.

*APRAC = Air Pollution Research Advisory Committee.
1A = refers to the present version of the model.

B. Traffic Data

1. Based primarily on CO emissions from a network of traffic road segments or links.

2. Primary network or link - all major freeway and surface arterial streets

3. Each link is identified by:

   a. ADT and VPH
   b. coordinate system
   c. road type

(1) freeway
(2) arterial
(3) local street

C. Secondary traffic network

1. Estimate total vehicle miles traveled on streets not representative by the primary network.

a. total fuel consumption (entire area)
b. less than DVM traveled on primary links
c. secondary travel is distributed by relative traffic densities of local streets for each grid area.

D. CO Emissions

1. $E = \alpha S^{-B}$

Where α &B are constants that depend on the characteristics of the emission control devices and vehicle mix.

α &B are determined by plotting E.F. vs. speed on log-log paper (straight line)

$E = \alpha S^{-B}$

$\log E = \log \alpha - B \log S$

where $\log \alpha$ = intercept
B = slope

2. Modify α & B based on California Department of Transportation emission factors or latest EPA study.

E. Intraurban Diffusion

1. Gaussian distribution of CO - See Figure 4-10

   a. σ_z represents the vertical spread of the plume. See Figure 4-11

2. Area segments are spaced logarithmically

   a. oriented normal to wind
   b. overlay traffic network

3. Box model - applied when elevated inversion exists.

F. Extraurban Diffusion

1. To estimate CO concentration from upwind sources.

$$C_e = \frac{5.15 \times 10^{-11} F}{\bar{u} h}$$

   Where F = annual consumption of fuel gals per year with a 22.5° angular sector extending from 32 to 1000 KM upwind of receptor location.

2. Therefore input 16 sectors of fuel consumption.

3. $C = C_e + C_u$
   (C_e extraurban, C_u intraurban)

4. C_e can be set equal to baseline levels from air quality survey. In this case, set F = 0

GENERAL GAUSSIAN EQUATION

$$\frac{C(X,Y,Z)\,\bar{U}}{Q} = \frac{1}{2\pi\sigma_Y\sigma_Z}\left[\text{EXP}-\frac{1}{2}\left(\frac{Y}{\sigma_Y}\right)^2\right]\left[\text{EXP}-\frac{1}{2}\left(\frac{Z+H}{\sigma_Z}\right)^2+\text{EXP}-\frac{1}{2}\left(\frac{Z-H}{\sigma_Z}\right)^2\right]$$

C = CONCENTRATION

$\bar{U}$ = WIND SPEED

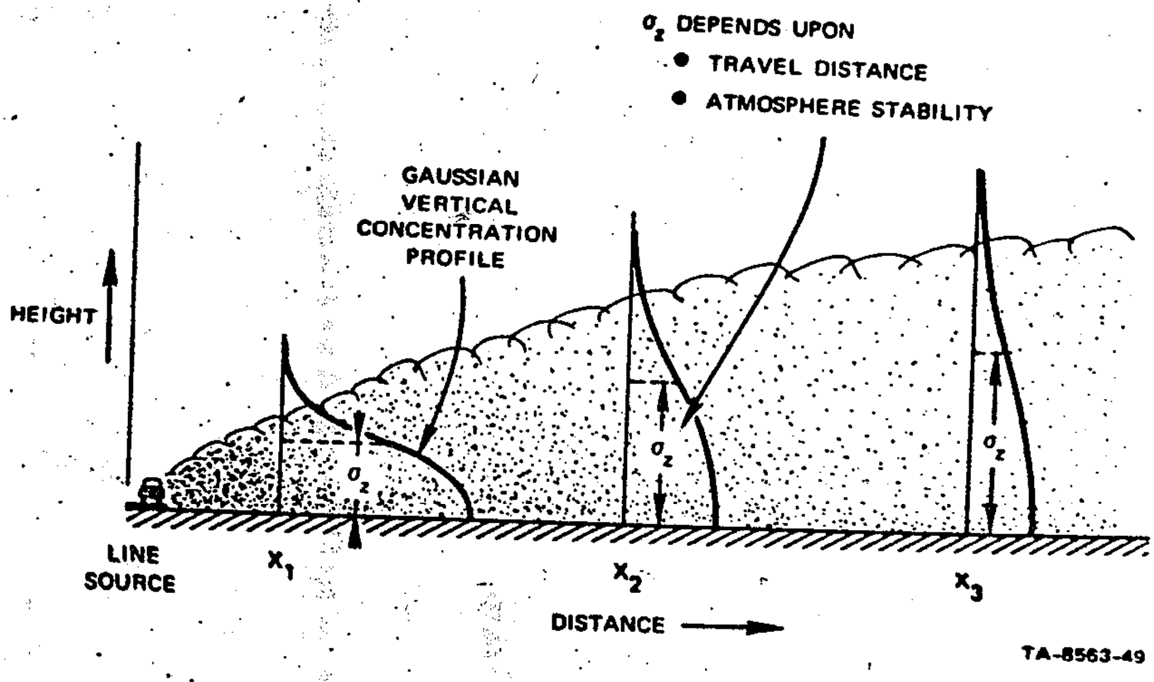
σ_Y, σ_Z = TURBULENCE PARAMETERS

Z = RECEPTOR HEIGHT

H = EFFECTIVE STACK HEIGHT

Y = RECEPTOR LOCATION FROM ℄ OF PLUME

FIGURE 4-10



VERTICAL DIFFUSION ACCORDING TO GAUSSIAN FORMULATION

is characterized by its standard deviation, σ_z. On the basis of experimental data, σ_z is taken to have the form

FIGURE 4-11

G. Local Street Canyon Diffusion

1. Street canyon effect (show overhead slide)

2. $C = \underbrace{C_e + C_u}_{\text{extra- \& intra-urban contribution}} + \underbrace{C}_{\text{street canyon effect}}$

H. Transport Wind, Mixing Depth and Stability

1. transport wind - use nearest airport
2. mixing depth

   a. closest USWB morning upper air sounding for temperature

   b. use maximum afternoon temperature at surface to predict maximum mixing depth

   c. morning or minimum mixing depth is determined using:

      (1) empirical relationship involving city size, urban and rural nighttime temperature

   d. hourly depths are <u>interpolated</u> based on observed hourly surface temperatures.

3. Stability index - basically Pasquill approach

   a. insolation
   b. wind speeds
   c. cloud cover

H. Changes in Model for Department of Transportation.

1. Input any desired maximum or minimum inversion height and interpolate for other hours

2. In street canyon option have building height as a variable

3. Input latest emission factors consistent with our present analysis

I. Basic Inputs

1. Options

a. Synoptic model - hourly CO concentrations as a function of time for comparisons and verification with observed concentrations. (10 receptor) or receptors.

b. Climatological model - frequency distribution or CO concentrations

c. Grid model - CO concentrations at various locations (up to 625)

d. Street canyon option for all cases above

2. Traffic

a. Coordinates all links in network
b. ADT, VPH
c. Type of roadway, freeway, street, etc.
d. Grid point spacing, usually 2 mi.sq.

M. Advantages

1. Simulates multi-day run easily
2. Computationally efficient
3. Provides information for location of CO stations for system planning.

VII. Photochemical Models

A. SAI Airshed Model - grid or eulerian model
B. GRC - DIFKIN trajectory model
C. PES - trajectory model
D. Operation of Photochemical Model

1. Divide Area into grids - Figure 4-12

2. Each grid must specify:

a. Emission fluxes of HC, NO_x, CO
b. Wind flow field and inversion characteristics
c. Initial concentrations of HC, NO_x, CO

3. Identify terrain features that will alter surface winds

4. Simulate real world transport, diffusion and reactions in atmosphere.

VIII. DIFKIN - Diffusion and Kinetics

A. Purpose - a predictive model to assess air pollution effects on a regional scale using trajectories.

1. Model air pollutants from:

a. Distributed transportation sources - networks of highways and surface streets

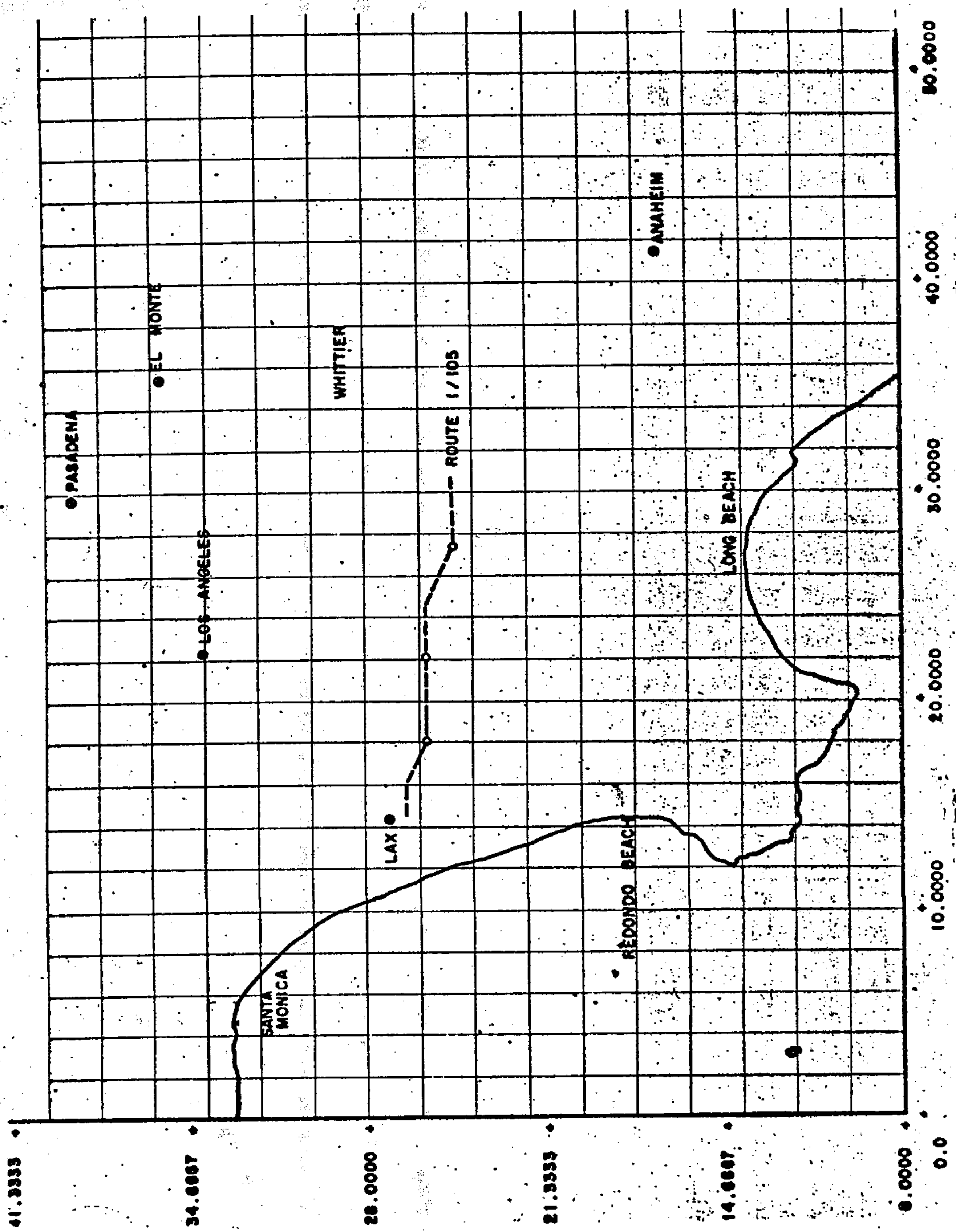

PASADENA
EL MONTE
LOS ANGELES
WHITTIER
ROUTE I/105
LAX
SANTA MONICA
REDONDO BEACH
LONG BEACH
ANAHEIM
41.3333
34.6667
28.0000
21.3333
14.6667
8.0000
0.0
10.0000
20.0000
30.0000
40.0000
50.0000

FIGURE 4-12

b. point sources - industrial plants

B. Model Characteristics

1. Lagrangian model coupled with vertical diffusion and chemical reactions.

2. Air parcel carries its own set of coordinates in a trajectory aligned with the wind direction and traveling at the prevailing horizontal wind speed.

3. DIFKIN computes the time dependent behavior of a moving air parcel in which a multicomponent gaseous mixture undergoes simultaneous diffusion and chemical reactions.

C. Basic Equation

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} = \frac{\partial}{\partial z}\left[D_z \frac{\partial c}{\partial z}\right] + R_i + S_i$$

Where: C = mass concentration

t = time

u = horizontal wind speed

x = downwind distance

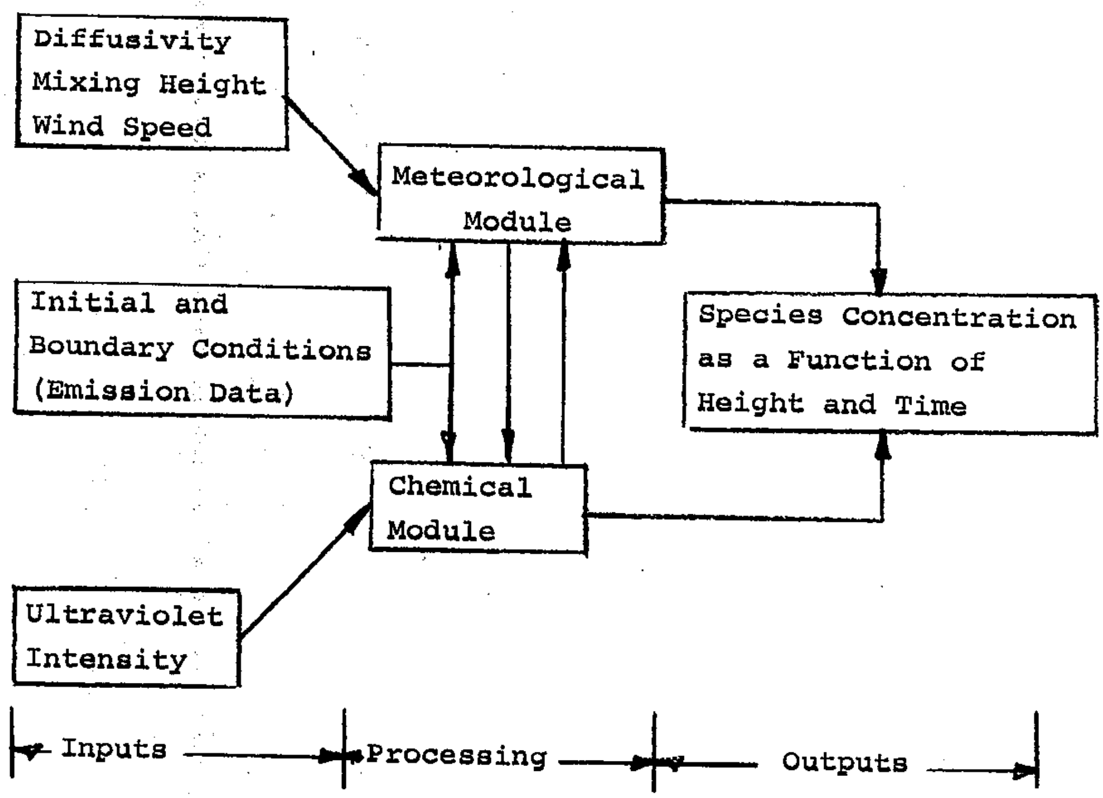
z = height above ground

D_z = vertical turbulent diffusion coefficient; function of time and z

S_i = production rate for emission sources

R_i = rate of production through chemical reactions

C. DIFKIN Flow Diagram



D. Meteorological Data Inputs

1. Surface wind speed as a function of time.

2. Mixing depth (inversion height) above ground surface.

3. Diffusivity coefficient = f (t,z)
   units - m^2/min   10 to 3000 m^2/min

4. Ultraviolet intensity - is input implicitly via the rate constant for the photo-disassociation of NO_2.

E. Emission Data Inputs

1. Transportation systems - highways, etc.
2. Point sources
3. Grid source analysis
4. Initial boundary conditions

    a. Emission data at ground surface
    b. Emission data at top of inversion

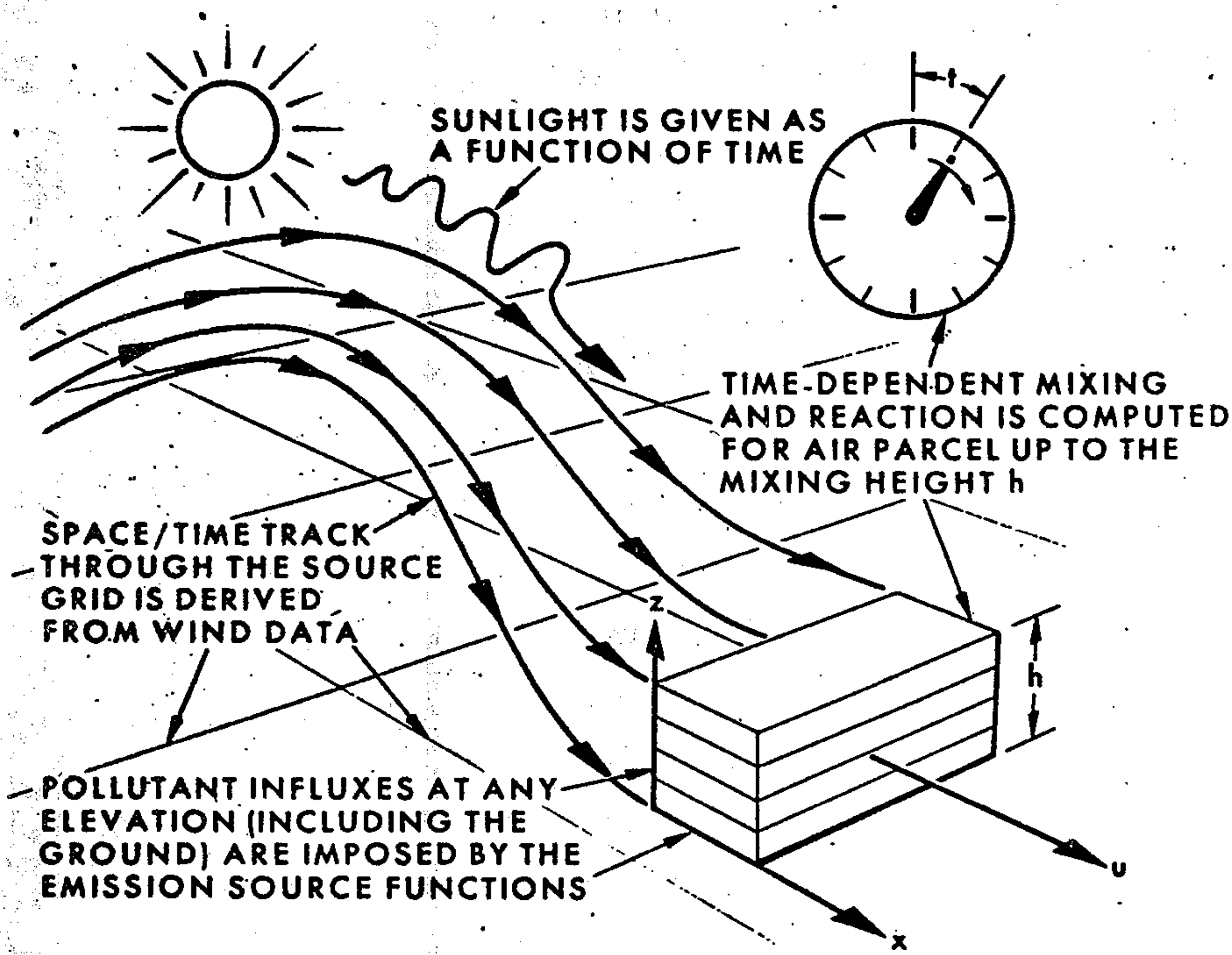
F. Chemical Rate Constants:

1. Nitric Oxide
2. Nitrogen Dioxide
3. Hydrocarbons
4. Carbon Monoxide
5. Ozone
6. Peroxyacetylnitrate (PAN)
7. Nitrous Acid
8. Nitric Acid
9. Hydroxyl Radical
10. Organic Radicals
11. Nitrogen Trioxide

G. Output of DIFKIN Model

1. Tabular Data
2. Graphical Data
3. Punched Output

H. Operation of Model - See Figure 4-13



Schematic of Diffusion Model for Air Pollution Simulation

FIGURE 4-13

I. Applications of DIFKIN

1. Applicable for project level analysis. See Figures 4-14 and 4-15.

2. Locate sources which produce "hot spots" for pollutant emissions using backward trajectories.

3. Predict pollutant concentrations in valleys.

4. Applicable for areas where terrain affects surface winds.

5. Computationally efficient

J. Limitations

1. Not directly applicable for convergence or divergence of wind flow fields.

2. Not applicable where vertical wind shear is an important parameter - multi-day runs.

3. Not applicable for transportation system planning.

4. Difficult to compare prediction to 1 hour NAAQS because moving trajectories - spatial average.

5. Trajectories are sensitive to exposure of existing wind stations; therefore must have weather stations located consistent with assumptions of the model.

6. Input requirements.

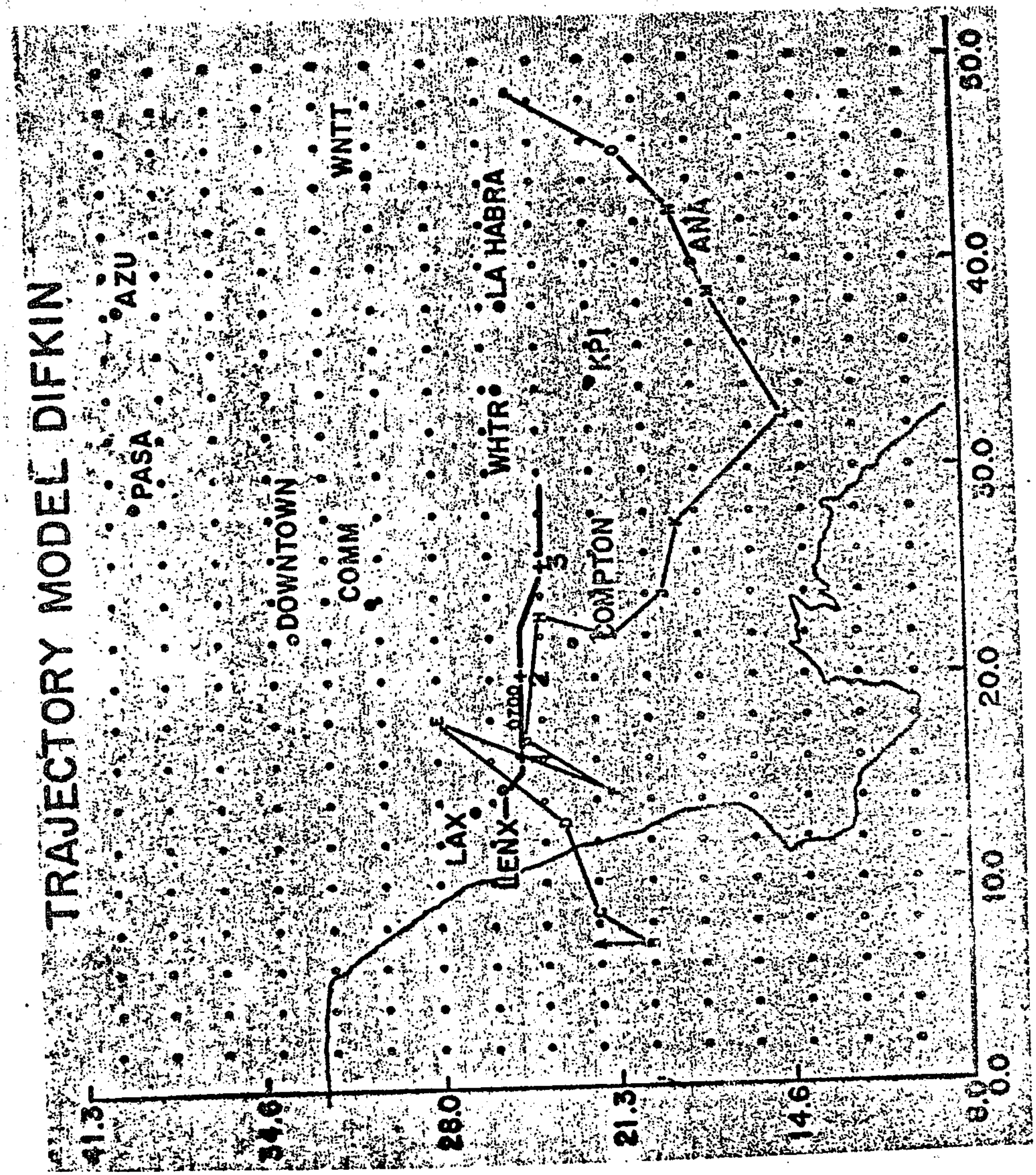

TRAJECTORY MODEL DIFKIN
AZU
PASA
DOWNTOWN
COMM
WNTT
LA HABRA
WHTR
KPI
ANA
COMPTON
LAX
LENX
0700
41.3
34.6
28.0
21.3
14.6
8.0
0.0
10.0
20.0
30.0
40.0
50.0

FIGURE 4-14

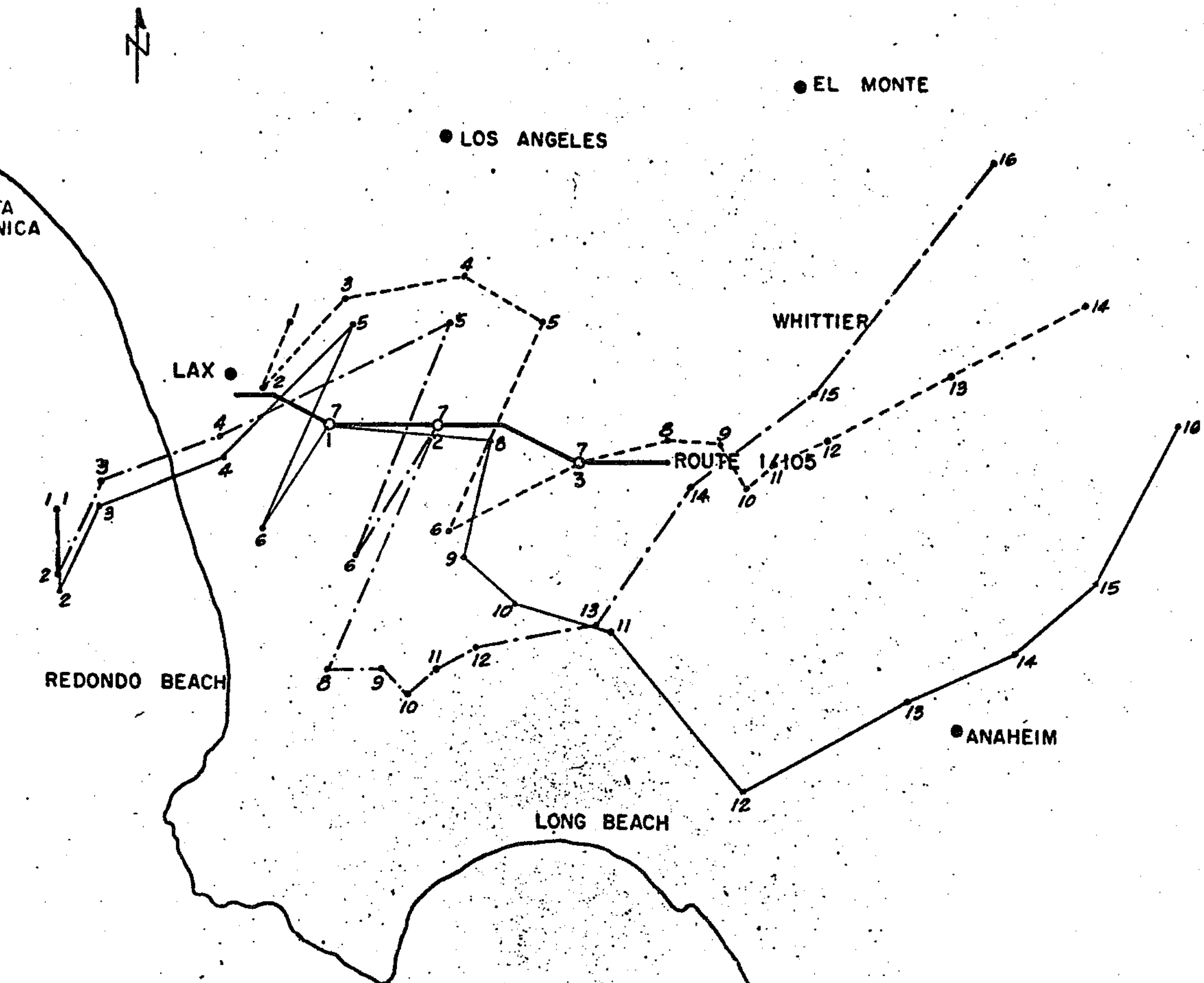

N
EL MONTE
LOS ANGELES
SANTA MONICA
LAX
WHITTIER
ROUTE 1/105
REDONDO BEACH
LONG BEACH
ANAHEIM
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

FIGURE 4-15

IX. SAI Airshed Model

A. Purpose - A predictive model to assess air pollution impacts on a regional scale using an eulerian coordinate system.

1. Model air pollutants from:

   a. distributed transportation sources - network of highways and surface streets.

   b. point sources - industrial plants

   c. aircraft sources

B. Model Characteristics

1. Eulerian model coupled with three dimensional diffusion and chemical reactions; allows wind convergence and divergence and elevated behavior to be all treated readily in this formulation

2. Predicts temporal and spatial distribution of pollutants for each grid in entire study area.

C. Basic Equation:

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} + w\frac{\partial c}{\partial z} = \frac{\partial}{\partial x}\left[K_h\frac{\partial c}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_h\frac{\partial c}{\partial y}\right] + \frac{\partial}{\partial z}\left[K_v\frac{\partial c}{\partial z}\right] + R_i + S_i$$

Where C_i = concentration of species i
U,V,W = wind components in x, y, z direction
K_h, K_v = horizontal and vertical diffusivity
R_i = rate of production of species i through chemical reactions.
S_i = rate of production of species i from source emissions.

D. System Overview - See Figure 4-16

E. Automated Meteorological Data Preparation Program (AMDPP)

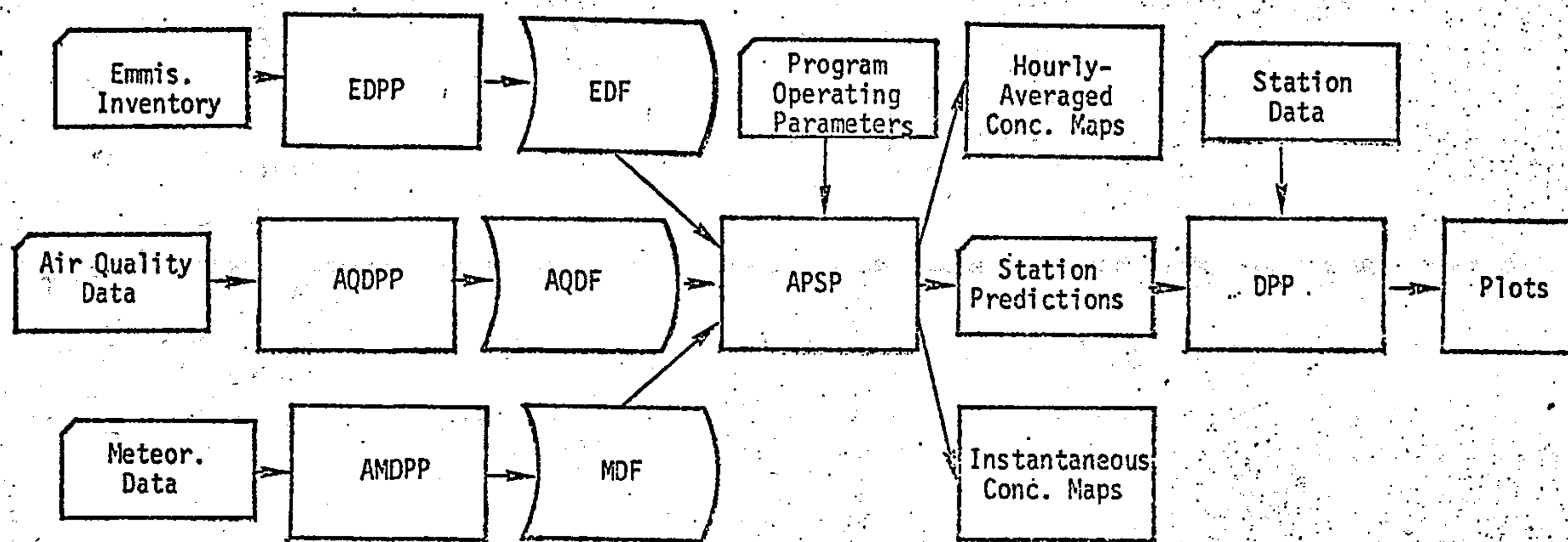
1. Purpose - The AMDPP is used to prepare meteorological data in a suitable format for direct input to the Atmospheric Pollution Simulation Program. Wind data and inversion soundings at points scattered throughout the modeling region are employed in an interpolation scheme which results in the calculation of wind speed and direction and mixing depth at each grid cell.

2. Input Data Requirements - Grid coordinates of each measurement site.

   Hourly-averaged wind speed and direction data
   Inversion soundings (as available)
   Miscellaneous program operating parameters.

3. Output Capabilities - Printed maps displaying the spatial distribution of the wind speed, wind direction, and mixing depth at each hour.

SYSTEM FLOW DIAGRAM



AMDPP - Automated Meteorological Data Preparation Program

APSP - Atmospheric Pollution Simulation Program

AQDF - Air Quality Data File

AQDPP - Air Quality Data Preparation Program

DPP - Data Plotting Program

EDPP - Emissions Data Preparation Program

EDF - Emissions Data File

MDF - Meteorological Data File

FIGURE 4-16

F. Emissions Data Preparation Program (EDPP)

1. Purpose - The EDPP is employed to process motor vehicles, aircraft, and fixed source emissions data. Total emissions for each chemical species are calculated at every grid point as a function of the time and placed in the Emissions Data File (EDF) in a form suitable for use by the Atmospheric Pollution Simulation Program.

2. Input Data Requirements

Motor Vehicle Emissions

- daily vehicle miles travelled (VMT) on surface streets in each ground level grid cell (miles/day)
- daily VMT traveled on freeways in each grid cell (miles/day)
- average freeway and city street driving speed in each cell as a function of time
- temporal distributions for both surface street and freeway driving activity
- average hot and cold-start vehicle emission factors for HC, NO_x, and CO (grams/vehicle-day)
- reactive/unreactive hydrocarbon split for exhaust emissions

Aircraft Emissions

- emission factors for each aircraft class as a function of operating mode (lb./minute)

- amount of time each class of aircraft spends in each operating mode (minutes)

- average number of engines of each class of aircraft

- airport location

- total number of daily ground operations at each airport (operations/day)

- temporal distribution of ground operations at each airport

Fixed Source Emissions

- total emissions rate of HC, NO_x, and CO from fixed sources into each grid cell (kgm/hour)

3. Output Capabilities - Printed maps displaying the spatial distribution of reactive and unreactive hydrocarbon, NO, NO_2, and CO emissions at each hour

G. Air Quality Data Preparation Program (AQDPP)

1. Purpose - The AQDPP takes either measured or user-specified air quality data at a number of scattered sites throughout the modeling region and, through an interpolation procedure, computes both the initial and boundary concentration distributions for use in the airshed simulation.

2. Input Data Requirements

Grid coordinates for each measurement site

Hourly air quality data (measured or user-specified) for each pollutant species at each station

Miscellaneous program operating parameters

3. Output Capabilities

Printed maps displaying the initial concentration distribution on the grid for each species.

Printed tables illustrating the calculated hourly values of the boundary concentrations for each species.

H. Atmospheric Pollution Simulation Program (APSP)

1. Purpose

The APSP is used to carry out the actual airshed simulation. Emissions, meteorological and air quality inputs are processed to yield the spatial and temporal distributions of air contaminants throughout the modeling region. Of particular interest are the estimates of hourly-averaged ground level pollutant concentrations for reactive hydrocarbons, unreactive hydrocarbons, NO, NO_2, O_3, and CO.

2. Input Data Requirements

Meteorological Data File
Emissions Data File

Air Quality Data File

Modeling region characteristics

- maximum number of grid cells in each coordinate direction

- shape of the region

- topographic barriers

Chemical kinetics parameters

- reaction rate constants
- stoichiometric coefficients
- temporal characteristics of photolysis rate constants

Miscellaneous program operating parameters

- starting and stopping time of the simulation
- integration time step size
- time interval between ground level concentration map printouts

3. Output Characteristics

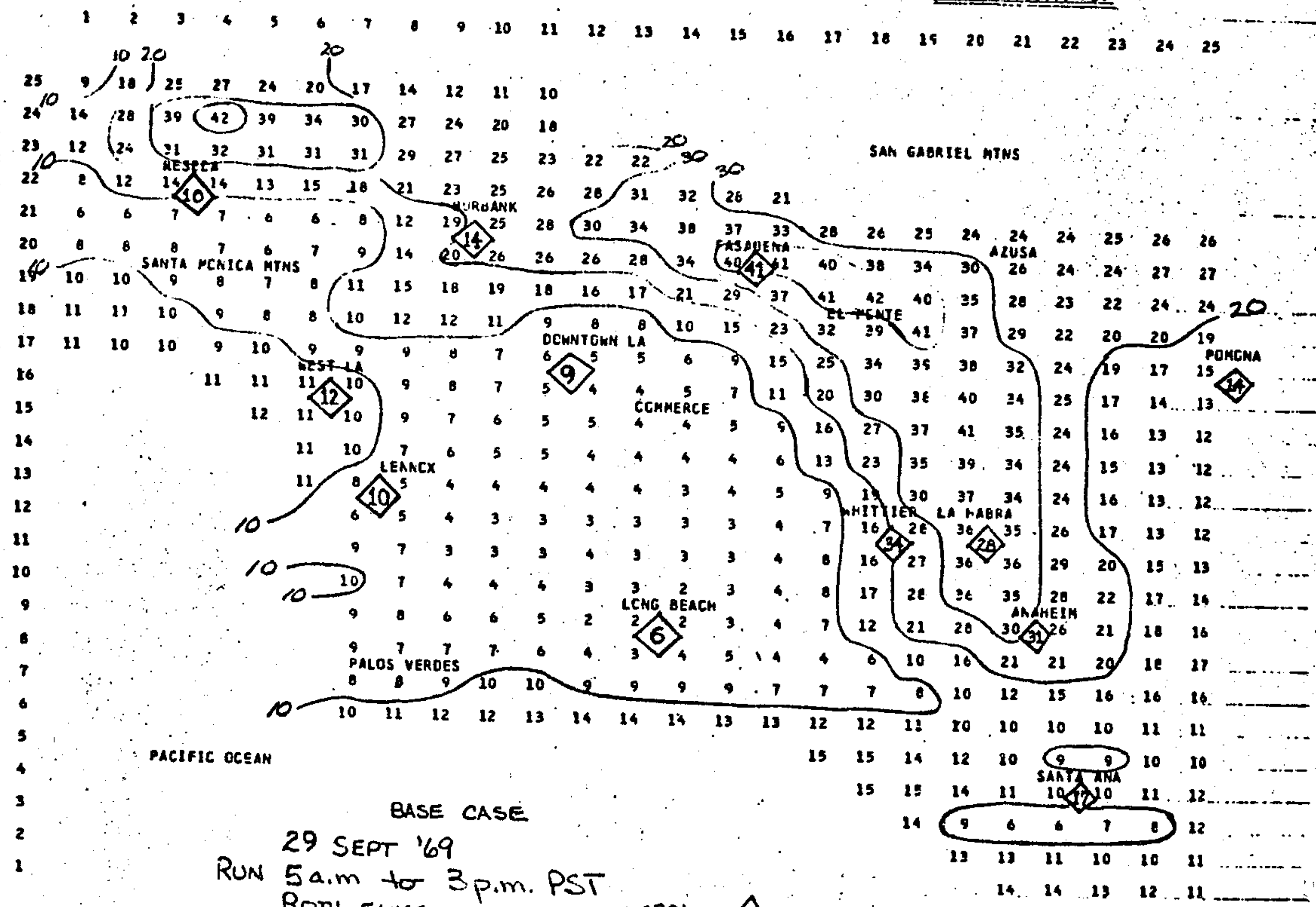
Printed maps illustrating predicted ground level concentrations at regular time intervals (user-selected) throughout the course of the simulation See Figures 4-17 and 4-18

E. Applications of SAI Airshed Model

1. System planning to determine the interrelationship of land use, transportation and air quality planning.

GRID MODEL SAI

AVERAGE GROUND LEVEL CONCENTRATIONS (PPHM) OF O3 BETWEEN THE HOURS OF 1100. AND 1200. PST



BASE CASE
29 SEPT '69
RUN 5 a.m to 3 p.m. PST
ROTH EMISSIONS INVENTORY (1970)

◇ MONITORING STATION

FIGURE 4-17

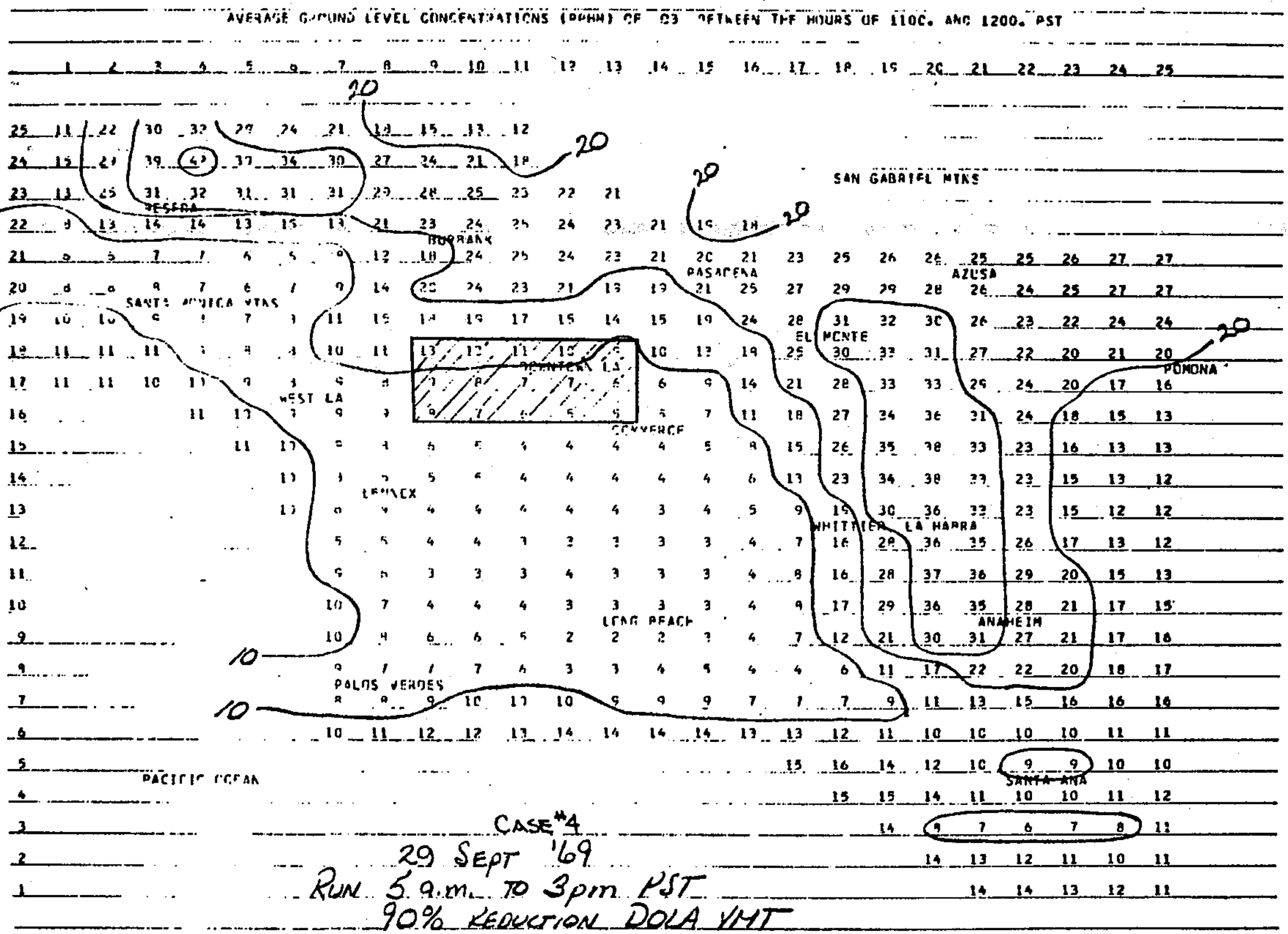

AVERAGE GROUND LEVEL CONCENTRATIONS (PPHM) OF O3 BETWEEN THE HOURS OF 1100. AND 1200. PST
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
SAN GABRIEL MTNS
BURBANK
PASADENA
AZUSA
SANTA MONICA MTNS
EL MONTE
POMONA
WEST LA
COMMERCE
LENNOX
WHITTIER
LA HABRA
LONG BEACH
ANAHEIM
PALOS VERDES
PACIFIC OCEAN
SANTA ANA
10
20
CASE #4
29 SEPT '69
RUN 5 a.m. TO 3pm PST
90% REDUCTION DOLA VMT

FIGURE 4-18

2. Applicable for areas where terrain effects alter surface winds.

3. Applicable for area where a convergence or divergence of wind flow field exists.

4. Applicable for areas where vertical wind shear is important.

5. Provides information for system planning and location of air monitoring stations.

F. Limitations of SAI Airshed Model

1. Expensive to run
2. Not applicable for project level analysis - too costly
3. Numerical diffusion problems
4. Cannot simulate multi-day runs - must be modified
5. Input requirements

G. Transportation Systems Analysis

1. See Figure 4-19

X. Validation of Regional Air Quality Models

A. DIFKIN, SAI, PES - Los Angeles Study

1. Poor data base for model inputs

2. Location of APCD stations were locally affected by:

a. high traffic densities
b. O_3 depression

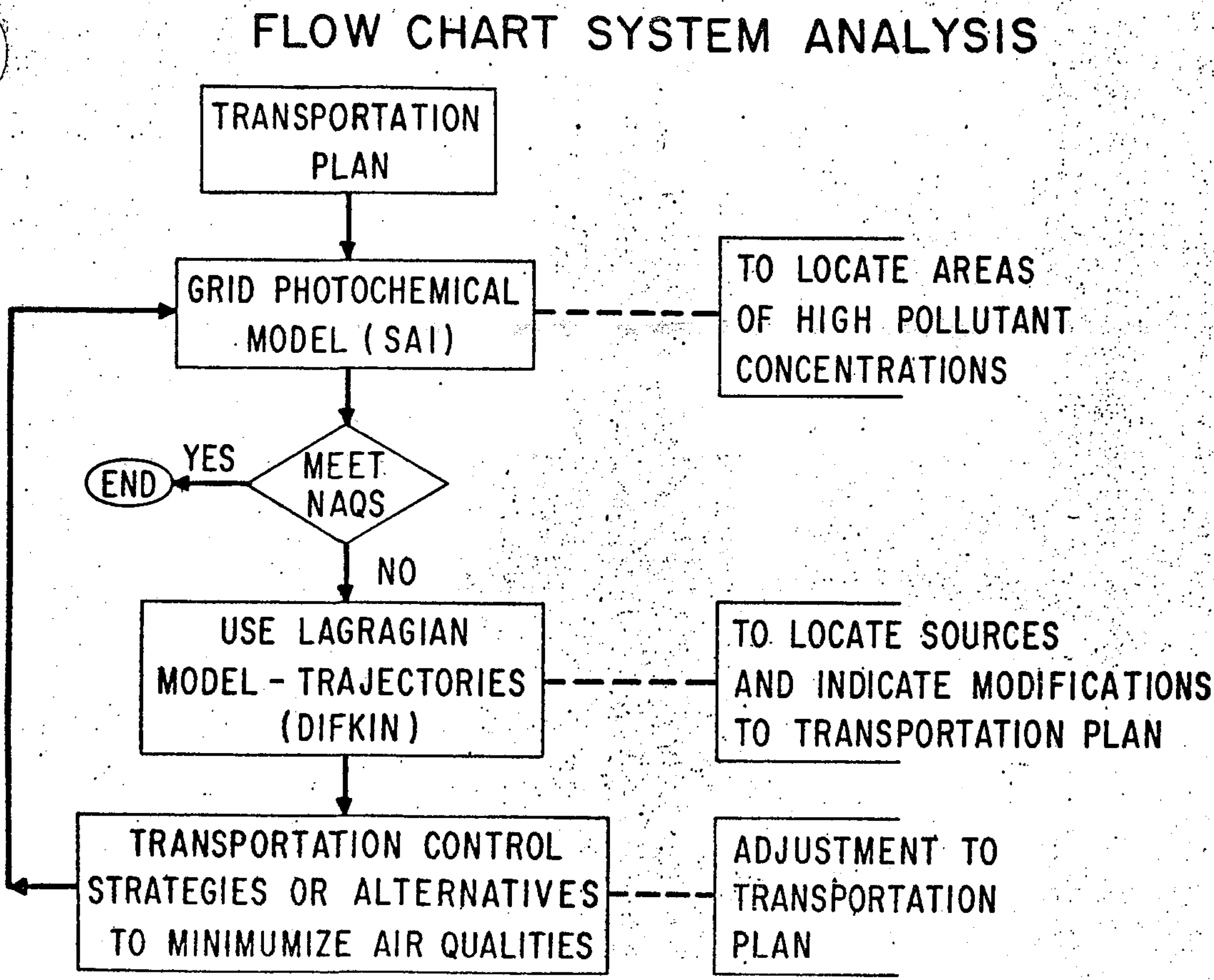

FLOW CHART SYSTEM ANALYSIS
TRANSPORTATION PLAN
GRID PHOTOCHEMICAL MODEL (SAI)
TO LOCATE AREAS OF HIGH POLLUTANT CONCENTRATIONS
MEET NAQS
YES
END
NO
USE LAGRAGIAN MODEL - TRAJECTORIES (DIFKIN)
TO LOCATE SOURCES AND INDICATE MODIFICATIONS TO TRANSPORTATION PLAN
TRANSPORTATION CONTROL STRATEGIES OR ALTERNATIVES TO MINIMUMIZE AIR QUALITIES
ADJUSTMENT TO TRANSPORTATION PLAN

FIGURE 4-19

3. Difficult to validate models unless these localized effects are considered in the model.

4. Need point measurements of air quality which is representative of entire grid area.

5. Poor exposure of meteorological data

   a. Location of APCD stations

   b. Stations with 1 hour averaging times vs instantaneous readings.

B. Consequences of using data that are not representative or based on assumptions of models.

1. Difficult to determine initial concentrations for each grid square with confidence

2. Difficult to determine the wind flow field and trajectories with confidence.

3. No confidence in validation results.

SECTION 5

VERIFICATION OF APRAC-1A

SACRAMENTO AND VICINITY : BOUNDARIES OF APRAC STUDY

● RECEPTOR LOCATIONS : IN FIELD AND IN MODEL (1-9)

■ AIR RESOURCES BOARD (10)

AIRPORTS

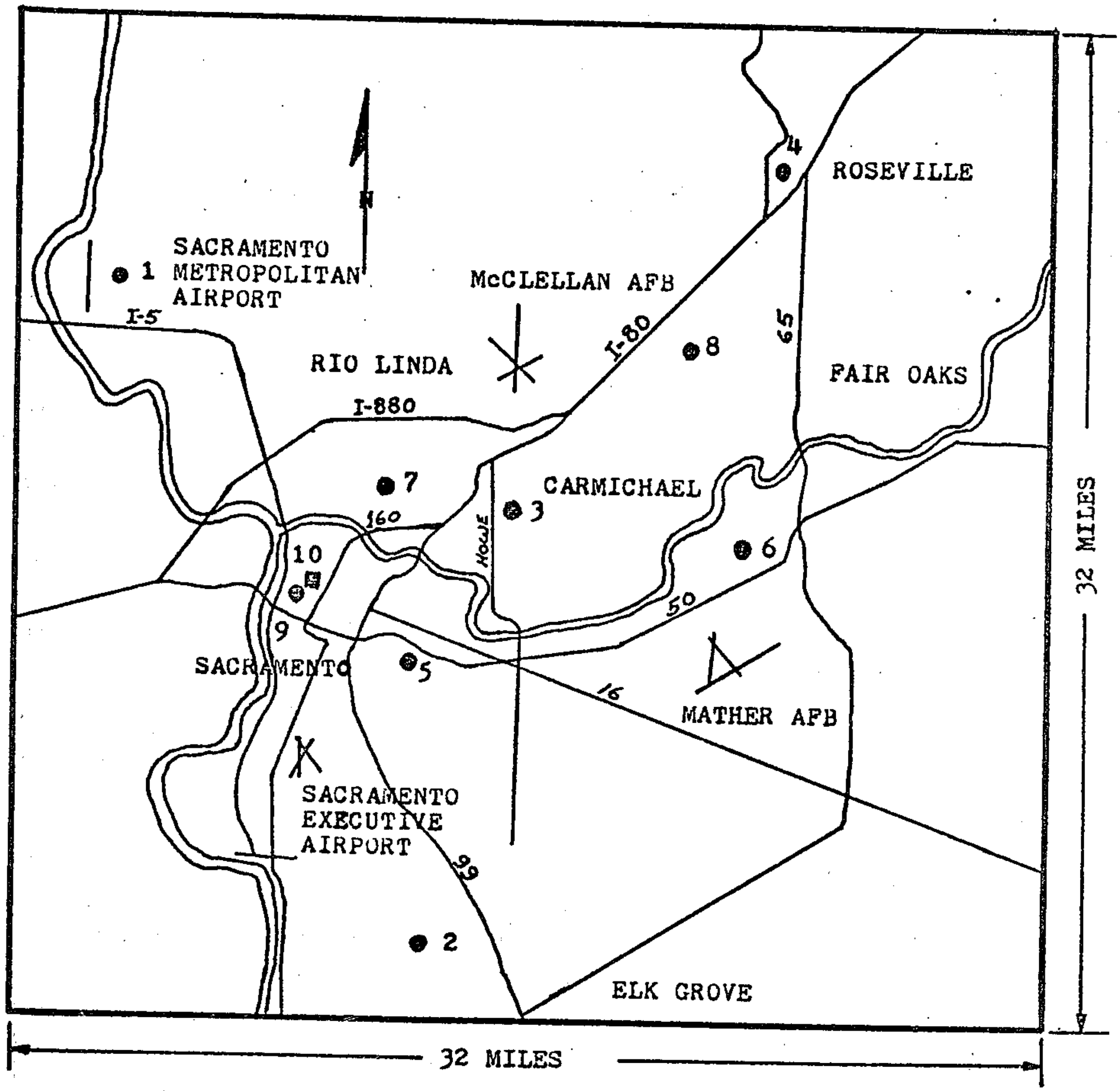
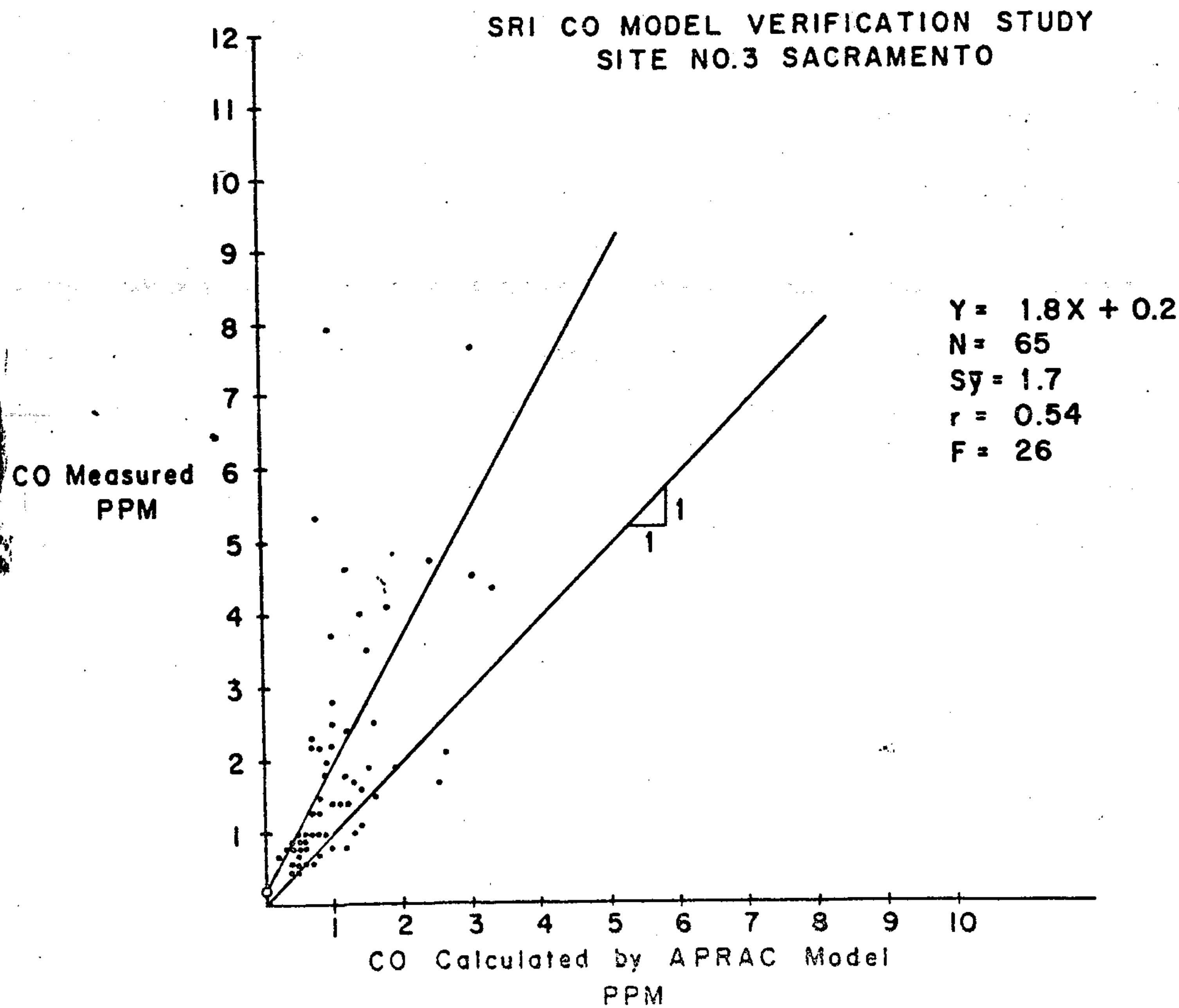


FIGURE 5-1



SRI CO MODEL VERIFICATION STUDY
SITE NO.3 SACRAMENTO
Y = 1.8X + 0.2
N = 65
Sȳ = 1.7
r = 0.54
F = 26
CO Measured PPM
CO Calculated by APRAC Model PPM
1
1
12
11
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10

FIGURE 5-2

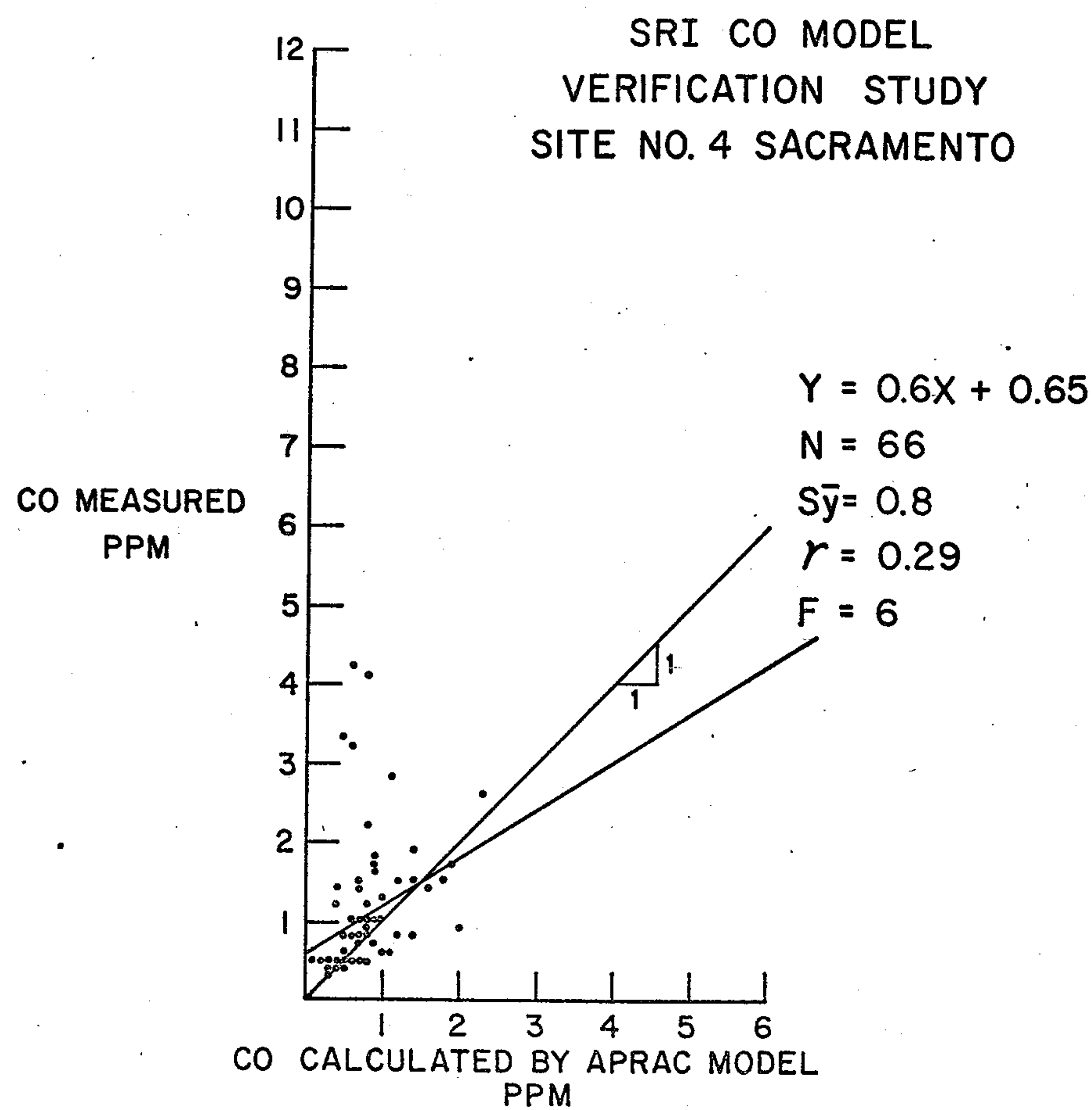

SRI CO MODEL
VERIFICATION STUDY
SITE NO. 4 SACRAMENTO
Y = 0.6X + 0.65
N = 66
Sȳ= 0.8
r = 0.29
F = 6
CO MEASURED
PPM
12
11
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
1
1
CO CALCULATED BY APRAC MODEL
PPM

FIGURE 5-3

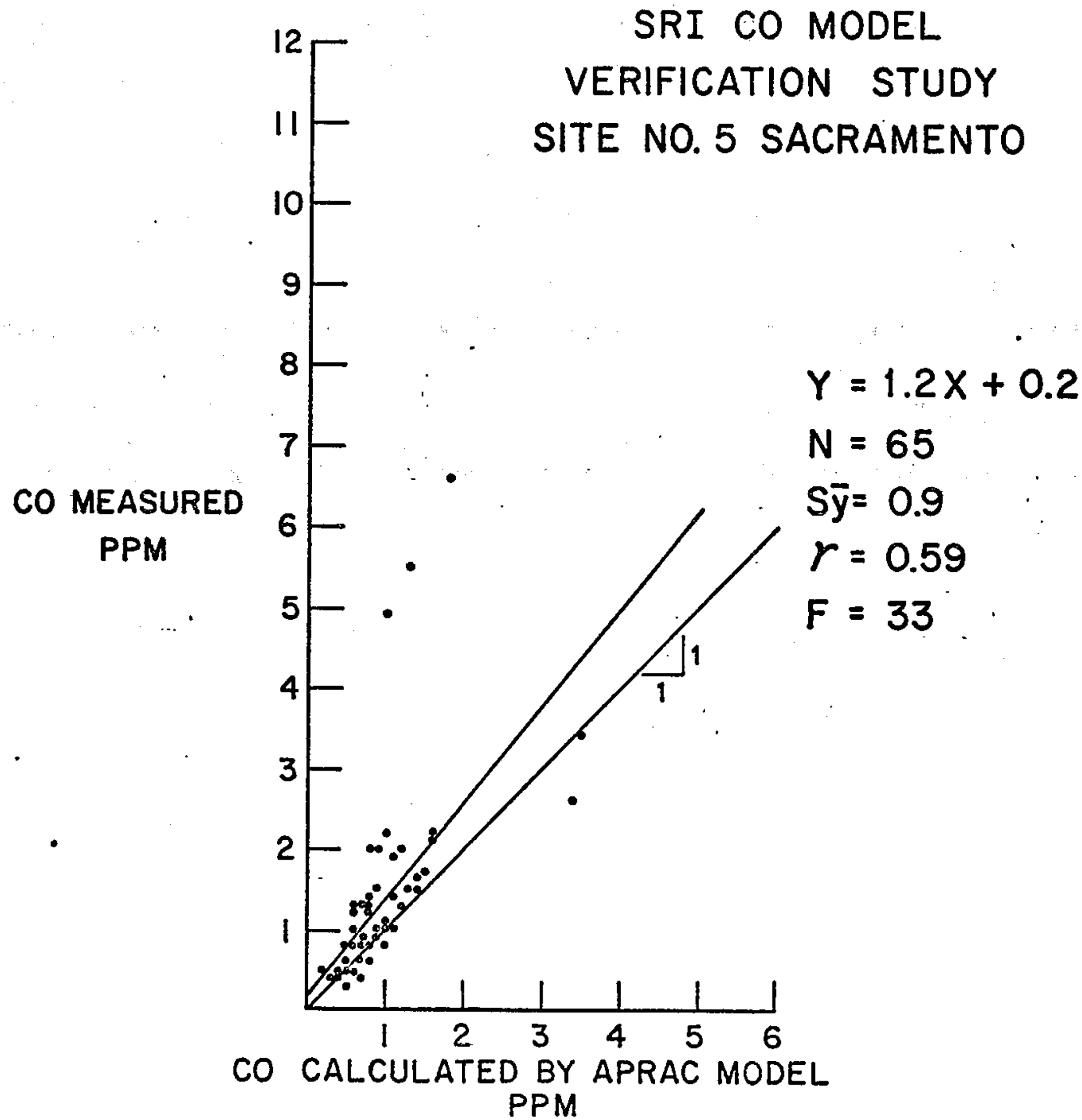

SRI CO MODEL
VERIFICATION STUDY
SITE NO. 5 SACRAMENTO
Y = 1.2X + 0.2
N = 65
Sȳ= 0.9
r = 0.59
F = 33
CO MEASURED
PPM
CO CALCULATED BY APRAC MODEL
PPM
12
11
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6

FIGURE 5-4

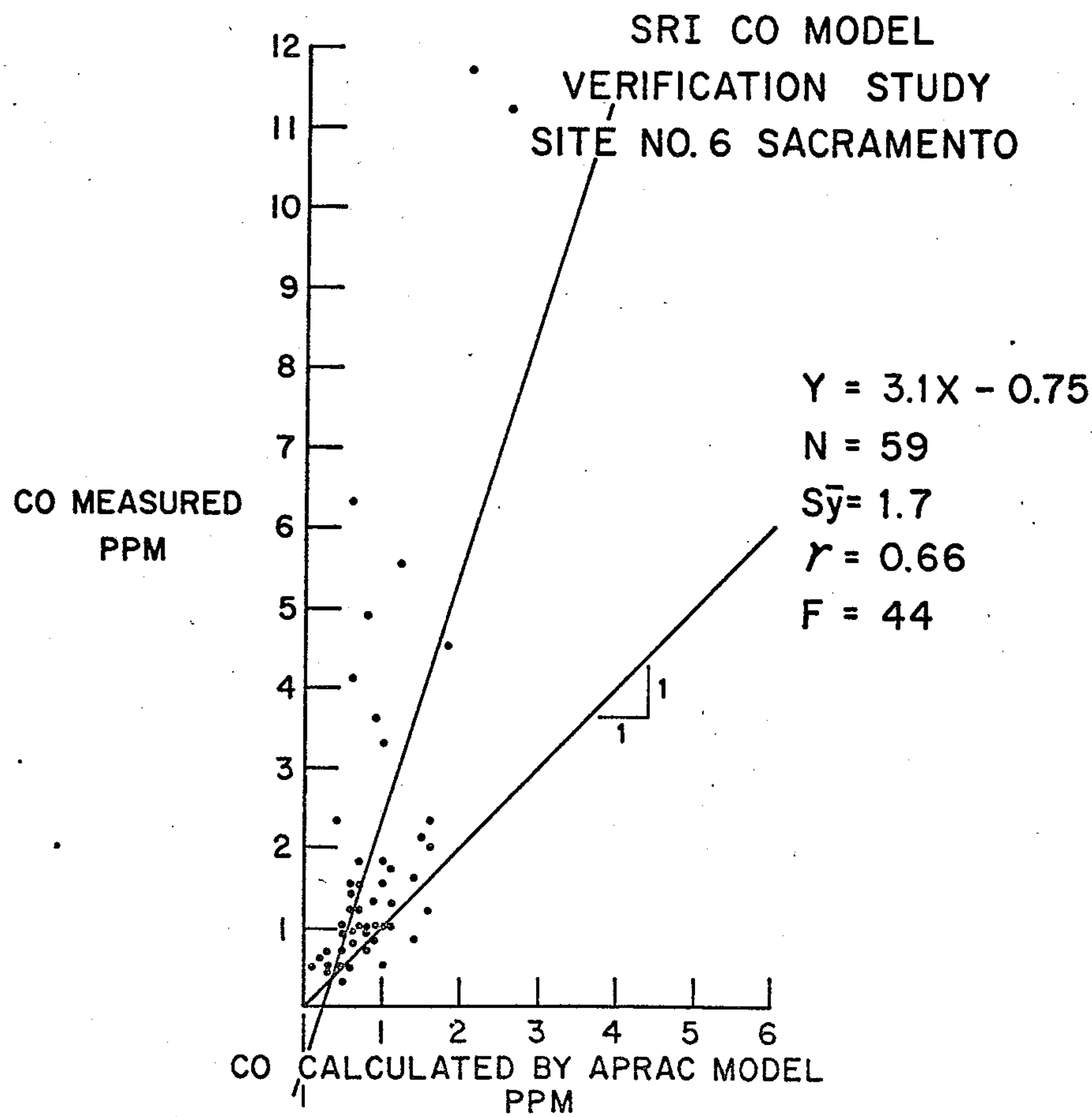

SRI CO MODEL
VERIFICATION STUDY
SITE NO. 6 SACRAMENTO
Y = 3.1X - 0.75
N = 59
$S\bar{y}$ = 1.7
r = 0.66
F = 44
CO MEASURED
PPM
12
11
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
CO CALCULATED BY APRAC MODEL
PPM

FIGURE 5-5

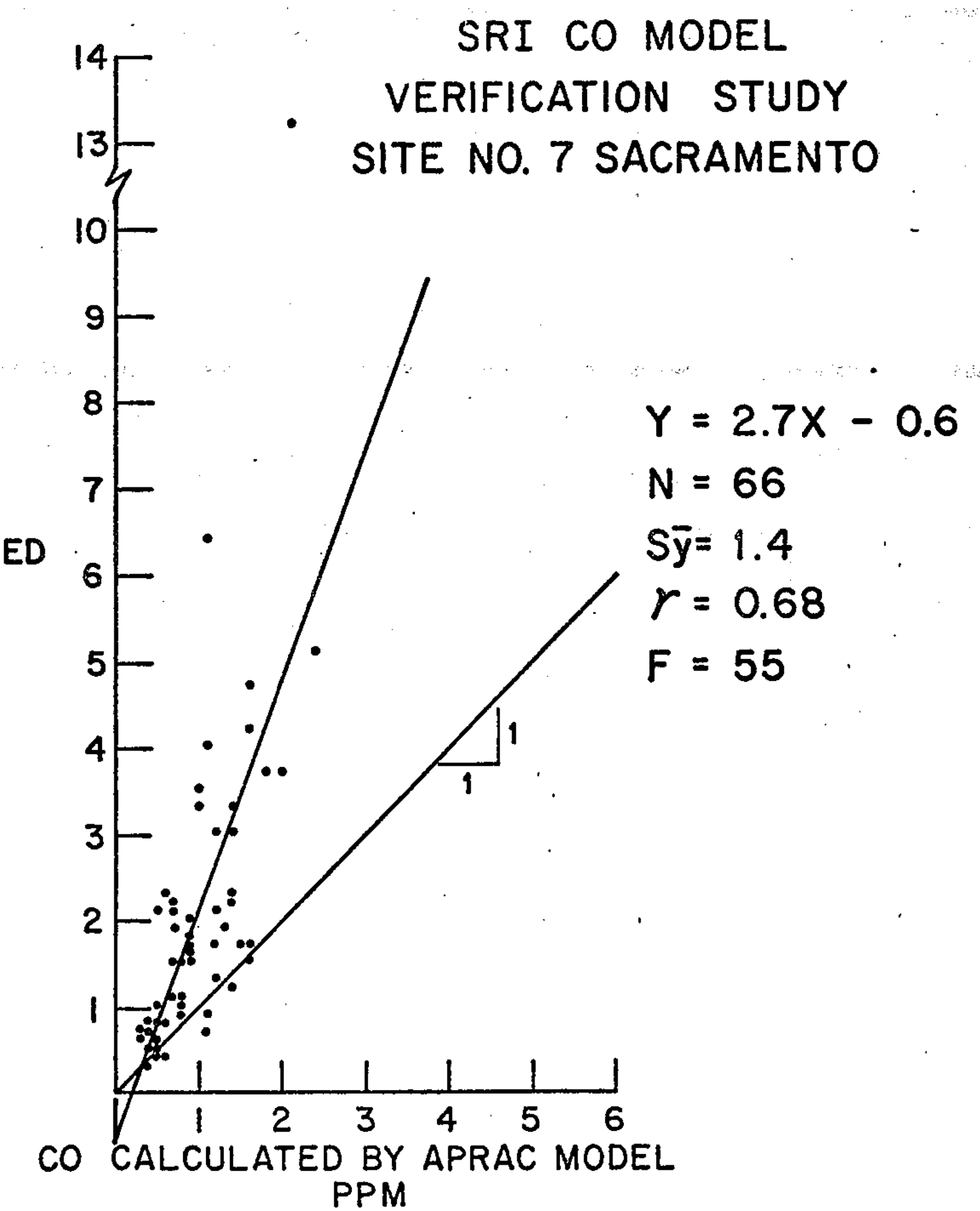

SRI CO MODEL
VERIFICATION STUDY
SITE NO. 7 SACRAMENTO
Y = 2.7X - 0.6
N = 66
$S_{\bar{y}}$ = 1.4
r = 0.68
F = 55
CO MEASURED PPM
CO CALCULATED BY APRAC MODEL PPM
14
13
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
1
1

FIGURE 5-6

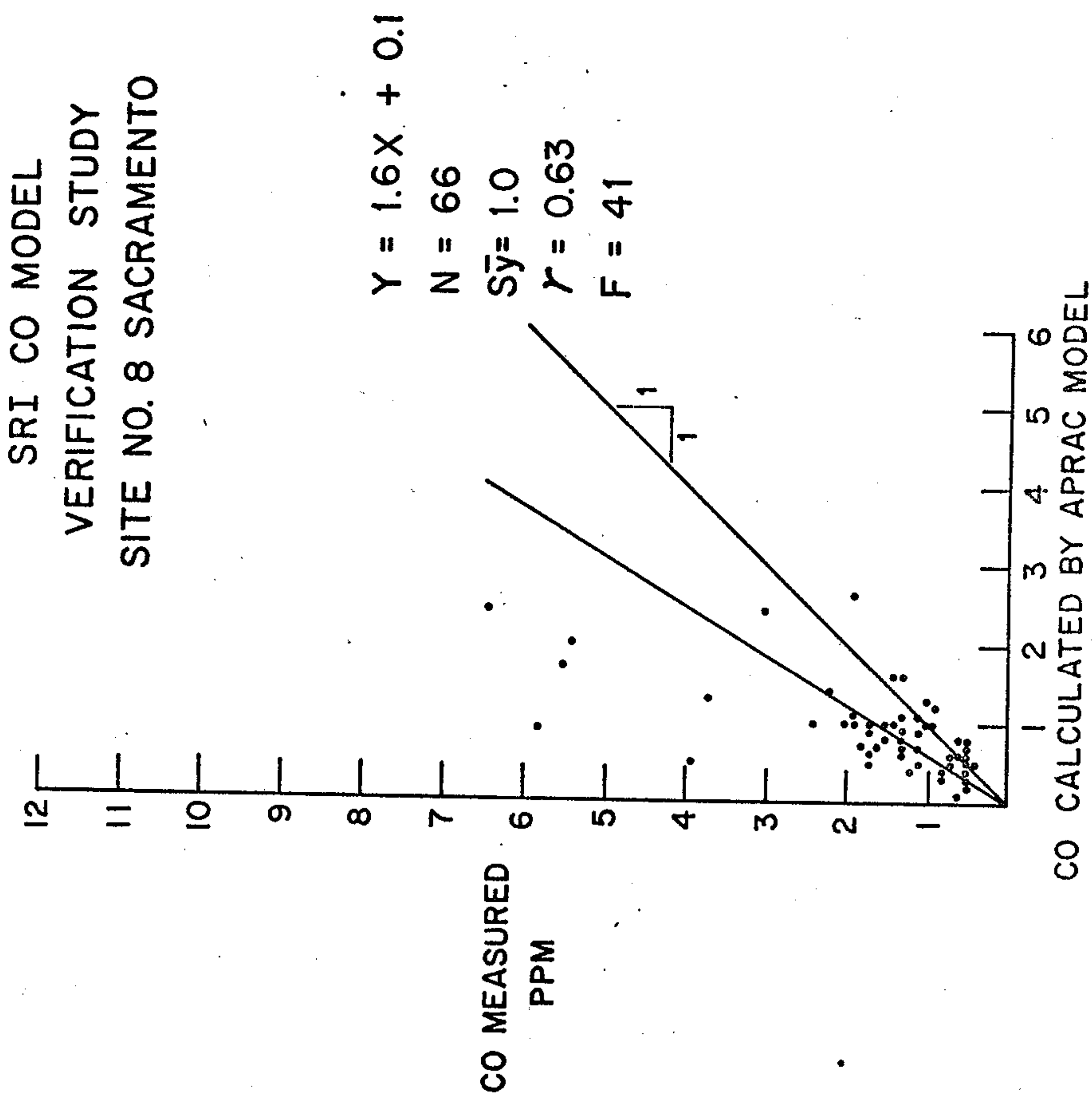

SRI CO MODEL
VERIFICATION STUDY
SITE NO. 8 SACRAMENTO
Y = 1.6X + 0.1
N = 66
$S_{\bar{y}}$ = 1.0
r = 0.63
F = 41
CO MEASURED
PPM
CO CALCULATED BY APRAC MODEL
12
11
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
1
1

FIGURE 5-7

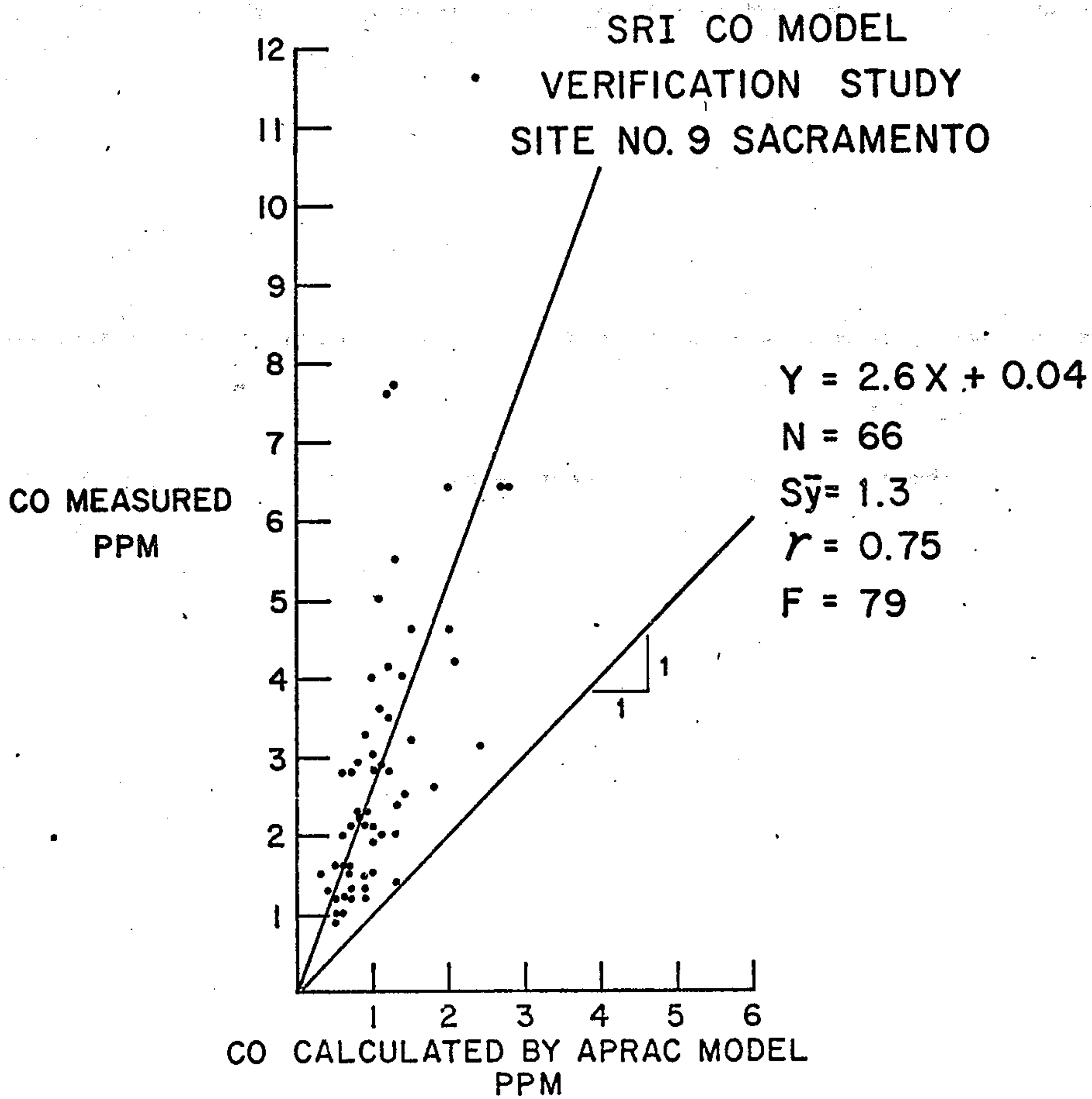
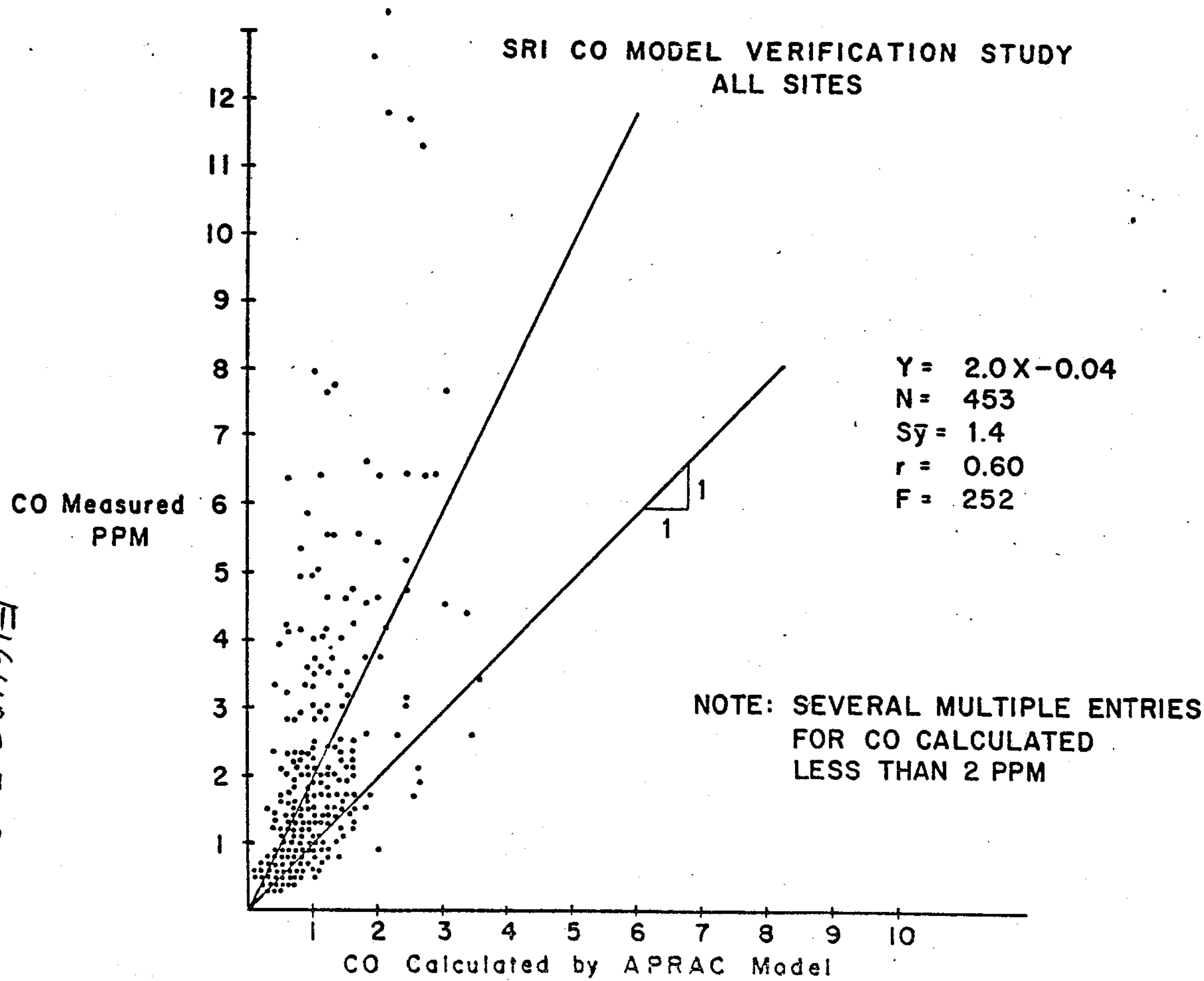

SRI CO MODEL
VERIFICATION STUDY
SITE NO. 9 SACRAMENTO
Y = 2.6 X + 0.04
N = 66
Sȳ = 1.3
r = 0.75
F = 79
CO MEASURED
PPM
CO CALCULATED BY APRAC MODEL
PPM
12
11
10
9
8
7
6
5
4
3
2
1
1
2
3
4
5
6
1
1

FIGURE 5-8



SRI CO MODEL VERIFICATION STUDY
ALL SITES
Y = 2.0X−0.04
N = 453
Sȳ = 1.4
r = 0.60
F = 252
NOTE: SEVERAL MULTIPLE ENTRIES
FOR CO CALCULATED
LESS THAN 2 PPM
CO Measured
PPM
CO Calculated by APRAC Model
1
1
1 2 3 4 5 6 7 8 9 10 11 12
1 2 3 4 5 6 7 8 9 10

FIGURE 5-9

POSSIBLE REASONS FOR
APRAC-1A UNDER-PREDICTIONS

1. Assume uniform wind flow field for entire study area.

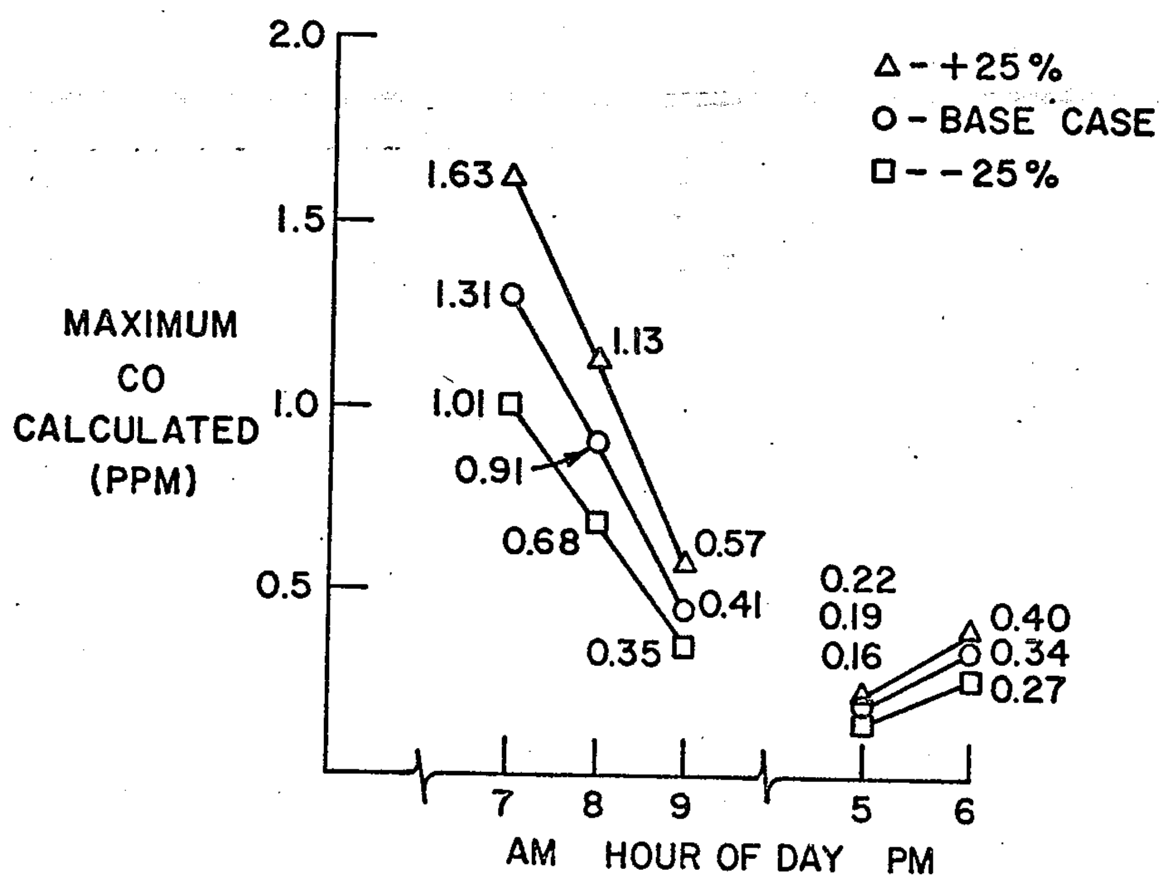
2. Steady state solution $\left(\frac{\partial c}{\partial t}=0\right)$ of governing partial differential equation of mass; therefore canot accumulate pollutant emissions and concentrations.

3. Previous verifications studies use street canyon option.

SECTION 6

SENSITIVITY ANALYSIS
OF
APRAC-1A

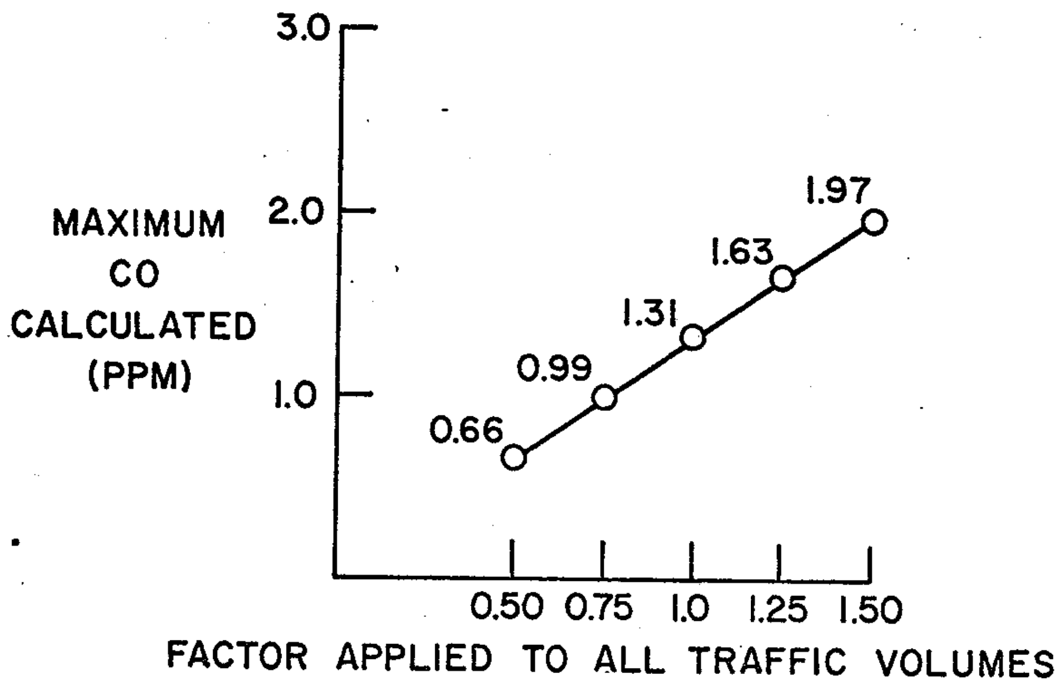
APRAC MODEL SENSITIVITY TO TEMPORAL VARIATIONS DURING PEAK HOURS



NOTE: HOUR ENDING "7" IS 6 TO 7

FIGURE 6-1

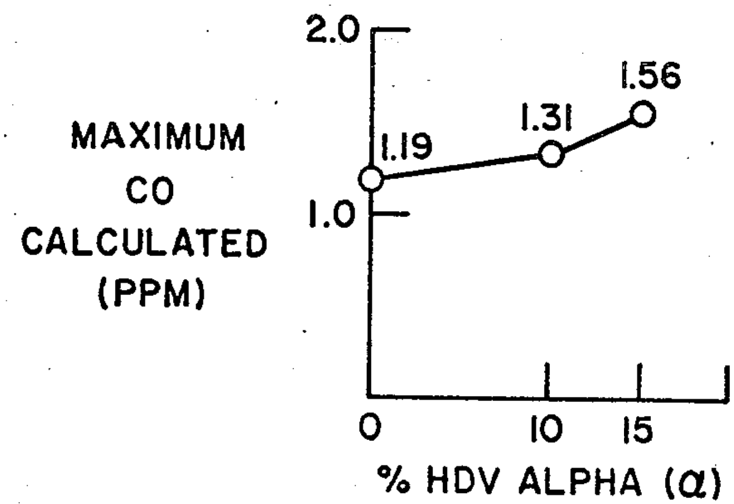
APRAC MODEL SENSITIVITY TO VARIATIONS IN TRAFFIC VOLUMES



NOTE: 1.0 IS THE BASE CASE

FIGURE 6-2

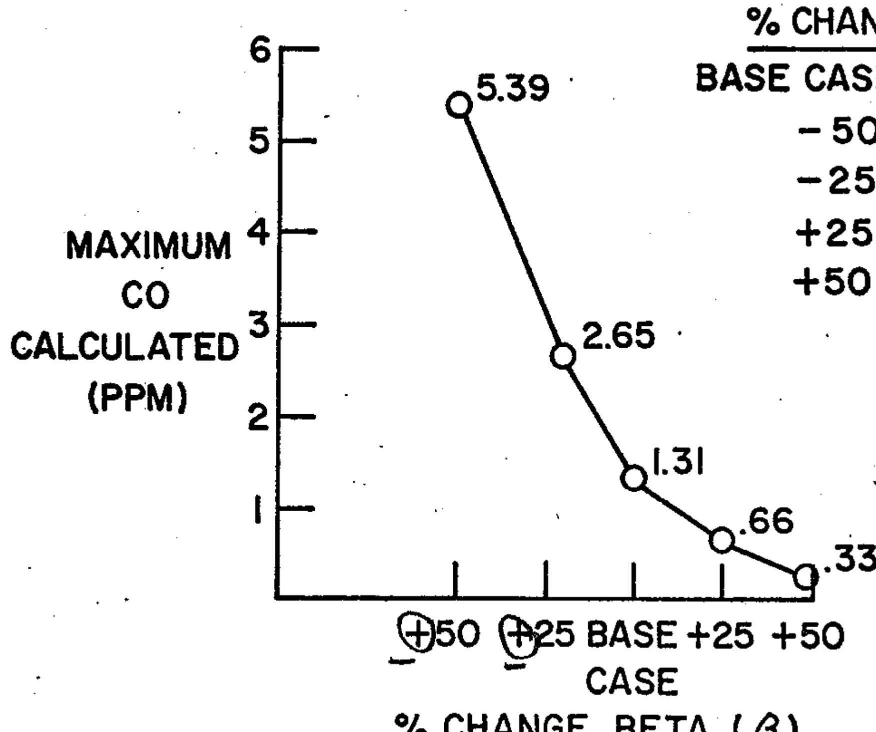
APRAC MODEL SENSITIVITY
TO PERCENT OF HEAVY DUTY VEHICLE MIX



NOTES: THE COEFFICIENT THAT INDICATES HEAVY DUTY VEHICLE MIXES. 10% IS BASE.

FIGURE 6-3

APRAC MODEL SENSITIVITY TO SPEED CORRECTION FACTOR



% CHANGE	β
BASE CASE 0	-.8430
-50	-.4215
-25	-.6323
+25	-1.0538
+50	-1.2645

NOTE: THE SLOPE OF THE LOG-LOG PLOT, THE EXPONENT OF THE EMISSION EQUATION

FIGURE 6-4

APRAC MODEL SENSITIVITY TO VARIATIONS IN VEHICULAR SPEED

APRAC LINK SPEED CODE	SPEED IN M.P.H.		
	REDUCED	B.C.	INCREASED
1	40	55	70
2	35	45	55
3	25	35	45
4	15	25	35
5	7	12	19

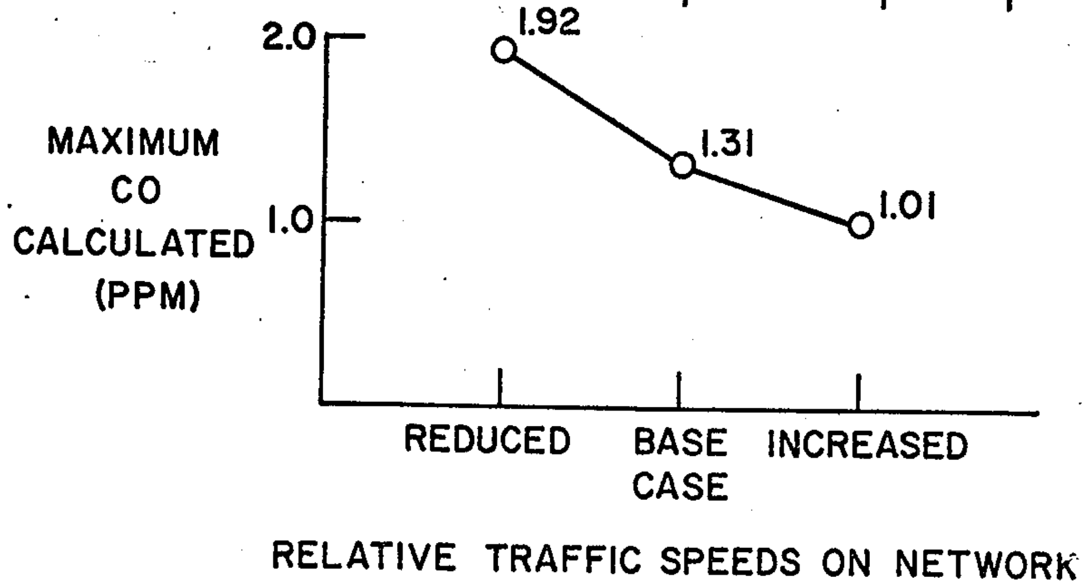
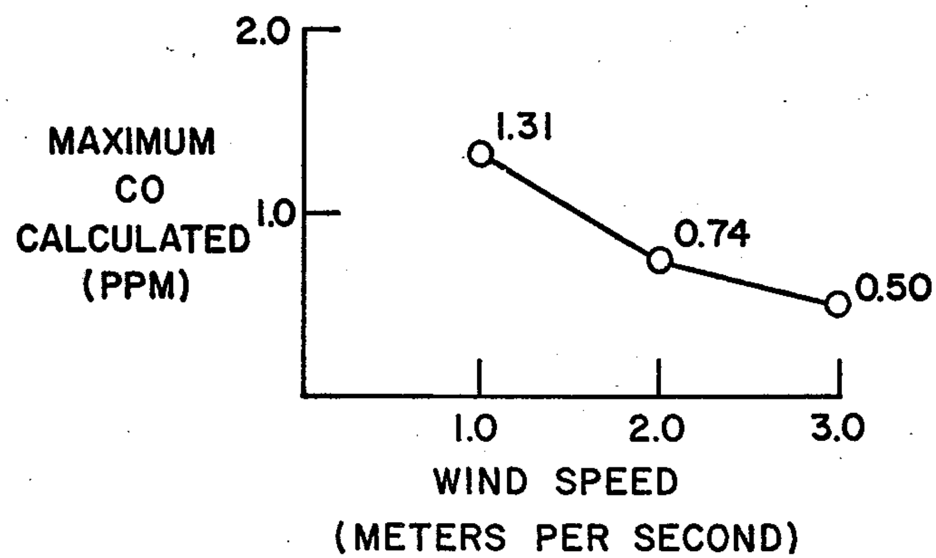


FIGURE 6-5

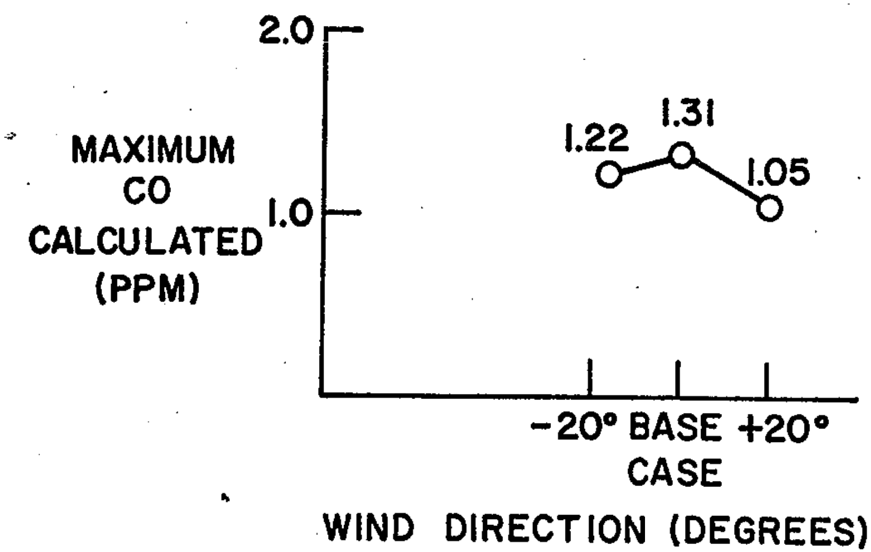
APRAC MODEL SENSITIVITY TO WIND SPEED



NOTE: 1.0 M/S IS MINIMUM SPEED USED IN COMPUTATION, ALSO WAS BASE CASE

FIGURE 6-6

APRAC MODEL SENSITIVITY TO WIND DIRECTION



NOTE: BASE CASE VALUE IS 340°

FIGURE 6-7

General Comments on APRAC-1A Sensitivity Analysis

- Beta Coefficient

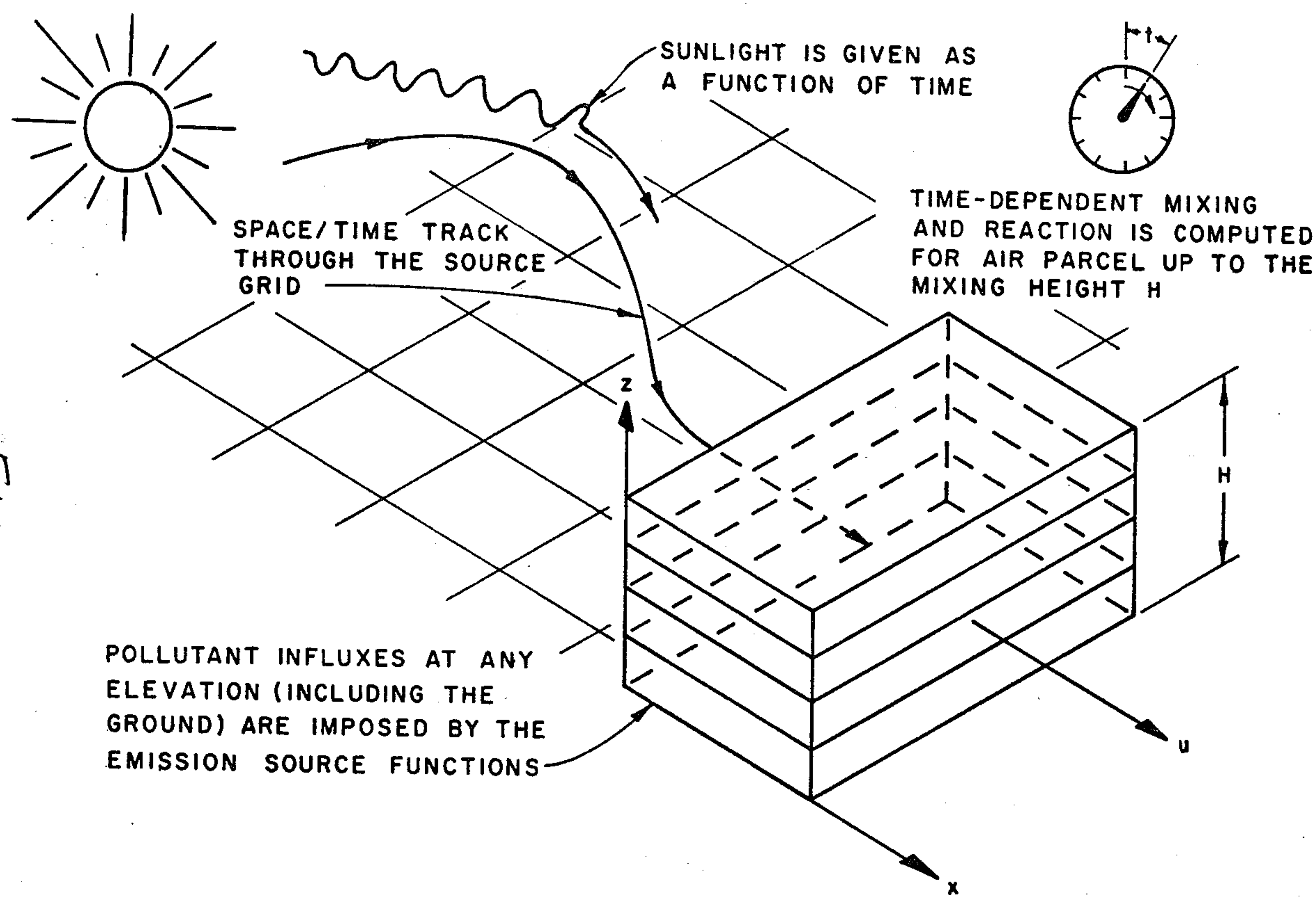
- Speeds

- Wind Speeds

- Others

SECTION 7

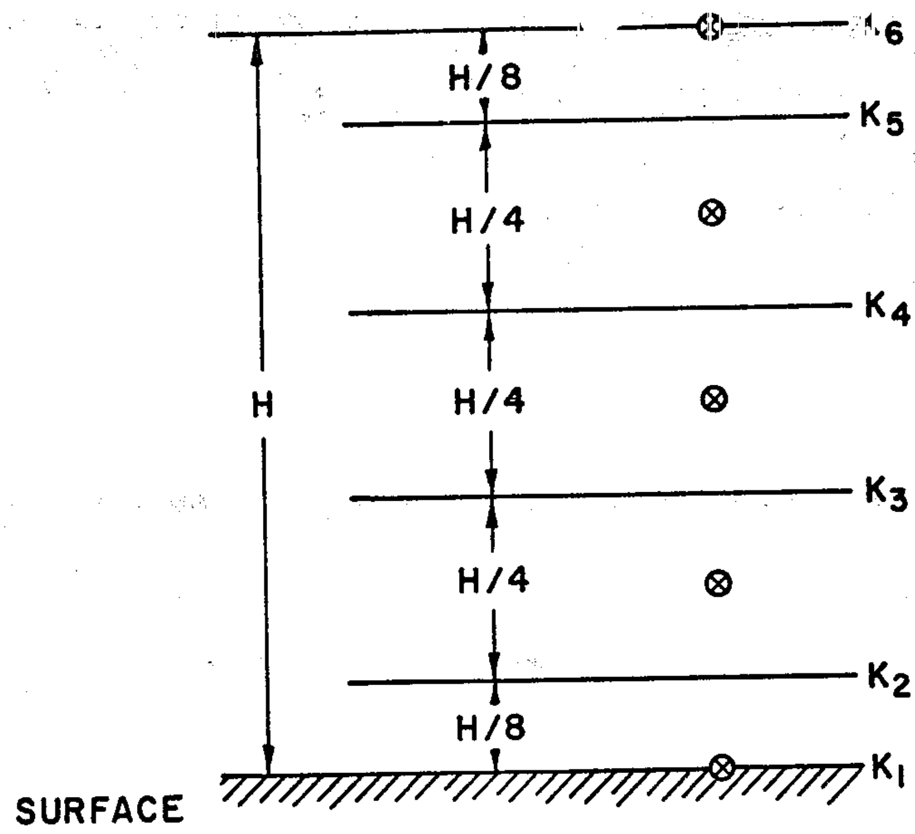
SENSITIVITY ANALYSIS OF DIFKIN AND SAI AIR QUALITY MODELS



SCHEMATIC OF DIFFUSION MODEL FOR AIR POLLUTION SIMULATION

ADAPTED FROM REFERENCE [17]

FIGURE 7-1



⊗ LEVELS FOR WHICH CONCENTRATION ARE CALCULATED.

—— LEVELS FOR WHICH VERTICAL DIFFUSIVITIES (K_I) ARE REQUIRED.

SCHEMATIC DIAGRAM OF VERTICAL STRUCTURE AS TREATED BY THE DIFKIN MODEL
(COURTESY STANFORD RESEARCH INSTITUTE)

FIGURE 2

FIGURE 7-2

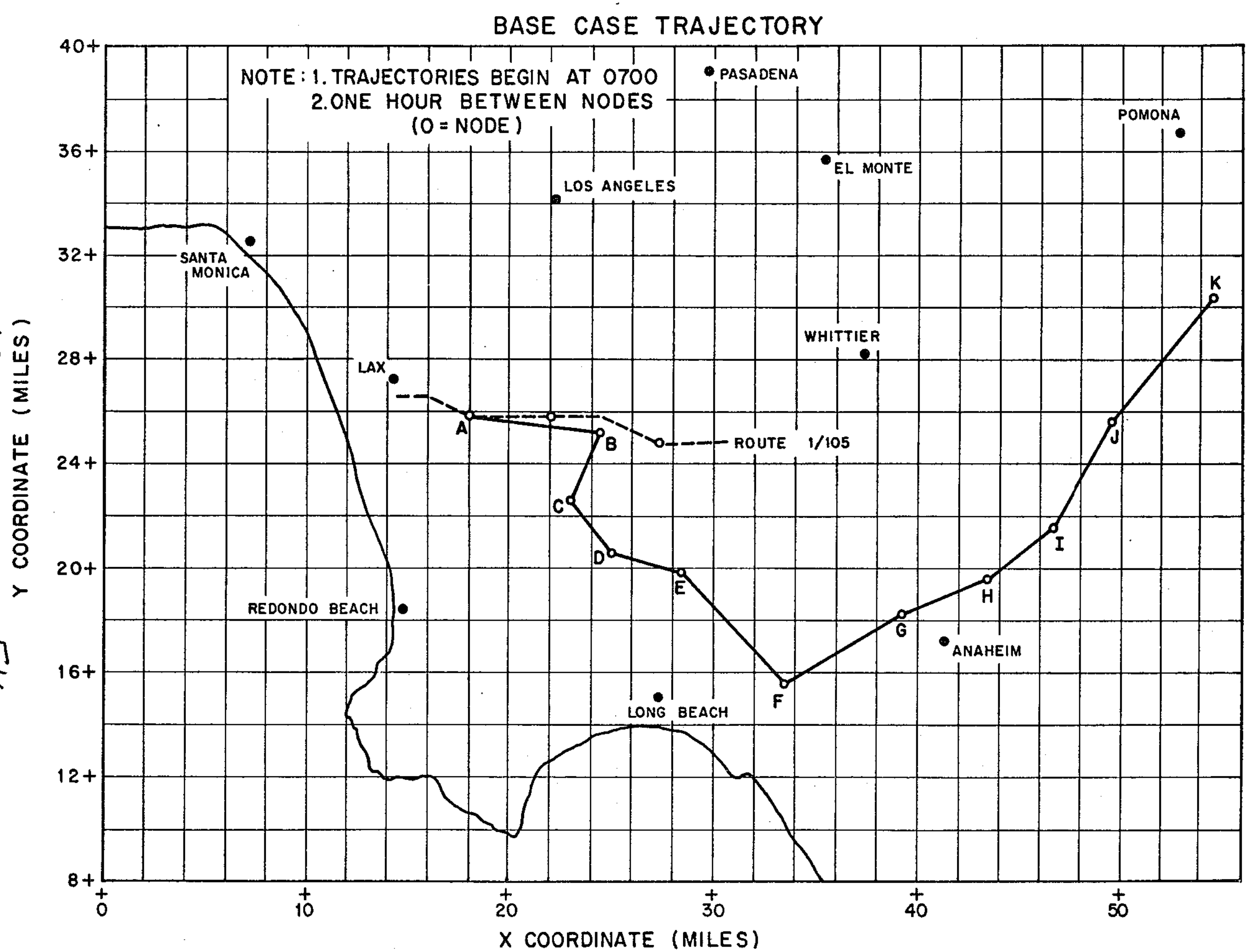

BASE CASE TRAJECTORY
NOTE: 1. TRAJECTORIES BEGIN AT 0700
2. ONE HOUR BETWEEN NODES
(O = NODE)
PASADENA
POMONA
EL MONTE
LOS ANGELES
SANTA MONICA
WHITTIER
LAX
ROUTE 1/105
REDONDO BEACH
ANAHEIM
LONG BEACH
A
B
C
D
E
F
G
H
I
J
K
Y COORDINATE (MILES)
X COORDINATE (MILES)
40
36
32
28
24
20
16
12
8
0
10
20
30
40
50

FIGURE 7-3

Conclusions from the Sensitivity Analysis of DIFKIN

The following conclusions are evidenced by research presented in the sensitivity report. They are drawn largely from the examination of a single trajectory.

1. Worst-case Difkin O_3 levels are associated with conditions conducive to maximum chemical activity. High levels occur with strong sunlight on a day with high initial RHC concentrations in proportions to initial NO concentrations. This day will have high ground diffusivities and an inversion base at about 400 meters. The trajectory will pass over areas of low NO emissions and high RHC emissions.
2. Worst-case levels for NO, NO_2, and RHC are reached on days not conducive to extreme chemical activity. The highest levels are seen for minimal (15 meter ^{2}/second) lower level diffusion rates and calm atmospheric conditions. Ground based inversions produce the highest concentrations in the primary pollutants.
3. Two model discontinuities have been revealed in this analysis. The first is in relationship to ground level diffusivities. This is discussed in the section titled "Diffusivity Coefficients". The second is related to the abrupt change of values for reaction rate constant K_4 from 40 pphm/min to 100 pphm/min when the ratio of initial concentrations of RHC to NO_x becomes less than 1.7.
4. Predicted concentrations for all pollutants can be extremely sensitive to small changes in trajectory when fluxes for either NO or RHC are nonuniformly distributed, spatially, over the basin being considered. The end O_3 concentrations of parallel trajectories may differ by an order of magnitude.

5. Simulations conducted to test the effect on oxidant levels by varying the temporal distribution of traffic, indicate that increasing traffic during peak periods (and lowering traffic during off-peak periods) favors lower downwind oxidant levels. The uniform traffic distribution will increase oxidant levels and decrease primary pollutant levels.

6. The mesh interval (individual air parcel height) used in the simulations affects the predicted concentrations. When the mesh interval is increased 50% the final O_3 level increased 33%. The mesh interval used in the base case is 115 meters with 5 vertical stations (4 cells).

RECOMMENDATIONS

The following recommendations are based upon the conclusions reached in this study:

1. Economy in computer costs may be realized by using a Lagrangian model such as DIFKIN on project level analyses. Worst-case pollutant days can be simulated using a variety of trajectories, all passing over a portion of the project. "With" and "Without" project comparisons can be made to determine the relative impact on the environment.
2. Also, the trajectory computation function of the Lagrangian model may be used in harmony with the Eulerian model in systems level analyses. If an area with air quality concentrations in excess of a standard (hot spot) is predicted with the Eulerian model, the backward trajectory can be computed and verified by the forward trajectory module portion of DIFKIN. The upwind emission sources leading to the hot spot can be altered as part of the transportation planning process. The Eulerian model can then be rerun to determine whether the transportation plan is effective in eliminating the hot spot.
3. The predicted concentrations can be very sensitive to small changes in trajector. It is recommended that the trajectories be computed with the program if a reliable network of surface wind speeds and directions are available with proper exposure.

If reliable data are not available, it is recommended that the trajectories be established based upon field experience and/or with the aid of a qualified meteorologist. Regardless, several parallel or nearly parallel trajectories passing over adjacent grid cells should be tested so that various combinations of NO and RHC fluxes can be evaluated to test for maximum pollutant concentrations.

4. Wind monitoring sensors for direction and speed used to compute trajectories should have proper exposure and low threshhold speed (approximately 1 mph or less).
5. Predicted ozone concentrations show high sensitivity to initial concentrations of NO and RHC even for low initial concentrations. For this reason and because accurate prediction of initial conditions is difficult especially for future years, consideration should be given to the representativeness of the initial RHC and NO_x concentrations based on the assumptions of the model.
6. Initial concentrations used for calibration and/or validation studies should represent a grid cell average rather than a localized emission source. Misleading results can be obtained when using a model calibrated with source-oriented data as initial concentrations.
7. Due to the ozone sensitivity to the vertical mesh interval, this model should be calibrated, validated, and applied using the same mesh interval. The number of vertical stations can be changed to model different inversion base heights, rather than altering the mesh interval.
8. Because of the rapidly advancing state-of-the-art of air quality modeling, the DIFKIN photochemical model (as well as all other models) should be continually calibrated and validated with a reliable data base consistent with the assumptions of the model.

SENSITIVITY OF O_3 TO VARYING DIFFUSIVITIES (K'_s) BELOW INVERSION BASE

INITIAL $RHC/NO_x = 2.1$ $K_4 = 40$

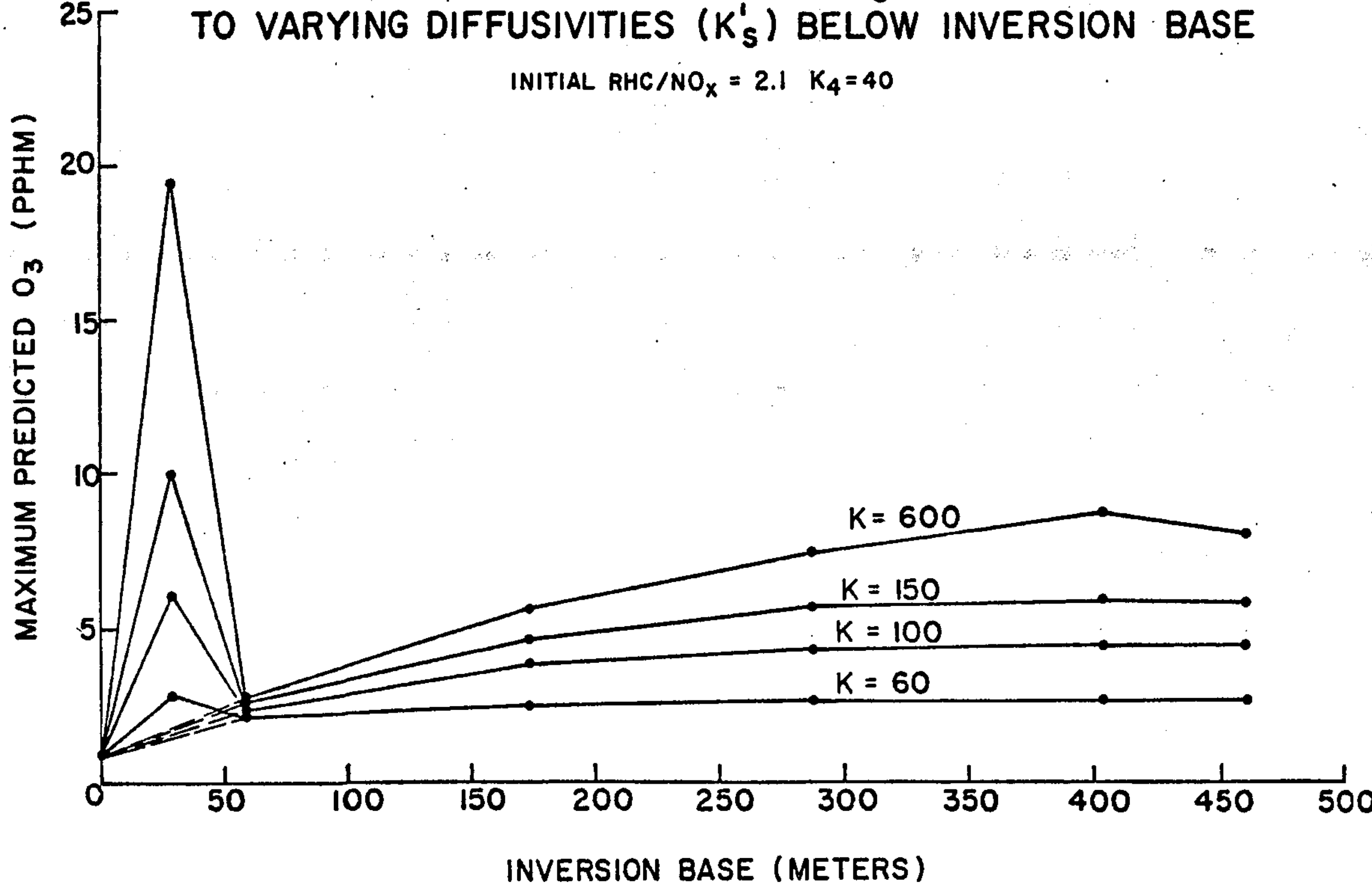
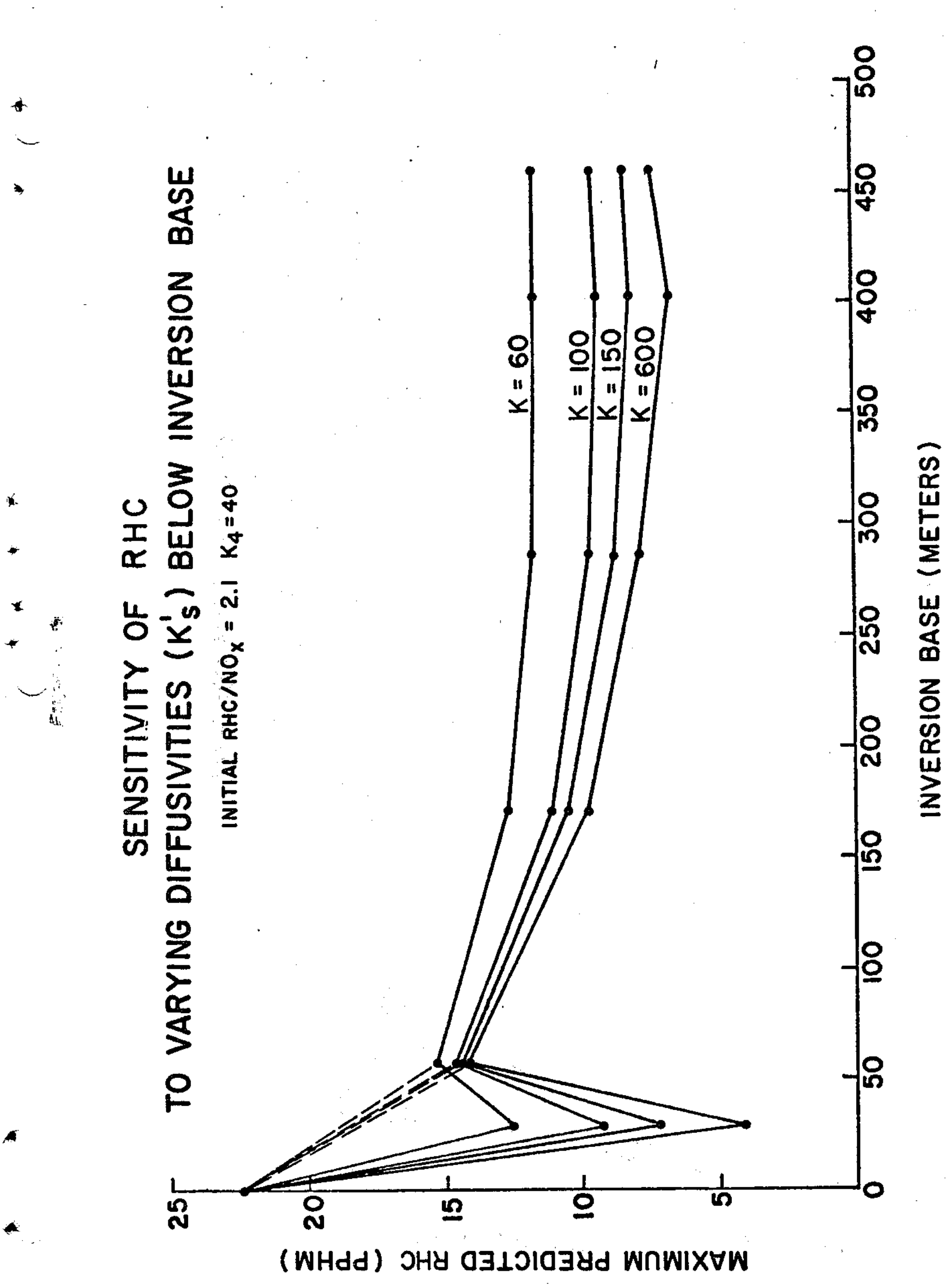


FIGURE 7-4



-197-

FIGURE 7-5

SENSITIVITY OF NO TO VARYING DIFFUSIVITIES (K_s') BELOW INVERSION BASE

INITIAL RHC/NO_x = 2.1 K_4=40

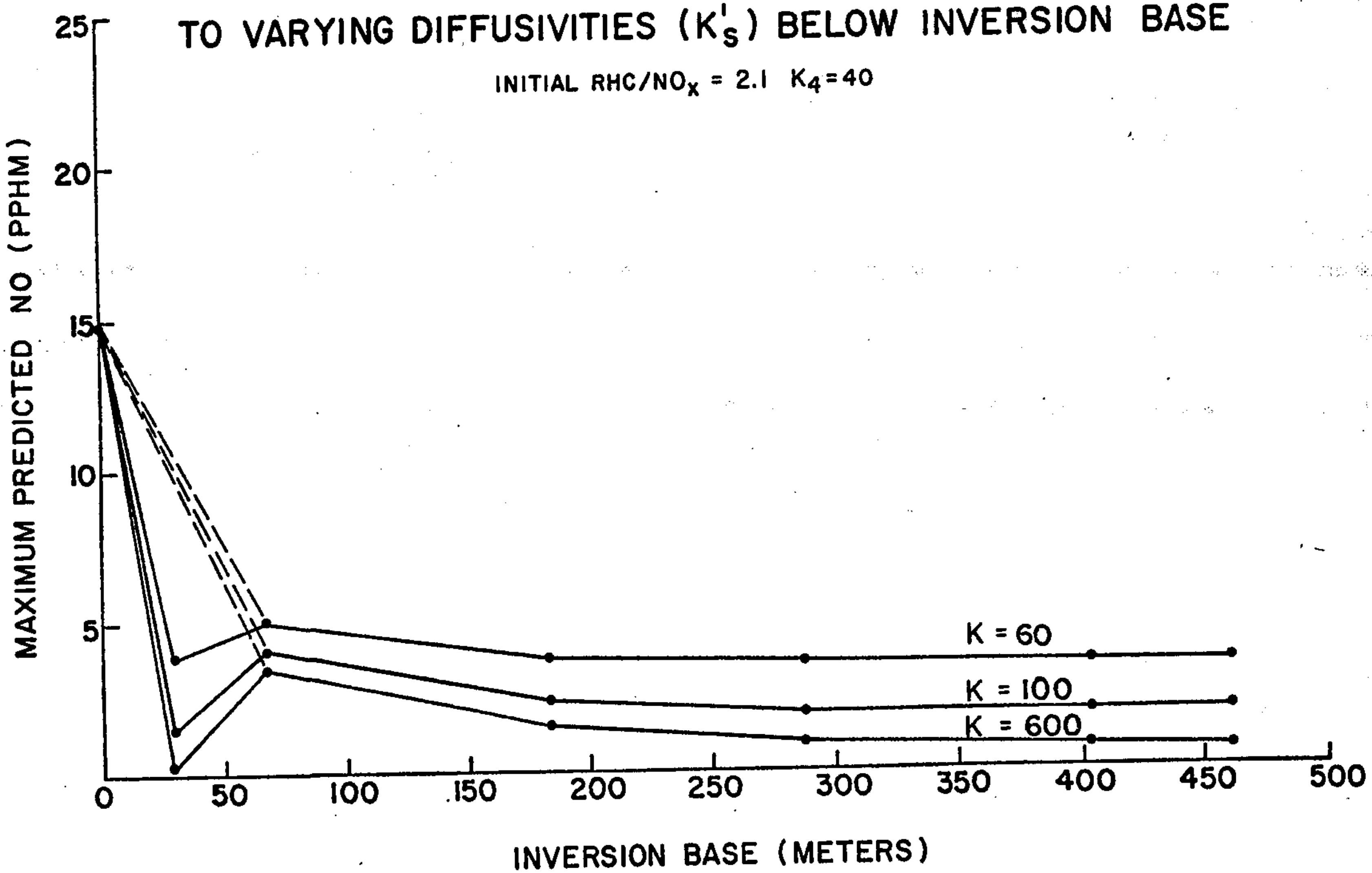
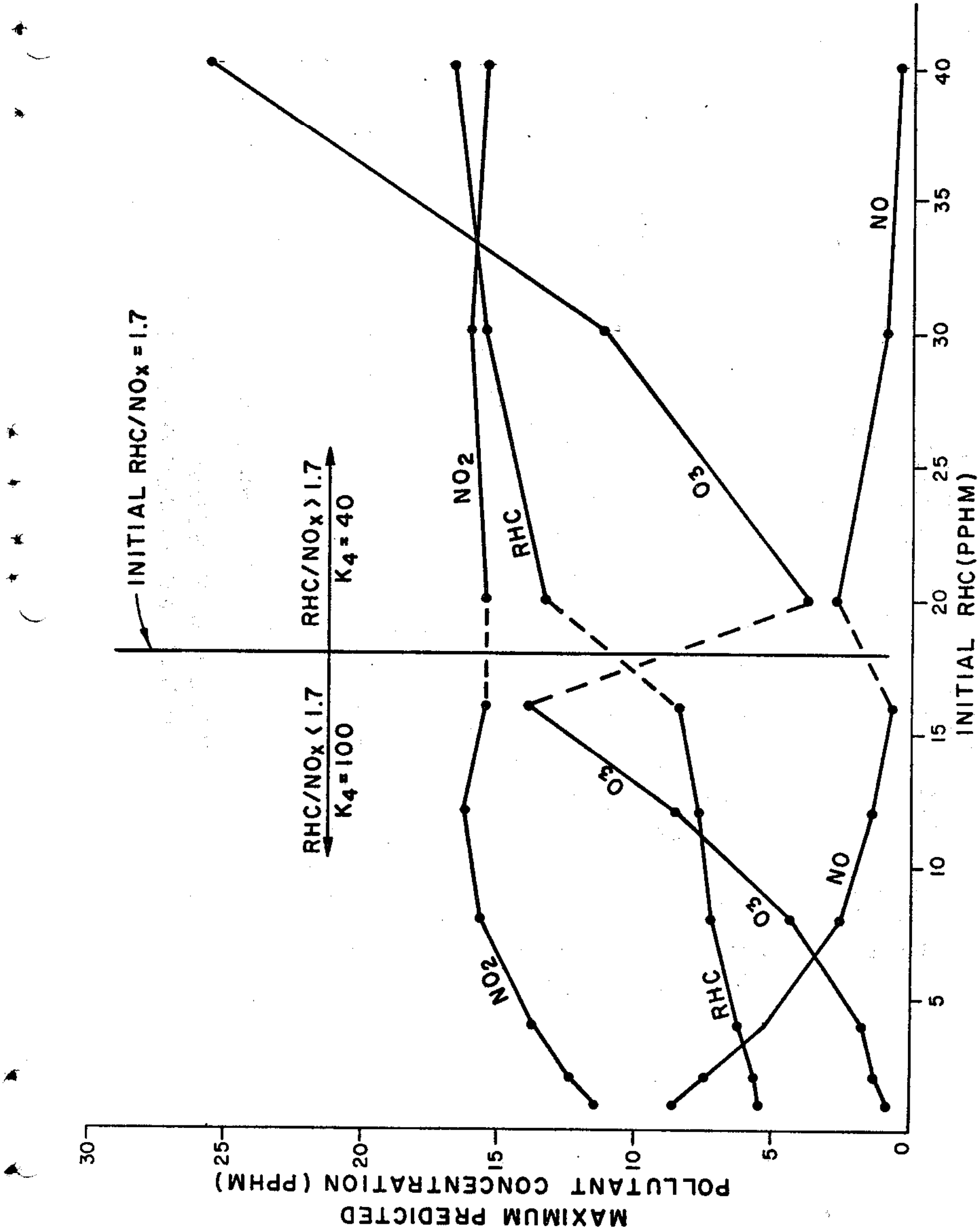
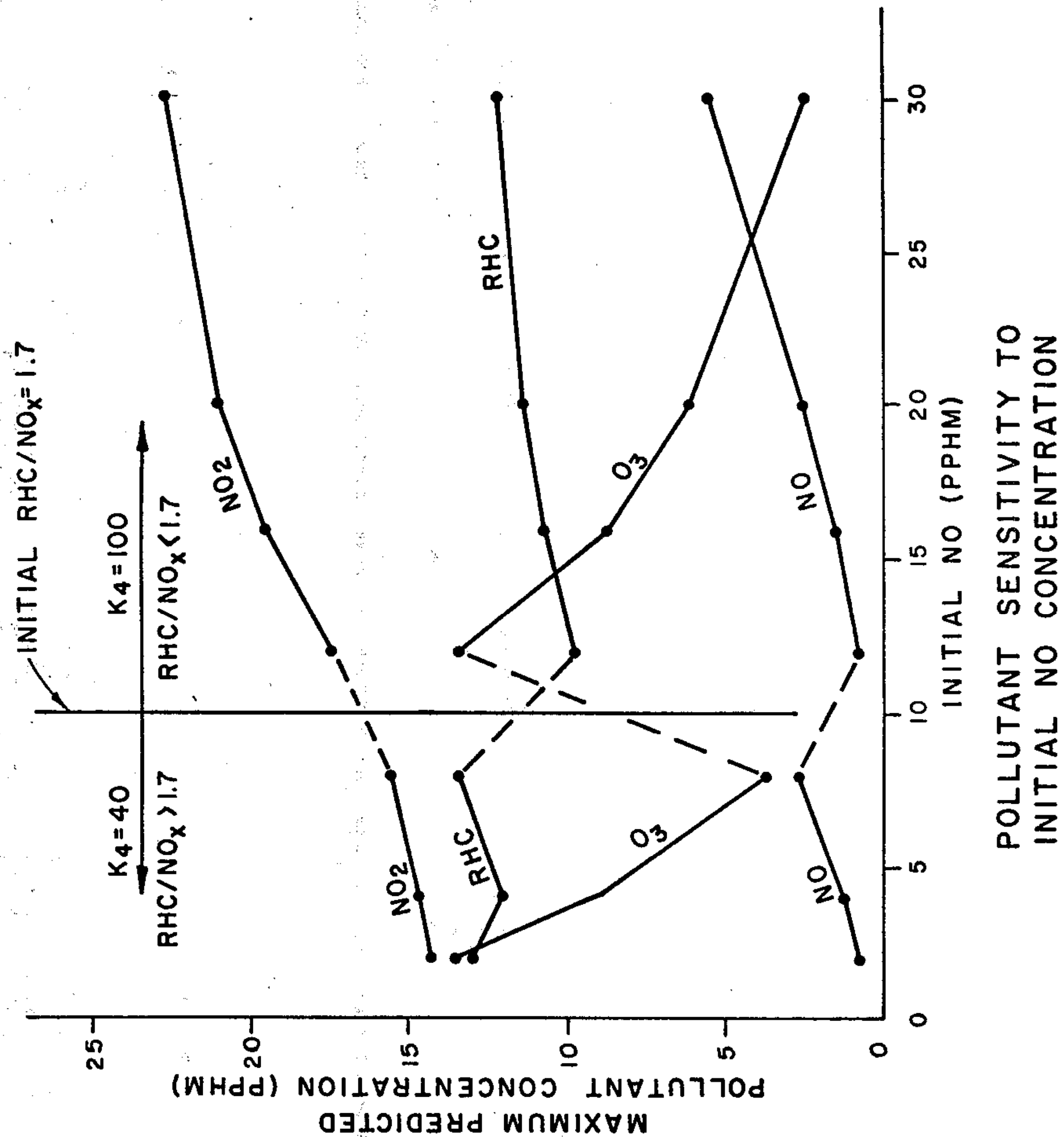


FIGURE 7-6



POLLUTANT SENSITIVITY TO INITIAL RHC CONCENTRATION

FIGURE 7-7



POLLUTANT SENSITIVITY TO
INITIAL NO CONCENTRATION
INITIAL NO (PPHM)
MAXIMUM PREDICTED
POLLUTANT CONCENTRATION (PPHM)
INITIAL RHC/NO$_x$= 1.7
K_4=40
RHC/NO$_x$ > 1.7
K_4=100
RHC/NO$_x$ < 1.7
NO2
RHC
O$_3$
NO
0
5
10
15
20
25
30

FIGURE 7-8

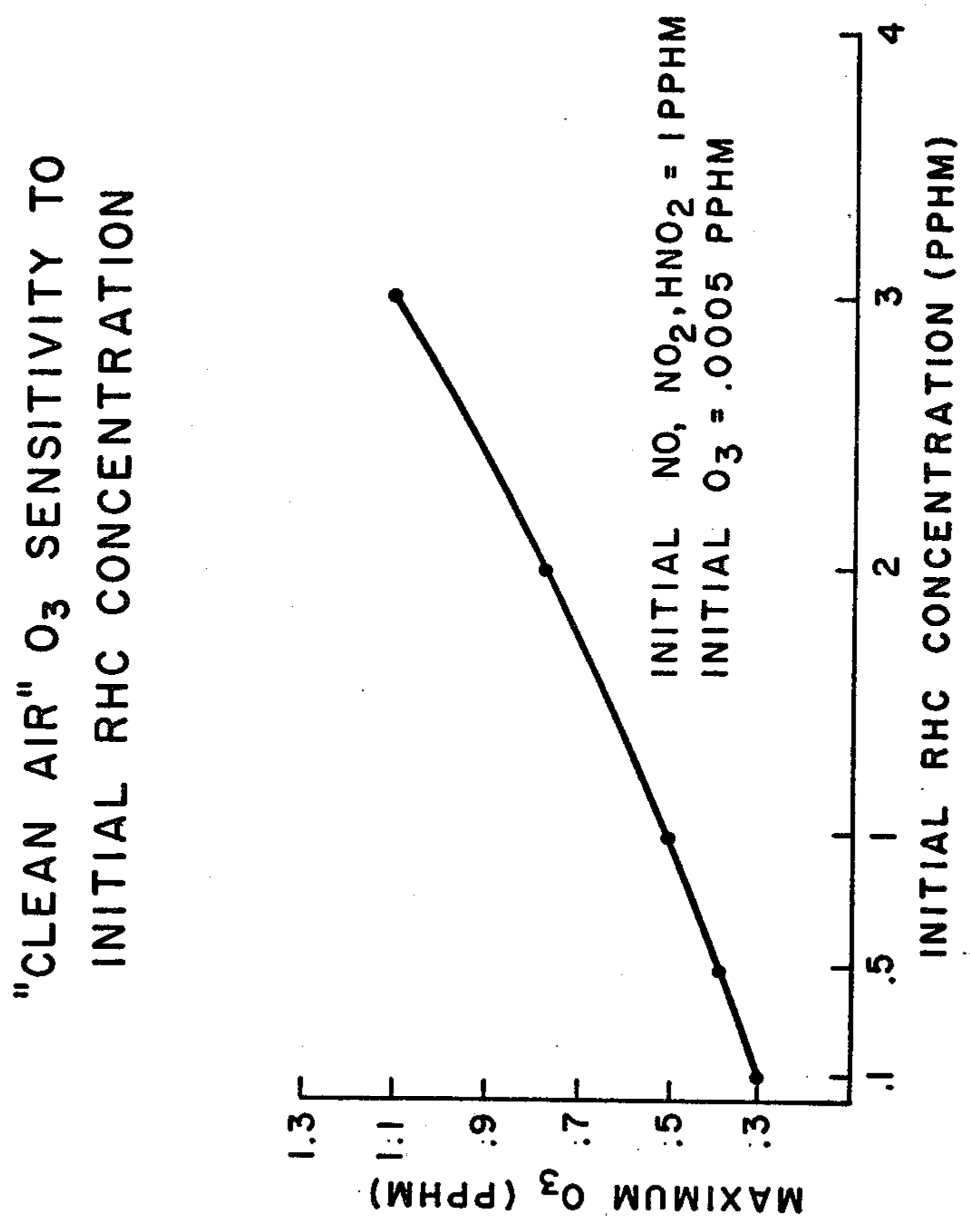

"CLEAN AIR" O3 SENSITIVITY TO
INITIAL RHC CONCENTRATION
INITIAL NO, NO2, HNO2 = 1 PPHM
INITIAL O3 = .0005 PPHM
MAXIMUM O3 (PPHM)
1.3
1.1
.9
.7
.5
.3
.1
.5
1
2
3
4
INITIAL RHC CONCENTRATION (PPHM)

FIGURE 7-9

"CLEAN AIR" O_3 SENSITIVITY TO INITIAL NO CONCENTRATION

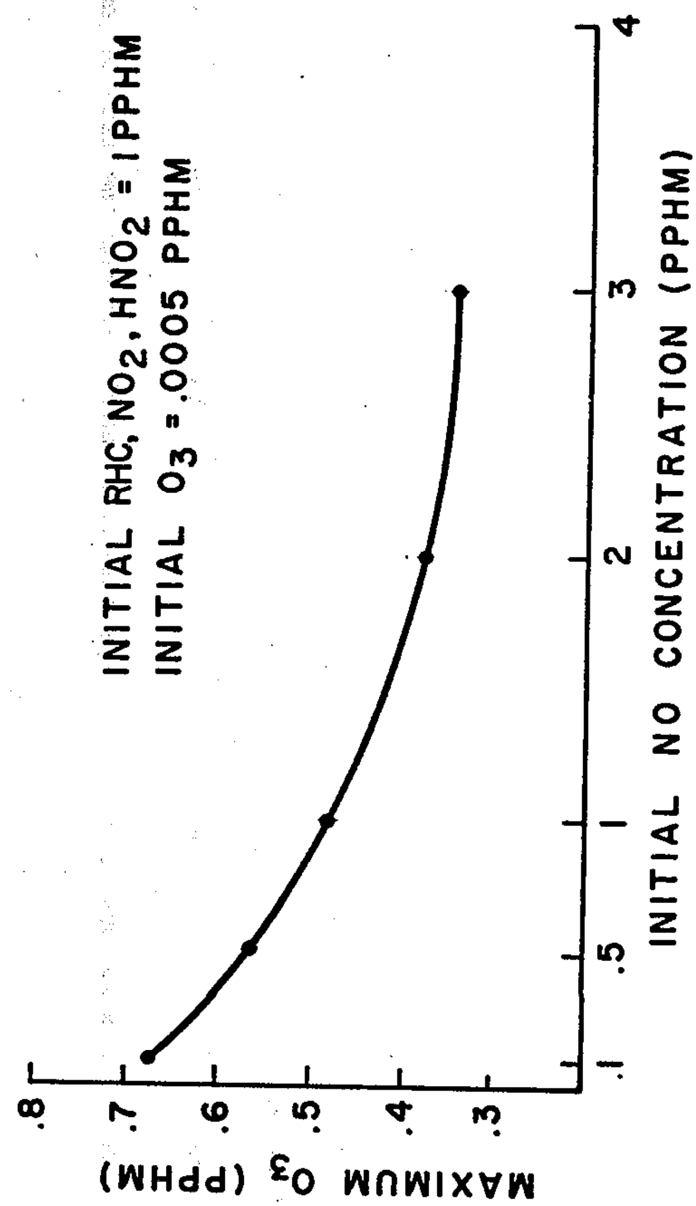


FIGURE 7-10

OZONE SENSITIVITY TO REACTION RATE CONSTANT K_1

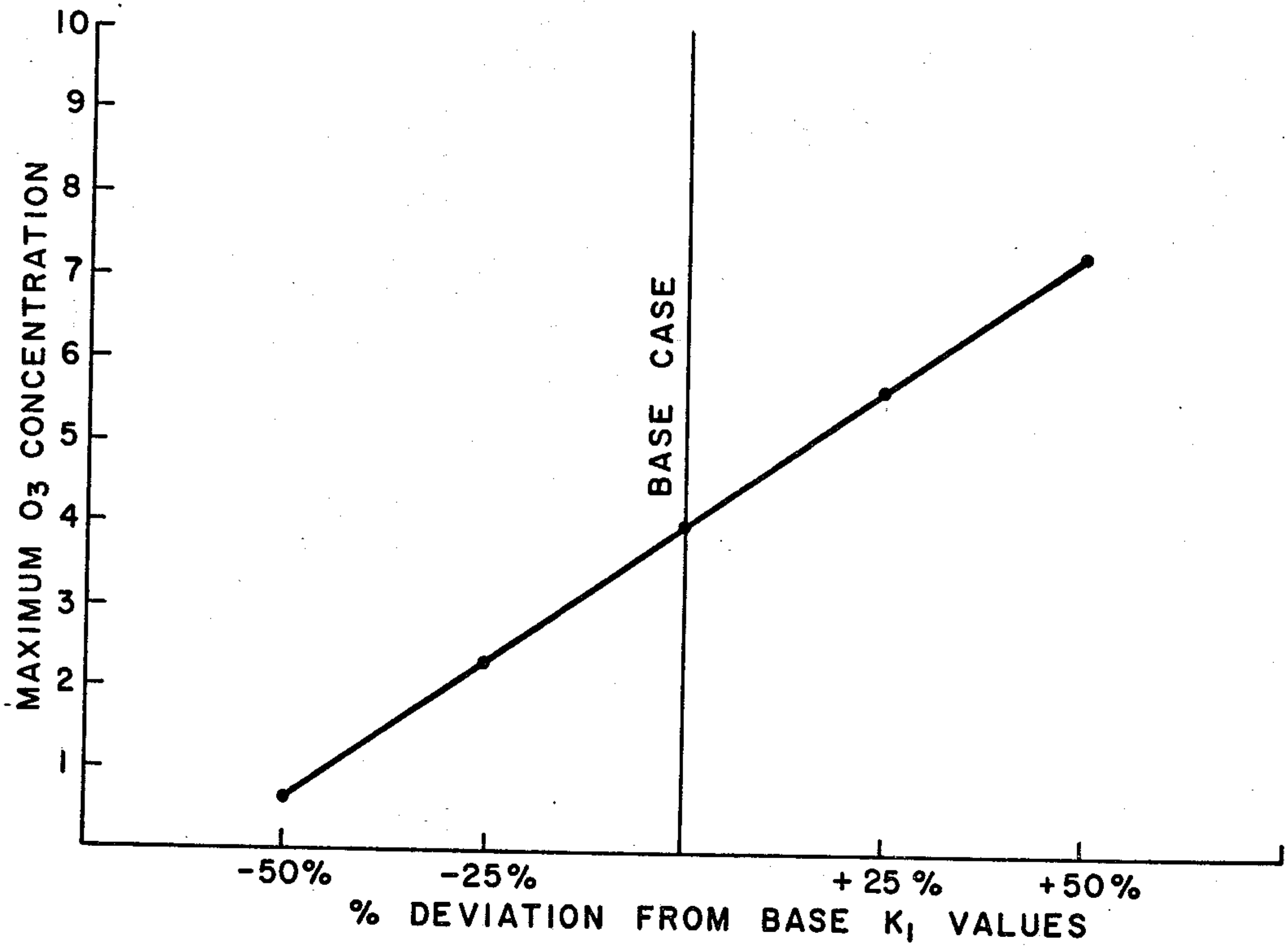


FIGURE 7-11

TRAJECTORY 'A' & 'B'

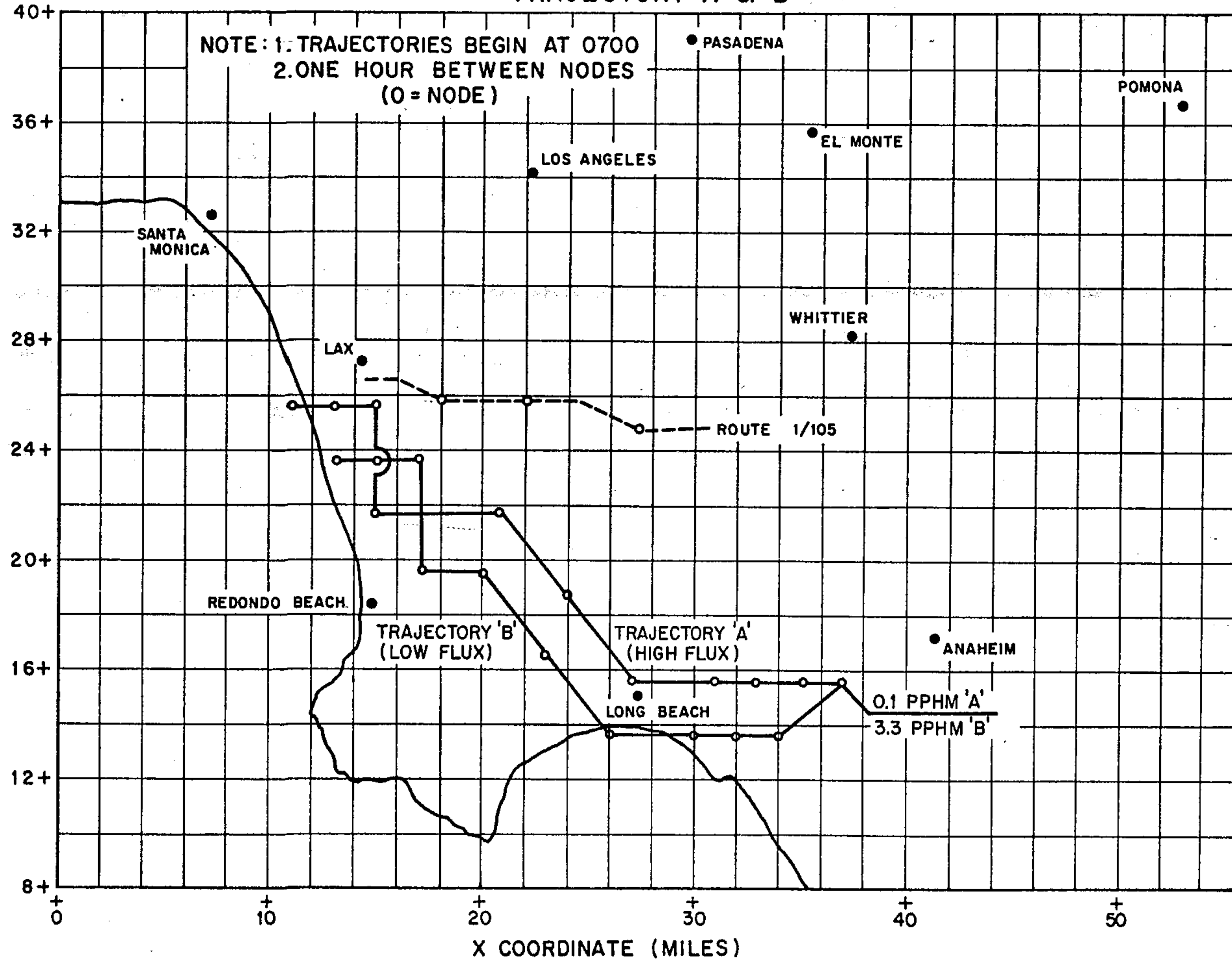


FIGURE 7-12

DIFKIN SENSITIVITY ANALYSIS

50% CHANGE IN INPUT PARAMETER

RANK	PARAMETER	% CHANGE O_3
1.	INITIAL HC CONC.	187
2.	REACTION CONSTANT K4	147
3.	INVERSION BASE HEIGHT	81
4.	REACTION CONSTANT K8	53
5.	INITIAL NO CONC.	47
⋮		
30.		

FIGURE 7-13

SUMMARY OF CASES INVESTIGATED IN THE SENSITIVITY STUDY -SAI MODEL

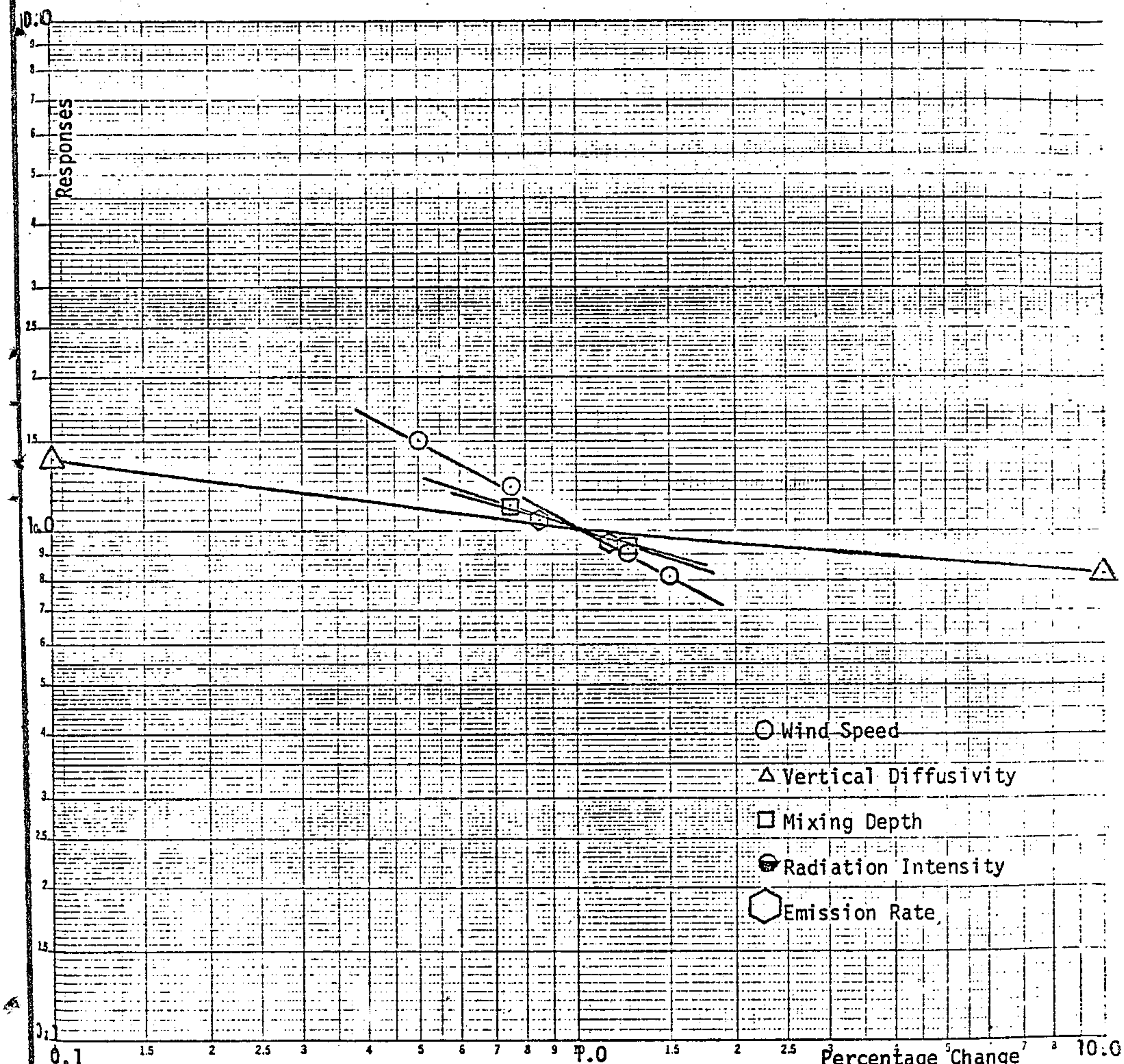
Input Parameter	Variations
Wind Direction	Station measurements* randomly perturbed by 0 or ±22.5°
	Values at each grid point**randomly perturbed by 0 or ±22.5°
Wind Speed	Station measurements* randomly perturbed by 0 or ±1 mph
	Values at each grid point** randomly perturbed by 0 or ±1 mph
	Station Measurements* decreased by 50%
	Station Measurements* decreased by 25%
	Station Measurements* increased by 25%
	Station Measurements* increased by 50%
Horizontal Diffusivity	Decreased to 0
	Increased to 500 m^2/sec
Vertical Diffusivity	Decreased to 0.5 m^2/sec
	Increased to 50 m^2/sec
Mixing Depths	Decreased by 25%
	Increased by 25%
Radiation Intensity	Decreased by 30%
	Increased by 30%
Emission Rates	Decreased by 15%
	Increased by 15%

*The station measurements will be subsequently interpolated, using techniques described in Liu, et al. (1973).

**These values are obtained from manually prepared wind data; see Reynolds, et al. (1973)

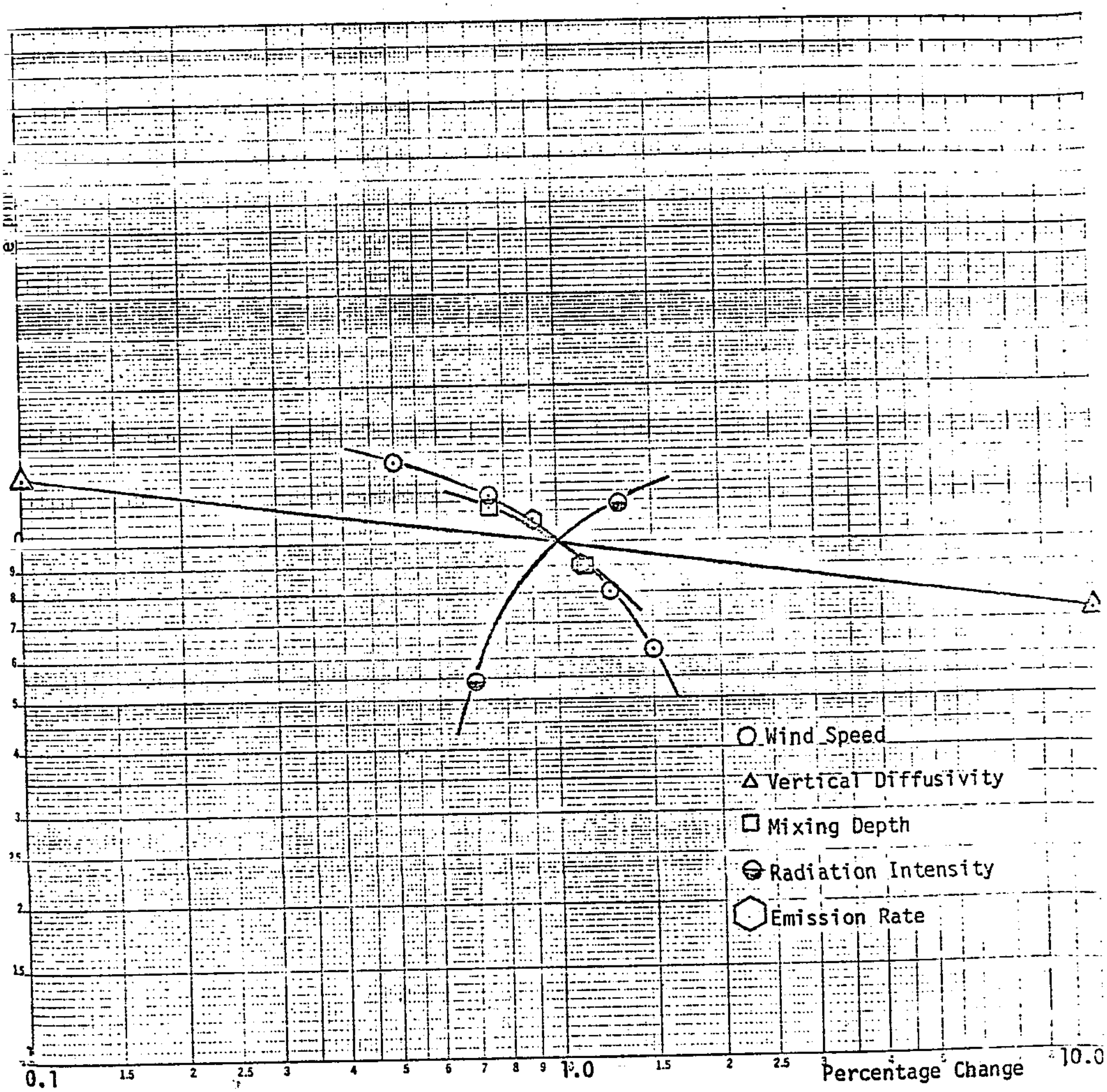
A value of 50 m^2/sec is used in the base case.

A value of 5 m^2/sec is used in the base case.



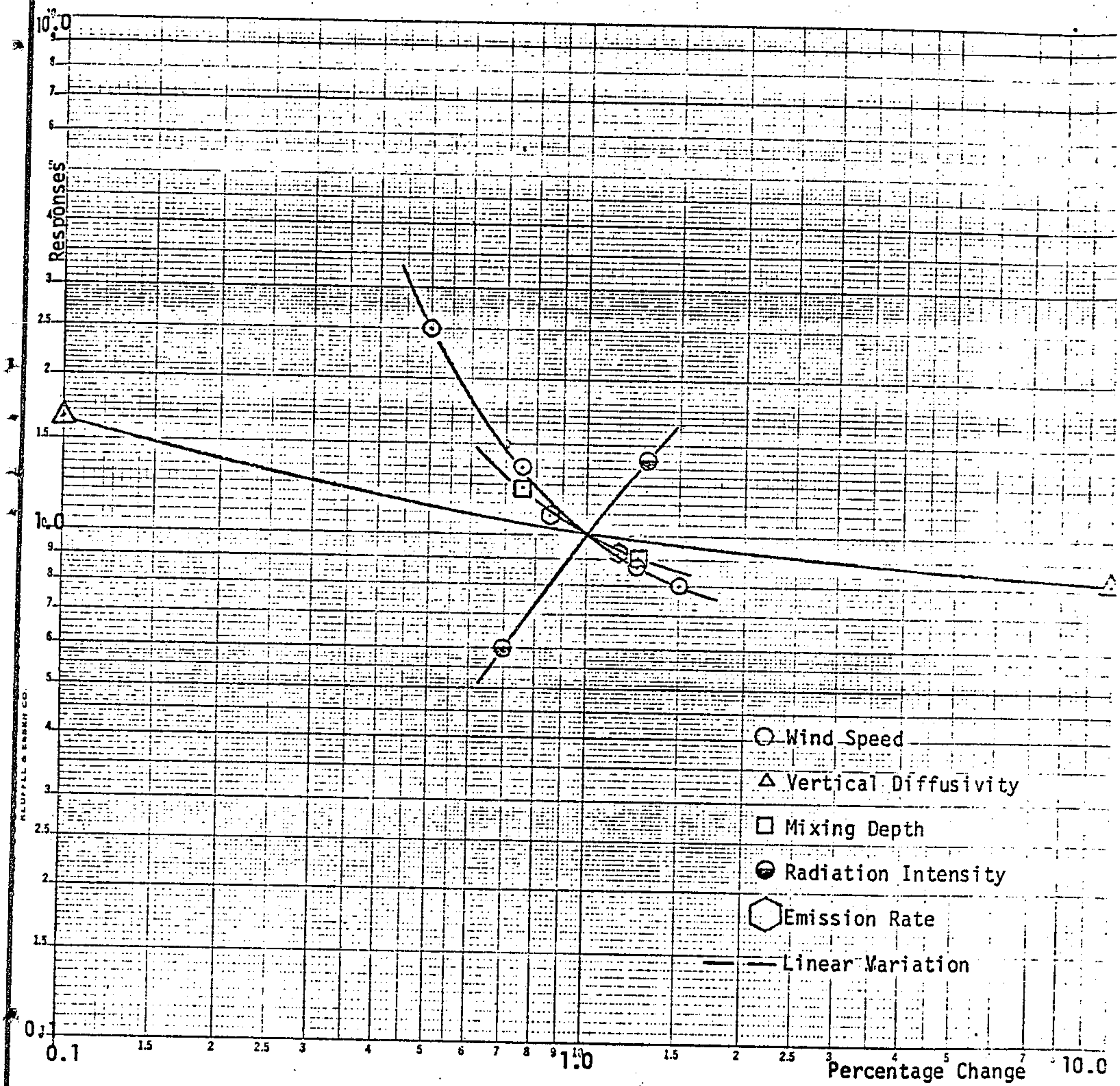
Average Effect on CO Concentration due to Changes in Input Parameters.

FIGURE 7-14



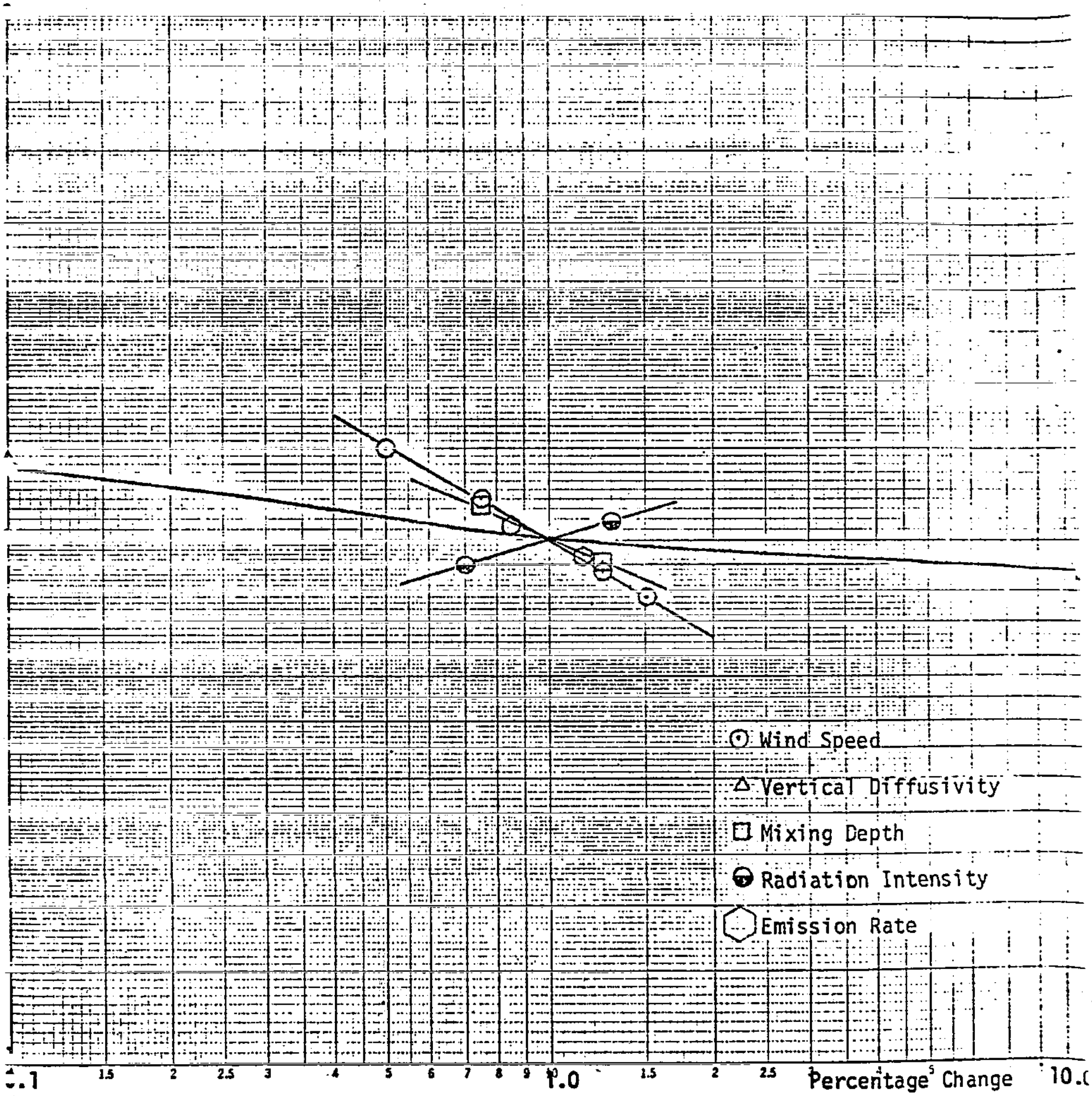
Average Effect on NO Concentration due to Changes in Input Parameters.

FIGURE 7-15



Average Effect on O_3 Concentration due to Changes in Input Parameters.

FIGURE 7-17



[redacted] Average Effect on NO_2 Concentration due to Changes in Input Parameters.

FIGURE 7-18

SENSITIVITY ANALYSIS-SAI MODEL

PARAMETER	CO	NO	O_3	NO_2
WIND SPEED	A	A	A	A
WIND SHEAR	—	—	A	—
VERTICAL DIFFUSIVITY	C	C	C	C
MIXING DEPTH	B	B	B	B
RADIATION INTENSITY	D	A	A	A
EMISSION RATE	B	A	B	B

FIGURE 7-18

GENERAL COMMENTS ON SAI MODEL

1) All sensitivity runs based condition on Sept. 29, 1969 in Los Angeles.

2) All grid concentrations were for ground level.

3) % response are for the maximum ground level grid independent of location in the study area.

4) The CO input and output responses have a linear response on log-log paper.

5) For NO, NO_2, and O_3 the input and output responses are generally non-linear.

6) Additional sensitivities need to be made are:

   a) effects of grid size on model predictions
   b) density of meteorological stations on model predictions
   c) density of air quality measurements on model predictions

SECTION 8

Issues that Must Be Resolved Before Implementing Regional Air Quality Models.

A. Define Study Area and interface of mobile and stationary source inventories for each grid; must use same coordinate system. See Figure 8-1 through 8-3.

B. Boundary Conditions - The location of all terrain features that may alter surface winds and effect transport of pollutants must be changed in the computer programs.

C. Meteorological Data Base - The surface wind flow field, vertical wind shear, diffusion coefficients, radiation intensity, and spatial distribution of surface based and elevated inversions must be described for study area.

D. Air Quality Data Base - The initial concentrations of reactive hydrocarbons, oxides of nitrogen, and carbon monoxide must be specified for the grids if chemical modules are to describe "real world" chemical reactions with any degree of accuracy.

E. Verification program to evaluate models - It has been requested by EPA Region 9 that verification studies be made for each study area.

F. Institutional Constraints - See Table 8-1 and 8-2.

G. Caltrans Involvement in Implementing Regional Air Quality Models

A. Design an air and meteorological survey consistent with model assumptions to provide a sufficient aerometric data base.

1. Bag sampling
2. Air quality van (s)
3. Aircraft package
4. Pibal
5. Weather stations
6. Solar radiation
7. Develop Diffusivity program as a function of land use

B. Modified Models for each study area

C. Provide leadership in transportation planning now including environmental inputs. (Action rather than a reaction agency)

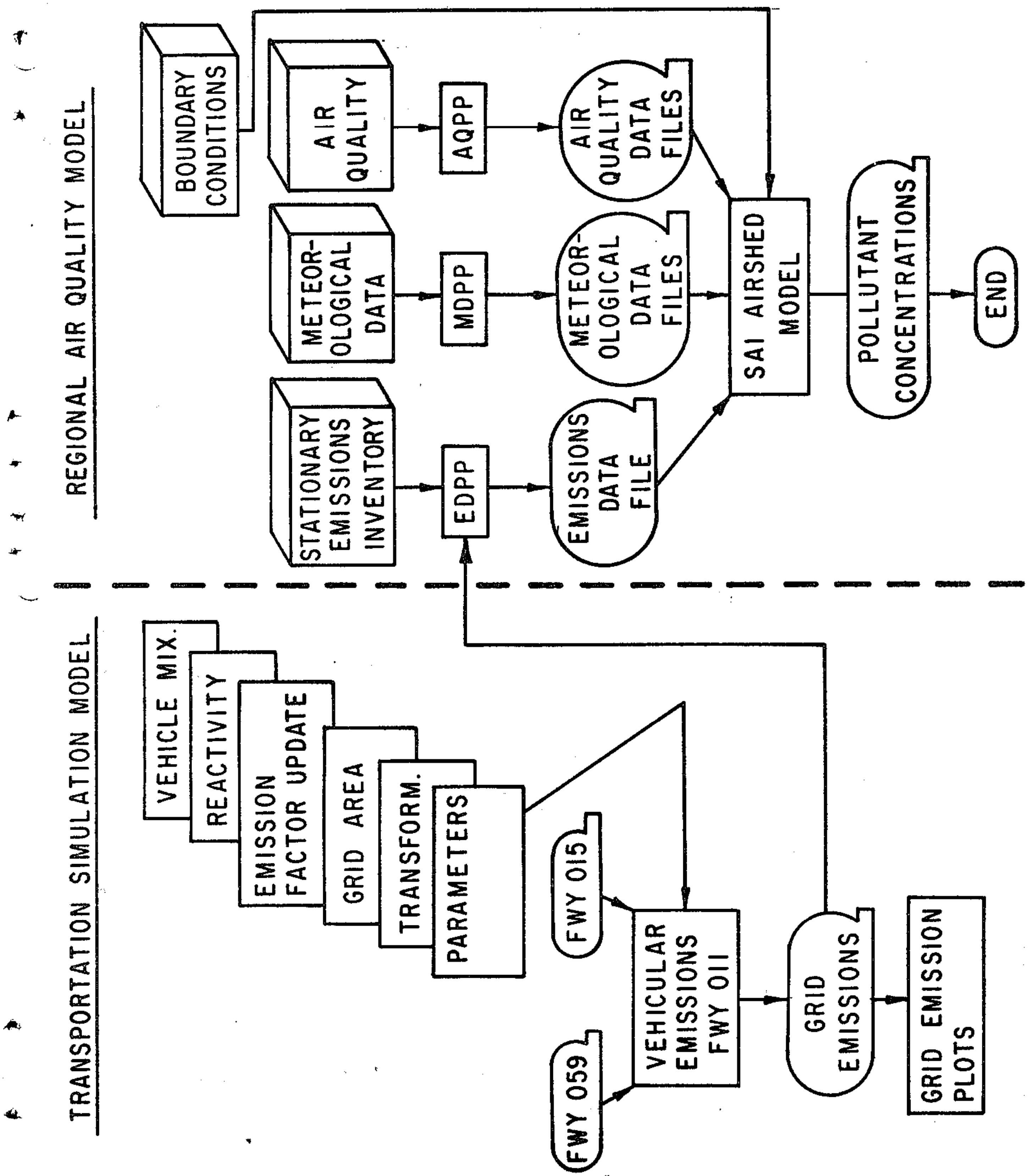

TRANSPORTATION SIMULATION MODEL
REGIONAL AIR QUALITY MODEL
VEHICLE MIX.
REACTIVITY
EMISSION FACTOR UPDATE
GRID AREA
TRANSFORM.
PARAMETERS
FWY 015
FWY 059
VEHICULAR EMISSIONS FWY 011
GRID EMISSIONS
GRID EMISSION PLOTS
STATIONARY EMISSIONS INVENTORY
EDPP
EMISSIONS DATA FILE
METEOR-OLOGICAL DATA
MDPP
METEOR-OLOGICAL DATA FILES
AIR QUALITY
AQPP
AIR QUALITY DATA FILES
BOUNDARY CONDITIONS
SAI AIRSHED MODEL
POLLUTANT CONCENTRATIONS
END

FIGURE 8-1

<u>FWY 059</u> - Network Data

1) Node Number
2) Node Coordinates
3) Link Distance
4) Peak and Off peak speeds

<u>FWY 059</u> - Trip Data

1) H-W
2) W-O
3) H-O

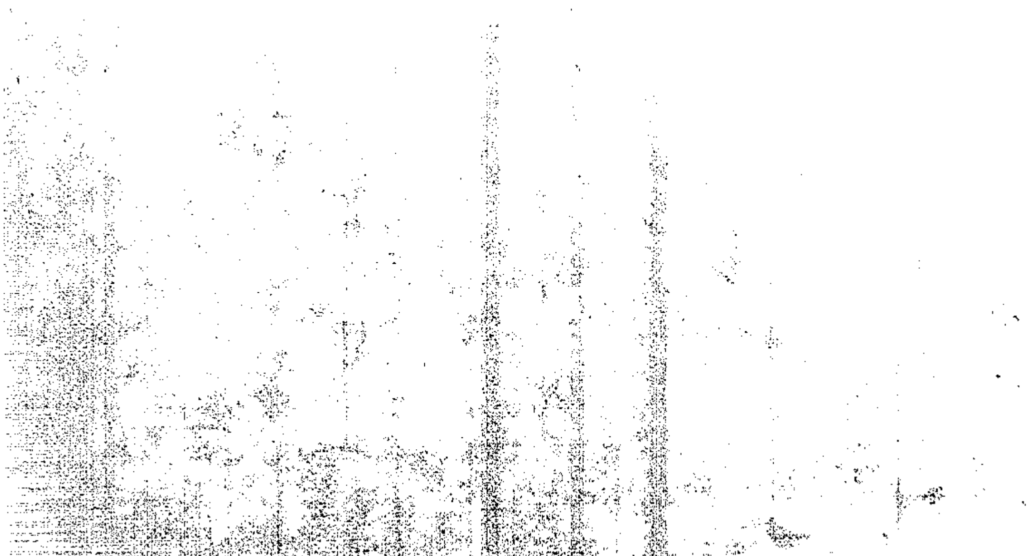
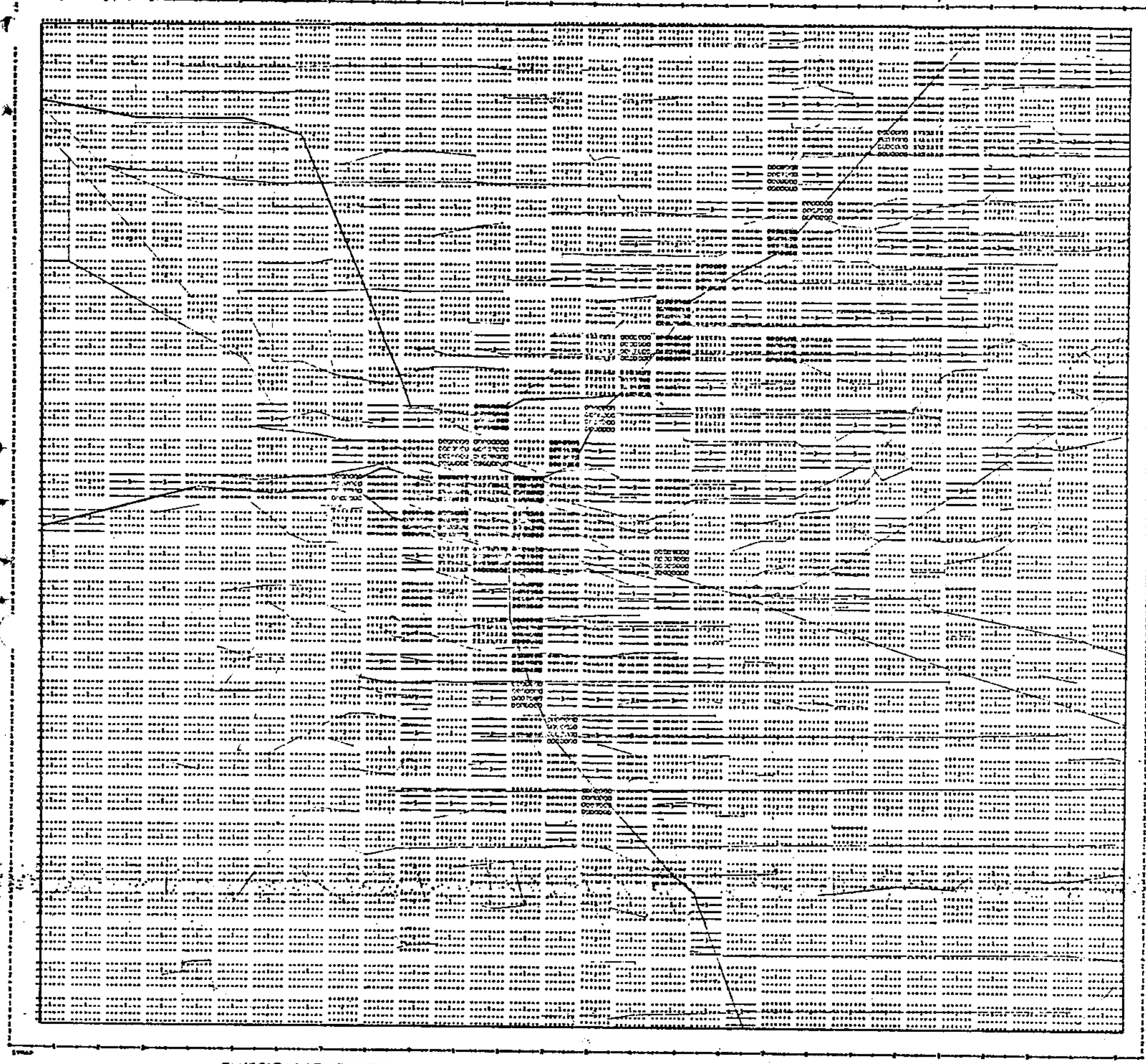


Figure 8-2

CARBON MONOXIDE VEHICULAR EMISSIONS (TONS/DAY)



EMISSION LEVEL KEY

LEVEL	1	2	3	4	5	6	7	8	9	10
SYMBOL										
FREQUENCY	433	219	98	56	26	8	12	8	8	2
MINIMUM	0.0	0.10	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00
XIMUM	0.10	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	55.00

DATA VALUE EXTREMES ARE 0.0–6.49 TONS/SQ KM.

SATS 1969 NETWORK PLOT

AIR QUALITY 1"= 4000'

SEPT. 1974

TAPE REEL NO. IS 011406

FIGURE 8-3

TABLE 8-1

BENCHMARK RESULTS *

Service Facility	Compile	Execute	Total
Lawrence-Berkeley Lab CDC 7600	$ 1.38	$ 2.10	$ 3.48
Information System Design Univac 1108	4.67	9.38	14.50
CDC 6600	11.49	22.51	33.00
UCL IBM 360/91	4.40	8.40	12.80
Teale Data Center	-	-	**29.77/21.67
Cal Tech (estimated)	3.12	3.33	5.45
National CSS	26.39	61.12	87.51
Timeshare IBM 370	10.10	31.83	41.93

* High priority rates; based on section of APSP characteristic of real program.

** Two identical runs give different costs.

TABLE 8-2

COST ESTIMATES FOR SAI MODEL TEALE DATA CENTER

Grid Size	Simulation Time	Cost
25 x 25	10 hours	$ 238
50 x 100	10 hours	$ 2,000
50 x 100	Multi-3 day run at 24 hr/day	$ 14,400

TOTAL RESIDENCE TIME IN TEAL DATA CENTER

Grid Size	Simulation Time	Residence Time
25 x 25	10 hours	2 hours
50 x 100	10 hours	16 hours
50 x 100	Multi-3 day runs 24 hrs/day	38.4 hours

ALTERNATIVE SOLUTION

1) Use data preparation programs at Teale Data Center.

2) Run simulations on LB CDC 7600 computer.

3) Teale Data Center would coordinate the data processing between CDC 7600 and Caltrans.

SECTION 9

A CONSISTENT SCHEME

FOR

CALCULATING DIFFUSIVITIES

LAND USE AND ITS EFFECTS
ON ATMOSPHERIC TURBULENCE

I. General Characterization of Pollution Models

Emissions	→	Transport and Diffusion	→	Transformations Removal Process
(Sources)		(Meteorology)		(Photochemistry)

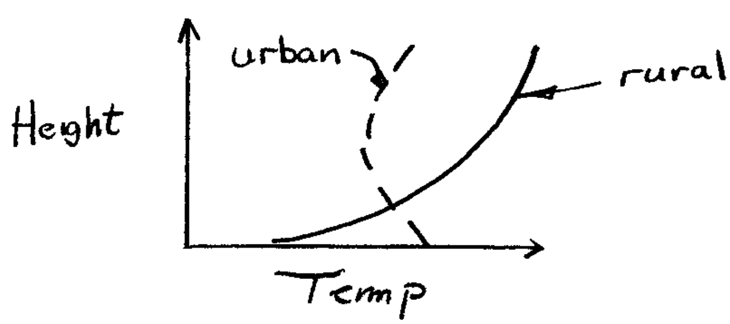
II. Land Use Enters Directly as:

A. Emissions

1. Industrial
2. Commerical
3. Office
4. Central Business District
5. Residential
6. Parks and Recreational Areas

B. Urban Heat Island (known ~ 150 years)

1. Cities warmer than rural areas



2. Generally there are no ground base inversions in cities or urban areas.

III. General Properties of Turbulence

A. Mechanical turbulence - caused by the movement of air passing over the earth's surface; turbulence caused through wind shear and roughness.

1. Intensity; U_* = friction velocity

$$U_* = \sqrt{\frac{\tau_0}{\rho}}$$

where τ_0 = stress that air exerts on ground surface

ρ = density of air

2. Order of magnitude range of U_* - 50cm/sec to 1m/sec

3. Rate of Generation of Mechanical Turbulence;

$$U_*^2 \frac{\partial u}{\partial z} = f\left(\begin{matrix}\text{friction velocity} \\ \text{\& wind shear}\end{matrix}\right) \qquad (1)$$

How do you measure U_*? Research effort use drag plate.

In micrometeorology wind shear can be expressed as:

$$\frac{\partial u}{\partial z} = \frac{u_*}{kz} \qquad (2)$$

Semi-empirical results discovered by German scientists in 1930's. Valid for neutral conditions.

where u_* = friction velocity

k = Von-Karman constant = 0.35

z = height above ground surface

Intergrating EQ (2)

$$u = \frac{u_*}{k} \ln\left(\frac{z}{z_0}\right)$$

Where z_0 = aerodynamic roughness height; related to size of roughness element on surface; z_0 is large for residential areas and small for grassy areas.

Methods to calculate z_0:

a) $z_0 = 0.15hc$
where hc = height of canopy

b) Use table of z_0 developed by Sellers, Myrup and Morgan.

Substituting into EQ (1)

Rate of generation of mechanical turbulence

$$u_*^2 \frac{\partial u}{\partial z} = \frac{u_*^3}{kz}$$

Note: u_* is also function of land use

B. Thermal Turbulence - caused by sun heat ground surface

1. Intensity; $W_* = \left(\frac{gH}{\rho c_p T} z_i\right)^{1/3}$

where W_x = convective velocity
2-4m/sec

G = acceleration of gravity

ρ = air density

H = rate of heat transfer to ground

Z_i = mixing height

T = temperature

C_p = specific heat capacity of dry air at constant pressure

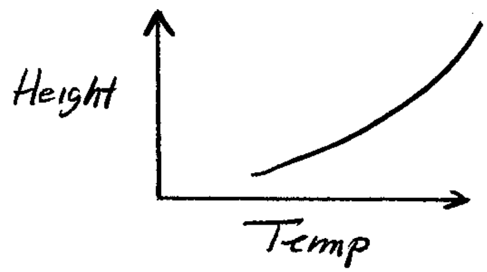
2. Rate of Generation of Thermal Turbulence ;

$$\frac{gH}{\rho c_p T}$$

Thermal turbulence is most intense aloft; mechanical turbulence is most dominating near surface.

C. Sinks of Turbulence

a. Stabiltiy



b. Dissipation Process

• Kinetic energy converted into heat

D. Scale Effects of Turbulence

1. Richardson studied atmospheric trubulence in early 1900's.

a) $\tau \propto \ell^{4/3}$ (4/3 power law)

where ℓ = relative size of turbulence

τ = time

b) turbulence grows with time

E. Stability Parameter

1. Pasquill or Turner stability classes - valid for flat open areas and applicable to Gaussian models.

2. $\left(\frac{Z}{L}\right)$ parameter

where Z = height above ground

L = Moni-Obukhov length

L is defined as

$$L = \frac{-e\ C_p T\ U^{*3}}{kgH}$$

where e = density of air

C_p = specific heat capacity of dry air at constant pressure

T = absolute temperature

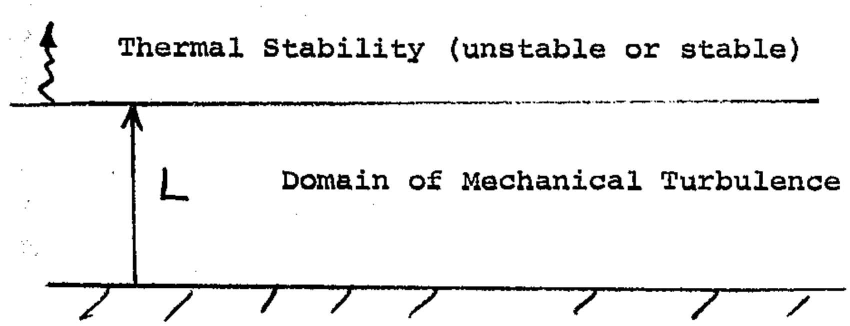
U* = friction velocity

k = Von-Karmon constant = 0.35

g = gravity

H = flux of sensible heat to the atmosphere

3. Physical interpretation of L :



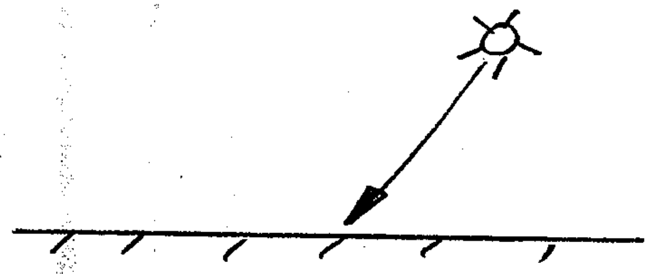
Range of L	Relative Value	Atmospheric Stability Condition
L -100m	large negative	unstable
-100 L -10m	small negative	moderate to very unstable
L 10^5m	infinity	neutral
L 10m	small positive	Very stable
L 10m	large positive	stable

Small negative number represent extremely unstable conditions.

Small positive number represent extremely stable conditions.

4. Factors in cities or urban areas that effect "L".

a) surface roughness
b) evaporation
c) anthropogenic heating - released from human activities
d) surface physical properties - albedo, heating conductivity and capacity, etc.



Energy from sun must
1. heat ground
2. heat air
3. evaporate water

$$R_n + Q_A = H + LE + S$$

where R_n = net radiation
Q_A = anthropogenic heating
H = energy to heat air
LE = energy to evaporate water
S = energy to heat soil

$$H = R_n + Q_A - LE - S$$

Bowen Ratio $B = \frac{H}{LE}$

B = 10 for deserts areas
B = 1 for oceans

5. Evaporation effects heat budget in urban areas

a) In cities the streets, freeways surfaces, roof tops etc. shifts energy balance from LE to H or S.

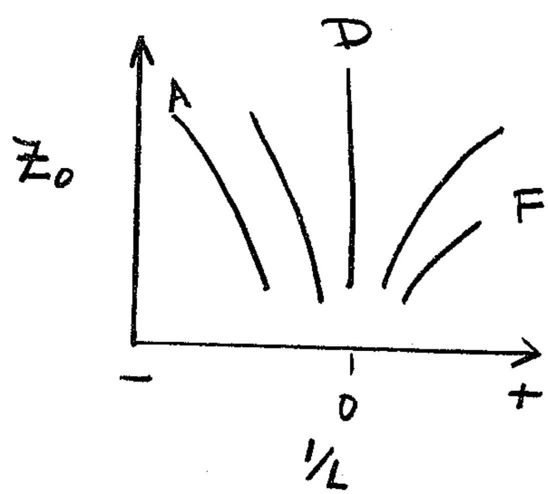
This effects "L" and stability in cities.

6. Characterization of LE as function of land use

a) Rural areas have high evaporation
b) Residential areas have moderate evaporation
c) Industrial areas have light evaporation.

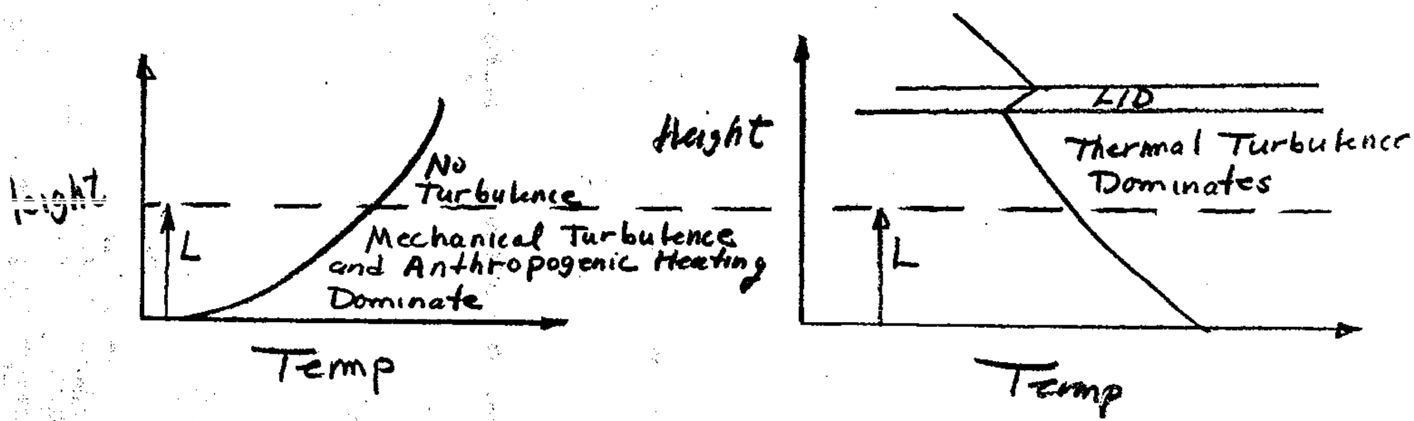
7. Methods to calculate "L"

a) Golder's relationship of L, Z_o and Pasquill stability classes.
See Figure 1 and 2.



b) Discuss neutral case with
1. small Z_o (rural area)
2. large Z_o urban area ($L=10^5$m)

IV. Summary of Land Use Effects on Turbulence



STABLE CASE

UNSTABLE CASE

Land Use in Urban Areas Effect Turbulence:

1. roughness - effect mechanical turbulence, U_*, Z_o
2. supressing evaporation - effect thermal turbulence (heats air or ground)
3. anthropogenic heat - released from human activities

MYRUP AND RANZIERI DIFFUSIVITY MODEL

I. General Air Quality Model Equation

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} + w\frac{\partial c}{\partial z} = \frac{\partial}{\partial x}\left[K_x \frac{\partial c}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_y \frac{\partial c}{\partial y}\right] + \frac{\partial}{\partial z}\left[K_z \frac{\partial c}{\partial z}\right] + R_i + S_i$$

where in general $K_x = K_y = 0$
and K_z = vertical diffusivity

1. Definition of K_z (based on molecular diffusivity)

$$F_p = -e\, K_z \frac{dc}{dz}$$

where F_p = vertical flux
e = density of air
$\frac{\partial c}{\partial z}$ = concentration gradient
K_z = diffusivity

This definition implies that K_z can be looked up in a handbook, a very unrealistic approach.

2. Over 50 years of research has been done on establishing the physical principles that govern the behavior of fluxes and gradients.

II. Reasons for Developing Diffusivity Model

1. Caltrans involvements in air quality models to simulate the temporal and spatial distribution of O_3.

2. Most models treated K_z as a "free parameter" since model builders thought little was known about K_z.

3. Caltrans was tired of seeing K_z treated as a free parameter since information was available to physically calculate K_z.

III. Physical Interpretation of K_z

$$K = \frac{L^2}{T} = \frac{L}{T} \times L$$

K = turbulence Intensity x Length Scale

Large K's results in large scale mixing
Small K's results in small scale mixing

IV. Diffusivity Model

A. Surface Layer, $- -5.0 < \frac{Z}{L} < 1.0$

B. Outer Layer, $-\frac{Z}{L} < 5.0$

V. Surface Layer Model

A. Diffusivity for momentum

$$K_m = K_z = \frac{k u_* Z}{\phi\left(\frac{Z}{L}\right)}$$

where $\phi\left(\frac{Z}{L}\right)$ = phi-function

$\phi\left(\frac{Z}{L}\right)$ is a function of atmospheric stability.

1. Stable: $\phi\left(\frac{Z}{L}\right) = 1 + 4.7\left(\frac{Z}{L}\right)$

2. Unstable: $\phi\left(\frac{Z}{L}\right) = \left[1 - 15\left(\frac{Z}{L}\right)\right]^{-1/4}$

3. Calculate U_* by:

$$U_* = \frac{k u}{\ln\left(\frac{Z_w}{Z_0}\right) + \frac{2}{L}\left(Z_w - Z_0\right)}$$

$$Z_w = Z_{ws} - h_c$$

where Z_{ws} = height above ground surface from which $\bar{U}$ is measured

h_c = canopy height

Z_o = aerodynamic roughness

VI. Outer Layer Model $-\frac{Z}{L} > 5$

$$K = C\,\varepsilon^{1/3} Z^{4/3}$$

Fundemental property of turbulence

where C = constant = 0.5

ε = dissipation rate, rate at which turbulence kinetic energy is converted to heat

Z = height above ground surface

Based on turbulent studies it can be shown

$$K_z = 0.5\left(-0.4\,\frac{Z}{L}\right)^{1/3} u_* Z$$

VII. Characteristics of Both Models

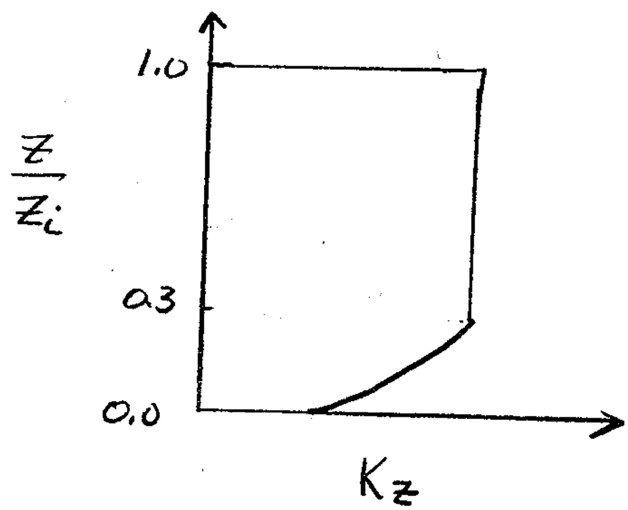
1. Both formulas indicate that K_z increase with height. This is not true because of inversion aloft suppress turbulence

2. Myrup studied the most recent boundry layer models and found that K_z remain constant above the ratio

$$\frac{Z}{Z_i} = 0.3$$

where Z = height above ground surface

Z_i = height of the base of elevated inversion.



This concludes the M & R Model. This model will be published in Journal of Atmospheric Sciences.

A Unified Approach to the Estimation of Diffusivity in the Planetary Boundary Layer

L. O. Myrup and A. J. Ranzieri

January 1975

A Unified Approach to the Estimation of Diffusivity in the Planetary Boundary Layer

L. O. Myrup and A. J. Ranzieri

ABSTRACT

A vertical diffusivity model consistent with the latest developments in theory and observations of the planetary boundary layer is developed. The model is meant for use in air pollution dispersion models and similar applications. The model uses conventional meteorological and land-use information and takes into account surface roughness, atmospheric stability, as specified by the Monin-Obukhov length, and evaporation.

1. Introduction

The planetary boundary layer is the location of whole range of phenomena of direct importence to human society and the local and global ecosystem of which it is a part. Transport and diffusion processes in the atmospheric boundary layer determine the air concentration of pollution for a given emission rate. Similarly, the extent of local climate modification through the release of anthropogenic heat or evaporation alteration due to changes in land-use is largely determined by boundary layer processes. Transport and diffusion of pollen is a very similar problem. The movement and disposal of flying insects is heavily influenced by these same processes. It should be remembered that the behavior of many flying insects, such as the African Desert locust, is of profound significance to the welfare of large numbers of human beings. In the oceanic boundary layer the transport and diffusion processes are an important part of the ecological dynamics of marine micro-organisms, the base of the entire oceanic food chain. We argue that there inumerable important applications for a simple and reliable process for calculating the effects of diffusion in the planetary boundary layer.

In the cases of most interest, such as photochemical smog or phytoplankton dynamics, the dispersion process is a relatively small part of a complex and difficult problem. It is not appropriate or helpful, therefore, to recommend the investigators studying such problems the use of the most advanced boundary layer models such as those of Mellor and Yamada (1974). A strategy of devoting great effort to a small part of the problem is not conducive to progress.

In order to handle diffusion in complex boundary layer processes most workers resort to the diffusivity concept. In the case of a vertical diffusive flux F_p, of prime importance in most cases, the diffusivity, K_p, for property of (specified per unit mass of air) is defined by:

$$F_p = - \rho K_p \frac{\partial \bar{p}}{\partial z} \quad , \qquad (1)$$

where ρ is air densiy, z is the vertical direction and the overbar an averaging procedure (of the order of 0.5 hr or larger if the averaging is temporal). It must be stated immediately that the diffusivity is a non-physical concept and one which modern experimentalists and theorists largely ignore. It is not hard to see why. Examination of the vertical profiles of humidity and potential temperature from the Wangara experiment (Clarke, et al., 1971) shows that the mean vertical gradient typically is near zero throughout a large portion of the boundary layer. In the case of potential temperature, the gradient can reverse so that diffusivity can be negative. Hence, diffusivity is hardly a constant to be looked up in a handbook although many workers from outside of meteorology tend to treat it as such. Instead, diffusivity is a complex function of the fluid motion and its stratification as modified by local boundary conditions. It is the objective of this paper to develop a simple model of the vertical distribution of diffusivity in the planetary boundary layer which is consistent with the most reliable observations, theory and numerical calculations. Since we have real-world application in mind, we have also endeavered to keep the data reguirements such that the model uses only routinely available meteorological and land-use information.

2. Estimation of Stability

All available information from observation and theory indicates that diffusivity is a strong function of local stability. By local stability, we mean the stability which is determined by land-use and which refers to a specific height. This is specified most basically by such parameters as z/L where z is height above the surface and L is the Monin-Obukhov length.

$$L = \frac{-\rho C_p T u_*^3}{kgH} , \qquad (1)$$

where ρ is air density, C_p is the specific heat capacity at constant pressure of dry air, T is absolute temperature, k is the von Karman constant with a value of 0.35 (Businger, et al., 1971), g is the acceleration of gravity, H is the flux of sensible heat to the atmosphere and u_* is a basic micro-meteorological parameter, the friction velocity. The friction velocity is given by

$$u_* = \left(\frac{\tau_o}{\rho}\right)^{1/2} , \qquad (2)$$

where τ_o is the frictional stress which the underlying surface exerts on the atmosphere (and vice versa). The friction velocity gives the order of magnitude of the turbulent velocity fluctuations near the surface which are associated with the roughness characteristics (mechanical turbulence).

The Monin-Obukhov length has the physical interpretation of being the height at which buoyancy forces become significant to the energetics of turbulence fluctuations. Under stable conditions (downward transfer of sensible heat) turbulence is supposed to vanish for z/L $\tilde{>}$ 0.85 (Ellison, 1957; Ellison and Turner, 1960). Under all conditions near the surface of the earth the characteristics of turbulence, including diffusivity are determined by the ratio, z/L.

Needless to say, the Monin-Obukhov length is not a quantity which is routinely measured and available from the local weather office. However, L may be estimated from conventional weather data. The most common stability classification used in air pollution meteorology was originally devised by Pasquill (1962) and later modified by Turner (1964). Essentially, Pasquill categories are functions of the radiation balance of the surface of the earth, which is estimated from the hourly sun elevation and cloud cover, and wind speed. Detailed directions for calculating Pasquill stability categories are given in Beaton, et al. (1972). It would be of great practical utility to be able to convert Pasquill categories to values of L. There are problems in doing this, however. When the Pasquill category is calculated for a given region, it applies to those locations that have the same land-use. Unfortunately, land-use almost always presents a checkerboard appearance on a regional scale and the microclimate and local stability can vary enormously within the same region for a given Pasquill category.

There are four factors which can cause local stability to vary from place to place. These are (1) surface roughness, (2) evaporation, (3) anthropogenic heating, and (4) surface physical properties (albedo, heat conductivity and capacity, emissivity, etc.). Surface roughness is a prime factor because it is directly associated with the turbulence level near the ground. The local evaporation rate (evapotranspiration when plants are involved) is a factor because the energy used to transform water from the liquid to the vapor state is unavailable to heat the underlying surface or air. Consequently, local areas of high evaporation are noticeably cooler and generate less thermal turbulence. Heat released from human activities, such as transportation systems, industrial operations, or space heating, effects local stability directly through the augmented low-level heat input. This has the effect of preventing the formation of low-level inversions and augmenting thermal turbulence. Surface physical properties effect local stability through their influence on the radiation balance of the surface of the earth. The order in which four factors are listed above is also their order of importance in most land-uses. The relative importance of anthropogenic heating is most variable. It is possible that in local areas of very heavy energy use this factor may be comparable in importance to surface roughness. Conversely, in many land-uses, human-generated energy is of no importance whatsoever.

Golder (1970, 1972) has compiled an empirical relationship between Pasquill stability categories, calculated in the usual manner, and values of 1/L. Only surface roughness is taken into account. The data he uses are from micrometeorological sites where human energy release would not be present and surface physical properties would be comparable. Evaporation, however, remains problematical in the analysis. Examination of Golder's data shows the agreement between the two approaches to stability is moderately good. The overall separation between stable and unstable conditions is good and there is a clear tendency for 1/L to appraoch zero for large roughness values at the same Pasquill category. We interpret the scatter in Golder's results as being due to the variable importance of evaporation in the basic data. We conclude that, except in local areas of intense energy use, local stability is primarily determined by local roughness and overall, regional stability as specified by the Pasquill system of categories.

Figures 1 and 2 show the relationship between the roughness parameter, Z_o, Pasquill stability categories and the quantity 1/L (local stability at a height of 1 meter). The figures are based on Golder's data extended to the larger roughness values of the urban environment. These figures specify only a range of values for 1/L for a given Pasquill category. This is inherent in the data and reflects, we believe, evaporation variation. Therefore, for each stability category, we have indicated the more stable values of 1/L to be associated with high evaporation and the less stable values to low evaporation. Experience in micrometeorology (Sutton, 1953; Sellers, 1965) and in urban meteorology (Myrup and Morgan, 1972) indicates that irrigated crops, parks and open water are high evaporation areas. The predominant land-use category in urban areas, light density residential, is a moderate evaporation area. On the other hand, high-intensity uses such as the central business district, industrial, office building and shopping areas are characterized by low evaporation. As a general rule, the fraction by the land area covered by green, transpiring plants is a good indication of the relative importance of evaporation.

In order to use figures 1 and 2, an estimate of the roughness parameter, Z_o, must be obtained. Z_o may be calculated from wind shear measurement (Sutton, 1953) if these are available. It is also given as a function of land-use in Sellers (1965). The land-use approach is extended to urban categories in Myrup and Morgan (1972). Alternatively, Z_o may be calculated from the simple formula, $Z_o = 0.15\ h_c$ (Plate, 1971), where h_c is the "canopy height," i.e., the mean height of the surface roughness elements.

Thus, figures 1 and 2 may be used to convert Pasquill stability categories to values of 1/L on the basis of standard meteorological measurements, quantitative information concerning site roughness characteristics and qualitative estimates of the importance of evaporation in the urban environment. A more rigorous treatment of evaporation and consideration of the effect of anthropogenic heating will require further research.

3. Surface Layer Diffusivity

In our approach to the vertical distribtuion of diffusivity in the atmopsheric boundary layer, we shall distinguish between an inner and outer region. This is a common assumption in the theory of the planetary boundary layer (Tennekes and Lumley, 1972). The inner region is dominated by surface energy, mass and momentum transfer and local site characteristics and the constant flux layer assumption is acceptable. The outer region is more heavily influenced by larger scale phenomena such as the pressure gradient, the Coriolis force and the depth of the convectively mixed layer. The correct manner to "scale" the non-neutral outer region is a subject of continuing debate in the literature of the planetary boundary layer. In formulating our approach, we have been most influenced by the work of Deardorff (1972), Melgarejo and Deardorff (1974), Willis and Deardorff (1974) and Zilitinkevich and Deardroff (1974).

The definition of diffusivity implied by equation (1) may be specialized to any of several quantities. Diffusivities for momentum, heat and water vapor are most commonly best known. Diffusivity for momentum is generally regarded as the most important inasmuch as momentum transport is intrinsically involved with the entire phenomenon of turbulence. To our knowledge no diffusivities for air pollutants have been directly measured (i.e., simultaneous measurement of both flux and gradient) in a carefully controlled experiment. Therefore, we choose here to select the diffusivity for momentum to use to calculate the vertical flux of any gaseous air pollutant. It might appear that the diffusivity for water vapor might be the most appropriate to use for pollutant transfer inasmuch as both are mass fluxes. However, it is known that water vapor transfer is influenced by buoyancy forces arising out of the fact that water vapor is a lighter gas than dry air. When evaporation rates are large under unstable stratification, water vapor diffusivity is markedly increased over the value for momentum. No pollutant gases reach concentration levels to compare with water vapor, however (1 to 2% by mass), so we conclude that molecular weight should not be a factor. Hence, we assume all pollutants diffuse like momentum.

In the surface layer, the diffusivity for momentum can be shown to be given by

$$K_m = \frac{k u_* Z}{\phi\left(\frac{z}{L}\right)} \quad , \tag{4}$$

where the quantity in the numerator is the diffusivity for neutral conditions ($z/_L = 0$) and the quantity $\phi\ (\frac{z}{L})$ is a function of stability. Various empirical and theoretical prescriptions exist for the "phi function." From the work of Businger _et al._ (1971), we select

$$\text{stable:} \quad \phi_m(\frac{z}{L}) = 1 + 4.7\,\frac{z}{L} \quad , \tag{5}$$

$$\text{unstable:} \quad \phi_m(\frac{z}{L}) = (1 - 15\,\frac{z}{L})^{-1/4} \quad , \tag{6}$$

where the coefficients were empirically determined. We will discuss below the range of applicability of these functions.

The friction velocity u_*, may be determined from the stability modified log - law,

$$\frac{\partial u}{\partial z} = \frac{u_*}{kz}\ \phi_m\ (\frac{z}{L}) \quad , \tag{7}$$

where $u(z_w)$ is the mean wind speed measured at height z_w. Integrating equation (7) from $z = z_o$ (where $u = 0$) to $z = z_w$, we obtain

$$u_* = \frac{ku(z_w)}{\int_{z_o}^{z_w} \frac{\phi_m(\frac{z}{L})}{z} \partial z} \tag{8}$$

where we have taken u_* as constant with height (constant flux layer assumption). For convenience in evaluating the integral and because the stability correction is not as critical here, we select a form for ϕ $(z/_L)$ which is approximately valid for both unstable and stable conditions, $(1 + 2 \frac{z}{L})$, (Morgan et al., 1971). Equation (8) than becomes

$$u_* = \frac{ku(z_w)}{[\ln \frac{z_w}{z_o} + \frac{2}{L} (z_w - z_o)]} \tag{9}$$

Equations (4), (5), (6), and (9) constitute a complete model for calculating the diffusivity near the surface of the earth. To use the model, $z/_L$ must be determined from, for instance, Pasquill categories, and z_o must be specified, according to site characteristics, and a measured wind must be available. The phi-functions we have quoted are based on the common micrometeorological practice of specifying height not from the ground but from a reference height called the zero-plane displacement height. This height usually closely corresponds to the average height of the site roughness elements (trees, buildings, etc.), and its precise value is not critical. When surface roughness is small or when the calculation is being made at a height well away from the surface, this micrometeorological nicity can be ignored. However, the height z_w will normally be comparable with the average roughness elements and therefore this height should be reduced by the zero-plant displacement height.

4. Diffusivity in the Outer Layer

The data on which the surface layer model depends covers the stability range, $-2.5 \lesssim z/L \lesssim 1$. Inasmuch as the quantity $|L|$ can be less than 10 meters, additional relationships are needed for processes at greater heights. On the unstable side we will assume that surface layer model is valid up to $z/L = -5$. Above this height we will use the following relationship for diffusivity:

$$K = c\, \varepsilon^{1/3}\, z^{4/3} \quad , \qquad (10)$$

where ε is the dissipation rate (the rate at which turbulence kinetic energy is converted to heat) and c has a value of about 0.5. This relationship goes back to the work of Richardson (1926) who first noted that atmospheric diffusivities over a very wide range of scales appeared to follow a "4/3 law." The inclusion of $\varepsilon^{1/3}$ is made on the dimensional grounds suggested by the Kolmogorov (1941) theory of turbulence. This particular functional form for diffusivity has been used previously by Panofsky (1961) and discussed by Batchelor (1950). The utility of this approach for practical applications air quality and other depends on (1) the confidence one may place on the value of c and (2) the availability of a method of estimating the dissipation, ε. Near the surface of the earth, dissipation is known to equal shear production of kinetic energy (Wyngaard and Coté, 1971)

$$\varepsilon = u_*^2 \frac{\partial \bar{u}}{\partial z} \quad . \qquad (11)$$

Substitution of this relationship into equation (9) leads to the relation,

$$c = k^{4/3} = (0.35)^{4/3} = 0.25 \quad . \tag{12}$$

In the pure free convection regime, dissipation is constant with height (Willis and Deardorff, 1974; Lenschow, 1974) and is well approximated by

$$\frac{\varepsilon z_i}{w_*^3} = 0.4 \quad , \tag{13}$$

where z_i is the height of the inversion which caps the convective layer and w_* is a convective velocity, analogous to, and related to, u_*, given by

$$w_* = \left(\frac{gHz_i}{\rho C_p T}\right)^{1/3} = \frac{1}{k^{1/3}} \left(\frac{-z_i}{L}\right)^{1/3} u_* \quad , \tag{14}$$

where $^{z_i}/_L$ will be recognized as the overall stability of the entire convective layer. If we require both diffusivity formulae, equations (9) and (4), to be valid at the same level, as they must if the two approaches are compatible, we obtain:

$$K = c\ \varepsilon^{1/3}\ z^{4/3} = \frac{ku_* z}{\phi_m(\frac{z}{L})} \quad . \tag{15}$$

Substituting from equations (12) and (13) we obtain

$$c = \frac{k^{4/3}}{(-0.4\ \frac{z}{L})^{1/3}\ \phi_m(\frac{z}{L})} \tag{16}$$

The relationship expressed by equation (12) is known to be valid down to $\frac{-z}{L} = 10$ (Lenschow, 1974). We assume that it remains approximately true at $-z/_L = 5$ where we are extending the unstable phi-function from below. There evaluating equation (15) for $\frac{z}{L} = -5$, and using the previuosly given formulae for $\phi\ (\frac{z}{L})$, we obtain $c = 0.58$, a value about twice that previously obtained for very different conditions near the ground.

The agreement is close enough to lead one to look further into the variation of c with height in the region of overlap with the surface model. For unstable conditions Wyngaard and Coté (1971) find that

$$\varepsilon = \frac{u_*^3}{kz}\left[1 + 1/2\left(-\frac{z}{L}\right)^{2/3}\right]^{3/2} . \qquad (17)$$

In the overlap region we assume equation (14) is valid. Substituting the above relationship for ε into equation (14) and the previously given φ function for unstable conditions (equation 6), we obtain

$$c = \frac{k^{4/3}}{\left[1 - 15\left(\frac{z}{L}\right)^{-1/4}\right]\left[1 + 1/2\left(\frac{z}{L}\right)^{2/3}\right]^{1/2}} . \qquad (18)$$

Values of c calculated from this relationship rise smoothly from the near neutral value of 0.25 to 0.4 at z/L = -1 and level off at around 0.45 near z/L = -3, which is reasonably close to the value of 0.58 obtained for the pure corrective regime. We tentatively conclude that the factor c achieves a constant value of about 0.5 at $-z/L \gtrsim 5$ and we adopt that value for the calculation of diffusivity in the outer region.

Equations (9), (12), and (13) may be combined to give

$$K = c\,(-0.4\ z/L)^{1/3}\ u_* z , \qquad (19)$$

which we assume is valid for unstable conditions at and above -z/L - 5.

In general, the observational evidence above 100m is inadequate to verify more than the order of magnitude or estimates of diffusivity. In particular, more information is needed as to the shape of the diffusivity profile in the upper portions of convective layers. Diffusivity cannot increase indefinitely with height, as equation (18) states, because at some point the influence of the bounding inversion or stable layer must act to limit the value of diffusivity.

Under these circumstances, perhaps the best evidence comes from sophisticated numerical boundary layer models. One of the most advanced approaches we are aware of is that of Mellor and Yamada (1974), who present a hierarchy of models for the planetary boundary layer based on a consistent scheme for including effects of turbulence anisotropy at various levels of approximation (closure assumptions). Using data from the Wangara experiment (Clarke et al., 1971) as boundary and initial conditions, Mellor and Yamada integrate three models and find that the "level 2" model is adequate to describe the known properties of the planetary boundary layer. In the late afternoon, this model generates momentum diffusivities for boundary conditions taken from the Wangara data (Clarke et al., 1971) which rise to values near 3000 m^2/min at $z/z_i = 0.3$ and then are roughly constant until $z/z_i = 1$ is approached where diffusivity falls abruptly to zero. Using the same boundary conditions, equation (16) yields a diffusivity of 3390 $m^2\ min^{-1}$ indicating good correspondence between the two approaches at this height.

On the basis of the behavior of the models of Mellor and Yamada we now add to our diffusivity prescription the requirement that diffusivity for unstable conditions be constant for $\frac{z}{z_i} > 0.3$ and go to near zero for $\frac{z}{z_i} > 1.0$.

Under stable conditions, we must also specify diffusivity in the outer layer. We choose to invoke the condition, mentioned earlier, that turbulence vanishes at $z/L = 0.85$. Therefore, our method under stable conditions is that the surface layer formulation (equations 4, 5, and 9) holds until $z/L = 0.85$ is reached where the diffusivity drops to zero. This condition completes the diffusivity model.

5. Discussion

The diffusivity values which this model predicts are quite large for unstable conditions. Numbers of the order of thousands of $m^2\ min^{-1}$ are achieved at a height of 100 meters. These values are much larger than those which have been used recently in some models of photochemical air pollution (Eschenroeder, 1972). The scarse verification information available at and above 100 m supports the larger values. Lettau (1944) obtained a value of 6000 $m^2\ min^{-1}$ at 200 m for conditions of strong instability. Woskresenski and Matwejew (1960) made 225 estimates of momentum diffusivity from aircraft observations in the lowest 100 meters over the arctic sea. Their values generally ranged from 1,200 to 4,800 $m^2\ min^{-1}$. The calculations of Meller and Yamada (1974), mentioned above, also support large values of diffusivity for unstable conditions.

Agreement between the inner and outer layer diffusivity models (equations 4 and 9) is excellent. In fact, either formula can be extended well into the domain of validity of the other. For instance consider the model output given in table 1 for L = -25 m, Z_o = 1 m, z_i= 1000 m and u_{10} = 3 ms^{-1}. In this example, we hold the diffusivities constant above z/z_i = 0.3 as specified above. As can be seen the "inner law" gives larger values near the surface with the "outer law" becoming large at about z/L ≈ 10. The precise stability at which this occurs is, of course, dependent on the value of c accepted. Here we used 0.5.

Table 1

z (m)	-z/L	z/z_i	$ku_* z/\phi_m$	$c\,\varepsilon^{1/3} z^{4/3}$ $(m^2 s^{-1})$
1	0.04	0.001	16	8
10	0.40	0.010	227	165
25	1.00	0.025	697	560
50	22.00	0.050	1,640	1,410
100	4.00	0.10	3,890	3,560
200	8.00	0.20	9,240	8,960
300	12.00	0.30	15,300	15,400
400	16.00	0.40	15,300	15,400
600	24.00	0.60	15,300	15,400
800	32.00	0.80	15,300	15,400
1000	40.00	1.00	15,300	15,400
1200	-----	1.20	∿ 0	∿ 0

It is not surprising that both approaches to diffusivity give similar values. The $z^{4/3}$ hypothesis, equation (9), was used by Panofsky (1961) to obtain an alternate deviation of the so-called "KEYPS" formula, which is essentially an interpolation formula between the free convection and forced convection regimes.

There are three principle limitations to this model of which we are aware. The first, and probably most severe, is the fetch/height requirement on the inner law. The functional forms used to specify the diffusivity near the surface, equations (5) and (6), are based on measurements made in a boundary layer in which an equilibrium state has been attained between flux and gradient. The maximum height at which this state has been achieved is a function of the fetch over which homogenious surface conditions are found upwind. It is common in micrometeorology to quote a figure of 1/100 as the maximum value of the height/fetch ratio at which the micrometeorological flux/gradient relationships may be used. For the air quality applications we have in mind, and in the absence of any viable alternate approach, we suppose that the limit may be pushed to 1/50. That is, the surface layer diffusivity formulation is assumed to be valid only up to heights one-fiftieth the upwind distance over which homogenious land-use is found. In order to extend the approach to greater heights, the surface conditions such as the roughness parameter must be adjusted to reflect average conditions over an upwind fetch equal to fifty times the height in question.

A second limitation of this approach is found in the stable case. It is commonly observed that early morning surface inversions are surmounted by a deep, neutral layer capped by an elevated stable layer. Often these higher layers are left over from the mixing processes of the day before. Obviously vigorous mixing can be occuring in this elevated neutral layer. As given above, our diffusivity model would "turn off" the mixing at $z/L = 0.85$ and allow nothing to occur above. In many applications where the emphasis is on surface emission and their immediate fate, there would be no problem. However, in some cases, such as the photochemical air pollution problem, it may be important to carry on realistic diffusion calculations above a surface inversion. In that case we recommend that diffusivity in the elevated neutral layer be calculated as if the entire layer up to the boundary stable layer aloft was neutrally stratified (very large $|L|$).

Finally, our fundamental assumption is that the diffusing properties act like momentum so far as specification of diffusivity is concerned. We assume this in the absence of any information to the contrary. It is conceiveable that some pollutants, aerosols in particular, may behave differently. However, even in that case, correction factors should be simple functions of stability so that the general appraoch proposed here should still be useful.

In conclusion, we would like to point out that there has been a certain vagueness in the air quality modeling literature concerning diffusivity. In some cases it has been used as a free parameter to be adjusted to cause model output to agree with observations. Clearly, this is not acceptable. The proper strategy in model development is to systematically specify all model parameters on the basis of independent physical arguments. We intend this paper to be a contribution to that effort. Inasmuch as pollution emission is also highly dependent on land-use category (Myrup, 1975), we believe the use of a land-use based diffusivity model, such as the one presented here, will provide a much more rational basis for urban planning and decision making.

6. Summary of the Model Equations

For convenience, we summarize the final form the various equations used to calculate diffusivity.

(a) Stable conditions ($L > 0$).

$$K = Km = \frac{k u_* z}{\phi_m(\frac{z}{L})} ,$$

$$\phi_m (\frac{z}{L}) = 1 + 4.7 \; z/L ,$$

$$u_* = \frac{kU(z_w)}{[\ln \frac{z_w}{z_o} + \frac{2}{L}(z_w - z_o)]} ,$$

valid to $\frac{z}{L} = 0.85$, above which $K \simeq o$.

(b) Unstable conditions ($L < 0$).

(i) $z \leq -5L$

$$K = K_m = \frac{ku_* z}{\phi_m\ (z/L)}$$

$$\phi_m(\frac{z}{L}) = (1 - 15\ \frac{z}{L})^{-1/4}$$

u_* as above

(ii) $z \tilde{>} -5L$

$$K = 0.5\ (-0.4\ \frac{z}{L}\ )^{1/3}\ u_*\ z$$

u_* as above

(iii) $z \geq 0.3\ z_i$

K should be held constant at whatever value assigned at $z = 0.3\ z_i$

(iv) $z > 1.0\ z_i$

K should be set to zero or some convenient small number

(c) Neutral conditions

Use either method with a very large value of L (> 10^4m) or appropriate sign and, as above, setting K constant above 0.3 z_i at - zero above z_i.

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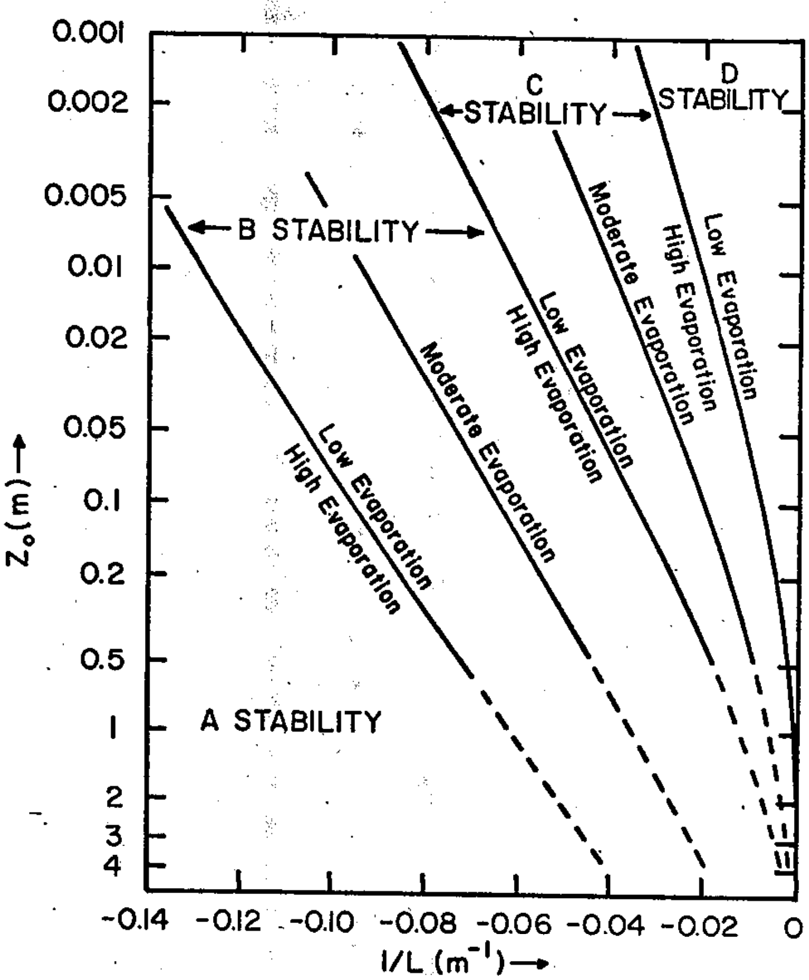
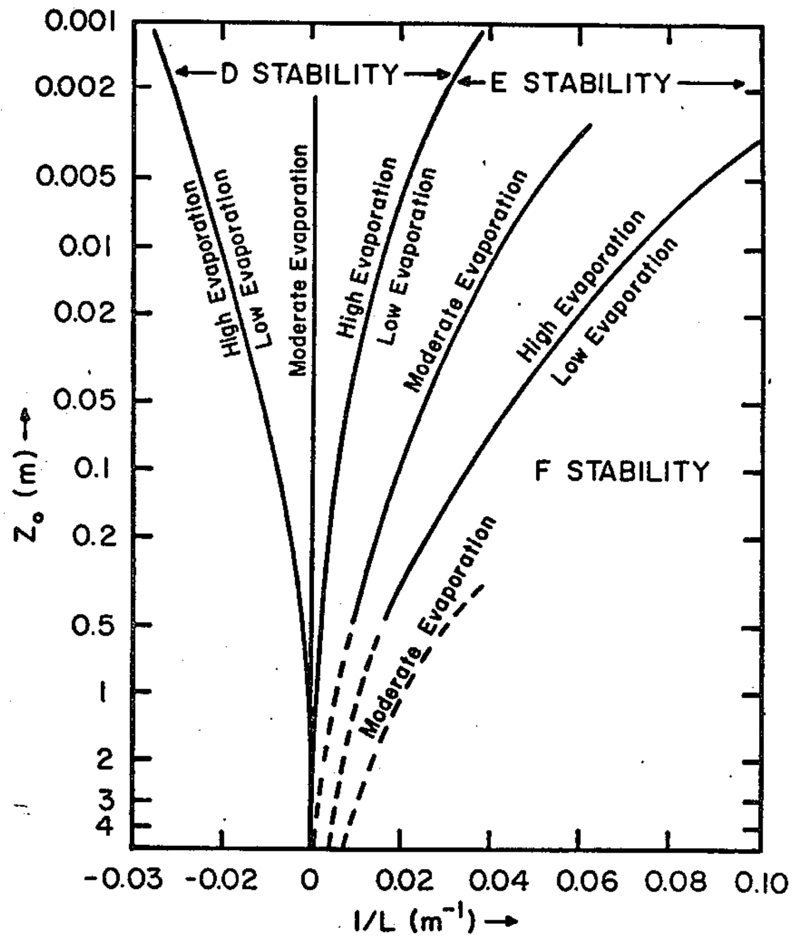
Figure Captions

Figure 1. Inverse Monin-Obukhov length as a function of the aerodynamic roughness length and Pasquill stability categories for unstable conditions (after Golder, 1970).

Figure 2. Inverse Monin-Obukhov length as a function of the aerodynamic roughness length and Pasquill stability categories for stable conditions (after Golder, 1970).



0.001
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
2
3
4
Z_o (m) →
−0.14
−0.12
−0.10
−0.08
−0.06
−0.04
−0.02
0
1/L (m^{-1}) →
A STABILITY
← B STABILITY →
C
← STABILITY →
D
STABILITY
Low Evaporation
High Evaporation
Moderate Evaporation
Low Evaporation
High Evaporation
Moderate Evaporation
High Evaporation
Low Evaporation


D STABILITY
E STABILITY
F STABILITY
High Evaporation
Low Evaporation
Moderate Evaporation
High Evaporation
Low Evaporation
Moderate Evaporation
High Evaporation
Low Evaporation
Moderate Evaporation
0.001
0.002
0.005
0.01
0.02
0.05
0.1
0.2
0.5
1
2
3
4
Z₀ (m) →
-0.03 -0.02 0 0.02 0.04 0.06 0.08 0.10
1/L (m⁻¹) →

INTERFACE OF DIFFUSIVITY MODEL WITH AIR QUALITY MODELS

Air quality models are generally based on the solution of the conservation of mass. The conservation of mass equation for a given air pollutant species chemical reaction can be expressed as (20).

$$\frac{\partial c}{\partial t} + u\frac{\partial c}{\partial x} + v\frac{\partial c}{\partial y} + w\frac{\partial c}{\partial z} = \frac{\partial}{\partial x}\left[K_H \frac{\partial c}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_H \frac{\partial c}{\partial y}\right] + \frac{\partial}{\partial z}\left[K_V \frac{\partial c}{\partial z}\right] + R_i + S_i$$

Where c = concentration of pollutant specie

x,y,z = Cartesian coordinates

u,v,w = wind speed in the x,y, and z directions respectively

K_H, K_V = horizontal and turbulent diffusivities

R = rate of production of species i through chemical raction

S = rate of production of species i from source emissions

In this equation K_V is synonymous to K_M, the momentrum diffusivity.

The numerical solution of equation (20) is solved using either a eulerian or lagrangrian coordinate system. The eulerian coordinate system is fixed to the surface of the earth while the lagragrian coordinate system is a moving system. The eulerian solution is commonly referred to as grid model while the lagragrian solution is a trajectory model.

In the grid model the study region is divided into a three dimensional array of cells. Each cell can vary from 1 km to 4 km on a side and on the order of 10 to 100 meters high. The size of each cell, of course, will depend on the size study area, spatial distributions of emission fluxes of pollutants and terrain affects that may alter the surface winds. The solution of equation (20) is achieved by numerically integrating the equation in three dimensional space and in time over each grid.

In the trajectory model, a column of air followed through the study area as it is moved by the surface winds. The pollutants are emitted into the column as fluxes at the ground surface. As the column passes over the study area chemical reaction take place in the column. The trajectory solution involves the integration of equation (20) along the trajectory path with the following assumption that $v = w = K_x = 0$. This is required in order to maintain the group of cells in the column.

Figure 9-3 shows a typical study area for the Los Angeles area with 2 x 2 mile grid square.

Both of these models requires K_v as an input parameter. The following discussion will illustrate how the diffusivity model can be used to generate the required diffusivities.

For the given study area the grid model will calculate the wind flow field for each grid square for each hour of simulation based on existing meteorological sources. In order to use the diffusivity model presented in this report, the aerodynamic roughness parameter Z_o must be estimated for each grid square. This can be done by using aerial photographs, land use plans or field inspection. Table 2, or the expression $Z_o = 0.15\ h_c$, can be used as previously discussed. Once this is completed and with Z_o and $\bar{U}$ (surface winds) known, the procedure for calculating the diffusivity profiles as a function of time and location can be made.

A similar procedure can be followed using a trajectory model.

<u>Grid Models (Regional)</u>

1. For grid models, develop the hourly surface wind flow field for each grid square in the study area.

2. For each grid (using the wind speed calculated in Step 1 above) calculate the Turner stability class using the cloud cover and ceiling height representative for each grid.

In those study areas where two or more meteorological sources exist which measure cloud cover and ceiling height, care and judgment must be exercised in determing what station measurements of cloud cover and ceiling height are representative for each portion of the study region. A typical example is the Los Angeles Basin where the coastal strata exists along the coast but does not generally penetrate into the San Fernando Valley. Figure 9-4 illustrates the region and terrain in the area.

Under these conditions, the measured cloud cover and ceiling height at Burbank Airport would be most representative of the San Fernando Valley while Los Angeles International Airport is most representative for the portion of the basin along the coast.

3. For each grid the aerodynamic roughness height Z_o must be characterized based on Table 2 or calculated by $Z_o = 0.15\ h_c$. The Z_o should be representative of the land use in each grid. This information can be obtained from aerial photographs or from a field survey.

4. The spatial and temporal distributions of surface based and elevated inversions must be described for the study area. This may be different for portions of the study area due to the terrain effects. Care and judgment must be exercised in the representativeness of inversion conditions for the study area.

5. For each three-dimensional surface grid, and the vertical grids, the diffusivity profiles can be calculated using the diffusivity model described in this report.

6. It is suggested that the diffusivity profiles be a part of the air quality preparation program such as done in the SAI model for meteorology, emissions and initial concentrations. This would allow the user the ability to examine the diffusivity profiles before simulation runs are made.

Trajectory Models (Regional)

Figure 9-5 illustrates a trajectory passing over grids for given meteorological conditions. Under these conditions it is necessary only to determine Z_o for those grids which the trajectory passes over.

The same procedures described above would apply for each grid that the trajectory passes over.

The authors therefore conclude that the latest state-of-the-art diffusivity profile model can be integrated into air quality models and should provide a sound and rational approach for calculations of vertical diffusivities.

TABLE 2

ROUGHNESS LENGTHS FOR VARIOUS SURFACES

Type of Surface	Z_o (cm)
Smooth mud flats	0.001
Tarmac	0.002
Dry lake bed	0.003
Smooth desert	0.03
Grass (5-6 cm)	0.75
(4 cm)	0.14
(2-3 cm)	0.32
Alfalfa (15.2 cm)	2.72
Grass (60-70 cm)	11.4
Wheat (60 cm)	22
Corn (220)	74
Citrus Orchard	198
Fir forest	283
City land-use	
Light density residential	108
Heavy density residential	370
Office	175
Central Business District	321
Park	127

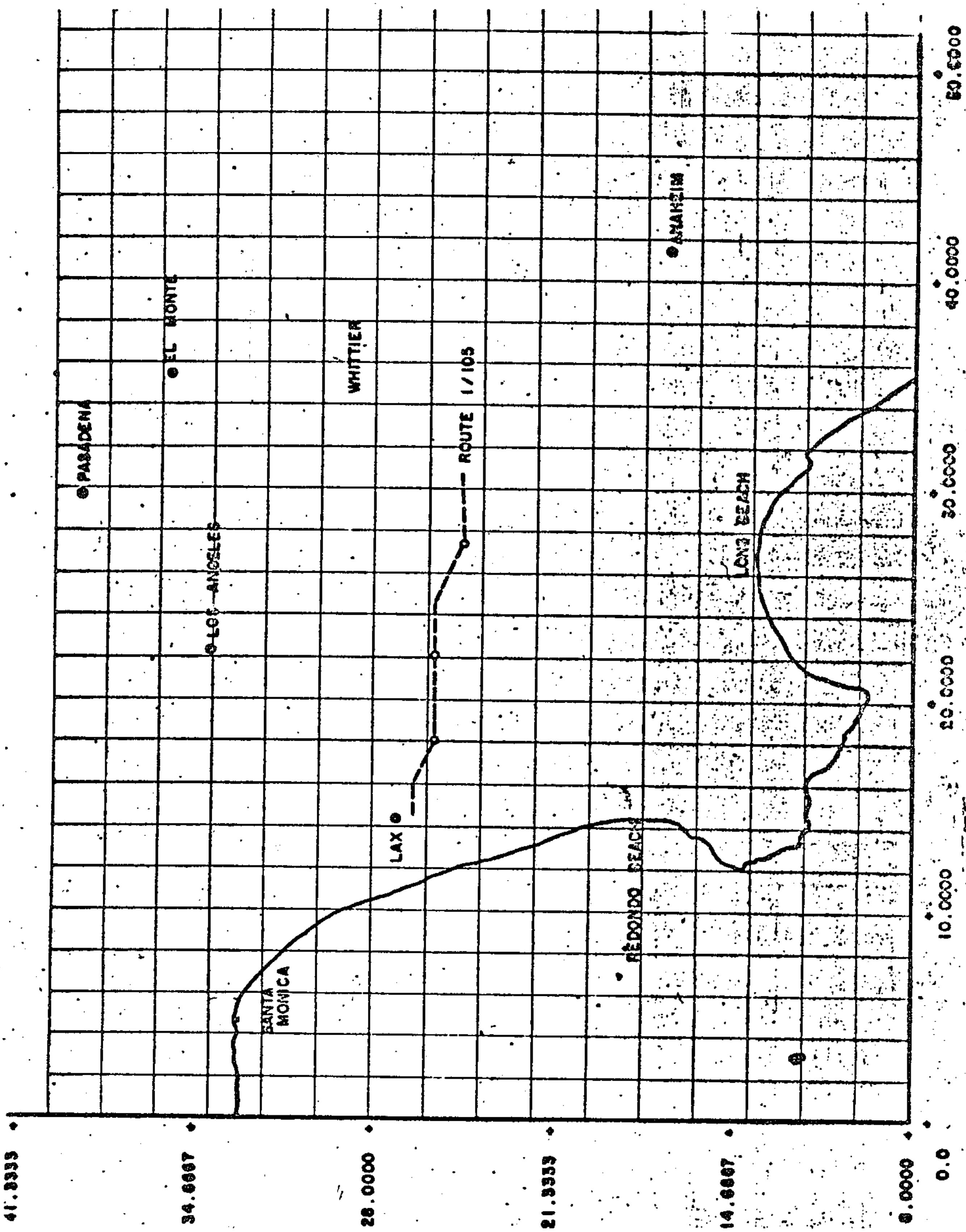

PASADENA
EL MONTE
LOS ANGELES
WHITTIER
ROUTE 1/105
LAX
SANTA MONICA
REDONDO BEACH
LONG BEACH
ANAHEIM
41.3333
34.6667
28.0000
21.3333
14.6667
8.0000
0.0
10.0000
20.0000
30.0000
40.0000
50.0000

FIGURE 9-3

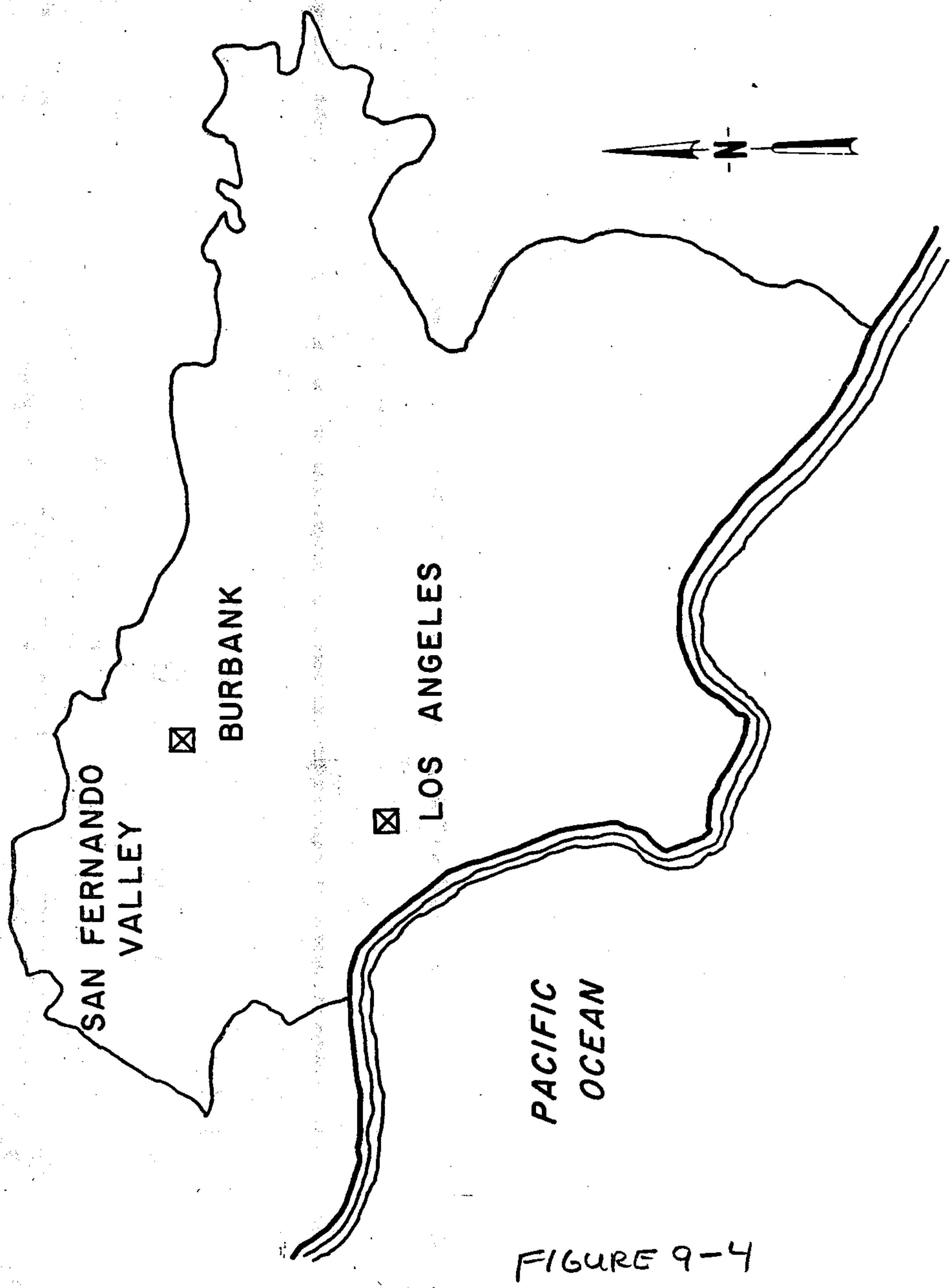


FIGURE 9-4

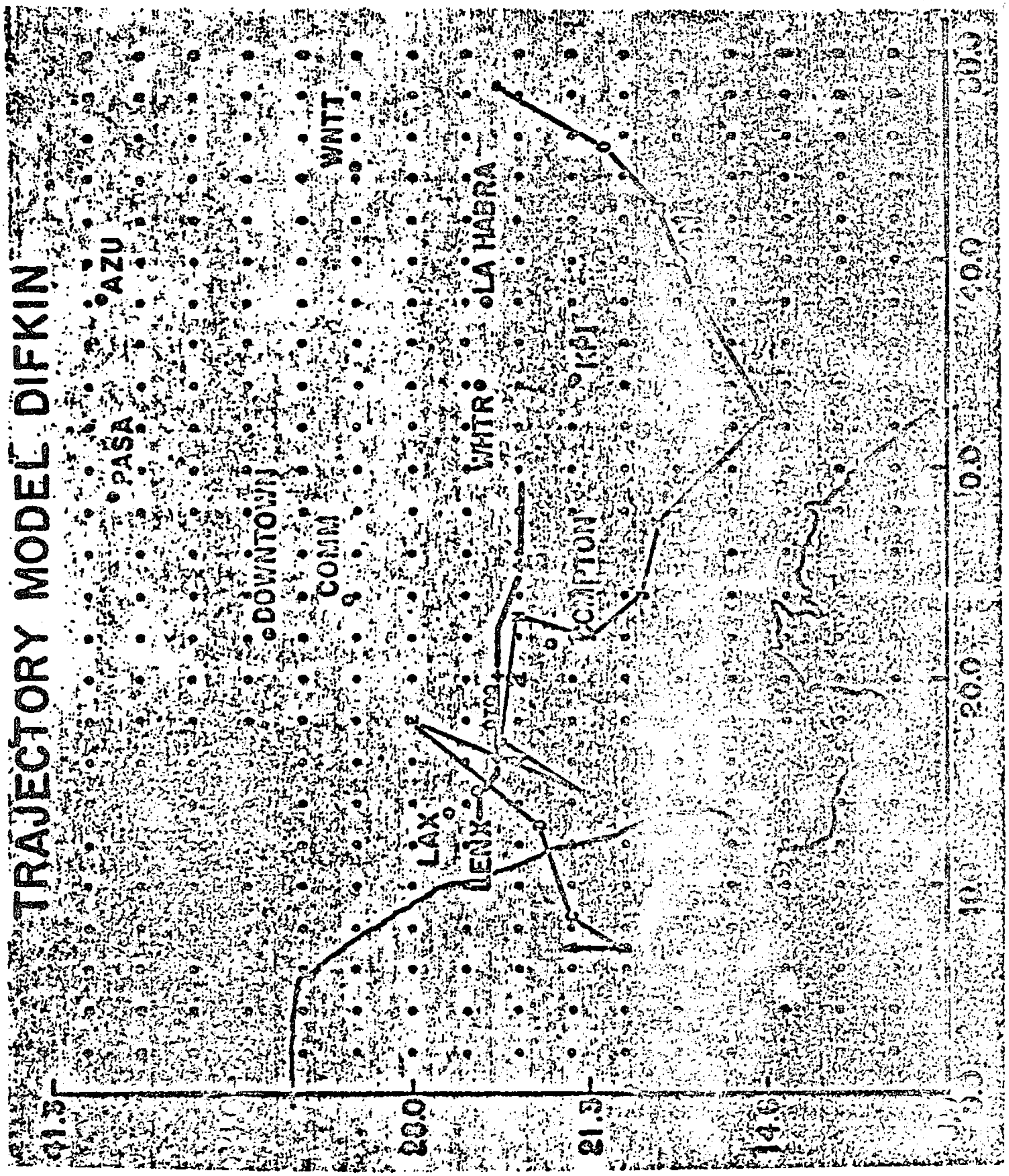

TRAJECTORY MODEL DIFKIN
PASA
AZU
DOWNTOWN
COMM
WNTT
WHTR
LA HABRA
LAX
LENX
20.0
21.3
14.6
0.0
20.0
40.0

FIGURE 9-5

By using this diffusivity model with air quality models, a more accurate prediction of air quality can be made. This will allow transportation planners and engineers to make further refinements on the evaluation of the interrelationships of land use, transportation and air quality planning and decision making.

EXAMPLES OF DIFFUSIVITIES CALCULATIONS

As an illustration of the application of this diffusivity model, six examples for various stabilities, land uses and wind speeds are discussed. Examples are given for diffusivities that can be used in grid or trajectory regional air quality models.

EXAMPLE 1: Office Building District and Unstable Conditions

Given: Figure 9-3 illustrates the study area and the grid network to be used to predict air quality. Let us assume for the sake of simplicity that the grid of interest is representative of an office building district. The average height of the canopy within the grid is 11.7 meters (38 feet). This can be estimated from land use plans and zoning restrictions. Each grid has surface dimensions of 2 k_m x 2 k_m on a side (typical for study areas of this size).

The base height of the afternoon elevated inversion is 500m. Assume that for the grid of interest the surface wind flow fields or trajectories were computed by such models as SAI Airshed Model or General Research Corporation Difkin Model. Let us further assume that the constructed surface wind field and trajectories were based on the wind system exposure criteria recommended by Caltrans at 10 m above the canopy or the average roughness elements. Therefore, the surface wind flow field and trajectories are representative of wind speeds measured.

For the grid of interest (grid A) the wind speed was calculated to be 4 m/sec for a mid-day condition. The cloud cover and ceiling height information were obtained from the closest airport and were assumed representative of the grid in question. Based on the calculated wind speed from the flow field analysis and cloud cover and ceiling height, Turner's Stability Class C was calculated for the grid.

Find: Vertical turbulent diffusivity for heights of 25 m up to the inversion.

Solution:

1. Calculate Z_o using $Z_o = 0.15\ h_c$

   $Z_o = 0.15\ h_c = 0.15\ (11.7) = 1.75$ m

2. For this grid with Stability Class C, $Z_o = 1.75$ m and low evaporation (Figure 1) obtain $1/L - 0.004$
   Therefore $L = -1/0.004 = -250$ m

3. Calculate U_* using equation (9)

$$U_* = \frac{ku}{\left[\ln\left(\frac{Z_W}{Z_o}\right) + \frac{2}{L}\left(Z_W - Z_o\right)\right]}$$

Where $Z_W = 10$ meters, $Z_o = 1.75$ m, $L = -250_m$, $k = 0.35$. Therefore

$$U_* = \frac{0.35\ (4)}{\left[\ln\left(\frac{10}{1.75}\right) - \frac{2}{250}\left(10 - 1.75\right)\right]}$$

$$U_* = 0.836\ m/sec$$

4. For $Z = 25_m$ calculate the phi-function from equation (6)

$$\phi\left(\frac{Z}{L}\right) = \left(1 - 15\frac{Z}{L}\right)^{-0.25}$$

$$\phi\left(\frac{Z}{L}\right) = \left[1 - 15\left(\frac{25}{-250}\right)\right]^{-0.25} = 0.795$$

5. For $Z \leq 5L$

$$K_m = \frac{k u_* Z}{\phi\left(\frac{Z}{L}\right)} = \frac{0.35(0.836)\,25}{0.795}$$

$$K_m = 9.2\ m^2/sec$$

$$K_m = 9.2\frac{m^2}{sec} \times \frac{60 sec}{1 min} = 552\ m^2/min$$

Similar calculations can be made for various vertical heights, Z as shown in the following table. For this example, -Z/L never exceeds 5 so that the upper level model (equation 19) was not needed. Above 150 m the diffusivity remains constant as is reached at that height.

Z(m)	$\frac{Z}{L}$	Z/Zi	K(m^2/min)
25	-0.10	0.05	552
50	-0.20	0.10	1242
75	-0.30	0.15	2017
100	-0.40	0.20	2856
150	-0.60	0.30	4684
200	-0.80	0.40	4684
300	-1.20	0.60	4684
400	-1.60	0.80	4684
500	-2.00	1.00	4684
600	--	--	0

EXAMPLE 2: LIGHT DENSITY RESIDENTIAL AREA AND UNSTABLE CONDITIONS

Given: Same conditions as in Example 1 except that the Turner Stability Class is B, wind speed at 10 m above canopy is 2 m/sec and elevated inversion 1000 m. The site is located in a light density residential area with average canopy height 7.2 m (24 feet)

Find: Vertical diffusivity for heights of 25 m up to the inversion.

Solution:

1. Calculate Z_o using

$$Z_o = 0.15 h_c$$

$$Z_o = 0.15(7.2) = 1.08 m$$

2. For this grid with Stability Class B, Z_o = 1.08 m and moderate evaporation Figure 1.

$$\frac{1}{L} \sim -0.035$$

$$L \sim -\frac{1}{0.035} = -29 m$$

3. Calculate U_* using equation 9 with Z_W = 10 m, Z_o = 1.08 m, k = 0.35 and U = 2 m/sec.

$$U_* = \frac{0.35(2)}{\left[\ln\left(\frac{10}{1.08}\right) - \frac{2}{29}(10-1.08)\right]}$$

$$U_* = 0.437 \text{ m/sec}$$

4. For Z = 25 m calculate phi-function equation (6)

$$\phi\left(\frac{Z}{L}\right) = \left[1 - 15\left(\frac{25}{-29}\right)\right]^{-0.25} = 0.516$$

5. For Z $\leq$ 5L where Z = 25 m

$$K_m = \frac{k\,U_* Z}{\phi\left(\frac{Z}{L}\right)} = \frac{0.35\,(0.437)\,25}{0.516} = 7.41\ m^2/sec$$

$$K_m = 7.41\ \frac{m^2}{sec} \times \frac{60\ sec}{1\ min} = 445\ m^2/min$$

6. Similar calculations can be made for various vertical height Z as shown in the following table. The upper level diffusivities, calculated with equation (19) are shown in parenthesis for values below -Z/L = 5 so that agreement with the low level in the region of overlap may be judged. The diffusivity remains constant as Z/Zi = 0.3 is reached.

Z (m)	Z/L	Z/Zi	K (m^2/min)	
25	-0.86	0.025	445	
50	-1.72	0.05	1049	
100	-3.45	0.10	2483	(2218)
200	-6.90	0.20	5246	(5587)
300	-10.34	0.30		(9008)
400	-13.79	0.40		(9008)
600	-20.69	0.60		(9008)
800	-27.59	0.80		(9008)
1000	-34.48	1.00		(9008)
1200	-	-		0

a) Sample calculation of K for upper level diffusivity equation 19

$$K = 0.5 \left(-\frac{0.4Z}{kL} \right)^{1/3} U_* Z$$

For Z = 300m ($Z \geq -5L$), k = 0.35
L = -29m, $U_* = 0.437$m/sec.

$$K = 0.5 \left[\frac{-0.4(300)}{0.35(-29)} \right]^{1/3} (0.43)\ (300) = 150m^2/sec$$

$$K = 150m^2/sec. \times 60scc/min = 9008m^2/min$$

EXAMPLE 3: OFFICE BUILDING DISTRICT AND NEUTRAL CONDITIONS

Given: Same conditions as in Example 1 except that the Turner Stability Class is D, wind speed 5 m/sec at 10 m above the canopy. The site is located in the central business district with average canopy height of 21.4 m (=70 feet). The elevated inversion is at 500 m.

Find: Vertical diffusivity from 25 m to up the inversion.

Solution:

1. Calculate Z_o = 0.15 (21.4) = 3.21 m

2. For the neutral case it is recommended that equation (5) be used for the phi-function with L equal to 10^5 m. The diffusivity above Z/Z_i = 0.3 remains constant until the inversion is reached.

3. Calculate U_* using equation (9) with Z_w = 10 m, Z_o = 3.21 m, k = 0.35, L = 10^5 m, $\bar{u}$ = 5 m/sec

$$U_* = \frac{0.35\,(5)}{\left[\ln\left(\frac{10}{3.21}\right) + \frac{2}{10^5}(10 - 3.21)\right]} = 1.54\ \text{m/sec}$$

4. Calculate the phi-function using equation (5)

$$\phi\left(\frac{Z}{L}\right) = 1 + 4.7\left(\frac{Z}{L}\right)$$

However, since L is a large number 10^5 m $\phi\ (\frac{Z}{L})$ approaches 1.0. Therefore, $\phi\ (\frac{Z}{L})$ for all practical purposes of Z's up to the inversion is equal to 1.0.

5. Calculate K_m using equation (4)

$$K_m = \frac{k u_* z}{\phi\left(\frac{z}{L}\right)}$$

Where ϕ (Z/L) = 1.0 for the neutral case

a. Sample calculation for K_m at Z = 25 m
k_m = 0.35 (1.54) 25 = 13.5 m^2/sec
k_m = 13.5 x 60 sec/min = 807 m^2/min

6. Similar calculation can be made for various vertical heights Z as shown in the following table:

Z (m)	Z/Z_i	K (m^2/min)
25	0.05	807
50	0.10	1613
75	0.15	2417
100	0.20	3219
150	0.30	4817
200	0.40	4817
400	0.80	4817
500	1.00	4817
600	-	0

EXAMPLE 5: LIGHT DENSITY RESIDENTIAL AREA WITH WIND STATION IMPROPERLY EXPOSED.

Given: Same conditions as Example 2 (Light Residential Area) except the height of the wind station used to construct the wind flow field or trajectories is improperly exposed. This is typical of many of the existing sources of data from local air pollution control districts. Assume average canopy height (hc) is 7.2 m and height above ground surface of measured wind speed is 10 m.

Find: Determine what effects improper exposure have on vertical diffusivities from 25 m to inversion.

Solution:

1. Z_o = 1.08 m previously calculated in Example 2.

2. L = -29 m from Example 2.

3. Calculate U_* using equation 9 with U = 2 m/sec, Z_o = 1.08 m, k = 0.35 L = -29m and Z_w = 10-7.2 =2.8 m.

$$U_* = \frac{0.35\ (2)}{\left[\ln\left(\frac{2.8}{1.08}\right) - \frac{2}{29}(2.80 - 1.08)\right]} = 0.839 m/sec$$

4. Calculate phi-function equation (6) for Z = 25 m

$$\phi\left(\frac{Z}{L}\right) = 0.516 \text{ (Same as Example 2)}$$

5. For $Z \leq -5L$ where Z = 25 m

$$k_m = \frac{KU_*Z}{\phi(Z/_L)} = \frac{(0.35)(0.839)(25)}{0.516} = 14.2 m^2/sec$$

$$K_m = 14.2\ m^2/sec \times 60 = 851\ m^2/min$$

6. Similar calculations can be made for various Z heights as shown in the following table.

Z (m)	Z/L	Z/Z	Example 2 K (m^2/Min)		Example 5 K m^2/min	
25	-0.86	0.025	445		851	
50	-1.72	0.05	1049		2006	
100	-3.45	0.10	2483	(2218)	(4749)	(3860)
200	-6.90	0.20	5246	(5587)	(10021)	(9700)
300	-10.34	0.30		9008	17207	
400	-13.79	0.40		9008	17207	
600	-20.69	0.60		9008	17207	
800	-27.59	0.80		9008	17207	
1000	-34.48	1.00		9008	17207	
1200	-	-		-	-	

Since U_* is the only variable that changes in calculating K_m, the percent change in diffusivity assuming proper exposure of Example 2 as baseline is:

$$\% \text{ change in K} = \left(\frac{(U_*)_2 - U_{*5}}{U_{*2}} \right) \times 100$$

Where U_{*2} = .437 m/sec

U_{*2} = .839 m/sec

Therefore % change is

$$\% = \left| \frac{0.437 - 0.839}{0.437} \right| \times 100 = 92\%$$

This calculation emphasizes the importance of having proper exposure of meteorological wind stations to describe the surface wind fields and trajectories when applying regional air quality models. This also stresses that the diffusivities are not free parameters in models which may be adjusted to make model predictions agree with measured data.

SECTION 10

DESIGNING REGIONAL AIR QUALITY SURVEYS FOR MODEL INPUTS

ASSUMPTIONS:

1) APCD Station(s) are available
2) Caltrans Mobile Van
3) Automatic CO Bag Sampling
4) MWS
5) UV Radiometer(s)
6) Pibals
7) Aircraft Temperature package

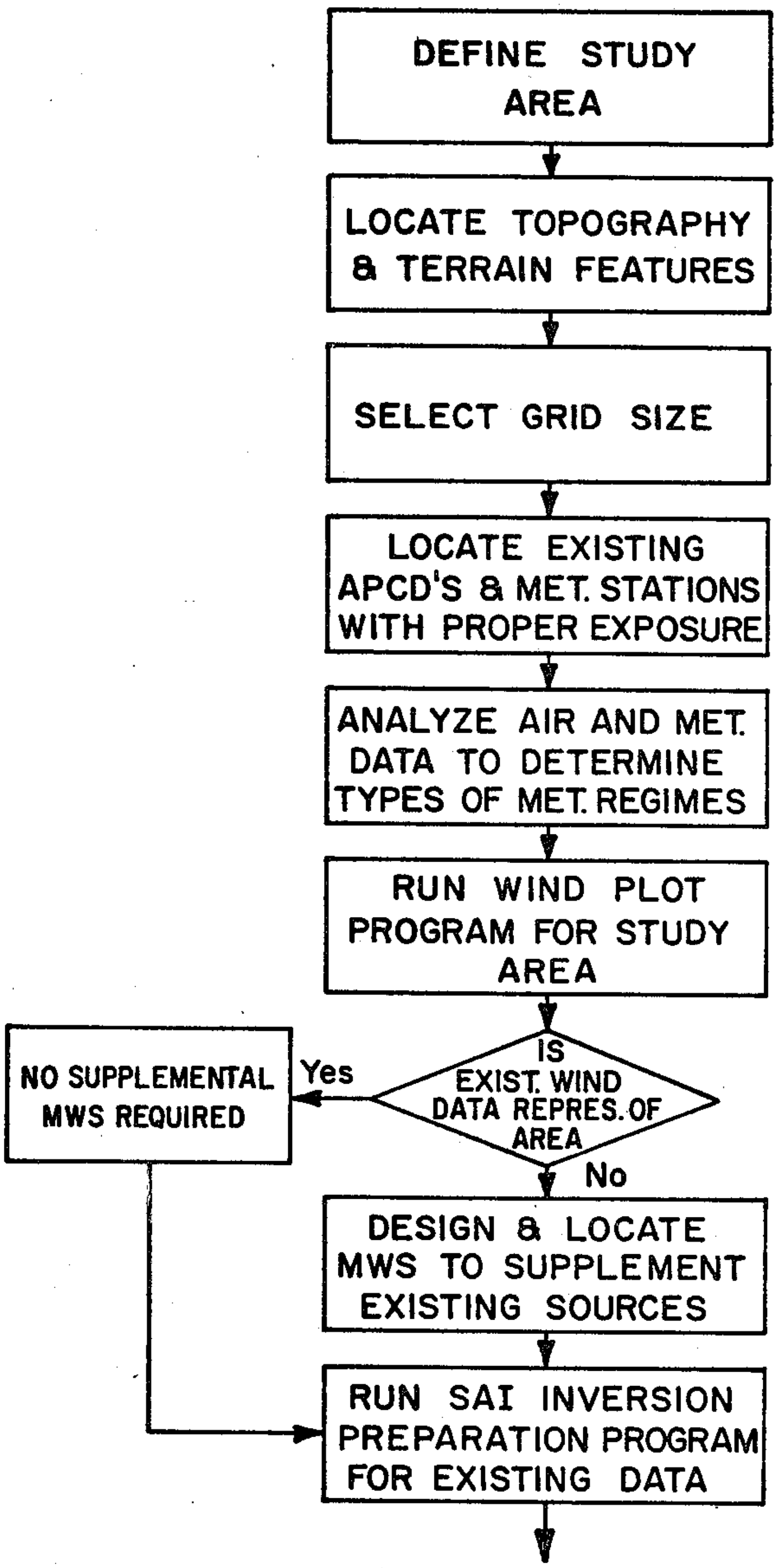

DEFINE STUDY AREA
LOCATE TOPOGRAPHY & TERRAIN FEATURES
SELECT GRID SIZE
LOCATE EXISTING APCD'S & MET. STATIONS WITH PROPER EXPOSURE
ANALYZE AIR AND MET. DATA TO DETERMINE TYPES OF MET. REGIMES
RUN WIND PLOT PROGRAM FOR STUDY AREA
IS EXIST. WIND DATA REPRES. OF AREA
Yes
NO SUPPLEMENTAL MWS REQUIRED
No
DESIGN & LOCATE MWS TO SUPPLEMENT EXISTING SOURCES
RUN SAI INVERSION PREPARATION PROGRAM FOR EXISTING DATA

FIGURE 10-1

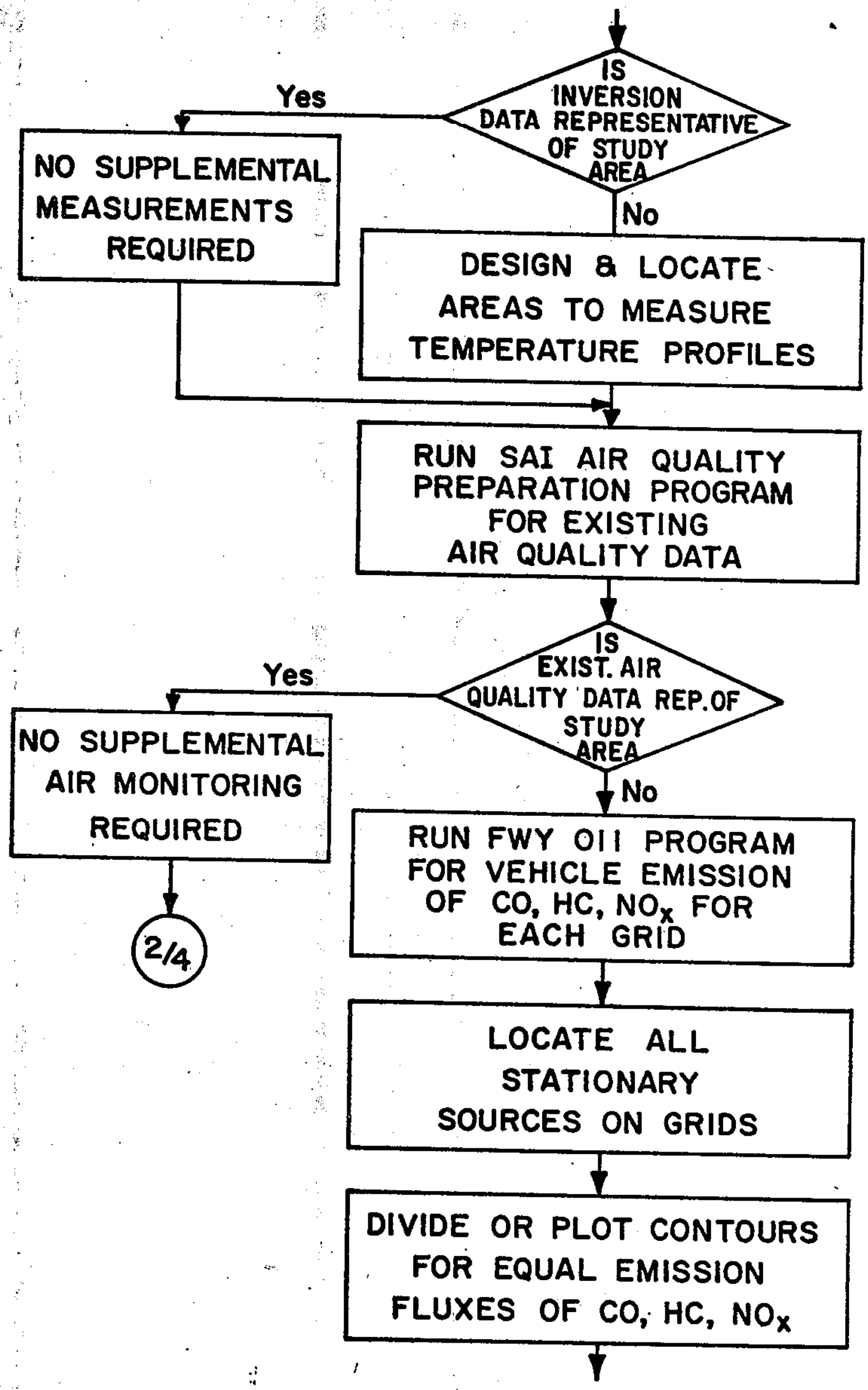

IS INVERSION DATA REPRESENTATIVE OF STUDY AREA
Yes
No
NO SUPPLEMENTAL MEASUREMENTS REQUIRED
DESIGN & LOCATE AREAS TO MEASURE TEMPERATURE PROFILES
RUN SAI AIR QUALITY PREPARATION PROGRAM FOR EXISTING AIR QUALITY DATA
IS EXIST. AIR QUALITY DATA REP. OF STUDY AREA
Yes
No
NO SUPPLEMENTAL AIR MONITORING REQUIRED
2/4
RUN FWY 011 PROGRAM FOR VEHICLE EMISSION OF CO, HC, NOx FOR EACH GRID
LOCATE ALL STATIONARY SOURCES ON GRIDS
DIVIDE OR PLOT CONTOURS FOR EQUAL EMISSION FLUXES OF CO, HC, NOx

FIGURE 10-2

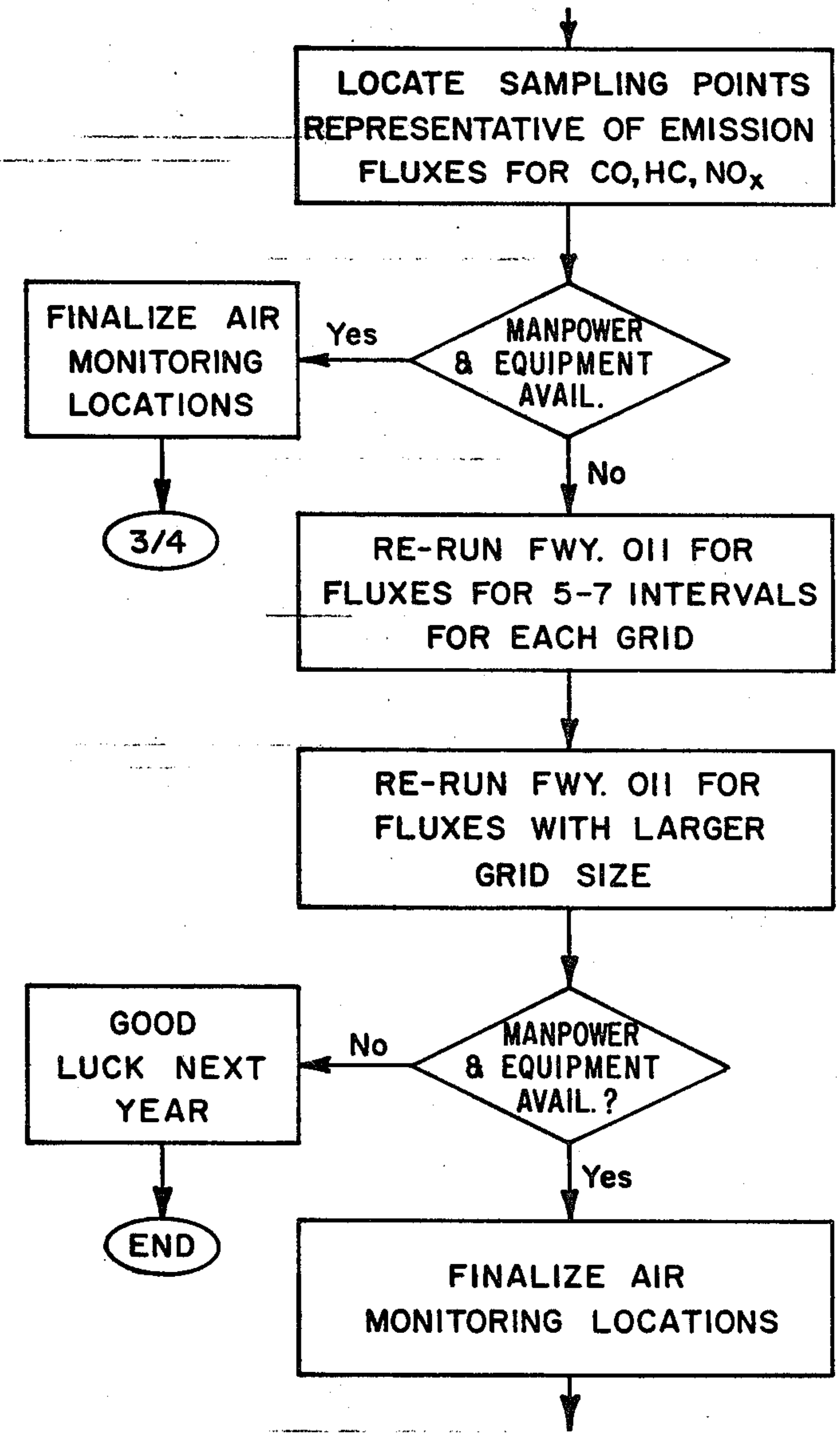

LOCATE SAMPLING POINTS REPRESENTATIVE OF EMISSION FLUXES FOR CO, HC, NO_x
MANPOWER & EQUIPMENT AVAIL.
Yes
FINALIZE AIR MONITORING LOCATIONS
3/4
No
RE-RUN FWY. 011 FOR FLUXES FOR 5-7 INTERVALS FOR EACH GRID
RE-RUN FWY. 011 FOR FLUXES WITH LARGER GRID SIZE
MANPOWER & EQUIPMENT AVAIL.?
No
GOOD LUCK NEXT YEAR
END
Yes
FINALIZE AIR MONITORING LOCATIONS

FIGURE 10-3

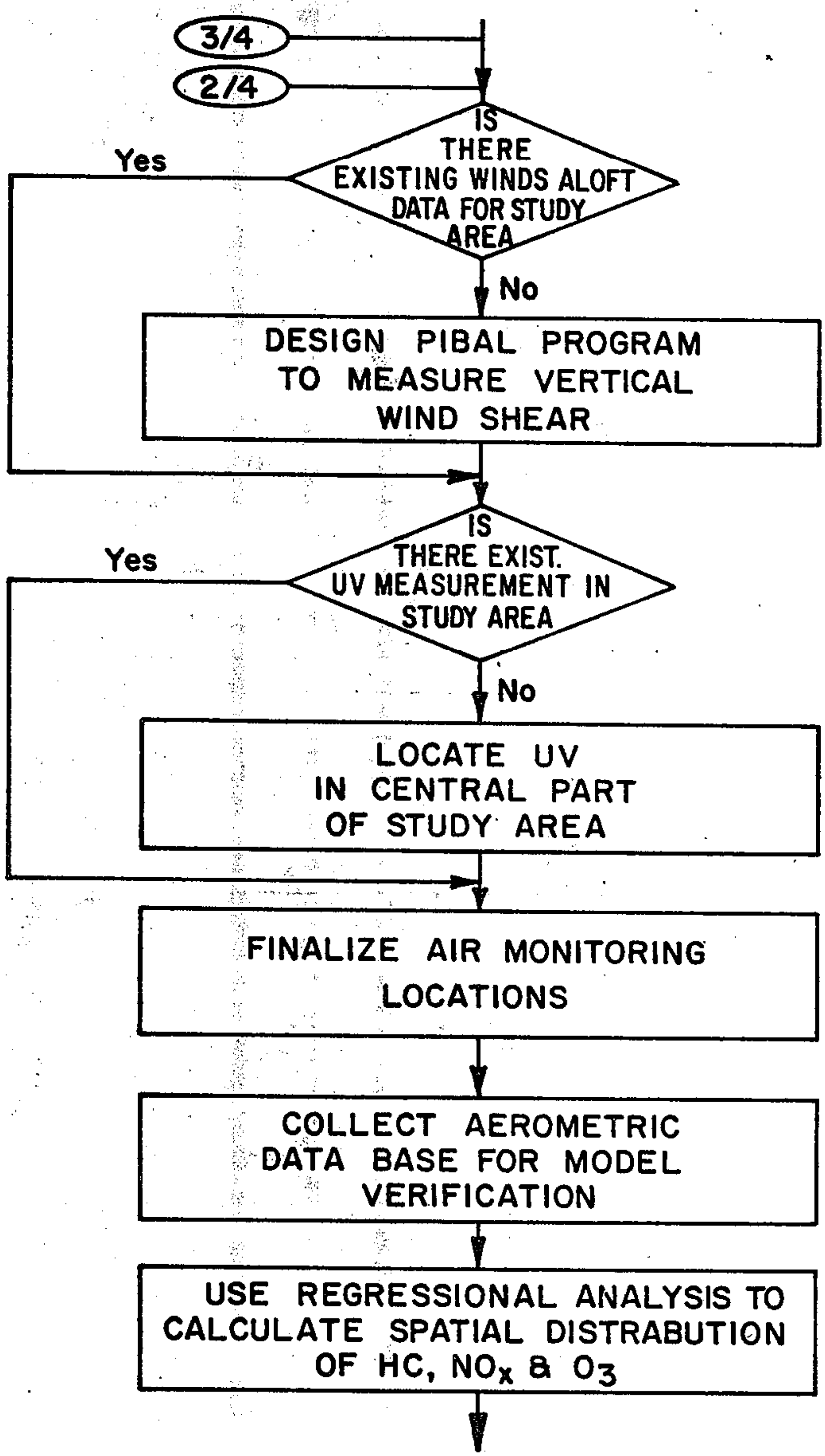

3/4
2/4
IS THERE EXISTING WINDS ALOFT DATA FOR STUDY AREA
Yes
No
DESIGN PIBAL PROGRAM TO MEASURE VERTICAL WIND SHEAR
IS THERE EXIST. UV MEASUREMENT IN STUDY AREA
Yes
No
LOCATE UV IN CENTRAL PART OF STUDY AREA
FINALIZE AIR MONITORING LOCATIONS
COLLECT AEROMETRIC DATA BASE FOR MODEL VERIFICATION
USE REGRESSIONAL ANALYSIS TO CALCULATE SPATIAL DISTRABUTION OF HC, NOx & O3

FIGURE 10-4

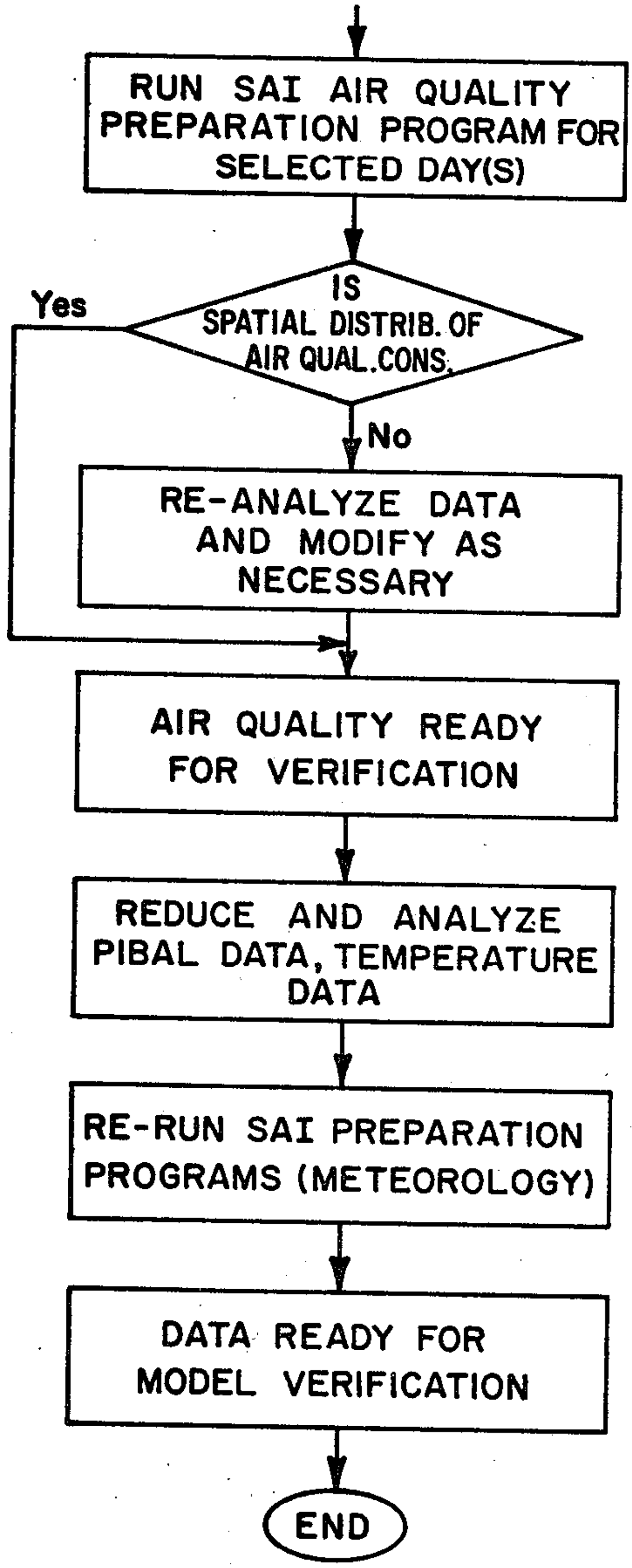

RUN SAI AIR QUALITY PREPARATION PROGRAM FOR SELECTED DAY(S)
IS SPATIAL DISTRIB. OF AIR QUAL. CONS.
Yes
No
RE-ANALYZE DATA AND MODIFY AS NECESSARY
AIR QUALITY READY FOR VERIFICATION
REDUCE AND ANALYZE PIBAL DATA, TEMPERATURE DATA
RE-RUN SAI PREPARATION PROGRAMS (METEOROLOGY)
DATA READY FOR MODEL VERIFICATION
END

FIGURE 10-5

I. Define Study Area

A. Consult with Local Land Use Planners

B. Major Considerations

1. Populated Areas
2. Areas of high emissions
3. Areas of high pollutant concentrations
4. Local community master plans for future development
5. Study area sufficiently large to make multi-day simulation runs

II. Locate topography and Terrain Features

A. Alter surface winds
B. Influences source - receptor relationships

III. Select Grid Size

A. South Coast Air Basin - 2 x 2 sq. in.
B. Sacramento - 2 x 2 KM
C. San Diego - 2 x 2 KM
D. Fresno - 1 x 1 km
E. Grid limitations 50 x 100

IV. Locate Existing APCD with proper exposure

A. Calibration and Maintenance schedule
B. Type of instrumentation
C. Complete instrument summary sheet (see survey sheet)

V. Locate Existing Meteorological Sources with Proper Exposure

   A. Eliminate all stations with instantaneous measurements of wind speed and direction.

   B. Eliminate all stations with marginal exposure.

VI. Determine Meteorological Regimes for Model Verification and Future Air Quality Predictions

   A. Trend Analysis

      1. Use existing meteorological data
         a. Airport data
         b. APCD stations
         c. Caltrans data

   B. Vertical Temperature Stratification

      1. Radiosondes
      2. Aircraft flights (ARB, etc.)
      3. Acoustical sounder
      4. Radio controlled airplane

   C. Use existing air quality data

      1. APCD stations
      2. Caltrans
      3. Consultant contracts

   D. Consultation at Local and State Levels

      1. APCD - air pollution meteorologist
      2. ARB - Division of Meteorology and Land Use Planning

E. Determine Meteorological Conditions

1. Sea Breeze
2. Weak Santa Ana
3. Strong Santa Ana
4. Northerly winds
5. Special conditions

VII. Run Wind Plot Program (> 3 met stations)

A. For selected meteorological condition(s) with all instantaneous and poor exposure sites eliminated.

B. Check flow field for consistency

1. input errors
2. improper exposure
3. Other

C. Evaluate resulting wind flow field for representativeness of study area.

VIII. Existing Data Not Representative of Study Area

A. Design meteorological survey and monitoring program using Caltran MWS to supplement existing data sources.

IX. Existing Vertical Temperature Data Not Representative

A. Use supplemental aircraft flights, acoustical sounder to supplement data

B. Time Periods - 0600, 1200, and 1800 hrs. every other day

X. Run SAI Quality Preparation Program (> 3 APCD stations)

A. For day(s) for the meteorological regimes (Section VII)

B. Check concentration field for consistency

1. input errors
2. improper exposure
3. Other

C. Evaluate resulting concentration field for representativeness of study area

XI. Run FWY 011 Program

A. Vehicle emissions for CO, HC, NO_x for each grid.
B. Use all 10 class intervals for detailed spatial resolution.
C. Use 5, 6, or 7 class width intervals depending on days per week of field sampling.
D. Increase size of grid and re-run FWY 011 program to determine areas of common fluxes. (Includes stationary emissions for each grid)
E. Leads to identification of grid areas with common emission rates of pollutants.

XII. Design Pibal Program to Measure Vertical Wind Shear

A. Daily releases at central location

1. 1000 and 1400 hrs.

B. Intensive Study (eposidic conditions)

1. Three locations using single theodolite triangulation methods.
2. Pibal releases hourly for 48 hours minimum.

3. Rotate Van daily

   a) Systematic sampling
   b) Random sampling

4. Sample at least 12 hours per day, preferably 24 hours.

C. Bag Sampling for CO

1. To verify transport and diffusion in model(s)

2. In general monitor for CO at least six locations in study area

   a) influx
   b) central portion
   c) outflux

3. Locate samplers at least 200 ft from local surface streets.

4. Monitor 24 hours per day

D. Aircraft Measurements of Air Quality

1. Bag sample for NO_x, HC, CO.
2. Dasibi Monitor for O_3.

E. Initial Correlation with APCD

1. Creditability
2. Beginning, midway, end - consistency check

XIII. Location of UV Radiometer

A. Central Valley Areas

1. Central location of study area
2. One UV radiometer at ground level

B. Coastal Areas

1. Morning stratus along coast
2. Inland areas

XIV. Finalize Air Monitoring Locations

A. Considerations

1. pollutant transport
2. influx and outflux of pollutants
3. areas of high emissions
4. location of receptors
5. Future development of land use
6. 24-hour sampling
7. Representative measurements based on assumption of model(s).

B. Air Quality Van

1. Monitor for CO, HC, NO_x and O_3
2. Locate Van at least 200 feet from local sources of emissions

a) $NO+O_3 \rightarrow NO_2+O_2$
b) Elevated HC and CO concentration

XV. Collect Aerometric Data Base for Model Verification

A. Coordination with ARB, APCD, and Caltrans

XVI. Regression Analysis to Calculate Spatial Distribution of Pollutants

A. Correlation to APCD (fixed station)

B. Parameters

1. wind speed
2. wind direction
3. stability
4. inversion heights
5. time of day
6. concentrations CO, HC, NO_x, O_3
7. Others

C. Form of Equation

$$y = a + bx_1 + cx_2 + dx_3 + \ldots + kx_n$$

D. Predict spatial distribution of pollutants for meteorological conditions selected.

AIR QUALITY SURVEYS

1. Locate monitoring sites consistent with model assumptions to predict air quality

   a) 200 feet from local surface streets to eliminate O_3 depression and high HC and CO concentrations

   $$NO + O_3 \longrightarrow NO_2 + O_2$$

   b) Monitor at least 12 hours per day with van and 24 hours per day with automatic CO bag samplers.

2. Quality Assurance Control

   a) Have APCD's complete instrument summary for air monitoring hardware.

   b) Locate Van and CO samplers next to APCD intake for correlation

      1. Beginning
      2. Midway
      3. End - for consisting check

   c) Daily spans and zeros

   d) AIHL calibration

3. Coordinate with local community and APCD

METEOROLOGICAL SURVEY

1. Locate all terrain that affects or alters surface winds
2. Locate all existing stations (use meteorological instrument summary)
3. Eliminate all instantaneous measurements and poorly exposed stations
4. Calibrate all MWS at Translab or MRI before monitoring
5. Locate MWS for a consistent boundary layer
   a) Height of $\bar{\bar{U}}$ to distance Ratio 100:1
   b) land use
   c) influx
   d) outflux
6. Vertical wind shear (Pibal Releases)
   a) one central location daily - 10 a.m., 2 p.m.
   b) intensive effort - three locations 2 days for 48 hours
7. Aircraft Flights
   a) Flight every 2 days in smog season
   b) " " 3 " " winter season
   c) 3 flights per day 0600, 1200, 1600
   d) daily if possible
8. UV Radiometer - locate at central part of study area
9. Coordinate with local community, APCD, ARB, Translab

TRAFFIC FOR MODEL VALIDATION

1. Temporal variation for common regions or grids (not entire area)
2. % HDV for each grid (not entire area)
3. Use Fwy 011 program for lastest TCP for 1975 or lastest analysis

EMISSION INVENTORY

1. Vehicles Emissions
   a) DOTP - Fwy 011 program
2. Stationary Emissions
   a) APCD
   b) ARB
   c) Consistency check
3. Coordinate all emission inventories with local community, APCD, and ARB for consistency
4. Aircraft Emission - Use District 07 approach

AIR QUALITY INSTRUMENTATION SURVEY

LOCATION : BY : DATE :

1. A. MANUFACTURER :

   B. MODEL NO. : C. NAME :

2. A. PARAMETER B. PRECISION C. ACCURACY

3. MAINTENANCE SCHEDULE :

4. CALIBRATION SCHEDULE :

5. RECORDING INSTRUMENTS

   A. POWER SOURCE :

   B. AVERAGING TIMES :

   C. RECORDING METHOD :

   D. DATA HANDLING :

   E. PARAMETER/UNITS REPORTED

   F. CHART SPEED :

   G. SCALES :

   H. YEARS OF CONTINUOUS RECORD FOR INSTR. AT SAME LOCATION

6. EXPOSURE : A. OBSTRUCTIONS : B. TERRAIN :

   C. HEIGHT OF INTAKE :

7. PHOTOS : PANORAMICS AND 'CLOSE-UPS'

8. COMMENTARY : BY OF PHONE

und

WIND INSTRUMENTATION SURVEY

LOCATION : BY : DATE :

1. A. MANUFACTURER :

   B. MODEL NO. : C. NAME :

2. A. PARAMETER B. THRESHHOLD C. ACCURACY

   1. WIND SPEED :

   2. WIND DIRECTION :

3. MAINTENANCE SCHEDULE :

4. CALIBRATION SCHEDULE :

5. RECORDING INSTRUMENTS

   A. POWER SOURCE :

   B. AVERAGING TIMES :

   C. RECORDING METHOD :

   D. DATA HANDLING :

   E. PARAMETER/UNITS REPORTED

   F. CHART SPEED :

   G. SCALES :

   H. YEARS OF CONTINUOUS RECORD FOR INSTR. AT SAME LOCATION

6. EXPOSURE : A. OBSTRUCTIONS : B. TERRAIN :

   C. HEIGHT OF INSTRUMENTS :

7. PHOTOS : PANORAMICS AND 'CLOSE-UPS'

8. COMMENTARY : BY OF PHONE

2nd

REGIONAL AIR QUALITY MODELING VERIFICATION FOR SAN DIEGO AREA

1) Define Study Area

- CPO
- APCD
- Caltrans - District 11
- Translab

2) Select Grid Size

- Transform coordinate system to UTM
- Common Origin for mobile and stationary sources

3) Select Meteorological Conditions (APCD)

- Typical sea breeze - June
- Weak Santa Ana - August
- Strong Santa Ana - October

4) Collect Meteorological Data

- APCD
- Caltrans - District 11

5) Analysis of Wind Data

- Translab
- UCD - Myrup
- APCD
- District 11
- See Figure 1 & 2

6) Emissions Inventory

- Mobile - District 11 DOTP
- Stationary - APCD

7) Collection of Air Quality Data and Inversion Measurements and Analysis

- APCD
- District 11
- Translab

8) Field Survey of Existing Air and Meteorological Sources with Proper Exposure

- District 11
- APCD
- Translab
- UCD - Myrup

9) Finalize Design of Meteorological and Air Monitoring

- Translab
- APCD
- District 11

10) Coordination for Quality Assurance Control

- APCD
- District 11
- Translab
- AIHL

11) Data Reduction

- Consistent with Averaging Times
- SAROAD
- Cooperative Effort

12) Air Quality Data Base to Evaluate Land Use, Transportation and Air Quality Planning Requires

- Coordination
- Cooperation
- Multi-Team Effort

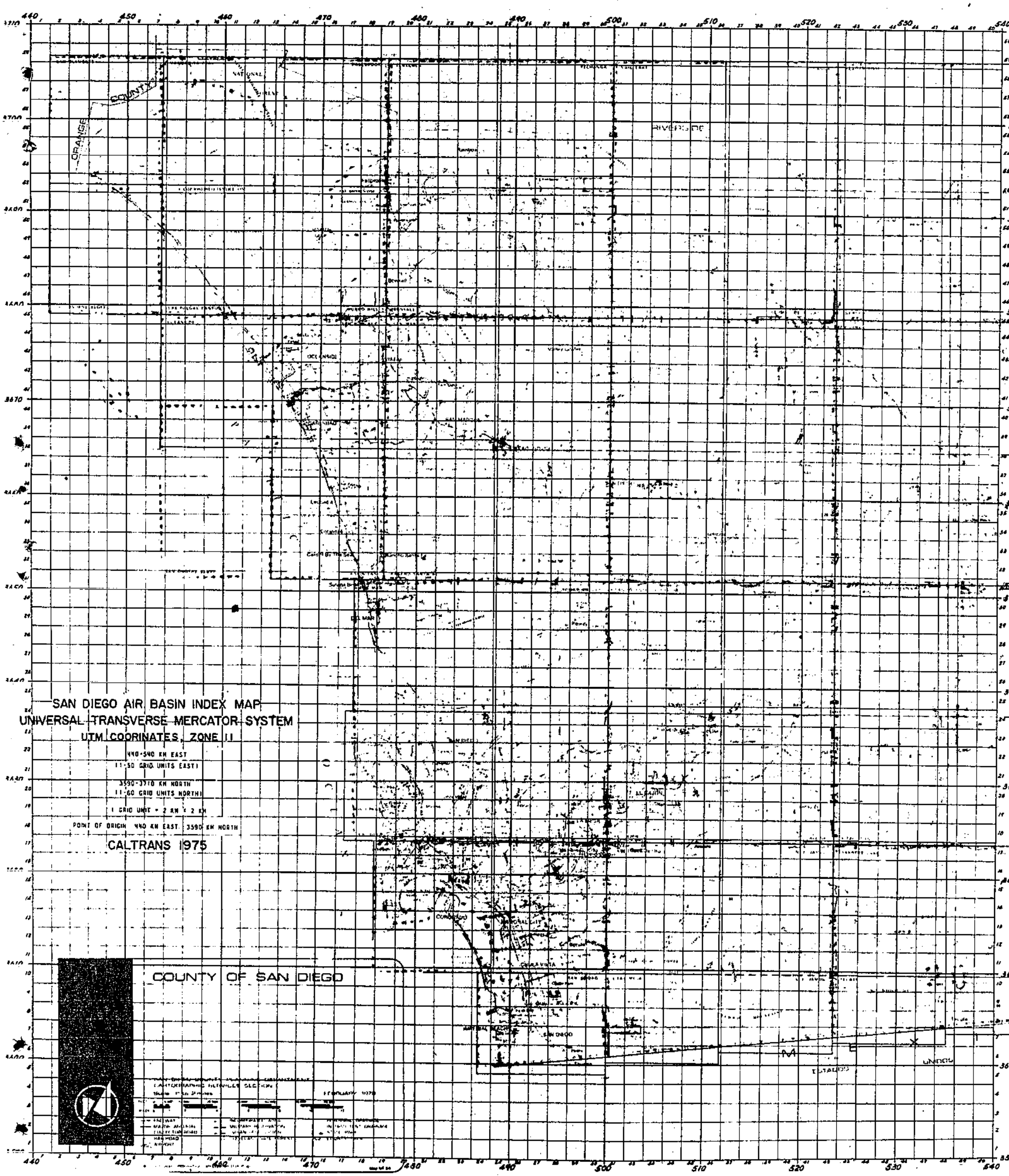

SAN DIEGO AIR BASIN INDEX MAP
UNIVERSAL TRANSVERSE MERCATOR SYSTEM
UTM COORINATES, ZONE 11
440-540 KM EAST
(1-50 GRID UNITS EAST)
3590-3710 KM NORTH
(1-60 GRID UNITS NORTH)
1 GRID UNIT = 2 KM x 2 KM
POINT OF ORIGIN 440 KM EAST, 3590 KM NORTH
CALTRANS 1975
COUNTY OF SAN DIEGO
ORANGE
COUNTY
RIVERSIDE

FIGURE 10-6

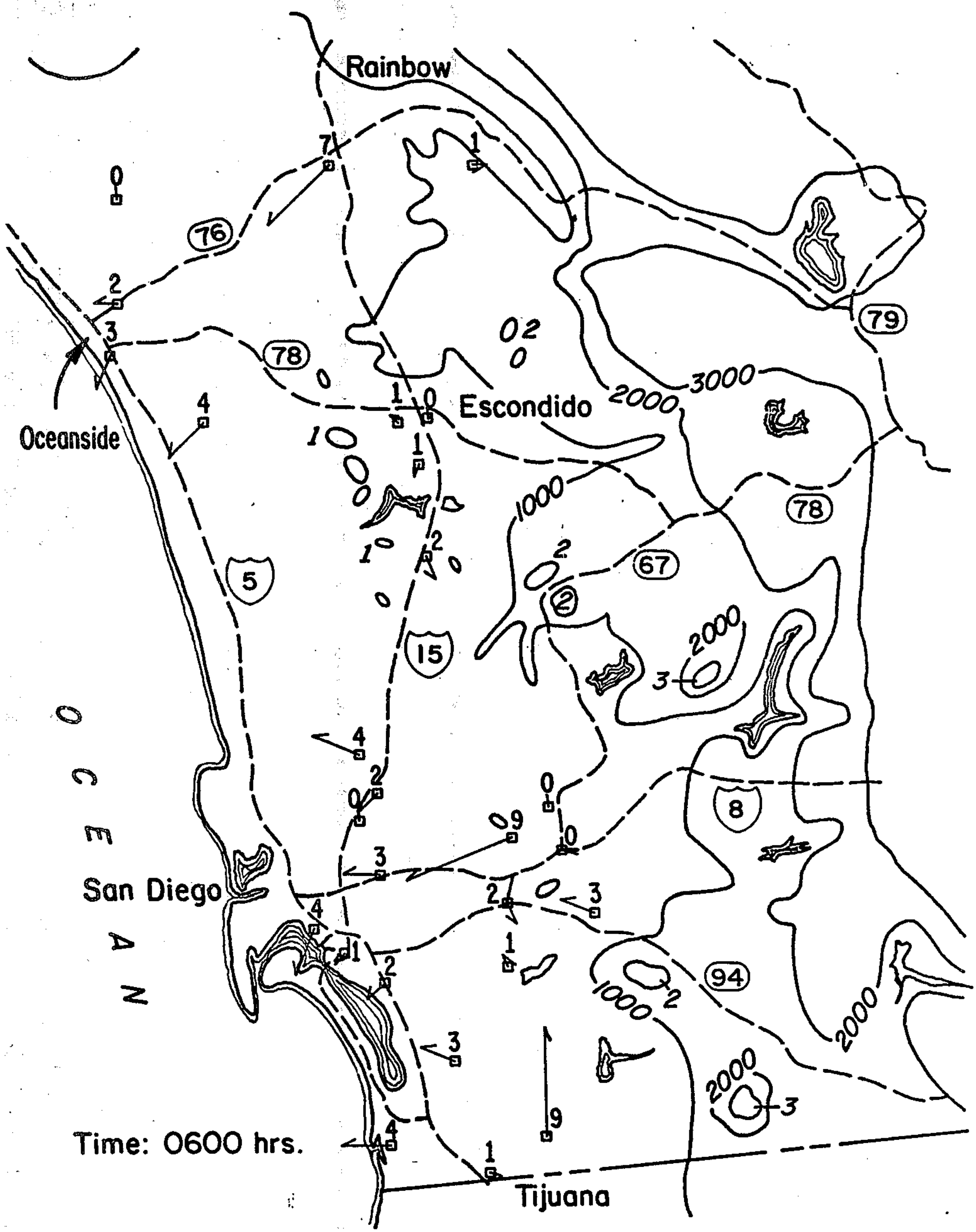

Rainbow
76
79
78
Oceanside
Escondido
2000
3000
1000
67
5
15
OCEAN
8
San Diego
94
Time: 0600 hrs.
Tijuana

FIGURE 10-7

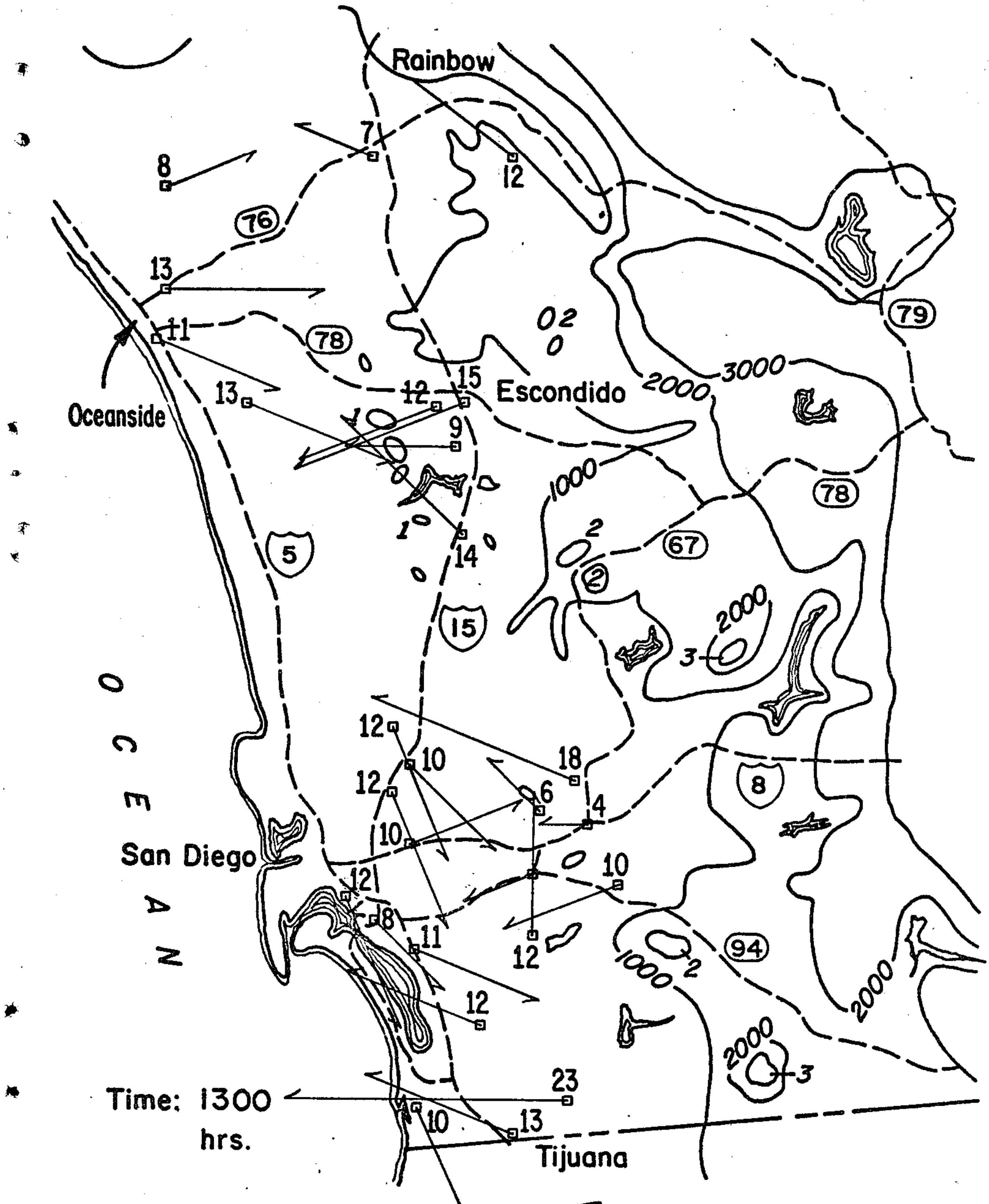

Rainbow
Oceanside
Escondido
San Diego
Tijuana
OCEAN
Time: 1300 hrs.
76
78
79
67
94
5
15
8
1000
2000
3000

FIGURE 10-8

COORDINATED MONITORING PROGRAM FOR SAN DIEGO

	Meteorological Stations	Air monitoring stations	Bag Sampling	UV Radiometer	Surface Lapse Rates	Aircraft Package	Pibals
APCD	8	8	-	2	-	-	-
District 11	14	1	20	-	-	-	-
Translab	7	3	-	-	2	1	3

SOUTH COAST AIR BASIN MODEL VERIFICATION PROGRAM

1. Define Study Area - South Coast Air Basin
2. Agencies Involved
   - District 07
   - District 08
   - ARB
   - San Bernardino APCD
   - Riverside APCD
   - L.A. APCD
   - Orange County APCD
   - Ventura County APCD
   - UCLA - Edinger
   - UCD - Myrup
   - SAI
   - MERC - Las Vegas
   - U.S.W.B.
   - Translab
   - EPA Region 9
   - FHWA
3. Sampling Periods
   - 6/15-8/15/75
   - 9/15-10-15/75
4. Use of Air Quality Van
   - for high O_3 area supplement with good exposure and compare with APCD (O_3 depression)
   - Quality Control check for APCD stations
   - Use as an additional monitoring site
5. See Slides of Monitoring Program

TABLE 1

REGIONAL SAMPLING PROGRAM (6/15/75 - 10/15/75)

SUMMARY

Measurements	No. of Sites	Frequency of Meas.	Comments
Surface Winds	42	Continuous	APCD & CALTRANS
Pibal	4	0600-1800 : 1/HR + 2200,0200	After alert announced
Radiosonde	3	0600,1200,1800 daily	More often if possible (Edwards AFB?)
Solar Radiation	5	daily	
Acoustic Sounders	3	continuous	Pasadena (Aerovironment) El Monte, San Bernardino
Aircraft	3 Van Nuys, FLA-Bob Off Shore	morning and noon	ARB, CALTRANS NERC - LV planes After alert announced
Air Quality	39	continuous	APCD's & ARB
HC Spectrum	2 (?)		
CALTRANS Van	2	12 hr/day	Air quality

SACRAMENTO REGIONAL STUDY

1) Define Study Area

- S.R.P.A.
- District 03 - DOTP
- Translab

2) Select Grid Size

- Translab

3) Analysis of Wind Data

- Existing Airports - Winter 74
- Non-uniformity of wind field

4) Field Survey of Existing Monitoring Systems

- Translab

5) Emissions Inventory

- Mobile - District 03 DOTP
- Stationary - ARB

6) Finalize Air Monitoring Program

- Translab

7) Coordination for Quality Assurance Control

- Translab
- AIHL

COORDINATED MONITORING PROGRAM FOR SACRAMENTO

	Meteorological Stations	Air Monitoring Stations	Bag Sampling	UV Radiometer	Surface Lapse Rate	Aircraft Package	Pibal
APCD	-	1	-	-	-	-	-
District 03	1	-	-	-	-	-	-
ARB	-	1	-	-	-	-	-
Translab	5	3	6	1	1	-	3
U.S.W.B.	-	-	-	-	-	1	-

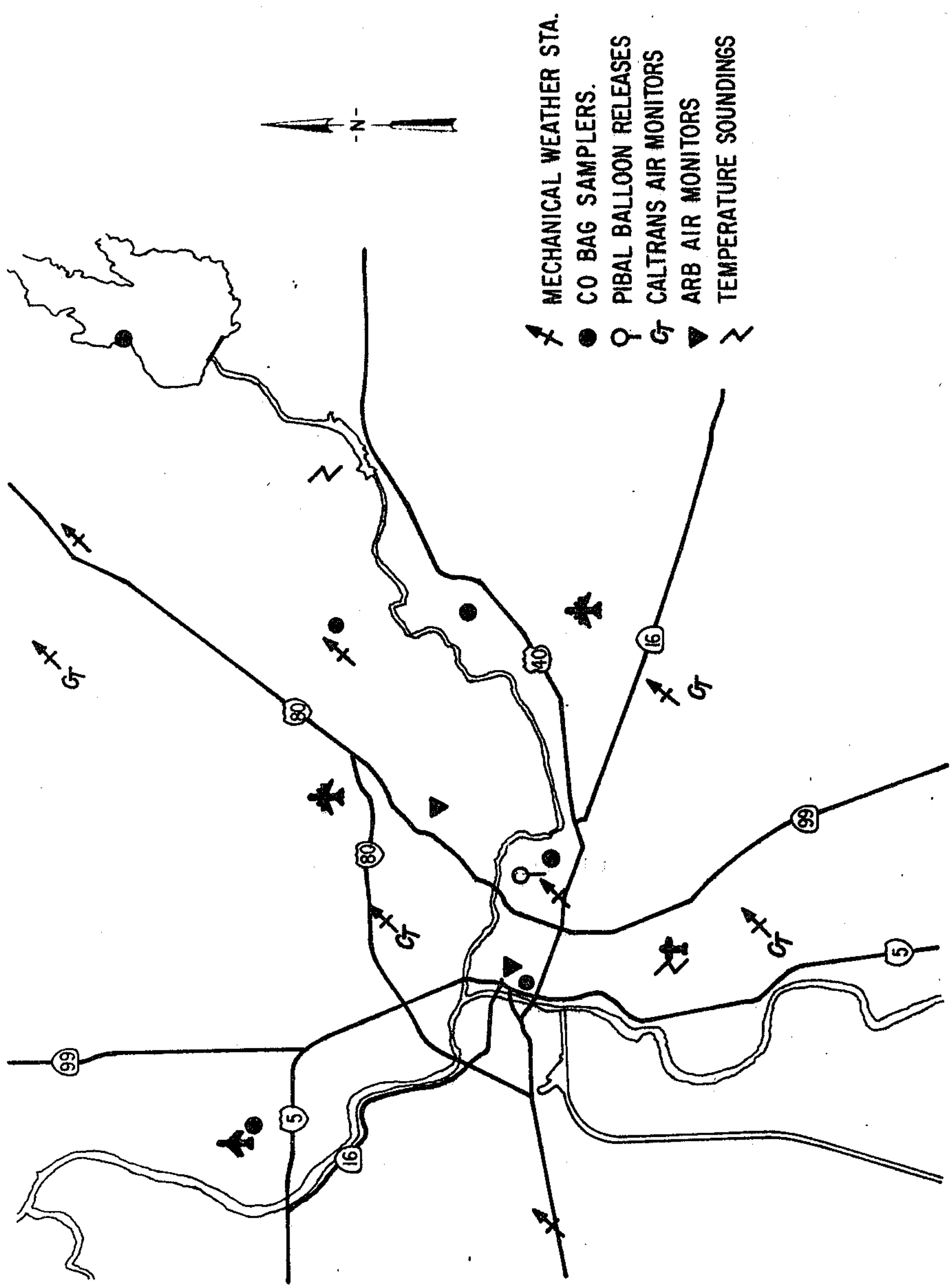

N
MECHANICAL WEATHER STA.
CO BAG SAMPLERS.
PIBAL BALLOON RELEASES
CALTRANS AIR MONITORS
ARB AIR MONITORS
TEMPERATURE SOUNDINGS
80
40
16
99
5
16
99
5
80

FIGURE 10-9

SECTION 11

QUALITY ASSURANCE

CONTROL FOR REGIONAL

AIR QUALITY MONITORING

I. Air Quality Instrumentation

A. Dynamic Calibration

B. Static Calibration

C. Secondary Calibration

D. Cross Correlation with APCD, ARB, AIHL

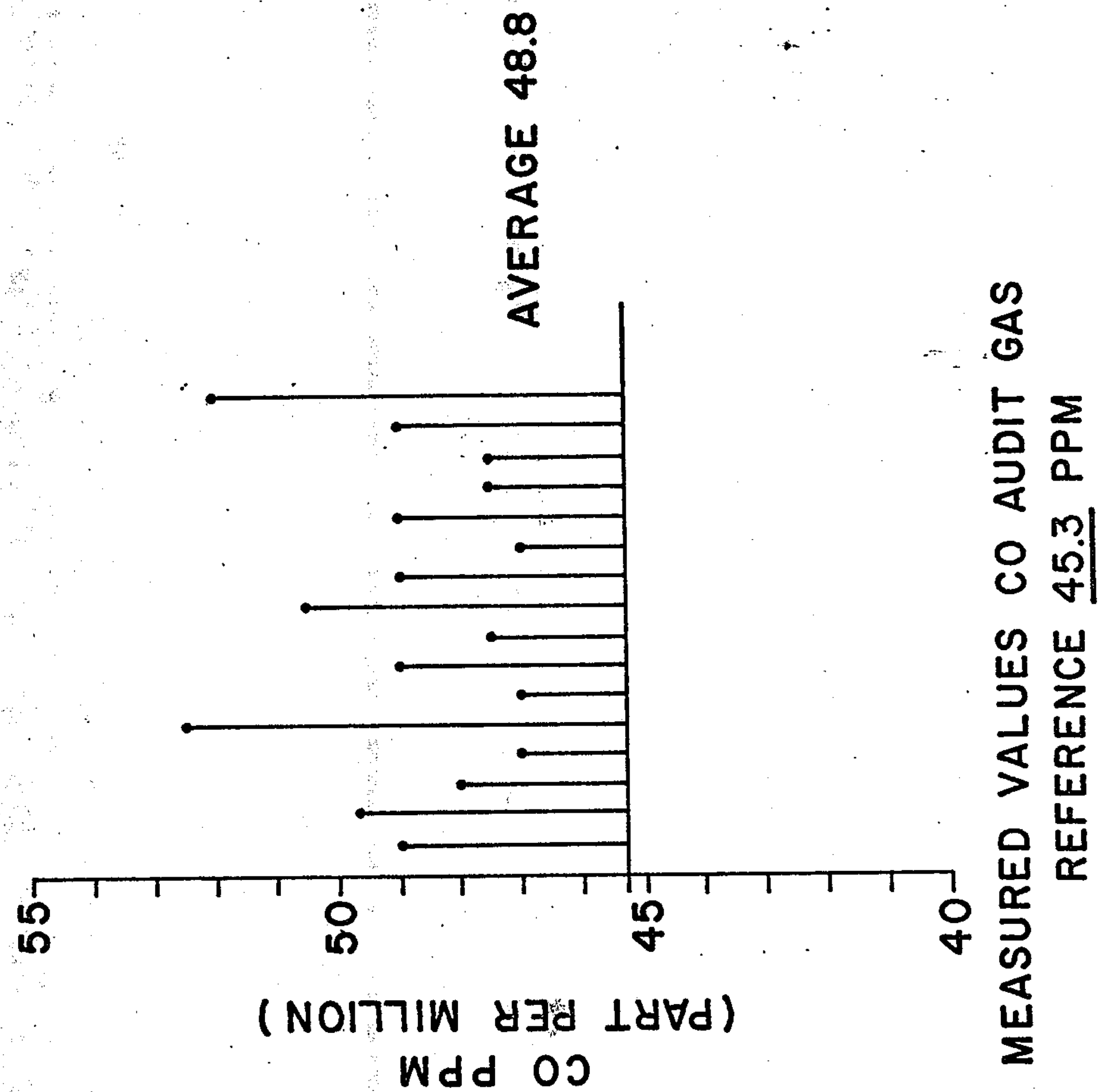
E. CO Audit Survey

II. Meteorological Instrumentation

A. Wind Tunnel Calibration

1. Translab

2. MRI



AVERAGE 48.8
55
50
45
40
CO PPM
(PART PER MILLION)
MEASURED VALUES CO AUDIT GAS
REFERENCE 45.3 PPM

FIGURE 11-1

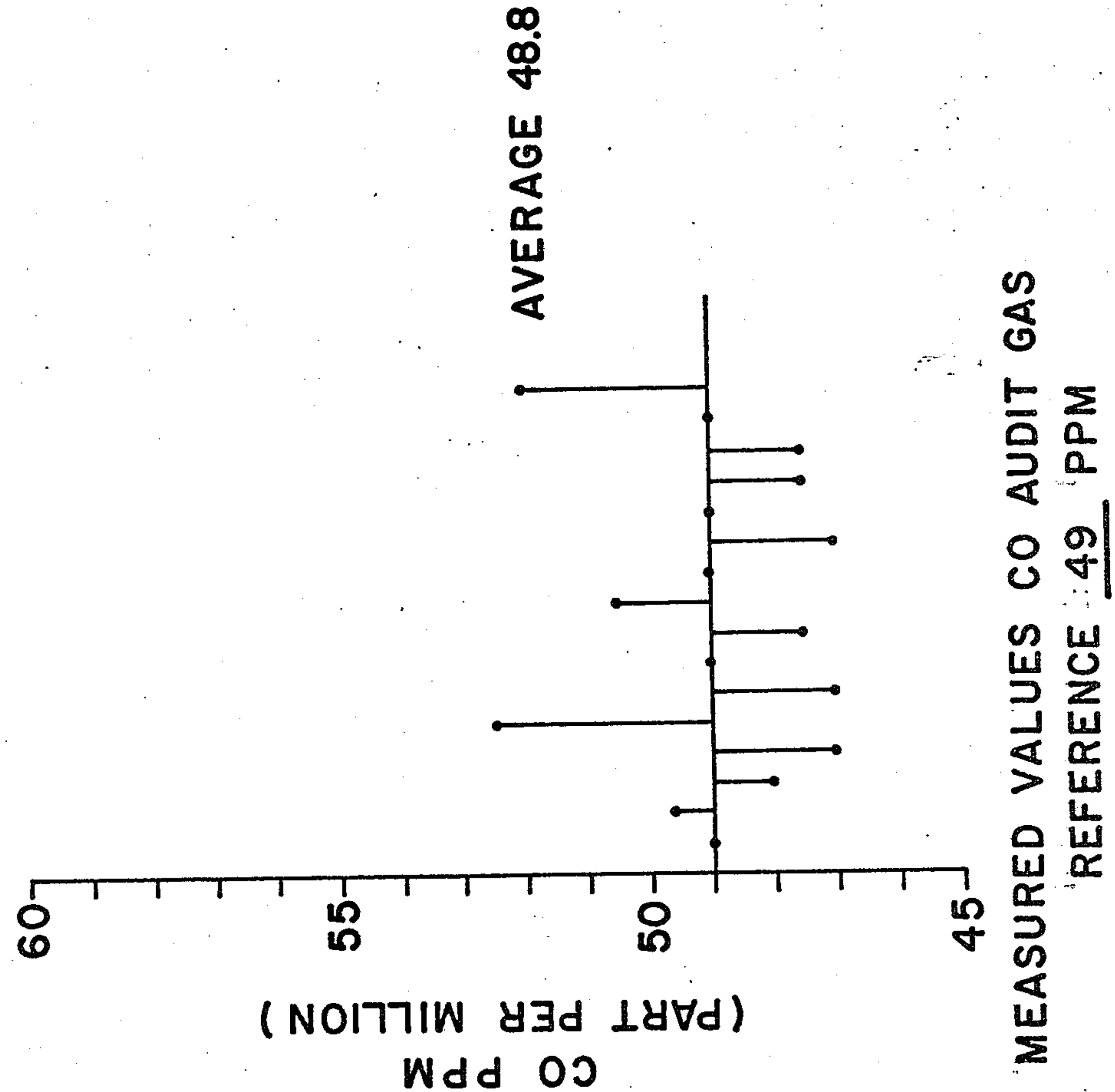

MEASURED VALUES CO AUDIT GAS
REFERENCE 49 PPM
AVERAGE 48.8
CO PPM
(PART PER MILLION)
60
55
50
45

FIGURE 11-2

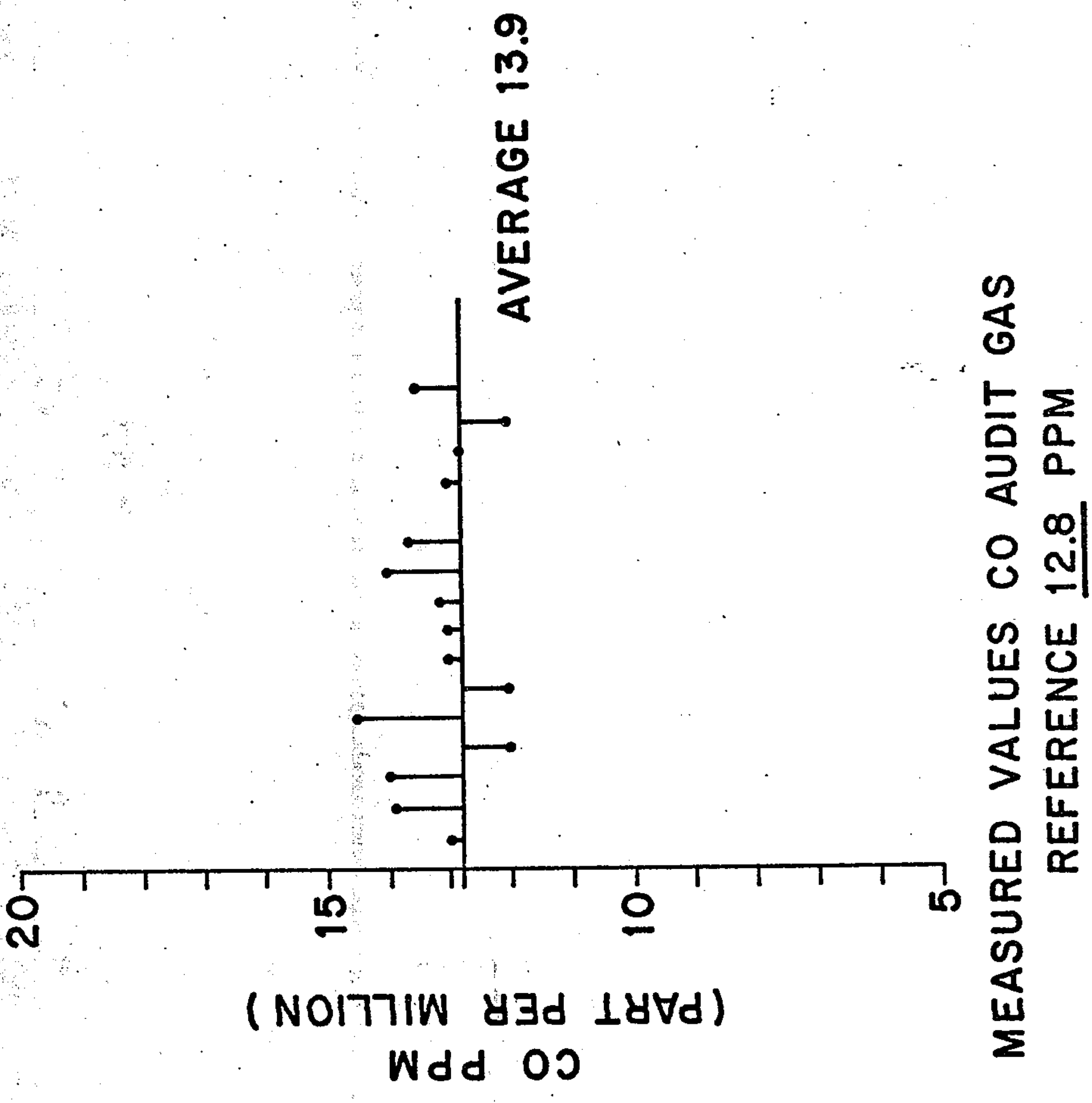
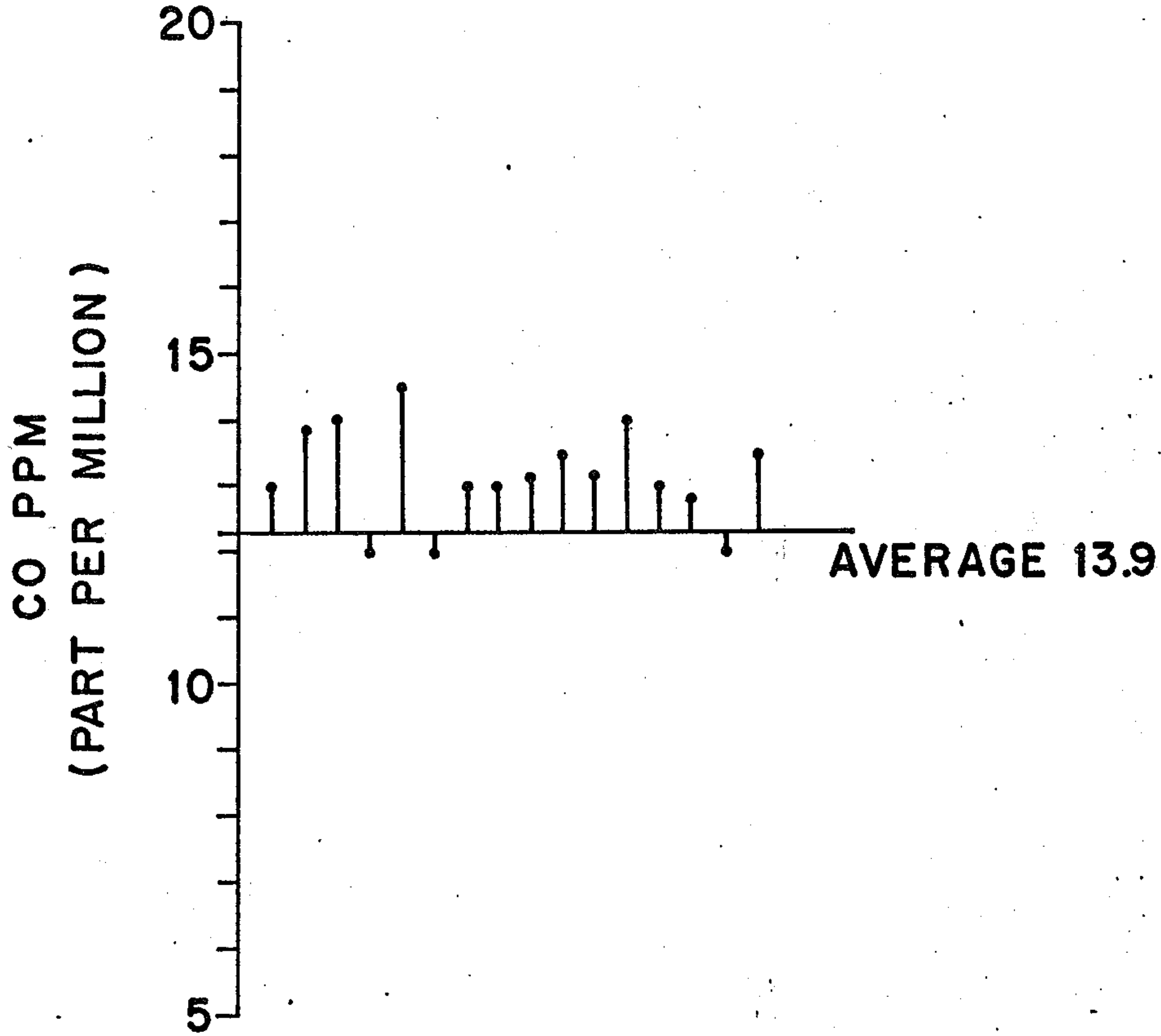
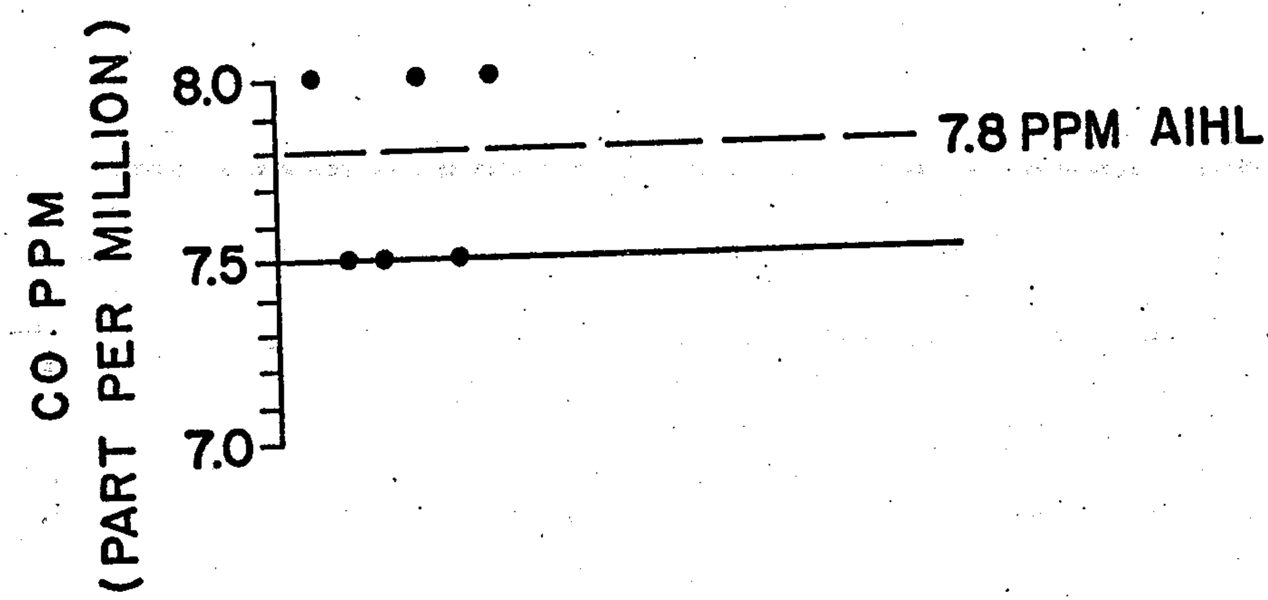

AVERAGE 13.9
MEASURED VALUES CO AUDIT GAS
REFERENCE 12.8 PPM
CO PPM
(PART PER MILLION)
20
15
10
5

FIGURE 11-3



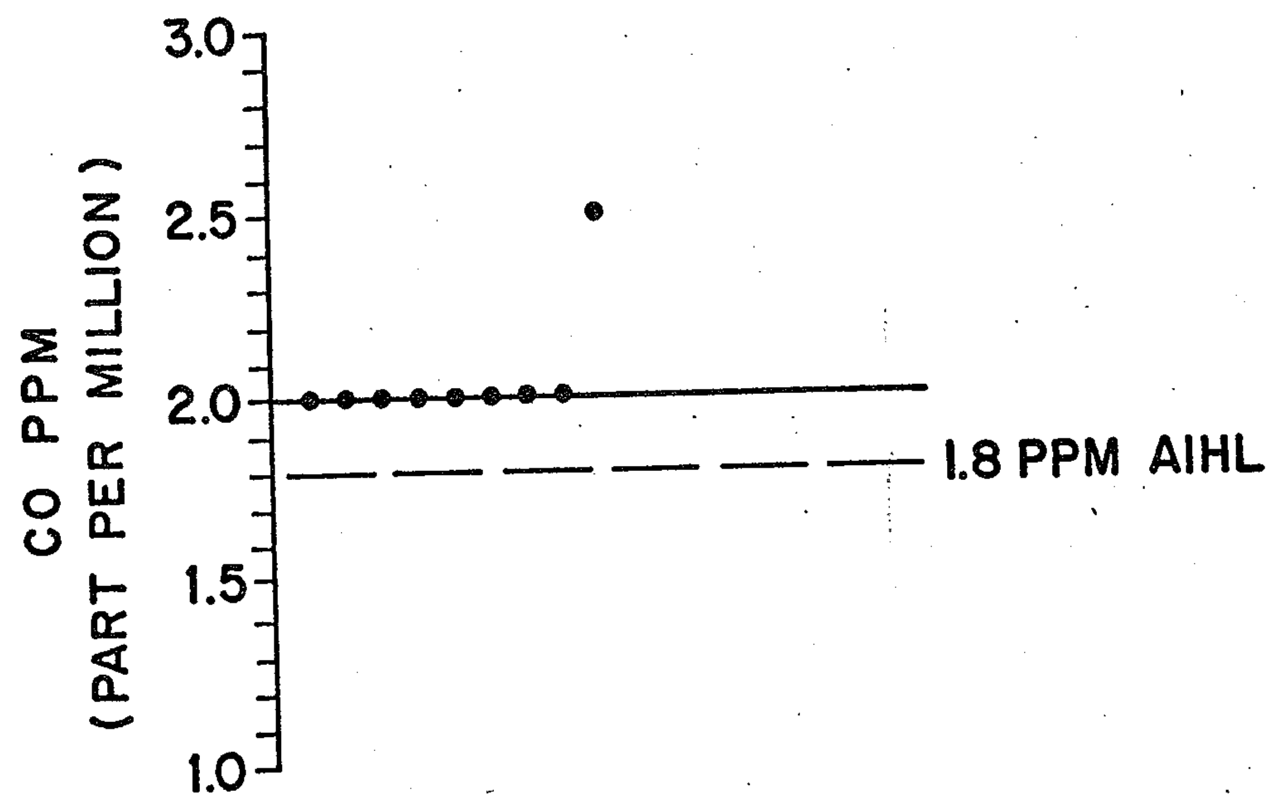
MEASURED VALUES CO AUDIT GAS
REFERENCE 12.3 PPM

FIGURE 11-4



MEASURED VALUES CO AUDIT GAS
REFERENCE 7.5 PPM

FIGURE 11-5



MEASURED VALUES CO AUDIT GAS
REFERENCE 2 PPM

FIGURE 11-6

SECTION 12

EMISSIONS INVENTORY

EMISSION INVENTORY

The new emission factors are based on (1) a recent 1,000 vehicle study made by the Environmental Protection Agency and reported in their Manual AP-42 entitled, "Compilation of Air Pollutant Emission Factors", (2) Scott Research Laboratory Report SRL 2148-07-0274 entitled "Driving Patterns at Various Average Route Speeds", and (3) a report from the Air Resources Board entitled "Interim Estimates of Emissions From Mobile Sources In California", April 25, 1975. These reports incorporate the latest available information such as new speed correction equations, the latest vehicle population distribution, emissions from heavy duty diesel powered vehicles, the interim California Emission Standards, modifications to the 1966-1970 Vehicle Retrofit Program, and new hydrocarbon reactivity factors.

The data used in calculating these emission factors are based on current technology and existing emission standards. Because of this, changes in such things as: the emission standards, retrofit requirements, shift to smaller cars, and new emission test data will cause these emission factors to be modified. When these changes are made, the emission factors will be updated and the modifications will be forwarded to the districts.

These new factors will replace the revised Air Quality Manual Modification numbers 3 and 4 currently in use. The emission factors are listed on the Tenet Time-Share Computer and can be accessed by linking '5;LAB;EMFAC'. This program will calculate total or reactive hydrocarbons, oxides of nitrogen, and carbon monoxide emission factors for any mix of light and heavy duty vehicles at average speeds from 10 to 60 mph based on the following mathematical equations:

$$e_{np} = \sum_{i=n-1}^{n+1} c_{ip} \; d_{ipn} \; m_{in} \; s_{ip}$$

where e_{np} = exhaust emission factor in grams per vehicle mile for calendar year n and pollutant p,

c_{ip} = the 1975 Federal test procedure emission rate for pollutant p (grams/mile) for the i^{th} model year, at low mileage. (table 12-1 thru 12-4). These low mileage emission rates are different from the new vehicle emission standards (tables 12-13 & 12-14) because the new vehicle standards are based on 50,000 miles of vehicle operation.

d_{ipn} = the controlled vehicle pollutant p emission deterioration factor for the i^{th} model year at calendar year n (tables 12-5 thru 12-8).

m_{in} = the weighted annual travel of the i^{th} model year during calendar year n (the determination of this variable involves the use of the vehicle model year distribution). (tables 12-9 thru 12-12).

s_{ip} = the weighted speed adjustment factor for exhaust emission for pollutant p for the i^{th} model year vehicles. (figures 12-1 thru 12-5).

In addition to exhaust emission factors, the calculation of hydrocarbon gasoline motor vehicle emissions involves evaporative and crankcase hydrocarbon emission rates. Evaporation and crankcase emissions can be determined using:

$$fn = \sum_{i=n-17}^{n+1} h_i \ m_{in}$$

where,

fn = the combined evaporative and crankcase hydrocarbon emission factor for calendar year n,

h_i = the combined evaporative and crankcase emission rate for the i^{th} model year (tables 12-1 thru 12-4).

m_{in} = the weighted annual travel of the i^{th} model year during calendar year n (tables 12-7 thru 12-10).

The pollutant emission rates (C_{ip}) are based on the vehicle emission standards and emission test data as published in AP-42 and ARB's "Interim Estimates of Emissions From Mobile Sources In California" (see tables 12-1 thru 12-4). The emission deterioration factors (d_{ipn}), were also obtained from these two references (see tables 12-5 thru 12-8).

The distribution of vehicle miles traveled by model year (M_{in}) was obtained from ARB and is based on vehicle population statistics from the California Highway Patrol(see tables 12-9 thru 12-12). This distribution considers light duty passenger cars, light duty trucks, heavy duty gasoline vehicles and heavy duty diesel vehicles.

The speed correction factors (S_{ip}) are based on a series of equations derived from EPA by the Scott Research Laboratory (report mentioned earlier) (see figures 12-1 thru 12-5). This report lists a different speed correction equation for each major automotive pollutant and for all vehicle model years tested (pre 1966 thru 1971, light duty only). The heavy duty vehicles, both gasoline and diesel, are assumed to have the same speed correction factors as the light duty vehicles. These speed correction factors replace those listed in AP-42.

These emission factors as listed on the Tenet computer system also take into consideration the modified Retrofit Emission Control Program for 1966 thru 1970 model year vehicles. The program asks the user if the project is within the six counties (Los Angeles, Ventura, Orange, Santa Barbara, San Bernardino, or Riverside) where this retrofit program was required based on vehicle license plate number. If the user responds yes, each yearly printout sheet will state "Project is within the 1966-70 RETROFIT AREA". If the user responds no, as would be the case in all the other counties, the retrofit portion of the calculations will be based on change-of-ownership statistics.

The Retrofit Program for 1955 thru 1965 vehicles was not included in this program because the vehicle miles traveled by these vehicles only amount to approximately 5% of the total miles traveled today. This percentage will be even less in future years.

Motorcycles are also not considered as a separate source of emissions in this program. They are,however,included in the light duty vehicle category. The reason for this is that it is expected that either the ARB or the EPA will soon establish emission standards for new motorcycles sold in California. Once this is done, the percent of emission contributed by motorcycles would greatly change, especially in future years. Therefore, it is felt that calculating emissions from motorcycles for future years would introduce larger errors than assuming that they act as light duty vehicles.

If the user of this program is making estimates of oxidant concentration, he should use the reactive hydrocarbon option as listed in the beginning of the program. This option uses the reactivity factors listed in table 12-15. These factors were obtained from ARB and EPA.

Figures 12-6 thru 12-17 show comparisons of the new versus old emission factor data. The most important changes are shown on Figures 12-8 and 12-9. These figures show the CO and NO_x emissions are significantly higher for most model years. Figures 12-11 and 12-13 on the other hand show that the emission control devices are not deteriorating as fast as originally projected. The result of these changes, which counteract each other, is shown on figures 12-14 thru 12-16. These figures show the actual changes in the composite emission factors from what it was previously. Figure 12-17 shows the changes in the reactive hydrocarbons which is primarily due to the increase in the HC reactivity factors (see table 12-15).

TABLE 12-1

EMISSION RATES FOR LIGHT DUTY VEHICLES

Below 3500 Feet in Elevation

	Passenger Cars					Light Duty Trucks				
Model Year	CO	NO_x	Exhaust HC	Crank. HC	Evap. HC	CO	NO_x	Exhaust HC	Crank. HC	Evap. HC
1960	87	3.6	8.8	4.1	3.0	87	3.6	8.8	4.1	3.0
1961	87	3.6	8.8	0.8	3.0	87	3.6	8.8	0.8	3.0
1962	87	3.6	8.8	0.8	3.0	87	3.6	8.8	0.8	3.0
1963	87	3.6	8.8	0.8	3.0	87	3.6	8.8	0.8	3.0
1964	87	3.6	8.8	0	3.0	87	3.6	8.8	0	3.0
1965	87	3.6	8.8	0	3.0	87	3.6	8.8	0	3.0
1966	59.9	8.0	6.0	0	3.0	59.9	8.0	6.0	0	3.0
1967	59.9	6.1	4.7	0	3.0	59.8	6.1	4.7	0	3.0
1968	44.8	6.7	5.1	0	3.0	44.8	6.7	5.1	0	3.0
1969	49.2	6.1	4.4	0	3.0	49.2	6.1	4.4	0	3.0
1970	49.5	4.6	4.6	0	0.5	49.5	4.6	4.6	0	0.5
1971	46.1	3.6	3.0	0	0.5	46.1	3.6	3.0	0	0.5
1972	37.4	3.7	3.0	0	0.2	37.4	3.7	3.0	0	0.2
1973	36.5	3.2	2.7	0	0.2	36.5	3.2	2.7	0	0.2
1974	30.5	2.2	2.6	0	0.2	30.5	2.2	2.6	0	0.2
1975	5.2	1.7	0.54	0	0.2	11.6	1.7	1.2	0	0.2
1976	5.2	1.7	0.54	0	0.2	9.8	1.7	0.54	0	0.2
1977	5.2	0.83	0.25	0	0.2	9.8	1.1	0.54	0	0.2
1978	2.0	0.22	0.25	0	0.2	9.8	1.1	0.54	0	0.2

TABLE 12-2

EMISSION RATES FOR LIGHT DUTY VEHICLES
Above 3500 Feet in Elevation

	Passenger Cars					Light Duty Trucks				
Model Year	CO	NO_x	Exhaust HC	Crank HC	Evap HC	CO	NO_x	Exhaust HC	Crank HC	Evap HC
1960	130	1.9	10	4.1	3.0	130	1.9	10	4.1	3.0
1961	130	1.9	10	0.8	3.0	130	1.9	10	0.8	3.0
1962	130	1.9	10	0.8	3.0	130	1.9	10	0.8	3.0
1963	130	1.9	10	0.8	3.0	130	1.9	10	0.8	3.0
1964	130	1.9	10	0	3.0	130	1.9	10	0	3.0
1965	130	1.9	10	0	3.0	130	1.9	10	0	3.0
1966	89.3	4.2	6.8	0	3.0	89.3	4.2	6.8	0	3.0
1967	89.7	3.2	5.3	0	3.0	89.7	3.2	5.3	0	3.0
1968	72.1	3.4	6.8	0	3.0	72.1	3.4	6.8	0	3.0
1969	60.6	2.9	5.4	0	3.0	60.6	2.9	5.4	0	3.0
1970	99	2.5	7.8	0	0.5	99	2.5	7.8	0	0.5
1971	101.7	2.4	5.5	0	0.5	101.7	2.4	5.5	0	0.5
1972	82.7	2.4	5.4	0	0.2	82.7	2.4	5.4	0	0.2
1973	80.7	1.9	4.9	0	0.2	80.7	1.9	4.9	0	0.2
1974	67.4	1.3	4.7	0	0.2	67.4	1.3	4.7	0	0.2
1975	11.9	1.0	1.0	0	0.2	25.2	1.0	2.2	0	0.2
1976	11.9	1.0	1.0	0	0.2	21.8	1.0	1.0	0	0.2
1977	5.2	0.5	0.25	0	0.2	21.8	0.7	1.0	0	0.2
1978	2.0	0.22	0.25	0	0.2	21.8	0.7	1.0	0	0.2

TABLE 12-3

EMISSION RATES FOR HEAVY DUTY VEHICLES
Below 3500 Feet in Elevation

	Gasoline Trucks					Diesel Trucks			
Model Year	CO	NO_x	Exhaust HC	Crank HC	Evap. HC	CO	NO_x	Exhaust HC	Crank & Evap. HC
1960	140	9.4	17	5.2	3.0	20.4	34	3.4	0
1961	140	9.4	17	0.8	3.0	20.4	34	3.4	0
1962	140	9.4	17	0.8	3.0	20.4	34	3.4	0
1963	140	9.4	17	0.8	3.0	20.4	34	3.4	0
1964	140	9.4	17	0	3.0	20.4	34	3.4	0
1965	140	9.4	17	0	3.0	20.4	34	3.4	0
1966	140	9.4	17	0	3.0	20.4	34	3.4	0
1967	140	9.4	17	0	3.0	20.4	34	3.4	0
1968	140	9.4	17	0	3.0	20.4	34	3.4	0
1969	140	9.4	17	0	3.0	20.4	34	3.4	0
1970	130	9.2	16	0	3.0	20.4	34	3.4	0
1971	130	9.2	16	0	3.0	20.4	34	3.4	0
1972	130	9.2	13	0	3.0	20.4	34	3.4	0
1973	130	9.2	13	0	0.2	19	26	2.6	0
1974	130	9.2	13	0	0.2	19	26	2.6	0
1975	98	5.8	8.1	0	0.2	14	16	1.6	0
1976	98	5.8	8.1	0	0.2	14	16	1.6	0
1977	81	2.8	4.1	0	0.2	12	8	0.8	0
1978	81	2.8	4.1	0	0.2	12	8	0.8	0

TABLE 12-4
EMISSION RATES FOR HEAVY DUTY VEHICLES
Above 3500 Feet in Elevation

	Gasoline Trucks					Diesel Trucks			
Model Year	CO	NO_x	Exhaust HC	Crank HC	Evap HC	CO	NO_x	Exhaust HC	Crank & Evap HC
1960	210	5	19	5.2	3.0	31	18	3.8	0
1961	210	5	19	0.8	3.0	31	18	3.8	0
1962	210	5	19	0.8	3.0	31	18	3.8	0
1963	210	5	19	0.8	3.0	31	18	3.8	0
1964	210	5	19	0	3.0	31	18	3.8	0
1965	210	5	19	0	3.0	31	18	3.8	0
1966	210	5	19	0	3.0	31	18	3.8	0
1967	210	5	19	0	3.0	31	18	3.8	0
1968	210	5	19	0	3.0	31	18	3.8	0
1969	210	5	19	0	3.0	31	18	3.8	0
1970	190	4.9	18	0	3.0	31	18	3.8	0
1971	190	4.9	18	0	3.0	31	18	3.8	0
1972	190	4.9	15	0	3.0	31	18	3.8	0
1973	190	4.9	15	0	0.2	29	14	2.9	0
1974	190	4.9	15	0	0.2	29	14	2.9	0
1975	143	3.1	9	0	0.2	21	8	1.8	0
1976	143	3.1	9	0	0.2	21	8	1.8	0
1977	118	1.5	5	0	0.2	18	4	0.9	0
1978	118	1.5	5	0	0.2	18	4	0.9	0

TABLE 12-5

CO DETERIORATION FACTORS FOR LIGHT DUTY VEHICLES

Model Year	Age of Vehicle (Years) 1	2	3	4	5	6	7	8	9	10	11	>11
Pre 1966 1/	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1966 2/	.98	1.11	1.17	1.21	1.23	1.25	1.26	1.28	1.28	1.29	1.30	1.30
1967	.98	1.08	1.14	1.17	1.18	1.20	1.21	1.27	1.22	1.23	1.23	1.24
1968	.97	1.16	1.27	1.32	1.36	1.39	1.41	1.43	1.45	1.45	1.46	1.47
1969	.96	1.20	1.34	1.41	1.47	1.50	1.53	1.55	1.58	1.59	1.60	1.61
1970	.96	1.21	1.35	1.43	1.48	1.52	1.55	1.58	1.60	1.62	1.63	1.63
1971	.98	1.09	1.15	1.18	1.20	1.22	1.23	1.24	1.25	1.25	1.26	1.26
1972	.96	1.20	1.34	1.42	1.47	1.51	1.54	1.56	1.58	1.60	1.61	1.62
1973	.97	1.17	1.28	1.34	1.38	1.41	1.44	1.46	1.47	1.49	1.49	1.50
1974	.94	1.31	1.54	1.67	1.76	1.83	1.89	1.93	1.97	2.00	2.02	2.03
1975 1/	.99	1.15	1.37	1.56	1.73	1.88	2.01	2.12	2.23	2.32	2.38	2.42
1976	.99	1.15	1.37	1.56	1.73	1.88	2.01	2.13	2.23	2.32	2.38	2.42
1977	.99	1.15	1.37	1.56	1.73	1.88	2.01	2.13	2.23	2.31	2.38	2.42
Post 1977	.99	1.15	1.37	1.56	1.73	1.88	2.01	2.13	2.23	2.31	2.38	2.42

a. Factors normalized 4000 miles.
b. Represents new model year production beginning Oct. 1 of inventory year.
1/ Pre 1966 and Post 1974 Deterioration Factors Derived From: "Supplement No. 2 for Compilation of Air Pollutant Emission Factors", EPA Publication AP-42 - Supplement 2, September, 1973, 3.1.2-7
2/ 1966-1974: ARB Div. of Implementation and Enforcement analysis of ARB, Div. of Vehicle Emission Control, "Automobile Emission Regression Report" 3rd Quarter, 1974.

TABLE 12-6

NO_x DETERIORATION FACTORS FOR LIGHT DUTY VEHICLES

Model Year	Age of Vehicles (years) 1	2	3	4	5	6	7	8	9	10	11	>11
Pre 1966 1/	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1966 2/	1.08	.69	.56	.50	.46	.44	.42	.41	.40	.39	.39	.38
1967	1.05	.79	.69	.64	.61	.59	.58	.57	.56	.55	.55	.54
1968	1.04	.82	.73	.69	.66	.65	.63	.62	.61	.61	.60	.60
1969	1.02	.90	.85	.82	.81	.79	.78	.78	.77	.77	.77	.76
1970	1.00	.99	.98	.98	.97	.97	.97	.97	.97	.97	.97	.97
1971	.99	1.03	1.05	1.06	1.07	1.07	1.07	1.08	1.08	1.08	1.08	1.08
1972	.99	1.03	1.05	1.05	1.06	1.07	1.07	1.07	1.07	1.08	1.08	1.08
1973	.99	1.06	1.10	1.12	1.13	1.14	1.14	1.15	1.15	1.16	1.16	1.16
1974	.96	1.21	1.36	1.44	1.49	1.53	1.56	1.59	1.61	1.63	1.64	1.65
1975 2/	1.00	1.03	1.08	1.12	1.15	1.18	1.21	1.24	1.26	1.28	1.29	1.30
1976	1.00	1.03	1.07	1.12	1.15	1.18	1.21	1.24	1.26	1.28	1.29	1.30
1977	.98	1.16	1.40	1.60	1.78	1.94	2.08	2.22	2.33	2.42	2.48	2.53
Post 1977	.98	1.16	1.40	1.60	1.78	1.94	2.09	2.22	2.33	2.42	2.48	2.53

a. Factors normalized to 4,000 miles.

b. Represents new model year production beginning October 1st of inventory year.

1/ Pre 1966 & Post 1974 derived from: "Supplement No. 2 for Compilation of Air Pollutant Emission Factors", EPA Publication AP-42-Supplement-2, September 1973, p. 3.1.2-7.

2/ Pre 1966 & Post 1974 deterioration factor derived from: "Supplement No. 2 for "Compilation of Air Pollutant Emission Factors", EPA Publication AP-42-Supplement-2, September 1973, p. 3.12-7.

TABLE 12-7

EXHAUST HC DETERIORATION FACTORS FOR LIGHT DUTY VEHICLES

Model Year	Age of Vehicle (Years) 1	2	3	4	5	6	7	8	9	10	11	>11
Pre 1966 1/	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1966 2/	.98	1.10	1.17	1.20	1.22	1.24	1.25	1.27	1.27	1.28	1.29	1.29
1967	.99	1.06	1.10	1.12	1.13	1.14	1.15	1.16	1.16	1.17	1.17	1.17
1968	.98	1.09	1.14	1.17	1.19	1.20	1.22	1.22	1.23	1.24	1.24	1.24
1969	.98	1.09	1.14	1.17	1.19	1.20	1.22	1.22	1.23	1.24	1.24	1.24
1970	.97	1.15	1.24	1.29	1.33	1.35	1.37	1.39	1.40	1.41	1.42	1.42
1971	.97	1.13	1.21	1.26	1.29	1.31	1.33	1.34	1.35	1.36	1.37	1.37
1972	.97	1.17	1.29	1.35	1.39	1.42	1.45	1.47	1.49	1.50	1.51	1.51
1973	.98	1.12	1.19	1.23	1.25	1.27	1.29	1.30	1.31	1.32	1.32	1.33
1974	.97	1.18	1.31	1.37	1.42	1.45	1.48	1.50	1.52	1.53	1.54	1.55
1975 1/	.99	1.13	1.33	1.49	1.63	1.76	1.88	1.99	2.08	2.15	2.20	2.24
1976	.99	1.13	1.33	1.49	1.63	1.76	1.88	1.99	2.08	2.15	2.20	2.24
1977	.99	1.13	1.33	1.49	1.63	1.76	1.88	1.99	2.08	2.15	2.20	2.24
Post 1977	.99	1.13	1.33	1.49	1.63	1.76	1.88	1.99	2.08	2.15	2.20	2.24

a. Factors normalized to 4,000 miles.

b. Represents new model year production beginning October 1st of inventory year.

1/ Pre 1966 & Post 1974 deterioration factor derived from: "Supplement No. 2 for Compilation of Air Pollutant Emission Factors", EPA Publication AP-42-Supplement-2, September 1973, p. 3.1.2-7.

2/ 1966-1974: ARB Div. of Implementation & Enforcement analysis of ARB Div. of Vehicle Emission Control "Automobile Emission Regression Report" 3rd quarter, 1974.

TABLE 12-8

Deterioration Factors for Heavy Duty Vehicles
Both Gasoline and Diesel Powered

Model Year	Vehicle Age, Years 0	1	2	3	4	5	6	7	8	≥9
					CO Deterioration Factor					
1974 & earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1975 & later	1.00	1.24	1.35	1.43	1.50	1.57	1.63	1.69	1.73	1.77
					NO_x Deterioration Factor					
1974 & earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1975 & later	1.00	1.11	1.18	1.20	1.22	1.23	1.24	1.25	1.27	1.28
					Exhaust HC Deterioration Factor					
1974 & earlier	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1975 & later	1.00	1.12	1.18	1.22	1.25	1.28	1.30	1.33	1.36	1.38

TABLE 12-9

Light Duty Passenger Vehicle Travel vs. Age

Vehicle Age (years)	% of Vehicles	Annual Mileage	% Distribution of Miles Traveled
1	8.2	17,500	17.6
2	10.4	13,000	16.9
3	9.0	12,000	12.9
4	8.9	10,500	11.1
5	9.7	9,900	11.5
6	8.5	8,300	8.4
7	7.3	7,500	6.6
8	7.5	6,500	5.8
9	7.4	5,000	4.4
10	5.9	3,300	2.3
11	4.5	1,200	0.6
12	3.3	1,200	0.5
13	2.0	1,200	0.3
14	1.8	1,200	0.3
15	1.3	1,200	0.2
16	0.7	1,200	0.1
>17	3.6	1,200	0.5
	100.%		100 %

TABLE 12-10

Light Duty Truck Travel vs. Age

Vehicle Age (Years)	% of Vehicles	Annual Mileage	% Distribution of Miles Traveled
1	8.5	17,500	18.7
2	13.5	13,500	22.7
3	8.8	12,000	13.1
4	8.4	10,500	11.0
5	8.0	9,900	9.9
6	6.0	8,300	6.2
7	5.0	7,500	4.7
8	5.3	6,500	4.3
9	5.5	5,000	3.4
10	4.8	3,300	2.0
11	3.9	1,200	0.6
12	3.1	1,200	0.5
13	2.2	1,200	0.3
14	2.4	1,200	0.4
15	2.1	1,200	0.3
16	1.4	1,200	0.2
≥17	11.1	1,200	1.7
	100%		100%

TABLE 12-11

Heavy Duty Gasoline Truck Travel vs Age

Vehicle Age (Years)	% of Vehicles	Annual Mileage	% Distribution of Miles Traveled
1	2.4	19,700	4.0
2	7.3	19,700	12.0
3	5.9	18,000	8.9
4	7.9	18,000	12.0
5	7.6	15,100	9.7
6	5.7	15,100	7.3
7	4.8	11,500	4.7
8	6.4	11,500	6.2
9	6.1	10,000	5.1
10	6.2	10,000	5.2
11	5.6	7,370	3.4
12	4.8	7,370	3.0
13	3.3	7,370	2.1
14	3.6	7,370	2.3
15	3.5	7,370	2.2
16	2.2	7,370	1.4
≥17	16.7	7,370	10.3
	100%		100%

TABLE 12-12

Heavy Duty Diesel Truck Travel vs Age

Vehicle Age (years)	% of Vehicles	Annual Mileage	% Distribution of Miles Traveled
1	5.2	78,600	7.6
2	10.8	78,600	15.7
3	8.7	72,000	11.6
4	9.0	72,000	12.0
5	10.0	60,200	11.2
6	8.1	60,200	9.0
7	6.1	45,700	5.1
8	8.0	45,700	6.8
9	6.6	39,900	4.8
10	5.7	39,900	4.2
11	4.3	29,400	2.4
12	3.2	29,400	1.7
13	2.2	29,400	1.2
14	2.1	29,400	1.2
15	1.6	29,400	0.9
16	1.1	29,400	0.6
≥17	7.3	29,400	4.0
	100%		100%

TABLE 12-13

NEW LIGHT DUTY VEHICLE EMISSION STANDARDS

YEAR	STANDARD	COLD START TEST	HYDROCARBONS	CARBON MONOXIDE	OXIDES OF NITROGEN
.ior to ...trols		7-mode	850 ppm	3.4%	1000 ppm
		7-mode	(11 gm/mi)	(80 gm/mi)	(4 gm/mi)
		CVS-75	11	96	2.9
966-1967	Calif.	7-mode	275 ppm	1.5%	no std.
968-1969	Calif. &	7-mode			
	Federal	50-100 CID	410 ppm	2.3%	no std.
		101-140 CID	350 ppm	2.0%	no std.
		over-140 CID	275 ppm	1.5%	no std.
970	Calif. & Federal	7-mode	2.2 gm/mi	23 gm/mi	no std.
971	Calif.	7-mode	2.2 gm/mi	23 gm/mi	4 gm/mi
	Federal	7-mode	2.2 gm/mi	23 gm/mi	-
1972	Calif.	7-mode or	1.5 gm/mi	23 gm/mi	3 gm/mi
		CVS-72	3.2 gm/mi	39 gm/mi	*3.2 gm/mi
	Federal	CVS-72	3.4 gm/mi	39 gm/mi	-
1973	Calif.	CVS-72	3.2 gm/mi	39 gm/mi	3 gm/mi
	Federal	CVS-72	3.4 gm/mi	39 gm/mi	3 gm/mi
1974	Calif.	CVS-72	3.2 gm/mi	39 gm/mi	2 gm/mi
	Federal	CVS-72	3.4 gm/mi	39 gm/mi	3 gm/mi

The values in parentheses are approximately equivalent values by 7-mode test.
ppm - parts per million concentration
gm/mi - grams per mile
7-mode - is a 137 second driving cycle test.
CVS-72 - is a Constant Volume Sample cold start test.

TABLE 12-13 (continued)

NEW LIGHT DUTY VEHICLE EMISSION STANDARDS

YEAR		STANDARD	COLD START TEST	HYDROCARBONS	CARBON MONOXIDE	OXIDES OF NITROGEN
1975	**PC	Calif.	CVS-75	0.9 gm/mi	9.0 gm/mi	2.0 gm/mi
	**PC	Federal	CVS-75	1.5 gm/mi	15 gm/mi	3.1 gm/mi
	**LDT	Calif.	CVS-75	2.0 gm/mi	20 gm/mi	2.0 gm/mi
	**LDT	Federal	CVS-75	2.0 gm/mi	20 gm/mi	3.1 gm/mi
1976	**PC	Calif.	CVS-75	0.9 gm/mi	9.0 gm/mi	2.0 gm/mi
	**PC	Federal	CVS-75	1.5 gm/mi	15 gm/mi	3.1 gm/mi
	**LDT	Calif.	CVS-75	0.9 gm/mi	17 gm/mi	2.0 gm/mi
	**LDT	Federal	CVS-75	2.0 gm/mi	20 gm/mi	3.1 gm/mi
1977	**PC	Calif.	CVS-75	0.41 gm/mi	9.0 gm/mi	1.5 gm/mi
	**PC	Federal	CVS-75	***0.41 gm/mi	***3.4 gm/mi	2.0 gm/mi
	**LDT	Calif.	CVS-75	0.9 gm/mi	17 gm/mi	2.0 gm/mi
	**LDT	Federal	CVS-75	NOT	ESTABLISHED	
1978	**PC	Calif.	CVS-75	****-0.41gm/mi	****-9.0 gm/mi	****-1.5 gm/mi
	**PC	Federal	CVS-75	0.41 gm/mi	3.4 gm/mi	0.40 gm/mi
	**LDT	Calif	CVS-75	****-0.9gm/mi	****17 gm/mi	**** 2.0 gm/mi
	**LDT	Federal	CVS-75	NOT	ESTABLISHED	

CVS-75 - is a Constant Volume Sample test which includes cold and hot starts.
* - hot 7-mode
** - PC - Passenger Cars LDT-Light Duty Trucks
***-Subject to possible one-year delay
**** Assumed Value

Crankcase Emissions

On all new vehicles manufactured for sale in California after January 1, 1964, crankcase emissions are virtually zero. Comparable Federal standards became effective in 1968 for light-duty vehicles.

Evaporative Emissions

Evaporative emissions of hydrocarbons have been 6 gms/ test for light-duty vehicles since 1970, and 2 gms/test since 1972. Starting in 1977 it will be 6 gms/test using the shed test method.

TABLE 12-14

NEW HEAVY DUTY VEHICLE EMISSION STANDARDS

YEAR	STANDARD	HYDRO-CARBONS	CARBON MONOXIDE	OXIDES OF NITROGEN
* 1969-1971	State-gasoline	275 ppm	1.5%	no std.
1972	State-gasoline	180 ppm	1.0%	no std.
1973-74	State-gasoline & diesel	HC + NO_x = 16 gm/BHP hr. CO = 40 gm/BHP hr.		
1975-76	State-gasoline & diesel	HC + NO_x = 10 gm/BHP hr. CO = 30 gm/BHP hr.		
1977	State-gasoline & diesel	1 gm/BHP-hr	25 gm/BHP-hr	7 gm/BHP-hr
		or { HC + NO_x = 5 gm/BHP hr. CO = 25 gm/BHP hr.		

gm/BHP hr. grams per brake horsepower-hour

* Federal standards remained at this level through 1973. The Federal Government adopted standards for heavy-duty gasoline and diesel vehicles for 1974 and subsequent model years which are identical to California's 1973-74 standards.

State Smoke Standards

1971 and later vehicles may discharge smoke no darker than Ringelmann 1 or 20 percent opacity for up to 10 seconds.

Vehicles sold before 1971 may discharge smoke no darker than Ringelmann 2 or 40 percent opacity for up to 10 seconds.

Crankcase Emissions

On all new vehicles manufactured for sale in California after January 1, 1964, crankcase emissions are virtually zero. Comparable Federal standards became effective in 1970 for heavy-duty vehicles.

Evaporative Emissions

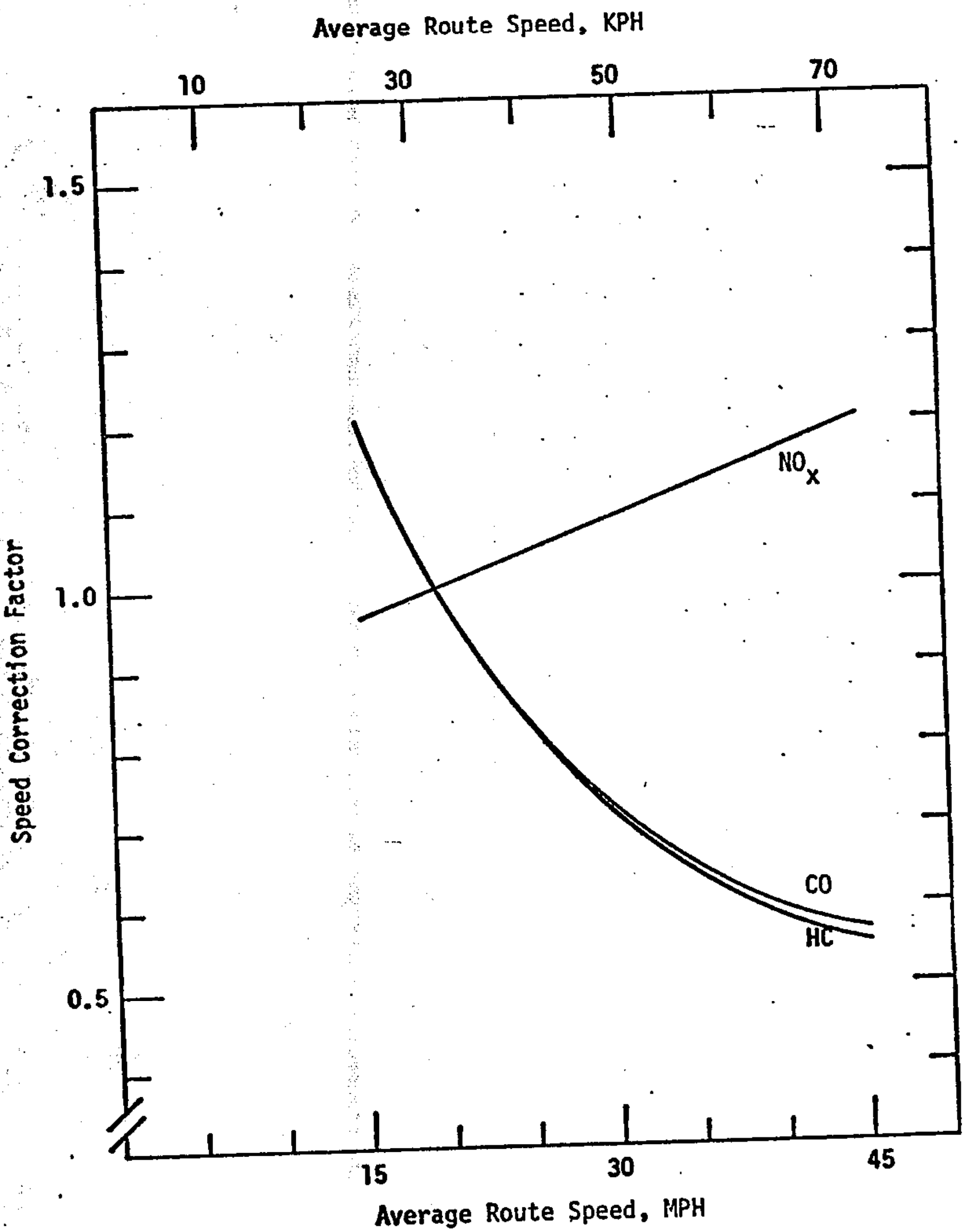
Evaporative emissions of hydrocarbons are 2 gms/test, effective 1973.

TABLE 12-15

REACTIVITY FACTORS

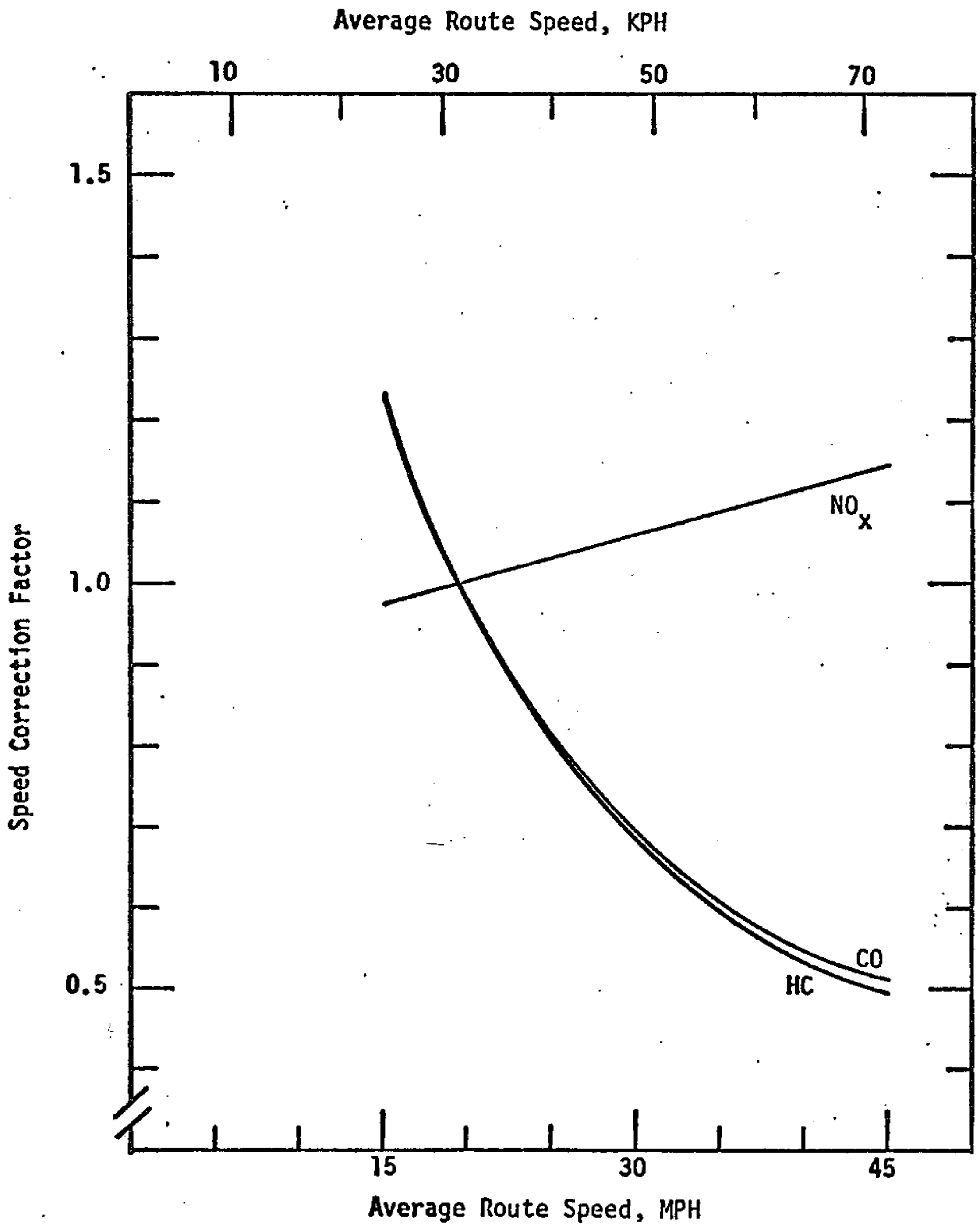
Emission Source	Factor
Exhaust from gasoline-powered vehicles (not equipped with catalytic converters)	0.8
Exhaust from gasoline-powered vehicles (equipped with catalytic converters)	0.64
Gasoline evaporation	0.95
Crankcase	0.88
Exhaust from diesel-powered vehicles	0.99

FIGURE 12-1



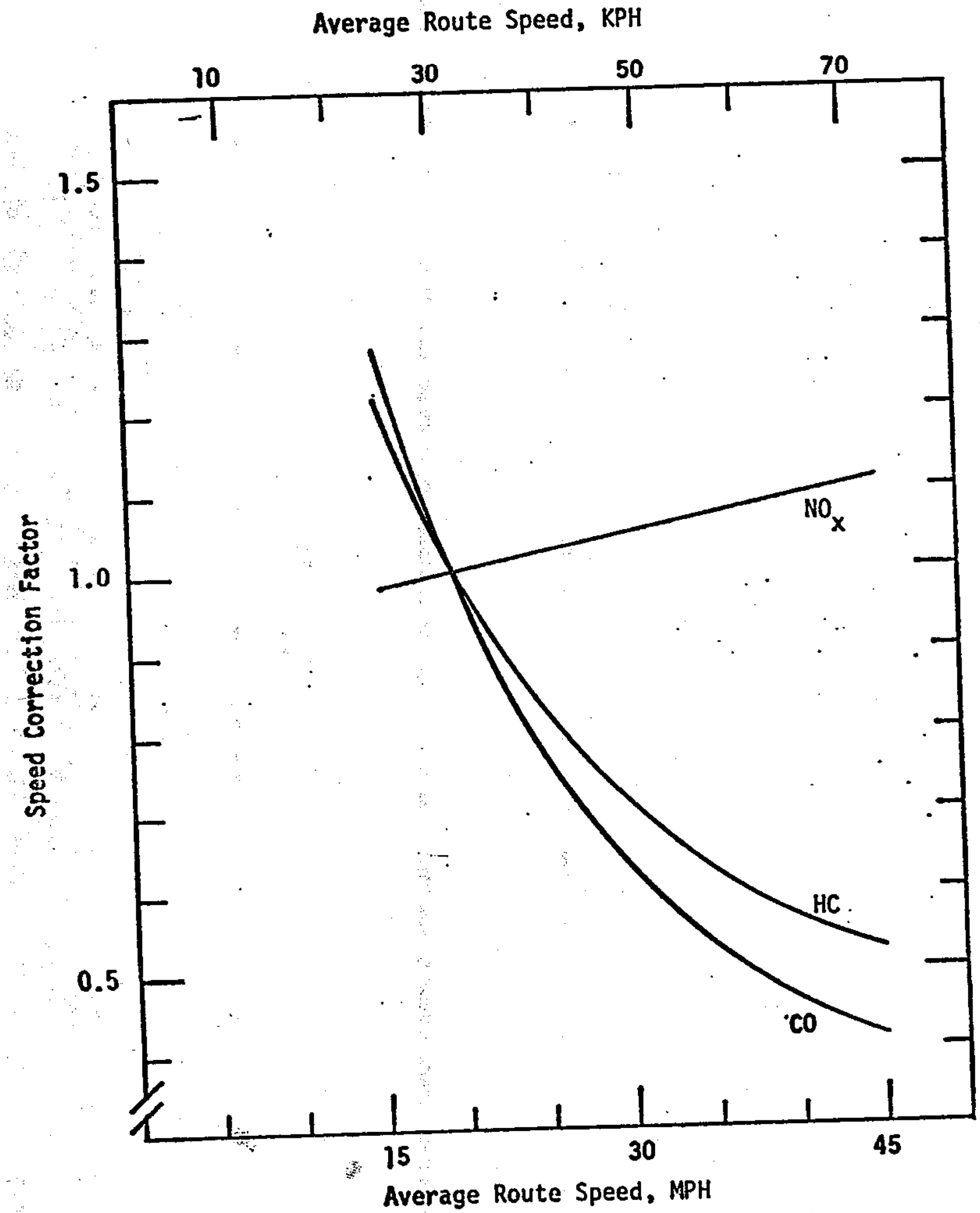
Speed Adjustment Factor for 1967 and Earlier Vehicles

FIGURE 112-2



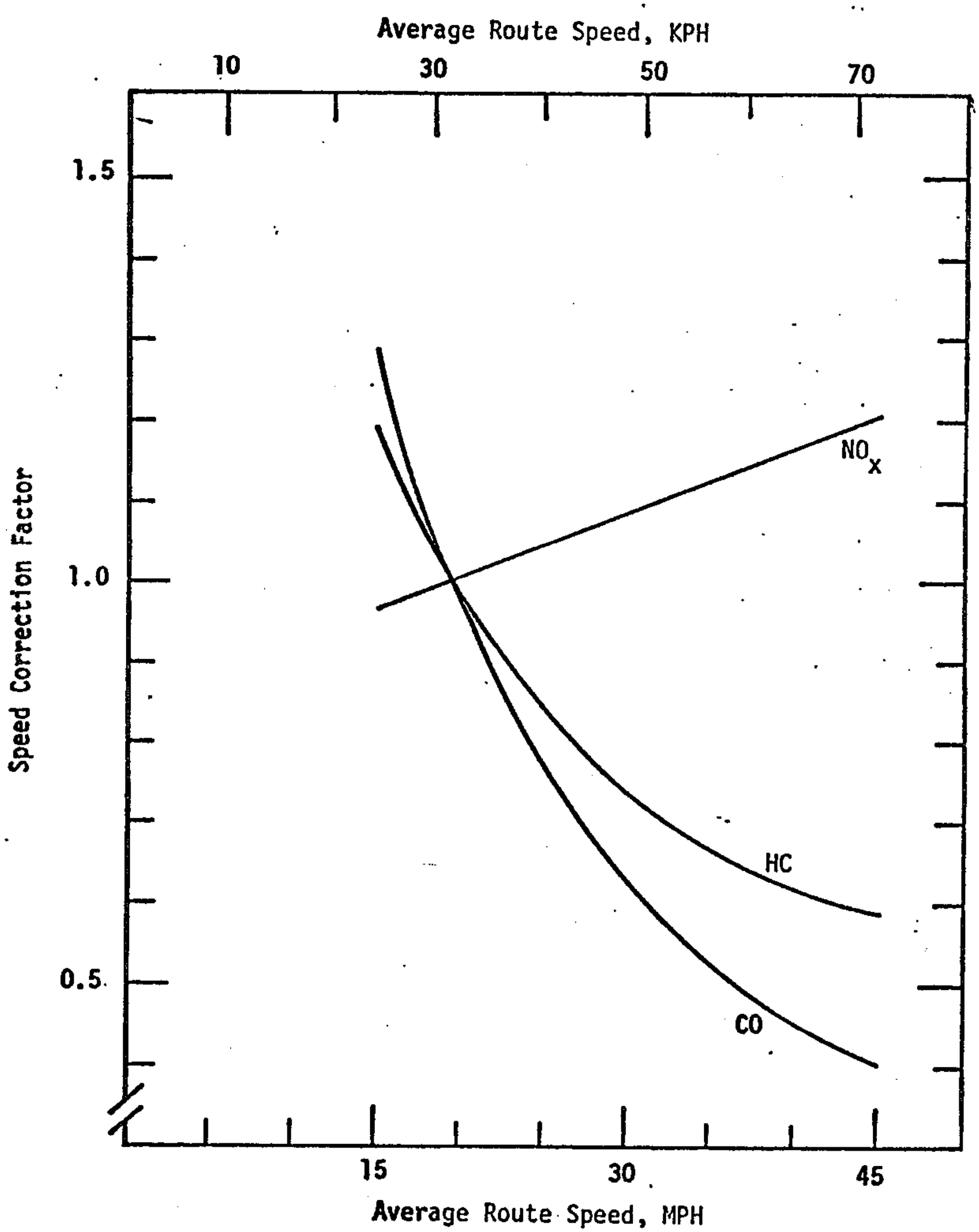
Speed Adjustment Factor for 1968 Vehicles

FIGURE 12-3



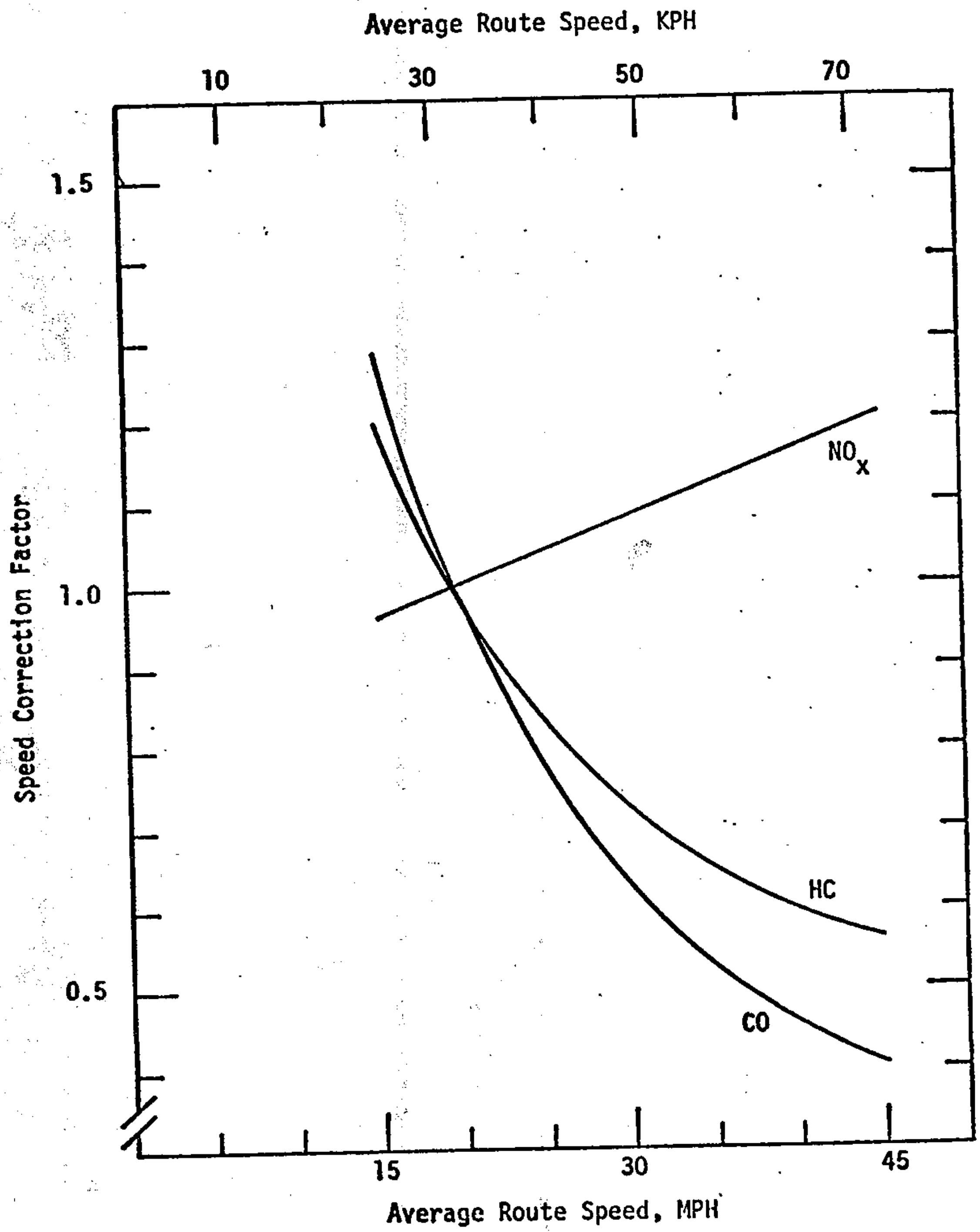
Speed Adjustment Factor for 1969 Vehicles

FIGURE 12-4



Speed Adjustment Factors for 1970 Vehicles

FIGURE E2-5



Speed Adjustment Factor for 1971 and later Vehicles

FIGURE 12-6

PERCENT OF MILES TRAVELED VS. LIGHT DUTY VEHICLE AGE

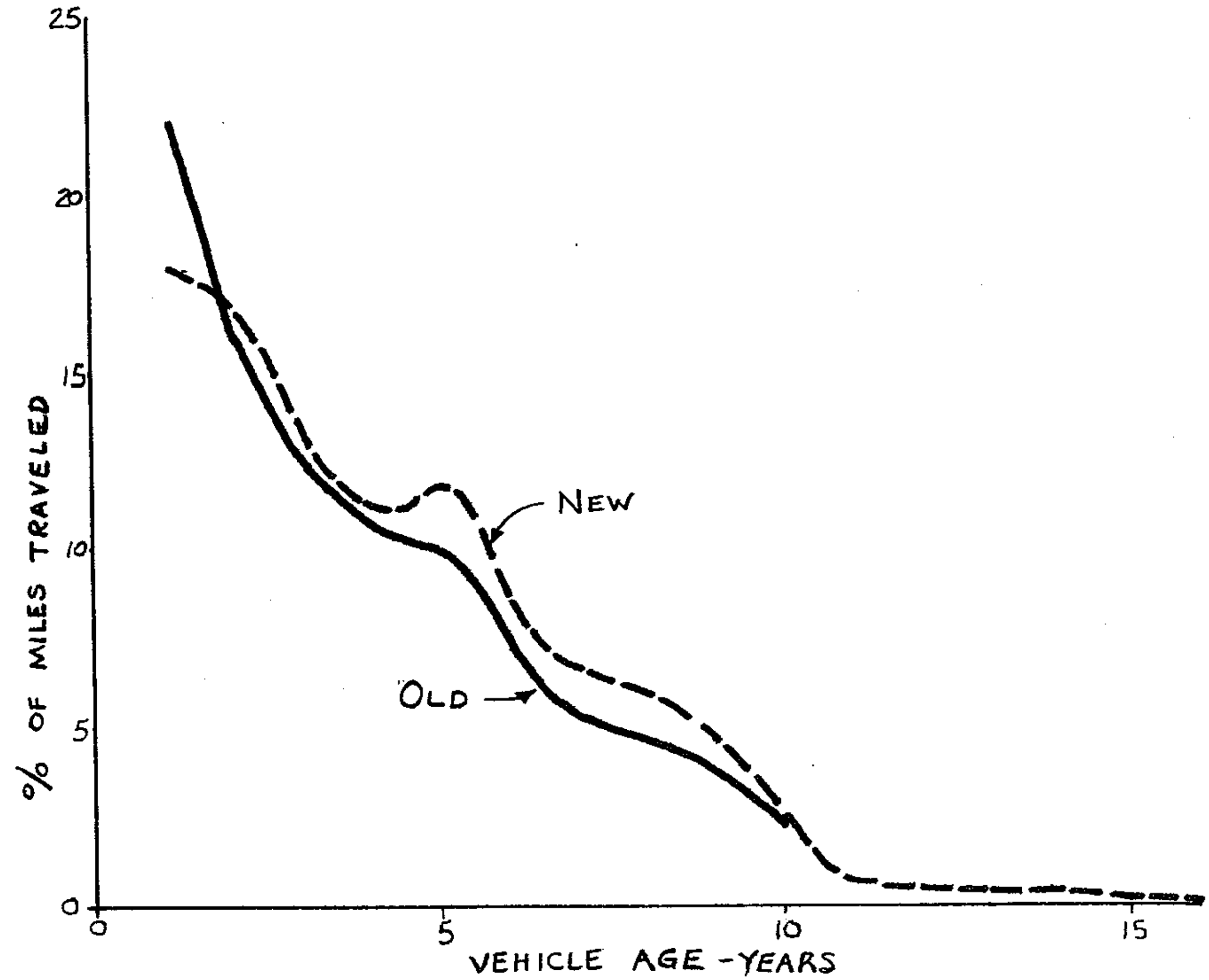


FIGURE 12-7

PERCENT OF MILES TRAVELED VS. HEAVY DUTY VEHICLE AGE

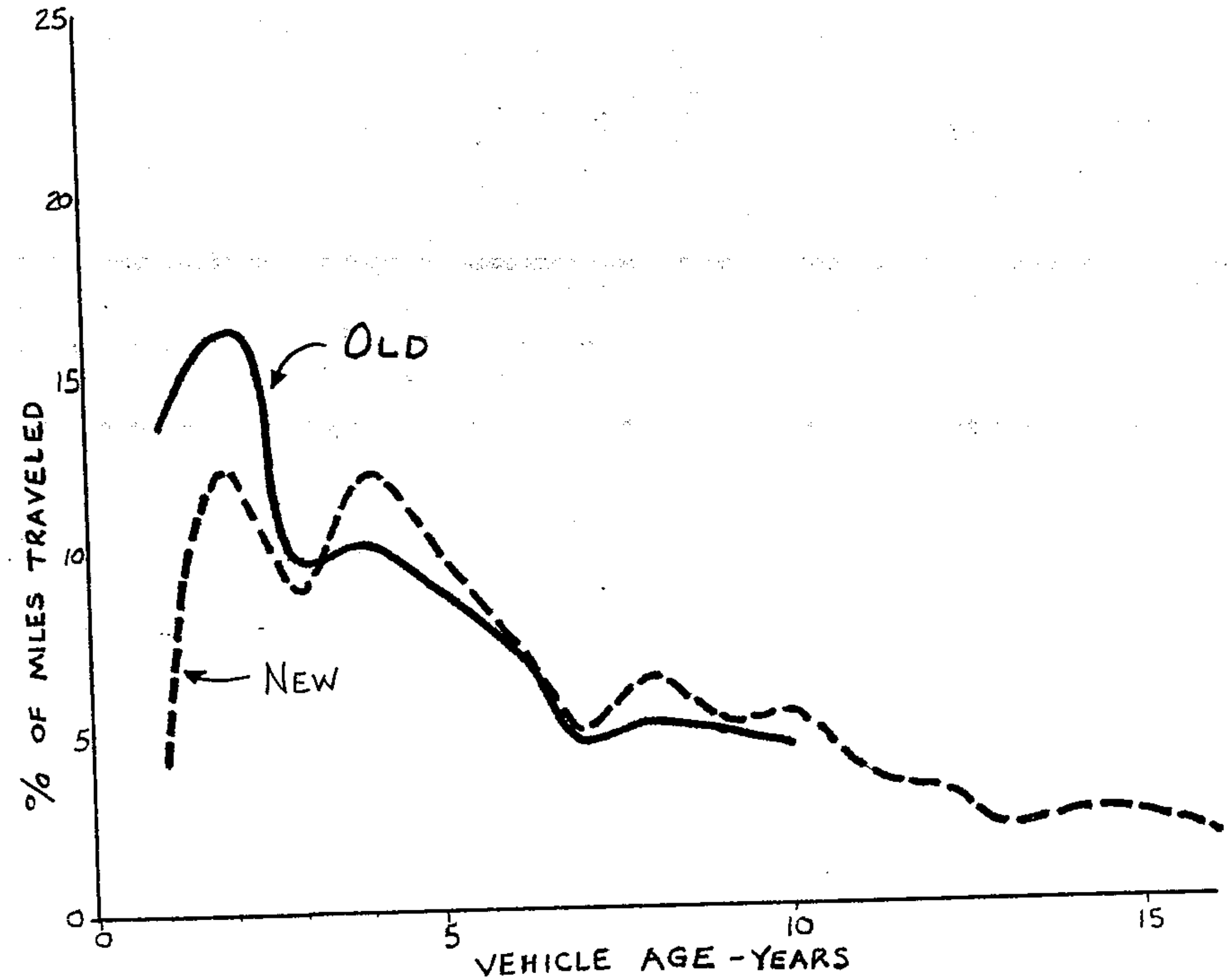


FIGURE 12-8

EXHAUST CO EMISSION FACTOR VS. YEAR

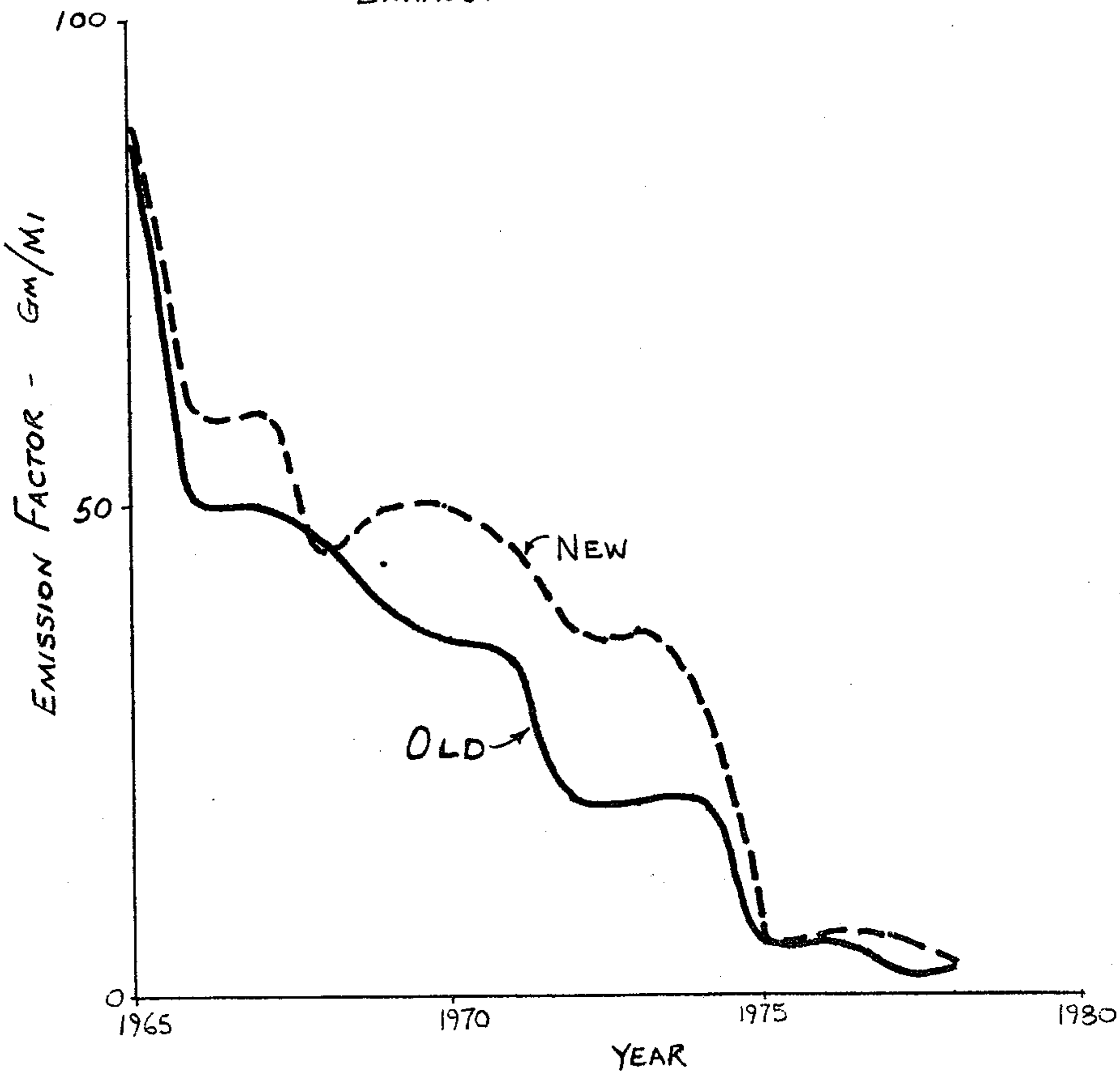


FIGURE 12-9

Exhaust NO_x Emission Factor vs. Year

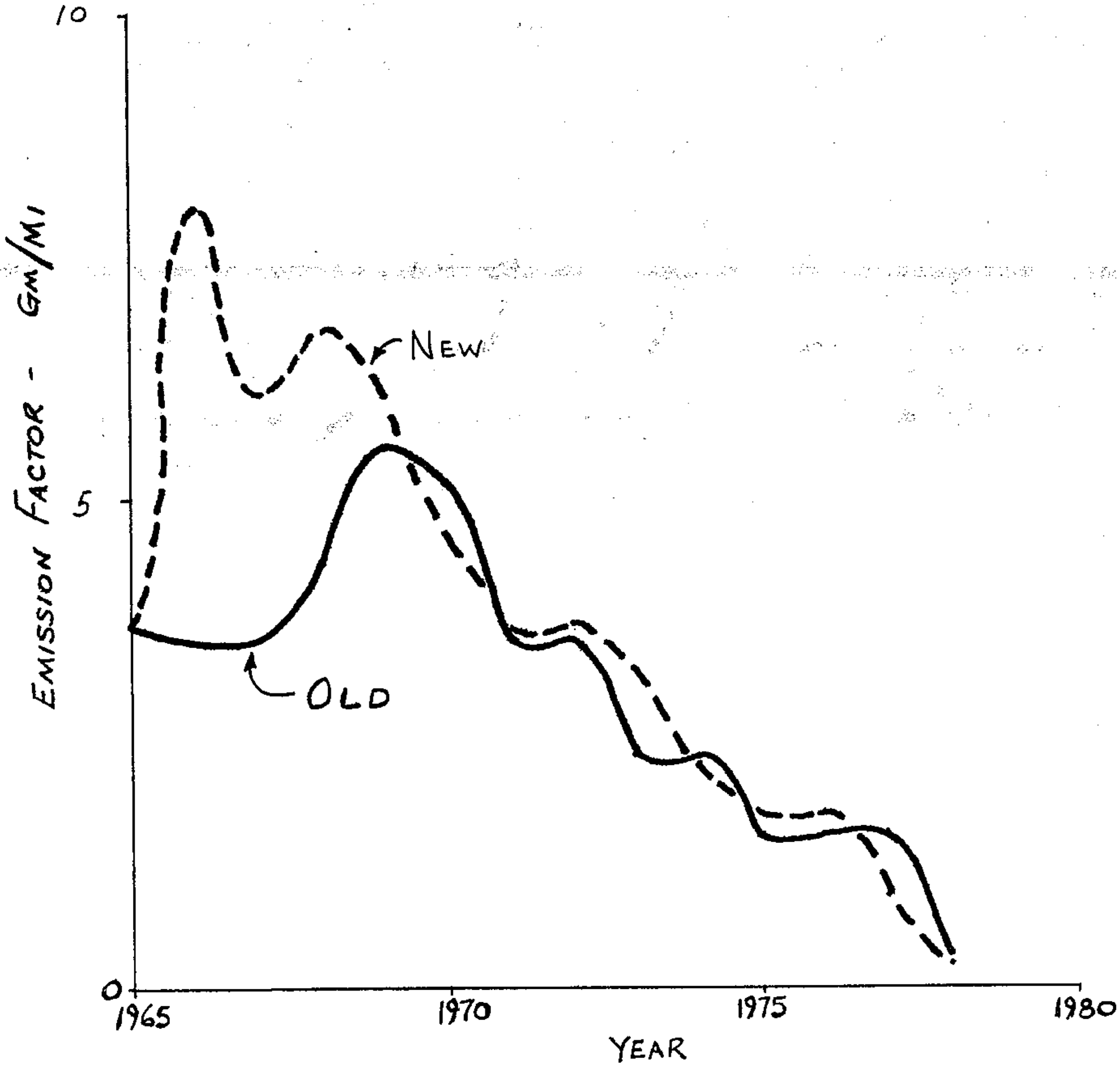


FIGURE 12-10

EXHAUST HC EMISSION FACTOR VS. YEAR

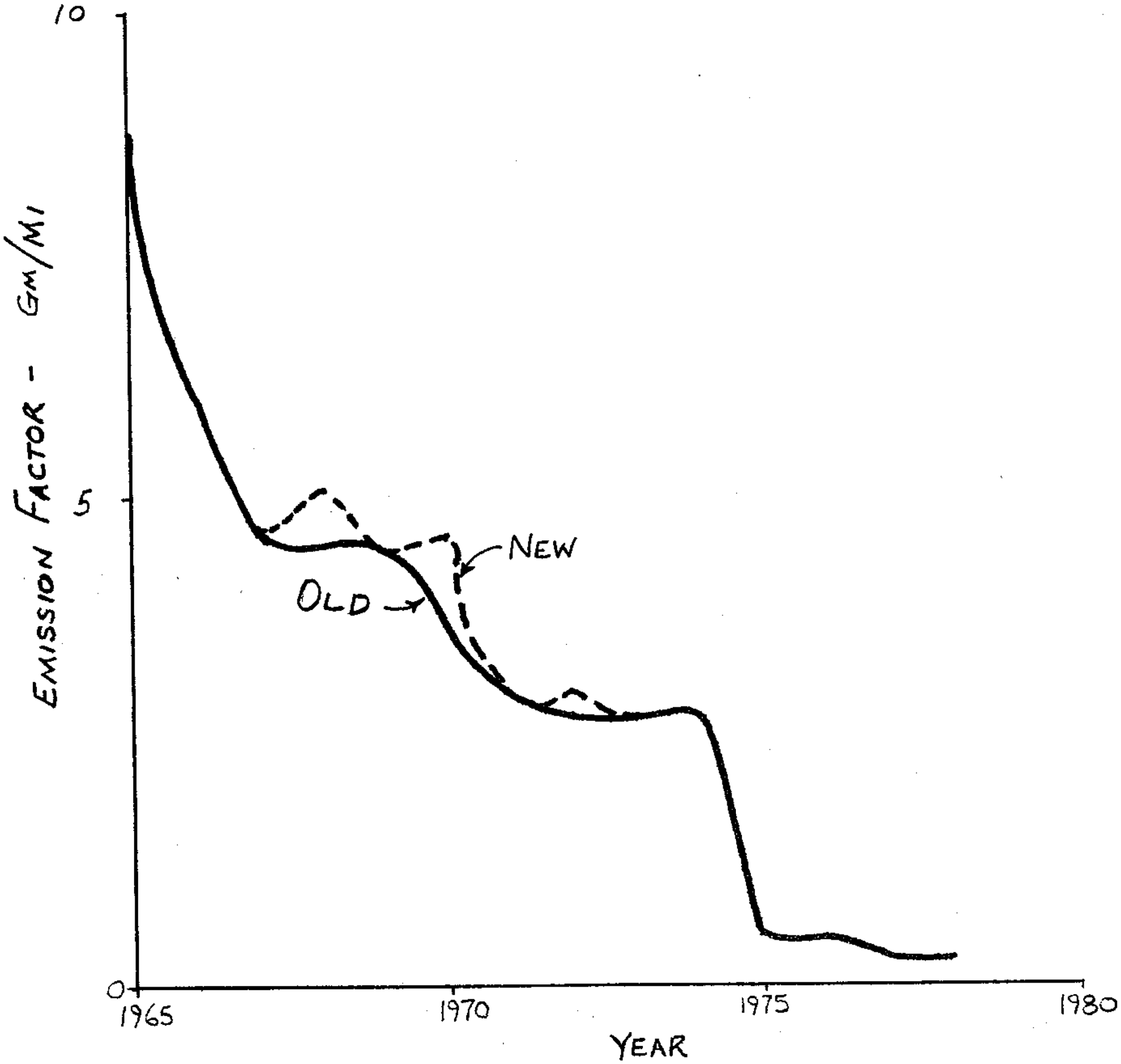


FIGURE 12-11

1975 LDV CO Deterioration Factors vs. Vehicle Age

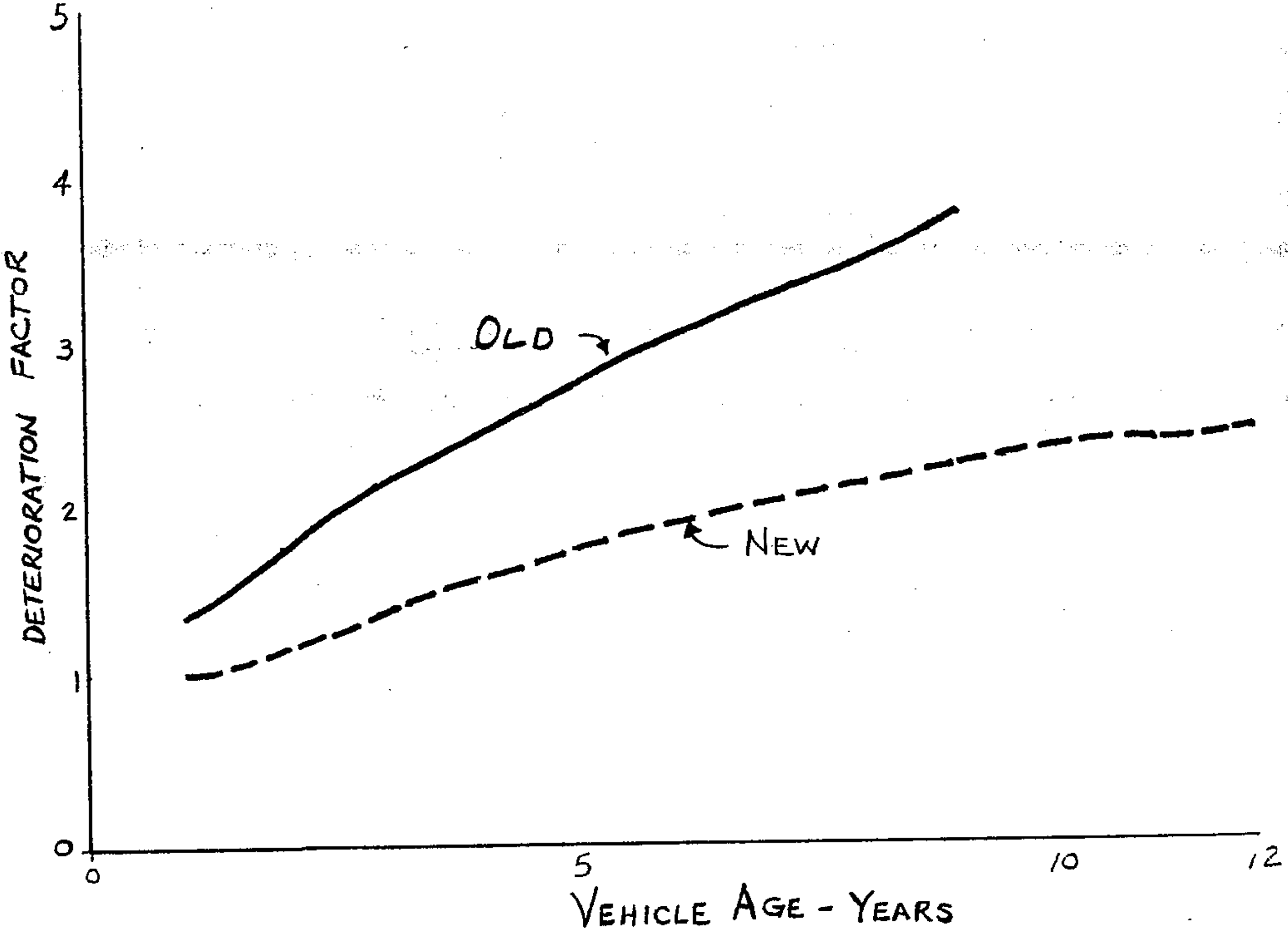


FIGURE 12-12

1975 LDV NO_X DETERIORATION FACTORS VS. VEHICLE AGE

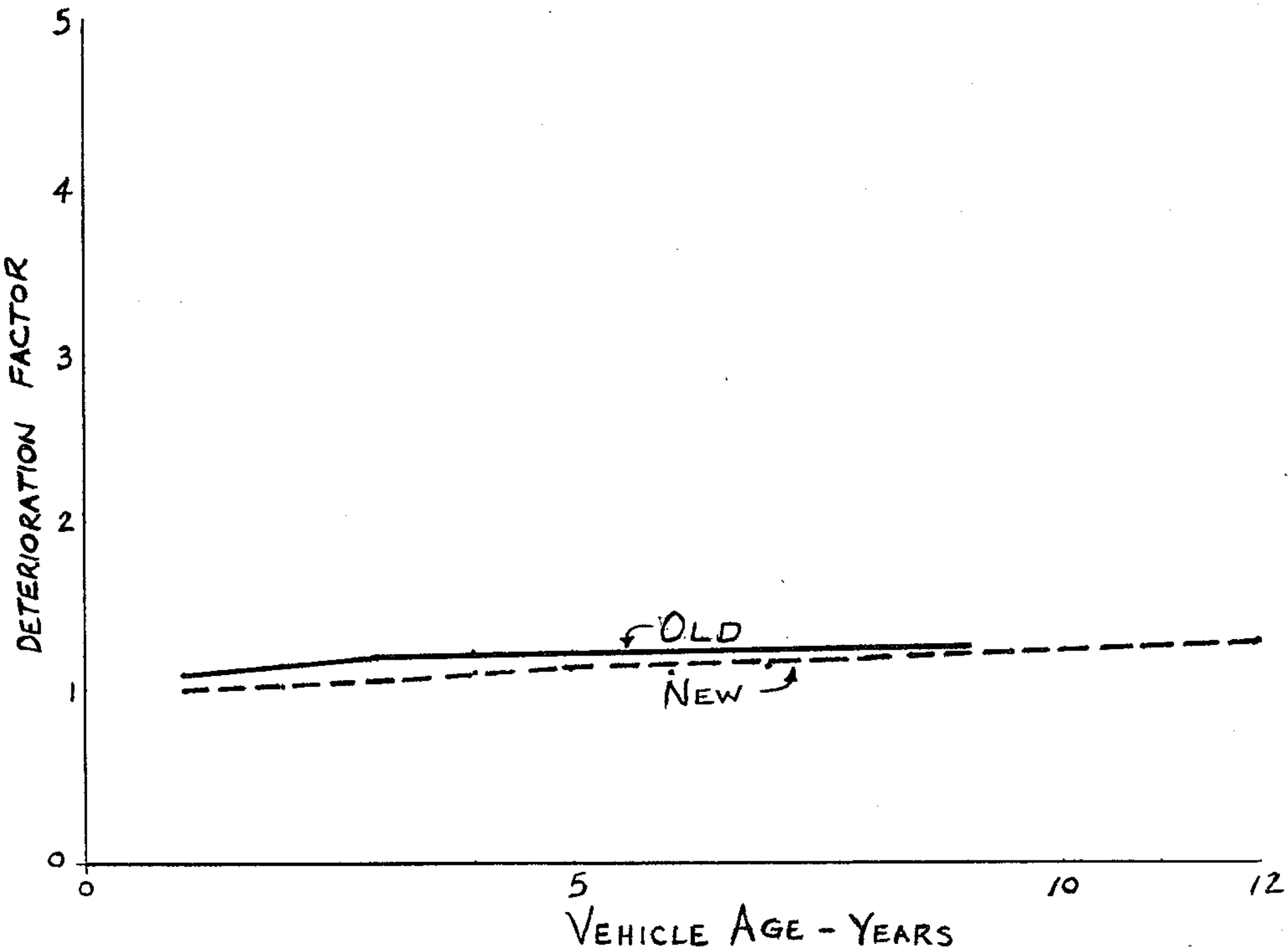


FIGURE 12-13

1975 LDV HC Deterioration Factors vs. Vehicle Age

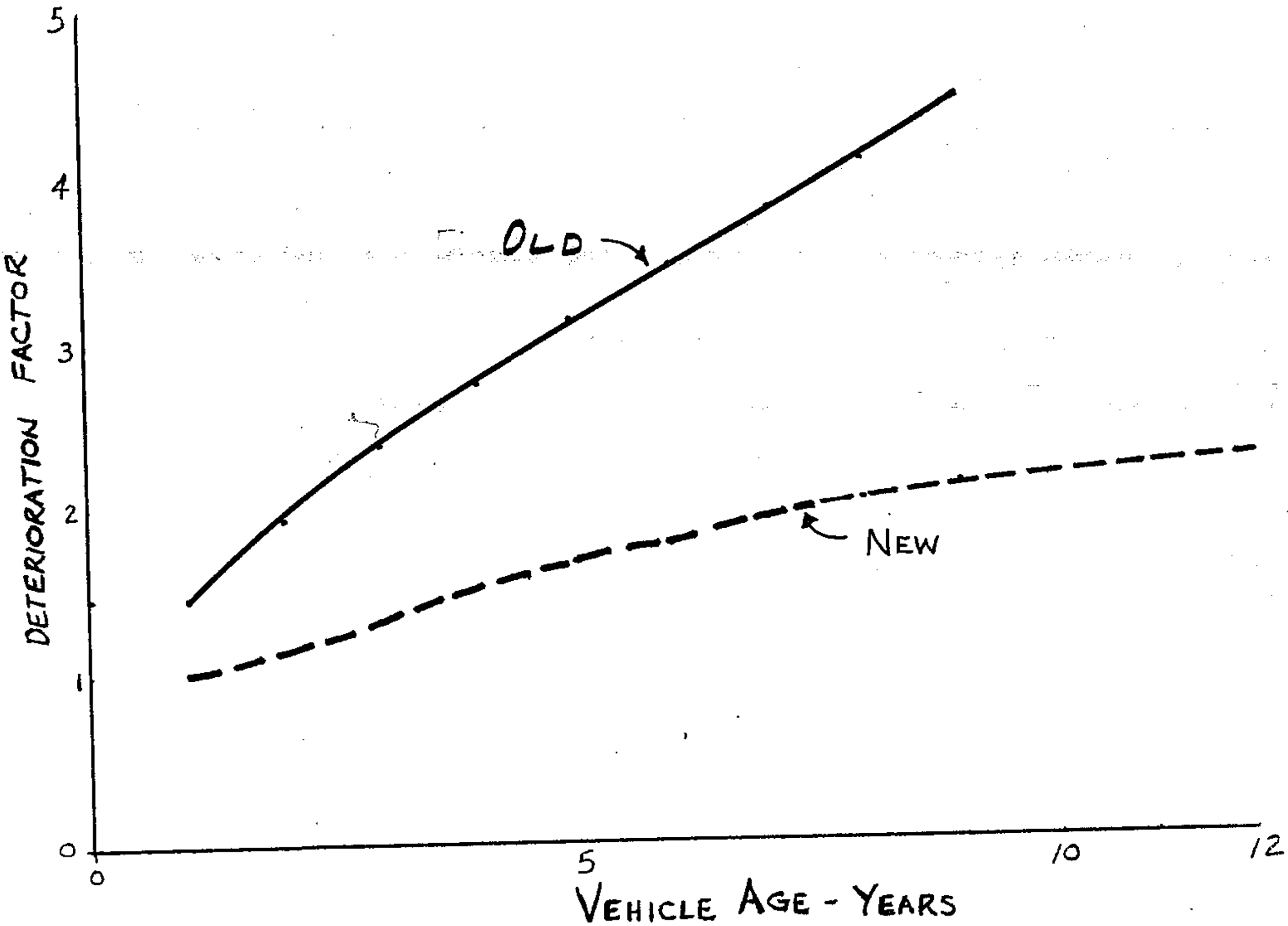


FIGURE 12-14

COMPOSITE CO EMISSION FACTOR @ 20 MPH VS. YEAR

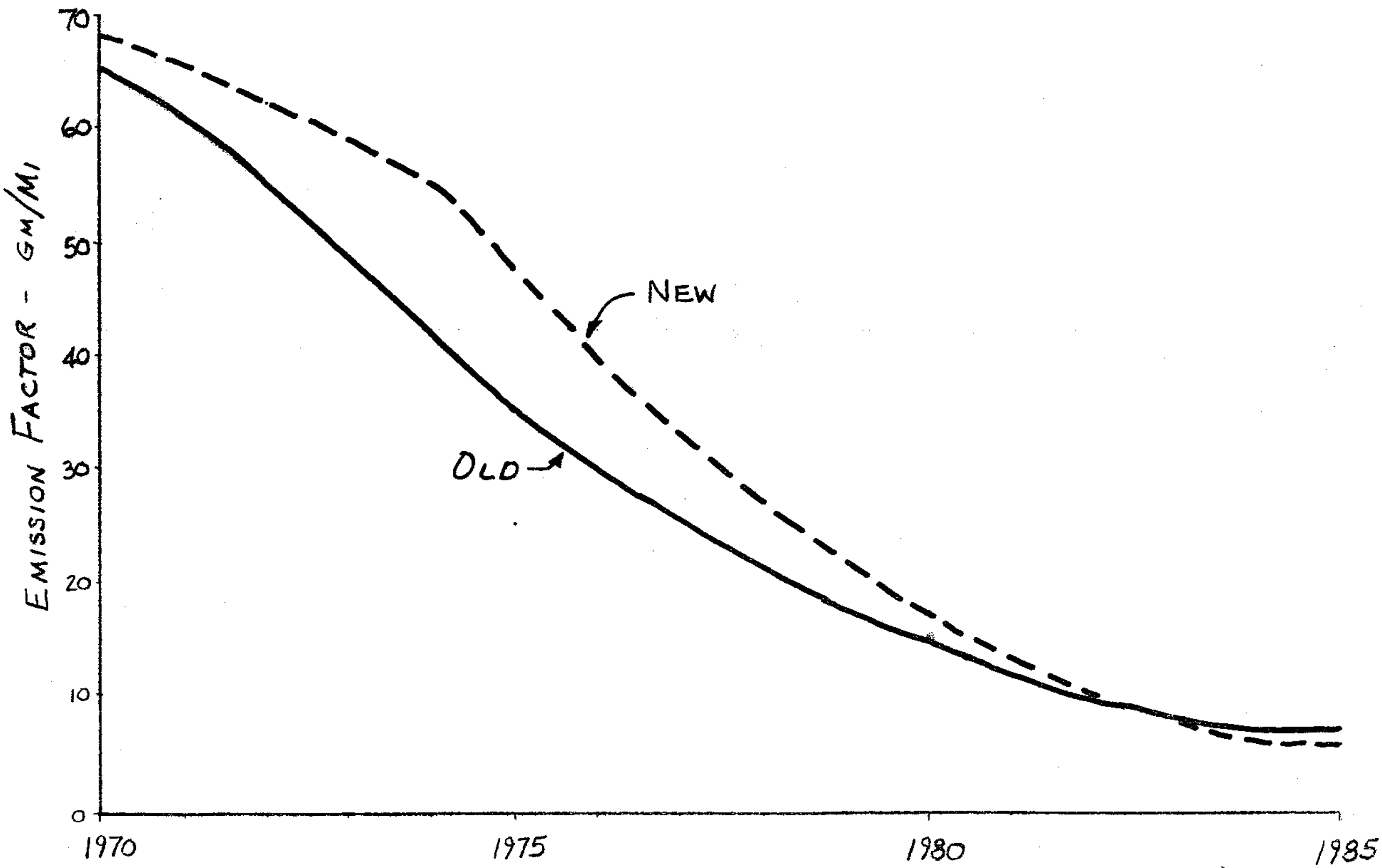


FIGURE 12-15

COMPOSITE NO_x EMISSION FACTOR @ 20 MPH VS. YEAR

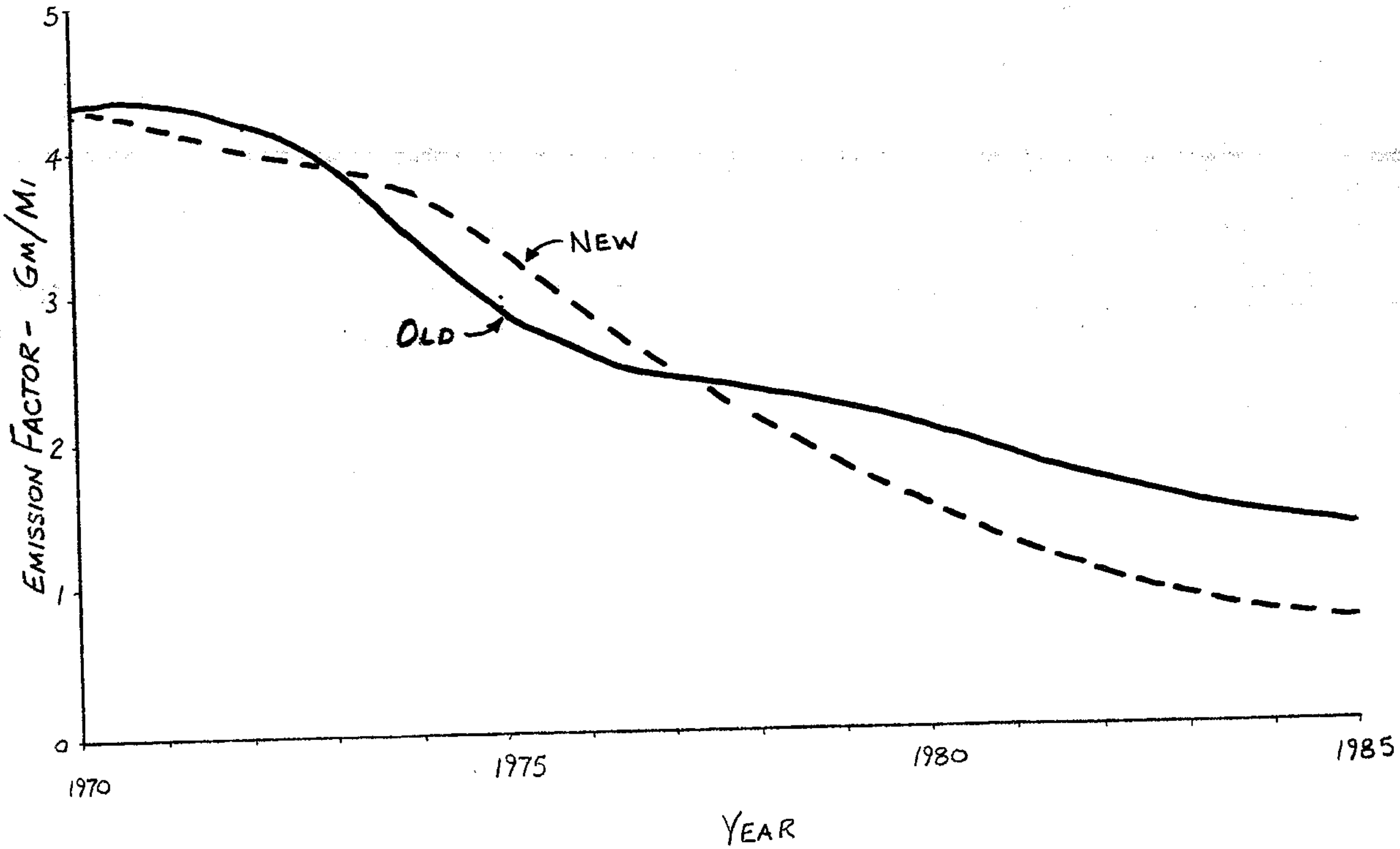


FIGURE 12-16

COMPOSITE HC EMISSION FACTOR @ 20 MPH VS. YEAR

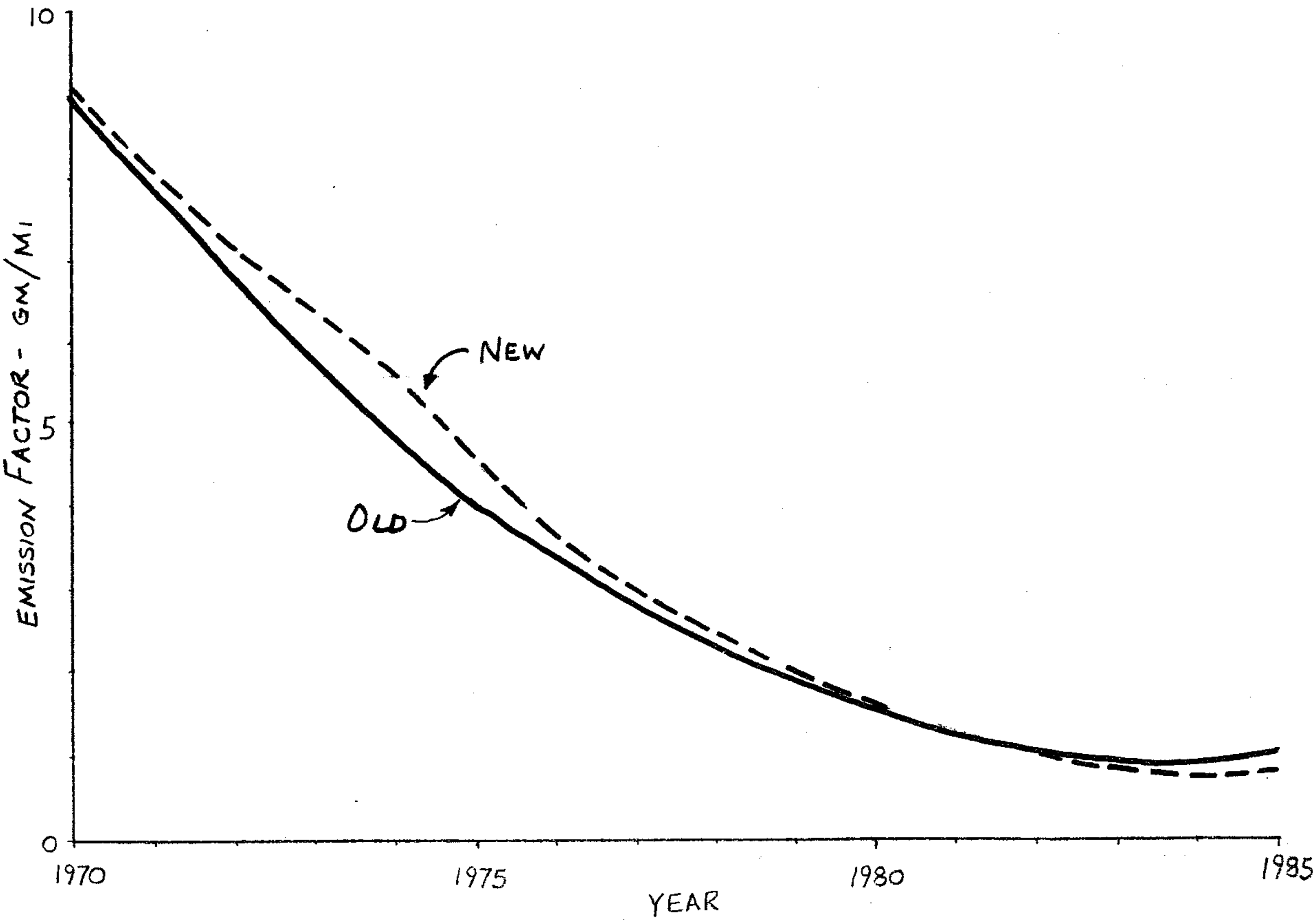
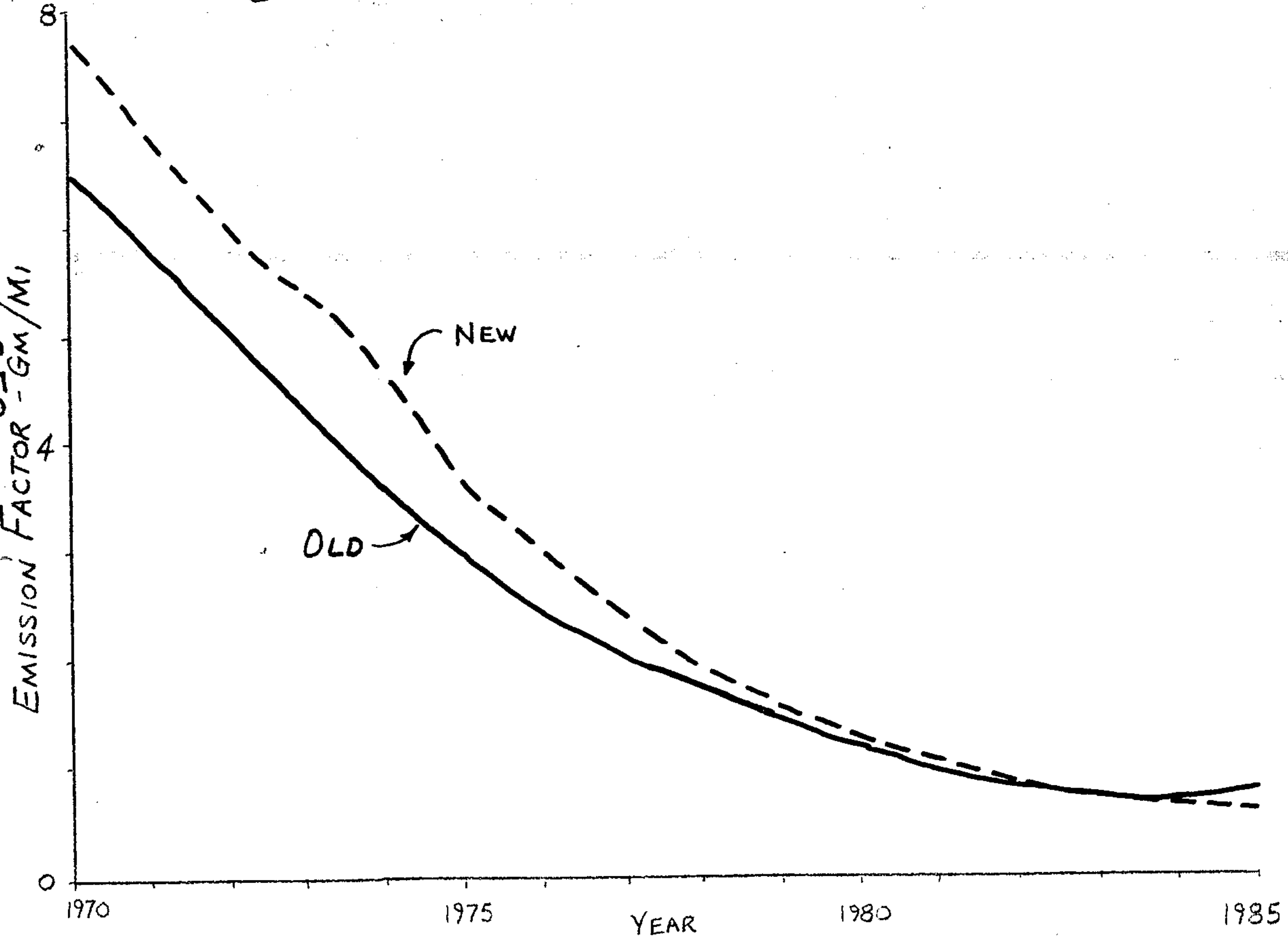


FIGURE 12-17

COMPOSITE REACTIVE HC EMISSION FACTOR @ 20 MPH VS. YEAR



SECTION 13
VEHICULAR EMISSIONS FOR PHOTOCHEMICAL MODELS

MAJOR ELEMENTS OF TRANSPORTATION MODELS

I REVIEW OF REQUIREMENTS OF PHOTO-CHEMICAL MODELS.

II ZONES, NETWORKS AND ASSIGNMENTS

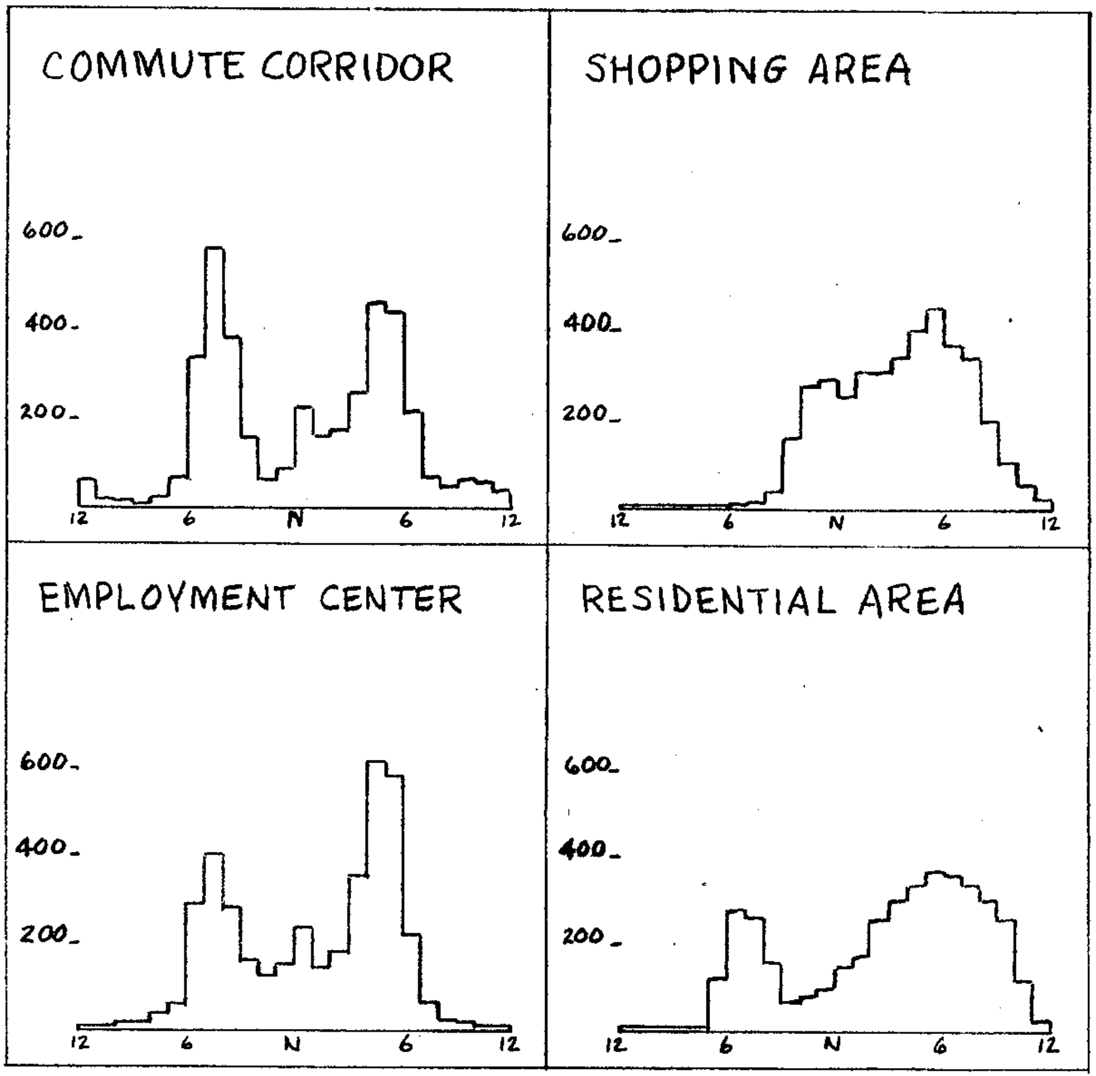
III ORIGIN AND DESTINATION STUDIES

IV VEHICLE EMISSIONS MODEL

V TRIP ESTIMATION MODEL

THE SAI MODEL REQUIRES THE TEMPORAL AND SPACIAL DISTRIBUTION OF POLLUTANT FLUXES (BY GRID SQUARE)

EMISSIONS IN KILOGRAMS VERSUS TIME OF DAY



TYPICAL LAND USE RELATED EMISSION EFFECTS

COMMUTE CORRIDOR

HOME TO WORK TRIPS
MORNING AND EVENING PEAKS
CONGESTED SPEEDS

SHOPPING AREA

HOME TO SHOP TRIPS
LATE MORNING THROUGH EVENING TRAVEL
HOT SOAKS SUBSTANTIAL
DELIVERY TRUCK TRAVEL

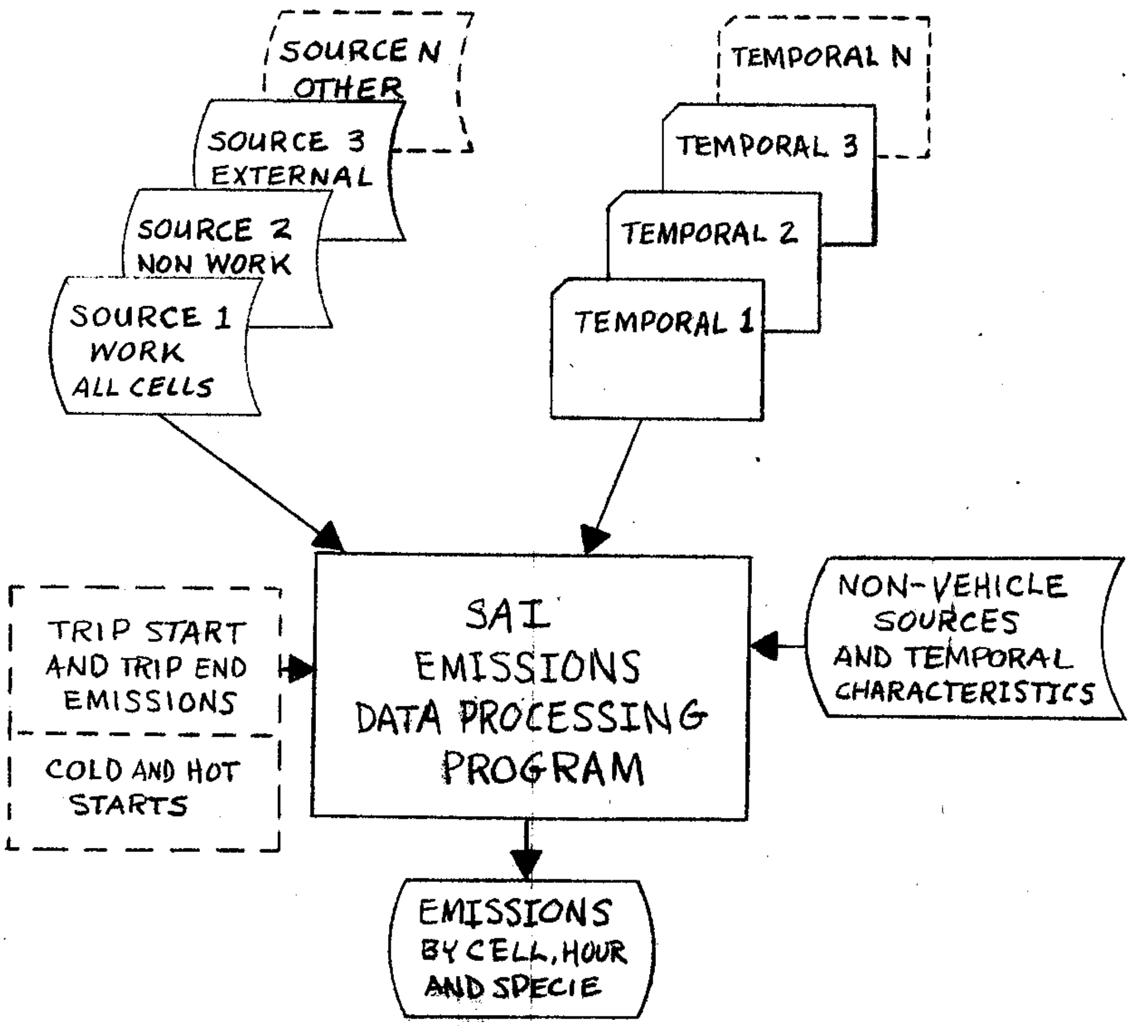
EMPLOYMENT CENTER

WORK RELATED TRAVEL
EARLY MORNING ARRIVALS
LONG HOT SOAKS
DAYTIME COMMERCE-SOME TRUCKS
EVENING COLD STARTS

RESIDENTIAL AREA

HOME BASED TRIPS
MORNING COLD STARTS
START AND END DAYTIME TRAVEL
EVENING HOT SOAK

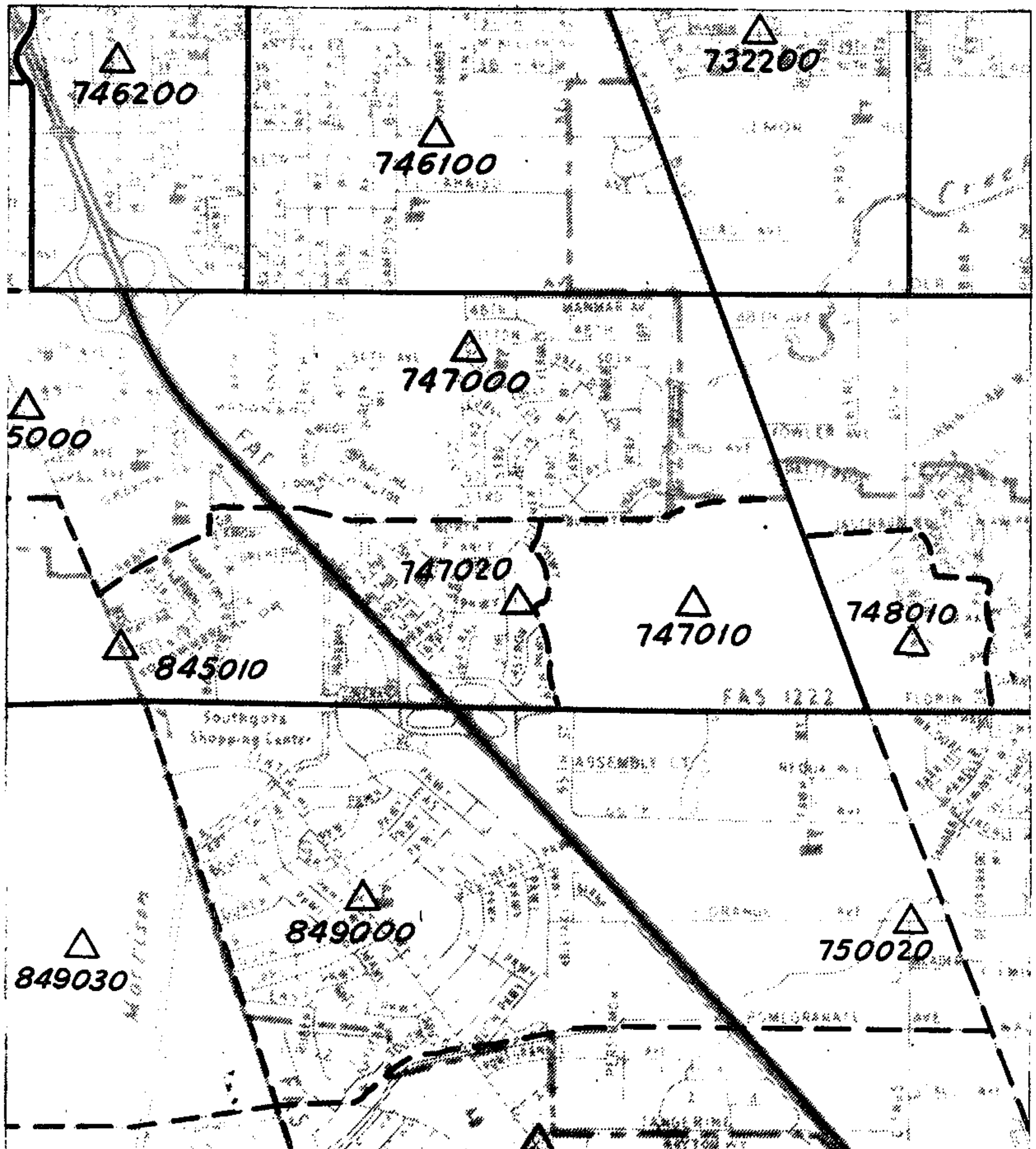
FOR PHOTO-CHEMICAL MODELS, DIFFERENT TRIP PURPOSES ARE TREATED AS DIFFERENT SOURCES WITH DIFFERENT TEMPORAL PATTERNS.



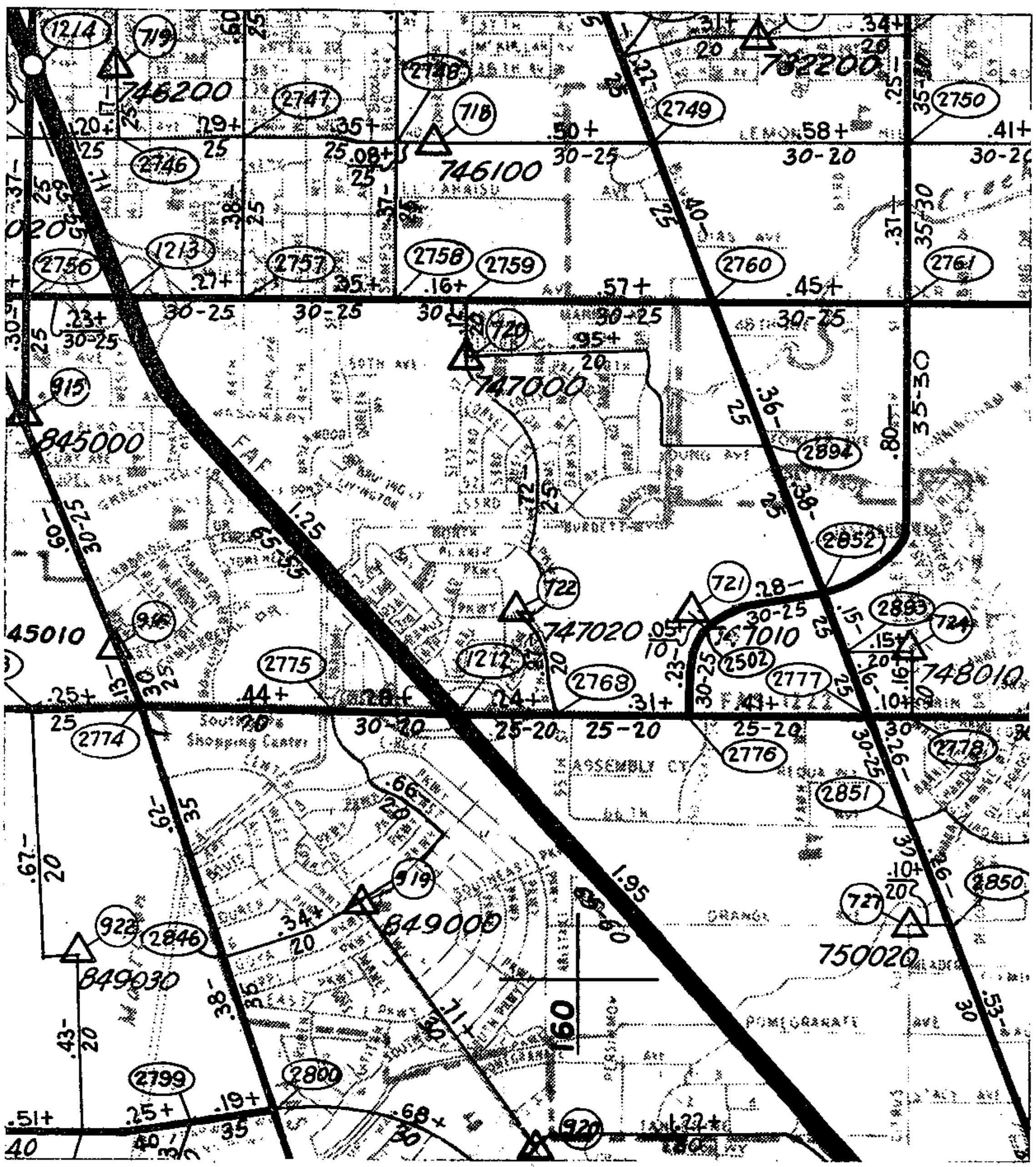
II ZONES, NETWORKS AND ASSIGNMENTS

ZONES AND CENTROIDS

- CENSUS TRACTS ARE DIVIDED INTO TRAFFIC ZONES
- ALL TRIPS START AND END AT CENTROIDS



ALL ROADS ARE REPRESENTED BY THE NETWORK DIRECTLY OR SUMMARILY AS <u>LINKS</u>



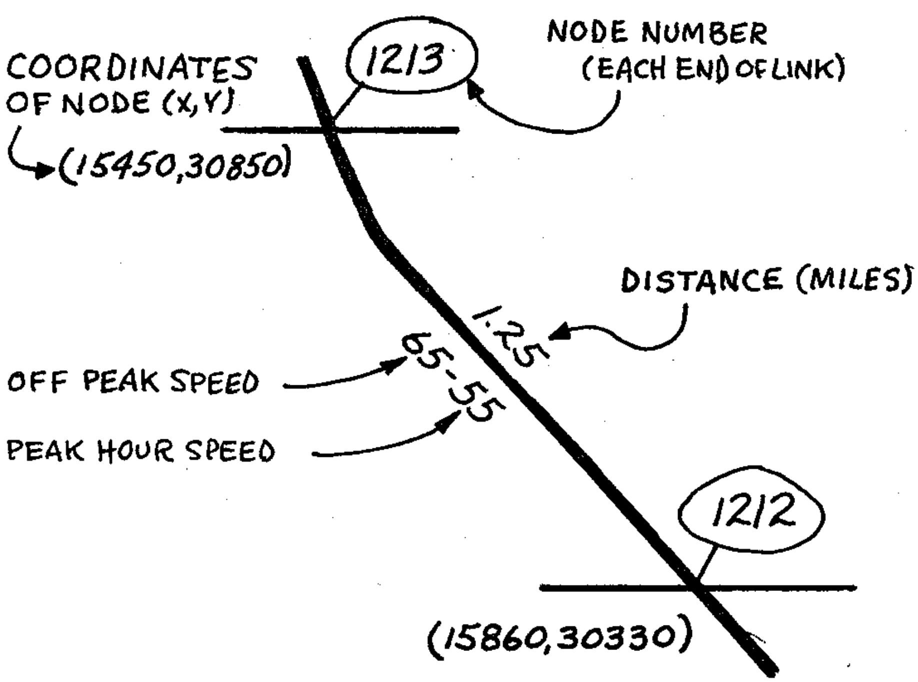
FOR EACH LINK THE FOLLOWING INFORMATION IS RECORDED:

NODE NUMBERS

LENGTH (DISTANCE IN MILES)

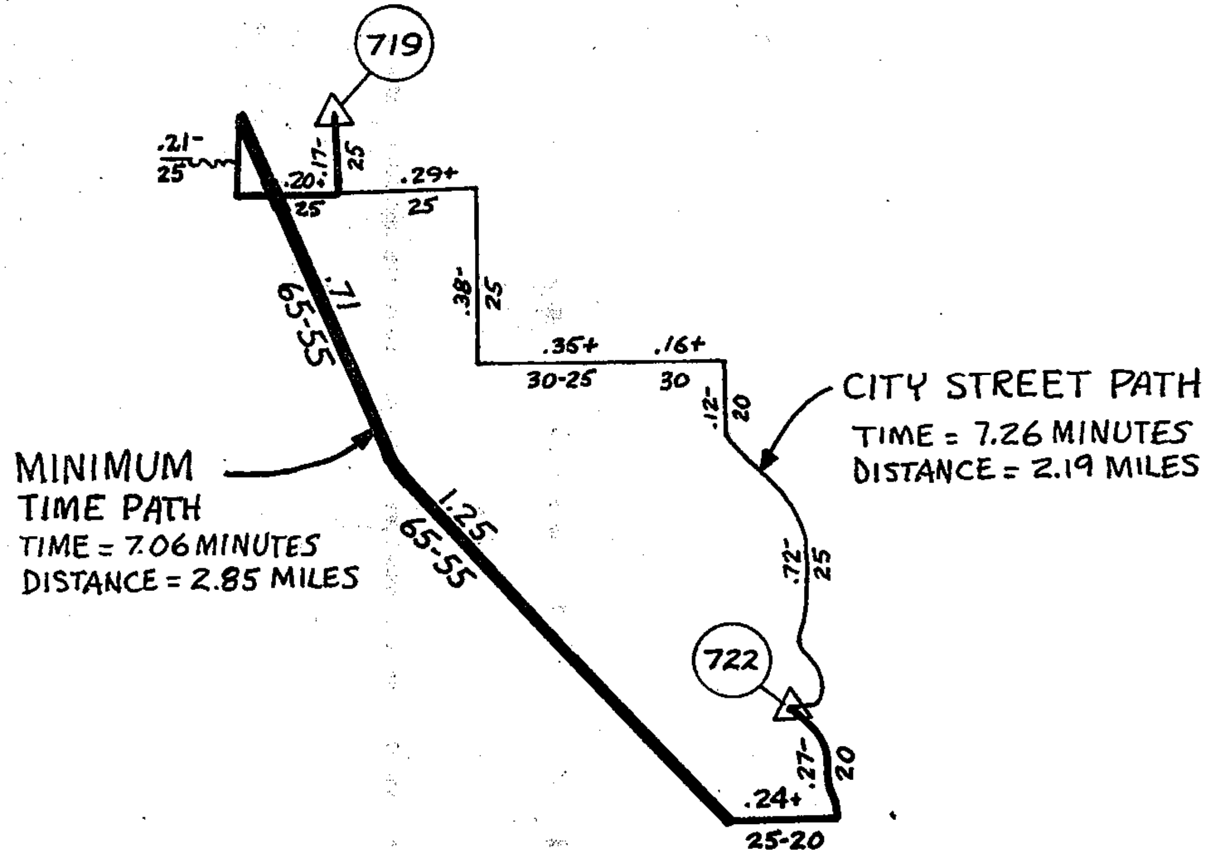
SPEED (PEAK AND OFF-PEAK IN MPH)

LOCATION (COORDINATES AT BOTH NODES)



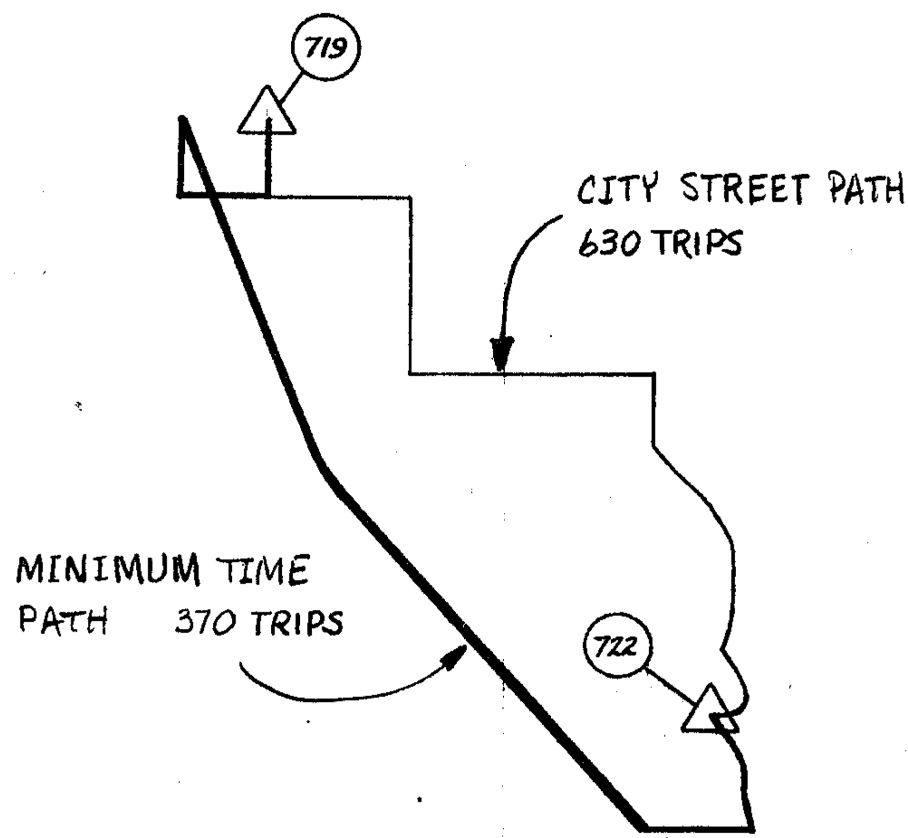
USING THE LINK INFORMATION ON THE NETWORK, MINIMUM TIME PATHS ARE CALCULATED.

PEAK HOUR TRAFFIC



TRIP ASSIGNMENT

TRIPS ARE DIVIDED BETWEEN MINIMUM TIME PATHS AND CITY STREET PATHS IN THE ASSIGNMENT PROCESS.



III ORIGIN AND DESTINATION STUDIES

HOME INTERVIEWS

ROADSIDE SURVEYS

SCREENLINE ANALYSIS

HOME INTERVIEWS

- HOUSING UNIT REPORT
  - HOW MANY RESIDENTS
  - HOW MANY VEHICLES
- OCCUPANT REPORT
  - PERSONAL CHARACTERISTICS
- TRIP REPORT
  - WHERE TRIPS BEGIN AND END
  - WHEN THE TRIP WAS MADE
  - WHY THE TRIP WAS MADE

SACRAMENTO AREA TRANSPORTATION STUDY

HOME INTERVIEW FORM

HOUSING UNIT SUMMARY

Confidential–The information obtained will be accorded confidential treatment. Individual reports will be used for statistical purposes only.

POPULATION AND VEHICLES

HOUSING UNIT TYPE

I. IDENTIFICATION

A SAMPLE NUMBER ☐☐☐☐☐☐☐ GROUP QUARTERS SEQUENCE ☐☐☐ ☐

B INTERVIEW ADDRESS ____

C TRAVEL DAY ____ ☐ TRAVEL DAY DATE ____ ☐☐☐

D. CITY CODE ☐☐ PHONE ____

E. HOUSING UNIT TYPE

SINGLE FAMILY STRUCTURE	A	☐
ROOMING HOUSE (5 OR LESS)	B	☐
ROOMING HOUSE (OVER 5)	C	☐
HOUSE TRAILER	D	☐
DUPLEX (2 UNITS)	E	☐
TRIPLEX (3 UNITS)	F	☐
FOURPLEX (4 UNITS)	G	☐
APARTMENT (5 OR MORE UNITS)	H	☐ → NO OF UNITS IN STRUCTURE ☐☐☐
HOTEL	I	☐
OTHER (DESCRIBE) ____	J	☐
MOTEL	K	☐
DORMITORY	L	☐
MILITARY BARRACKS	M	☐
YMCA OR YWCA	N	☐
FRATERNITY OR SORORITY	O	☐
UNKNOWN	P	☐

II. HOUSEHOLD INFORMATION

A HOW MANY PERSONS LIVE HERE? ☐☐ 5 YEARS OLD OR OLDER ☐☐

B DO YOU OWN OR RENT THIS RESIDENCE? (OWN 1) (RENT 2) (2ND HOME 3) (UNKNOWN 4) ☐

C HOW MANY VEHICLES ARE OWNED OR USED REGULARLY BY PERSONS WHO LIVE HERE? (INCLUDE COMPANY VEHICLES KEPT AT HOME) ☐

PASSENGER CARS (STATION WAGONS, ETC.) ☐

PICKUP OR PANEL TRUCKS (TOTAL) ☐ → HOW MANY HAVE PASSENGER PLATES (ABC 123 ETC) ☐

OTHER TRUCKS (TOTAL) ☐ → HOW MANY HAVE PLATES THAT START WITH W, X, Y & Z ☐

D. HOW MANY TRAILERS ARE OWNED BY PERSONS LIVING HERE? ☐ MISCELLANEOUS OWNERSHIP BY PERSONS LIVING HERE

HOUSE TRAILERS ☐ MOTORCYCLES (3 WHEELS OR LESS) ☐

BOAT TRAILERS ☐ CAMPER BODIES (NOT VEHICLES) ☐

OTHER UTILITY TRAILERS ☐ POWERED BOATS ☐

OTHER BOATS ☐

F HOW MANY GARAGE, CARPORT, OR DESIGNATED PARKING SPACES, OTHER THAN IN THE DRIVEWAY OR ON THE STREET, ARE AVAILABLE TO THIS HOUSEHOLD AT THESE PREMISES? ☐

G. DO PERSONS AT THIS ADDRESS DRIVE ANY OTHER VEHICLES? ____ YESTERDAY? ____

H WERE THERE VISITORS FROM OUT OF THE AREA YESTERDAY? ____

III. SUMMARY (Fill After Interview)

A NUMBER OF DRIVER TRIPS RECORDED ☐☐☐ NUMBER OF PASSENGER TRIPS PRIVATE ☐☐☐ PUBLIC ☐☐☐ NUMBER OF OTHER 1ST TRIPS ☐☐ TOTAL TRIPS ☐☐☐

B NUMBER OF HOUSEHOLD MEMBERS 5 YEARS OR OLDER MAKING TRIPS ☐☐ NOT MAKING TRIPS ☐☐ TRIPS UNKNOWN ☐

IV. ADMINISTRATIVE RECORD

INTERVIEWER ____

SUBSTITUTE TRAVEL DAY: ENTIRE H U ☐ PARTIAL ☐ NORMAL WEEKDAY ☐ FRI ☐ SAT ☐ SUN ☐ MON ☐

CALLS				APPOINTMENTS	
NUMBER	DAYS AFTER TRAVEL DAY	TIME	RESULT OF THIS CALL	DATE	TIME
1					
2					
3					
4					
5					
6					

CIRCLE CALL NUMBER ON WHICH INTERVIEW FINALLY COMPLETED OR ENTER NON-INTERVIEW CODE ☐

COMPLETED INTERVIEW 0

NON-INTERVIEW CODES

TYPE A: 1 SICKNESS; 2 NO ONE HOME; 3 REFUSED; 4 OTHER (SPECIFY); 5 PARTIAL

TYPE B: 6 VACANT; 7 DEMOLISHED; 8 COMMERCIAL USE; 9 TRANSIENT

INTERVIEWER'S NOTES AND COMMENTS ____

SUPERVISOR'S NOTES AND COMMENTS ____

FOR OFFICE USE ONLY

EDITED BY ____ DATE ____

CORRECTED BY ____ DATE ____

CODING	CODER	CHECKER	REVIEWER
HOUSEHOLD INFORMATION			
OCCUPANT INFORMATION			
TRIP INFORMATION			

COMPLETE AFTER INTERVIEW

RENT OR MARKET VALUE

1 2 3 4 5 6 7
8 = DON'T KNOW
9 = REFUSED

HOUSEHOLD INCOME

A B C D E F
G H I J K L M
N = DON'T KNOW
O = REFUSED

FORM H UP-251 REV 3 68

V. OCCUPANTS OF THE HOUSING UNIT

A. IDENTIFICATION

SAMPLE NUMBER ☐☐☐☐☐☐☐ GROUP QUARTERS SEQUENCE ☐☐☐ TRAVEL DAY ☐

DOUBLE CHECK FOR AGREEMENT WITH OTHER SIDE OF THIS FORM

SHEET ____ OF____

EMPLOYMENT

B	C	D	E	F	G	H	I		J	K	L							M	N
(1) PERSON LETTER	RELATIONSHIP TO HEAD OF HOUSEHOLD	SEX	AGE	WERE YOU AWAY FROM HOME YESTERDAY(TO)	DO YOU HAVE A VALID CALIF. DRIVERS LICENSE	(2) RESIDENCE STATUS	HOW LONG HAVE YOU LIVED IN THIS COUNTY?		WHERE DID YOU LIVE ONE YEAR AGO? (CALIF. COUNTY OR EXTERNAL STATE OR COUNTRY)	WERE YOU IN THE ARMED FORCES ONE YEAR AGO?	ARE YOU PRESENTLY (3)							IN WHAT INDUSTRY? (FOR CODE 1 ONLY IN COL. L)	WHERE DO YOU WORK? (FOR CODE 1 ONLY IN COL. L)
							YEARS	MONTHS			EMPLOYED	SEEKING WORK	RETIRED	STUDENT	HOUSEWIFE	DISABLED	OTHER		
A		M F		Y N	Y N U					Y N	1	2	3	4	5	6	7		
B		M F		Y N	Y N U					Y N	1	2	3	4	5	6	7		
C		M F		Y N	Y N U					Y N	1	2	3	4	5	6	7		
D		M F		Y N	Y N U					Y N	1	2	3	4	5	6	7		
E		M F		Y N	Y N U					Y N	1	2	3	4	5	6	7		
F		M F		Y N	Y N U					Y N	1	2	3	4	5	6	7		
G		M F		Y N	Y N U					Y N	1	2	3	4	5	6	7		
H		M F		Y N	Y N U					Y N	1	2	3	4	5	6	7		
I		M F		Y N	Y N U					Y N	1	2	3	4	5	6	7		
J		M F		Y N	Y N U					Y N	1	2	3	4	5	6	7		

(1) CIRCLE FOR PERSONS INTERVIEWED

(2) CODES FOR COLUMN H
1. CITIZEN - LEGAL RESIDENCE
2. CITIZEN - OTHER RESIDENCE
3. ALIEN - PERMANENT
4. ALIEN - TEMPORARY

(3) FOR HOUSEHOLD MEMBERS 14 YEARS OR OLDER

NOTES: ____________________

FORM H-UP-251 REV. (1/70)

SAMPLE NUMBER | GROUP QUARTERS SEQUENCE | TRAVEL DAY | TRAVEL DAY DATE | CITY CODE | SHEET ___ OF ___

VI TRIP REPORT

1	2	3	4	5	6	7	8	9	10	11	12	13	14
PERSON IDENT	TRIP NUMBER	ENTER ONE OF THE FOLLOWING (IN ORDER OF PREFERENCE) 1 THE NAMES OF THE STREETS OF THE NEAREST INTERSECTION OR 2 THE EXACT HOUSE NUMBER AND STREET OR 3 THE NAME OF A WELL-KNOWN BUILDING (SCHOOL STORE ETC) WHERE DID THIS TRIP BEGIN? (END?)	LAND USE	HOW DID YOU TRAVEL?	ASK OF TRUCK DRIVERS, AND PUBLIC BUS PASSENGERS (CODES D, & H ITEM 5) COMMODITY AND MASS TRANSIT DATA	WHAT WAS THE PURPOSE OF THIS TRIP? (IF SERVE PASSENGER OR CHANGE TRAVEL MODE, INDICATE THE ULTIMATE PURPOSE ALSO)	FIRST TRIP TO WORK PLACE?	TIME OF TRIP BEGINNING (END)	TIME SPENT WALKING AT TRIP BEGINNING (END) (IN MIN)	ASK OF VEHICLE DRIVERS ONLY (CODES A-D ITEM 5): USE FWY? FREEWAY USE	OVER-NIGHT TRIPS?	WHAT KIND OF PARKING WAS DONE?	PARKING AND VEHICLE OCCUPANCY DATA
PERSON LETTER	END / BEGIN			A AUTO DRIVER; B TAXI DRIVER; C PICKUP DRIVER; D TRUCK DRIVER; E AUTO PASSENGER; F TAXI PASSENGER; G PICKUP OR TRUCK PASS; H PUBLIC BUS PASS; I SCHOOL BUS PASS; K WALK, L MOTOR CYCLE (OTHER 1ST TRIP TO WORK)	COMMODITY CARRIED; COMMODITY WEIGHT; DID LICENSE START WITH W, X, Y OR Z? Y U N; WAS THIS TRIP MADE ONLY FOR YOUR BENEFIT? YES = 1 NO = 0; NO. OF TRANSFERS; TIME SPENT IN TRANSFERS (IN MIN); TOTAL COST OF TRIP (IN CENTS); WAS A VEHICLE AVAILABLE FOR THIS TRIP? Y N	FROM / TO: TOP, XOP; SERVE PASSENGER; CHANGE TRAVEL MODE; 1, 2 EARNING A LIVING: WORK PLACE, RELATED BUSINESS; 3, 4 LEISURE ACTIVITIES: HOME, 5 SOCIAL OR ENTERTAINMENT RECREATIONAL; 6, 7 OTHER ACTIVITIES: SHOPPING, EDUCATION, 8 OTHER (FAMILY, BUSINESS ETC)	N = 1; IF YES WAS THIS A CAR POOL? Y JOB, N NO, 1, 2	BEGINNING OF TRIP AM PM; END OF TRIP AM PM		FIRST ON RAMP Y N; LAST OFF RAMP Y N	AWAY FROM HOME OVER-NIGHT? Y N; HOW MANY NIGHTS	1 STREET FREE; 2 STREET METER; 3 LOT FREE; 4 LOT PAID; 5 GARAGE FREE; 6 GARAGE PAID; 7 SERVICE OR REPAIRS; 8 RESIDENT PROPERTY; 9 CRUISED; 0 NOT PARKED	TIME SPENT PARKING (IN MIN); TOTAL PERSONS IN VEHICLE 1 2 3 4 5 6 7 8 9+
SEX M F													

TRIP START AND END

TRIP MODE

TRIP PURPOSE

TIME OF START

ROADSIDE SURVEYS

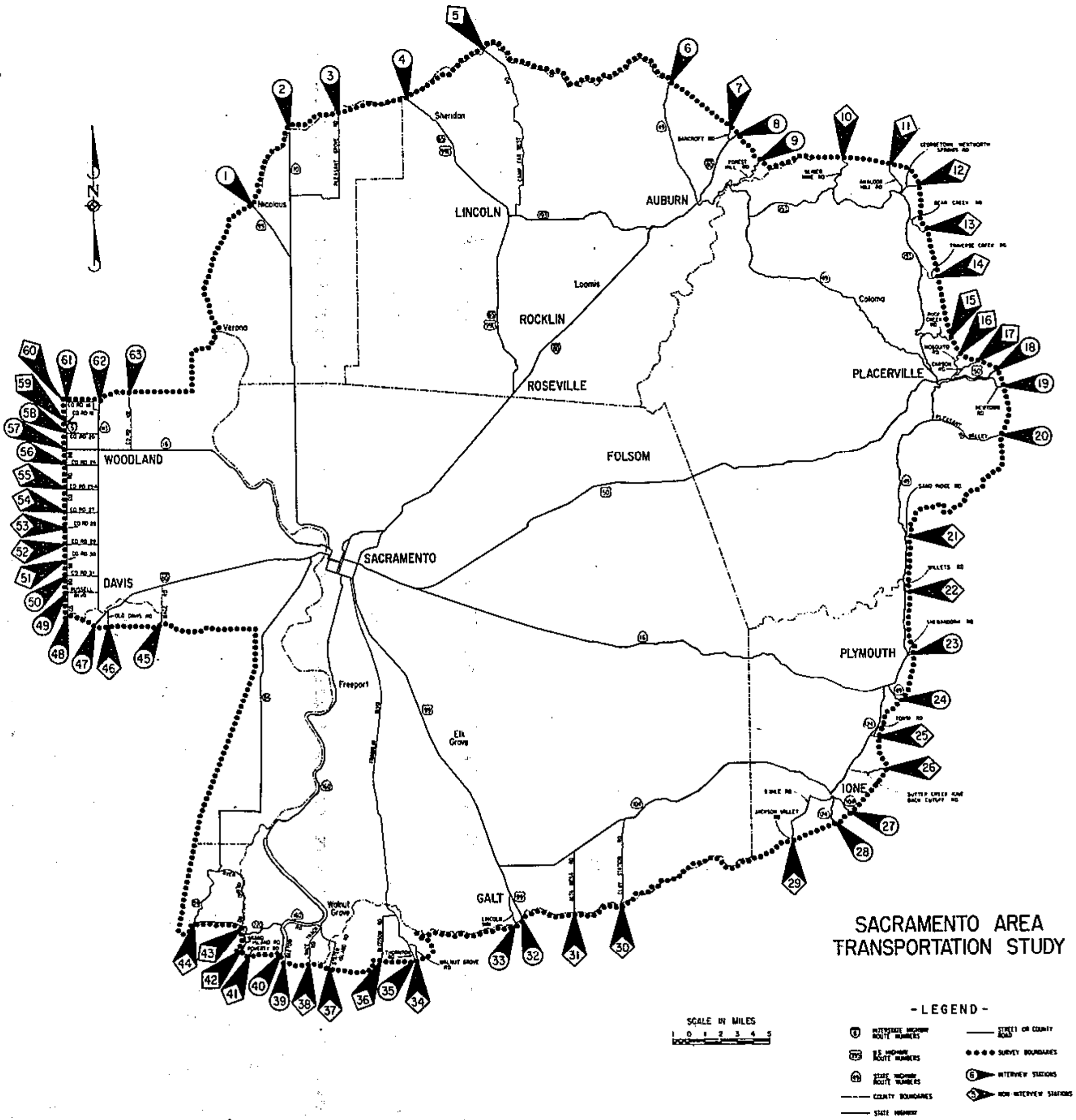
EXTERNAL REPORT (OUTBOUND)

LAST STOP

PURPOSE

TIME

CORDON STATION MAP



TRIP END

STATION [ ][ ]　N 1 | S 2 | E 3 | W 4

URBAN TRANSPORTATION STUDY

EXTERNAL INTERVIEW FORM

HOUR OF EXIT

DATE ________　HOUR BEGINNING 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00　________ Recorder　________ Serial

VEHICLE　TRIP START　TRIP PURPOSE

(1) Line No.	(2) Total Number in Vehicle Including Driver	(3) Type of Vehicle	(4) Where Do You Live? If in Area Internal City: Nearest Intersection or Street Address or Name of Building Etc. If Out of Area: External City or Place	(5) Non Residents (A): Where Did You Enter Area? Station	(6) When? Day (B)	(7) Last Stop Before Entering Area (External City or Place only)	(8) Where was your Last Stop (in Area)? Where Did This Trip Begin? Internal City and Nearest Intersection or Street Address or Name of Building, Etc	Col 9	(9) Purpose of Trip	Col 10	(10) Where Will You Stop Next? Where Will This Trip End? (External City or Place Only)	(11) Is This As Far As You Intend To Go?	(12) Furthermost Destination: External City or Place Only (Complete Only if Column 11 is No)	(13) Trucks Only: Commodity Carried	(14) Commodity Weight
1	1 2 3 4 5 6 7 8 9 Or more	A 2 2D 3 4 5 6	[ ][ ][ ][ ][ ][ ]	[ ][ ]		X[ ][ ][ ][ ][ ]	[ ][ ][ ][ ][ ][ ]	A B / J K L M N P R S T / X Y Z	Work / Related Business / Home / Social or Entertainment / Recreational / Shopping / Education / Serve Passenger / Change Travel Mode / Changing Residence / Other (Family Business, etc.) / Load Commodity / Unload Commodity / Load and Unload	A B / J K L M N P R S T / X Y Z	X[ ][ ][ ][ ][ ]	Yes 1 / No 2	X[ ][ ][ ][ ][ ]	INBOUND [ ][ ] / OUTBOUND [ ][ ]	INBOUND [ ][ ][ ] / OUTBOUND [ ][ ][ ]
2	1 2 3 4 5 6 7 8 9 Or more	A P 2 2D 3 4 5 6	[ ][ ][ ][ ][ ][ ]	[ ][ ]		X[ ][ ][ ][ ][ ]	[ ][ ][ ][ ][ ][ ]	A B / J K L M N P R S T / X Y Z	Work / Related Business / Home / Social or Entertainment / Recreational / Shopping / Education / Serve Passenger / Change Travel Mode / Changing Residence / Other (Family Business, etc.) / Load Commodity / Unload Commodity / Load and Unload	A B / J K L M N P R S T / X Y Z	X[ ][ ][ ][ ][ ]	Yes 1 / No 2	X[ ][ ][ ][ ][ ]	INBOUND [ ][ ] / OUTBOUND [ ][ ]	INBOUND [ ][ ][ ] / OUTBOUND [ ][ ][ ]
3	1 2 3 4 5 6 7 8 9 Or more	A P 2 2D 3 4 5 6	[ ][ ][ ][ ][ ][ ]	[ ][ ]		X[ ][ ][ ][ ][ ]	[ ][ ][ ][ ][ ][ ]	A B / J K L M N P R S T / X Y Z	Work / Related Business / Home / Social or Entertainment / Recreational / Shopping / Education / Serve Passenger / Change Travel Mode / Changing Residence / Other (Family Business, etc.) / Load Commodity / Unload Commodity / Load and Unload	A B / J K L M N P R S T / X Y Z	X[ ][ ][ ][ ][ ]	Yes 1 / No 2	X[ ][ ][ ][ ][ ]	INBOUND [ ][ ] / OUTBOUND [ ][ ]	INBOUND [ ][ ][ ] / OUTBOUND [ ][ ][ ]

FORM H UP 3 (Rev 4 55)　(A) Also For Residents With Thru Trips Today　(B) Number Of Days In Area 1 Today 2 Yesterday, Etc. 9 Maximum

SCREEN LINE ANALYSIS

- TABULATE TIME OF START BY TRIP TYPE
- ASSIGN SURVEY TRIPS BY TRIP TYPE
- SET UP SCREEN LINES
- COMPARE TEMPORAL PATTERN OF GROUND COUNTS TO ASSIGNED SURVEY TRIPS
- ADJUST TRIPS BY TYPE TO ACCOUNT FOR UNDER REPORTING OF TRIPS

TRIP TYPES ARE SUMMARIES OF THE TRIP PURPOSES ON THE TRIP REPORT

TRIP TYPES

1 H-O HOME ⟷ OTHER

2 O-O OTHER ⟷ OTHER

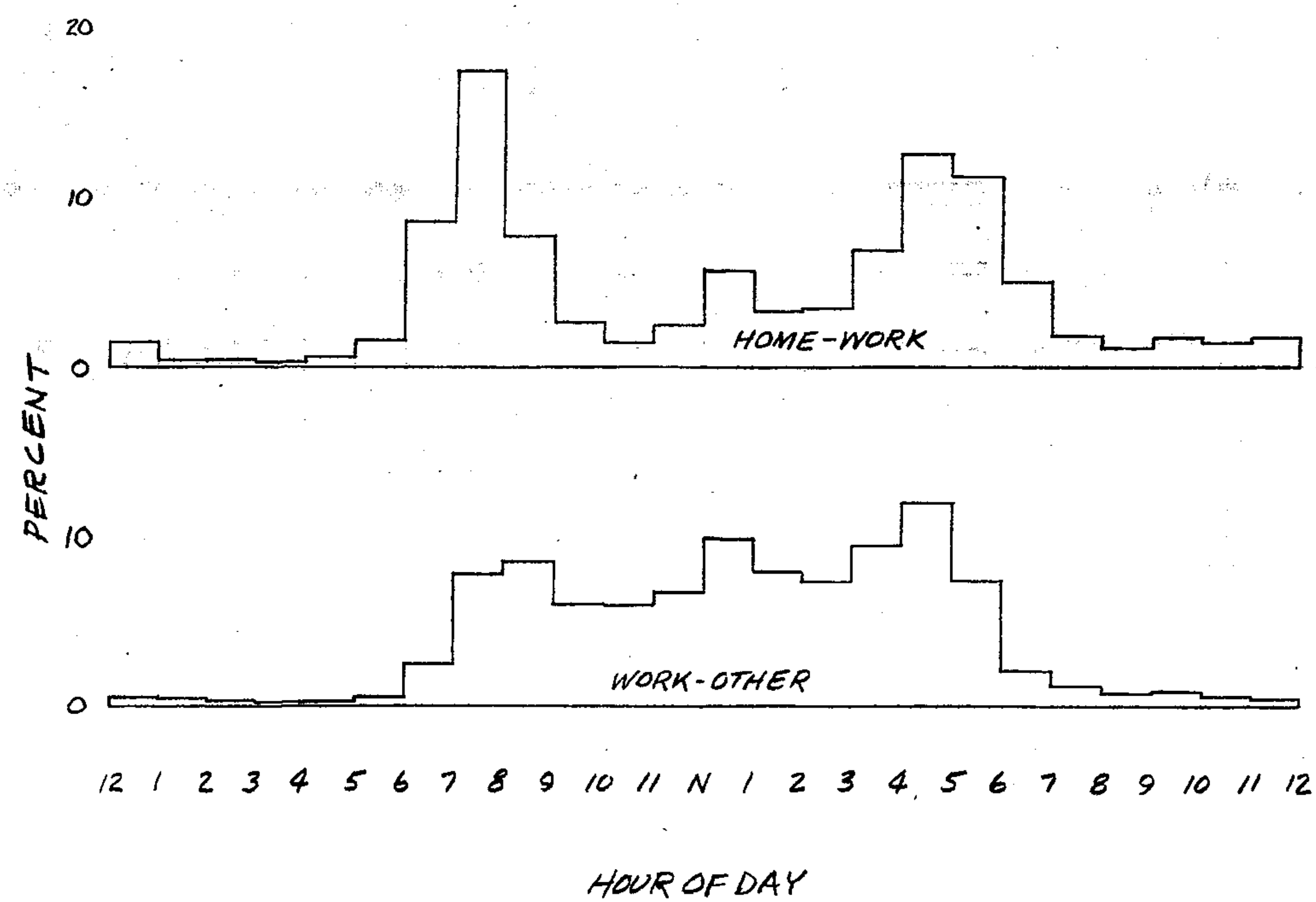
3 O-W OTHER ⟷ WORK

4 H-W HOME ⟷ WORK

5 H-S HOME ⟷ SHOP

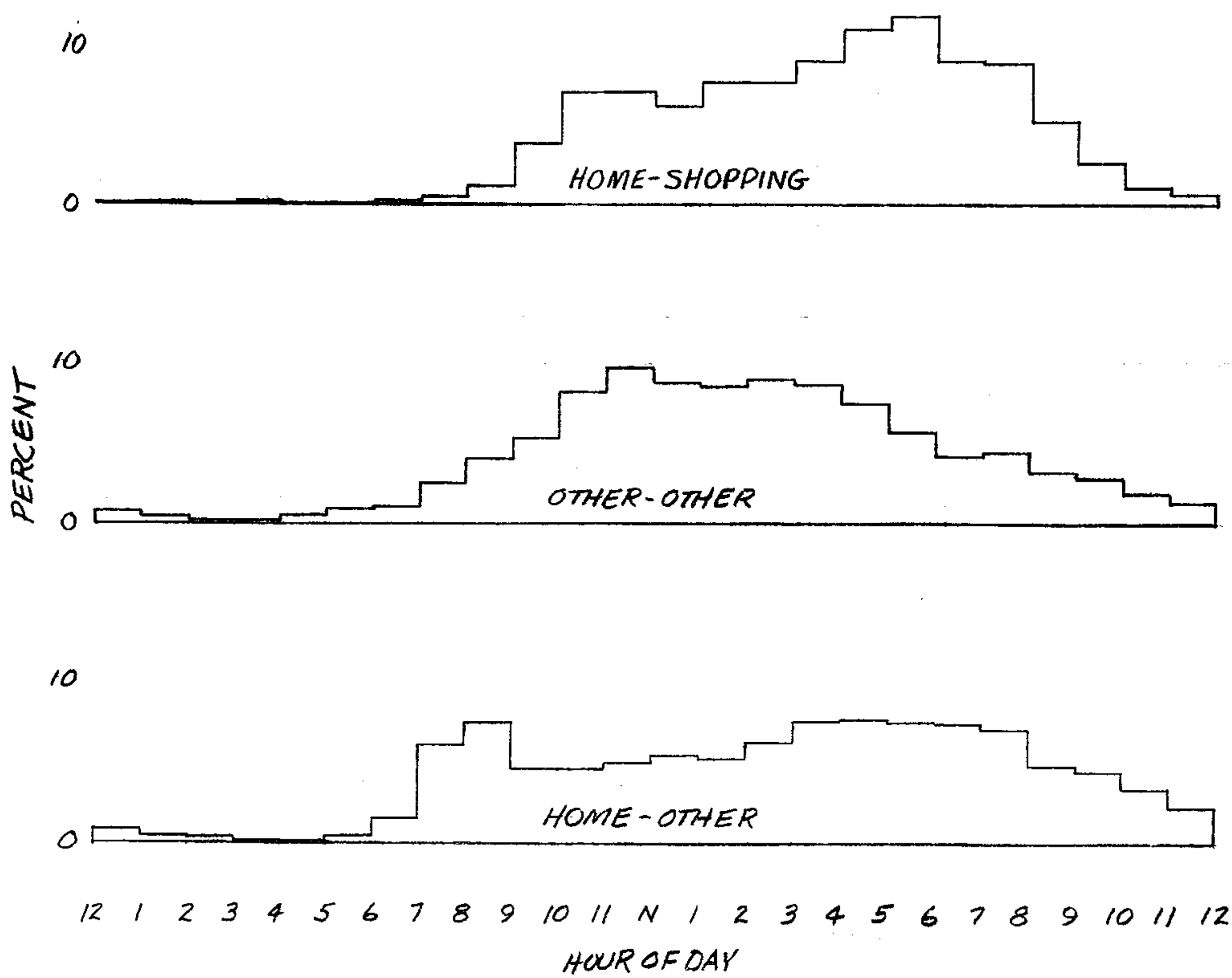
SATS ORIGIN AND DESTINATION

PERCENT OF TRIPS BY HOUR OF START (FROM TRIP REPORT)



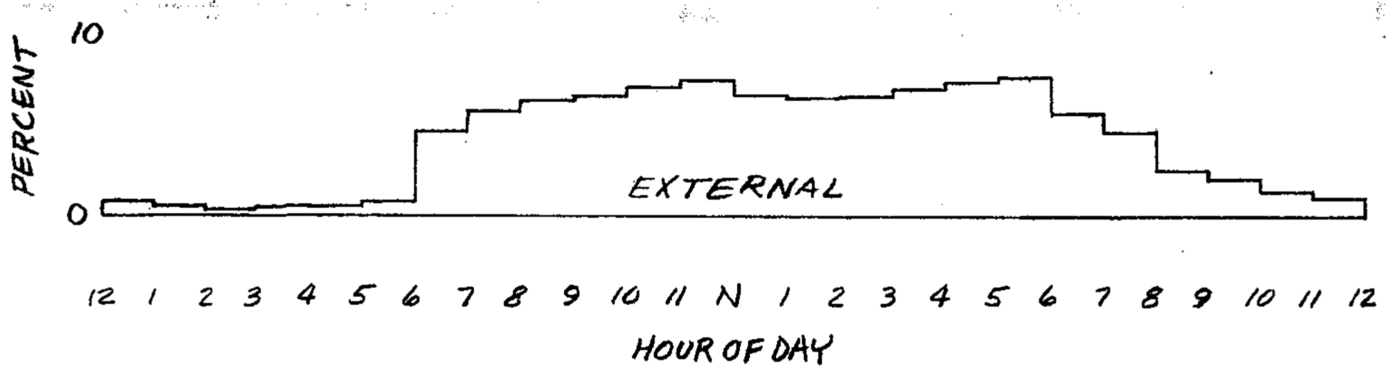
SATS ORIGIN AND DESTINATION

PERCENT OF TRIPS BY HOUR OF START (FROM TRIP REPORT)

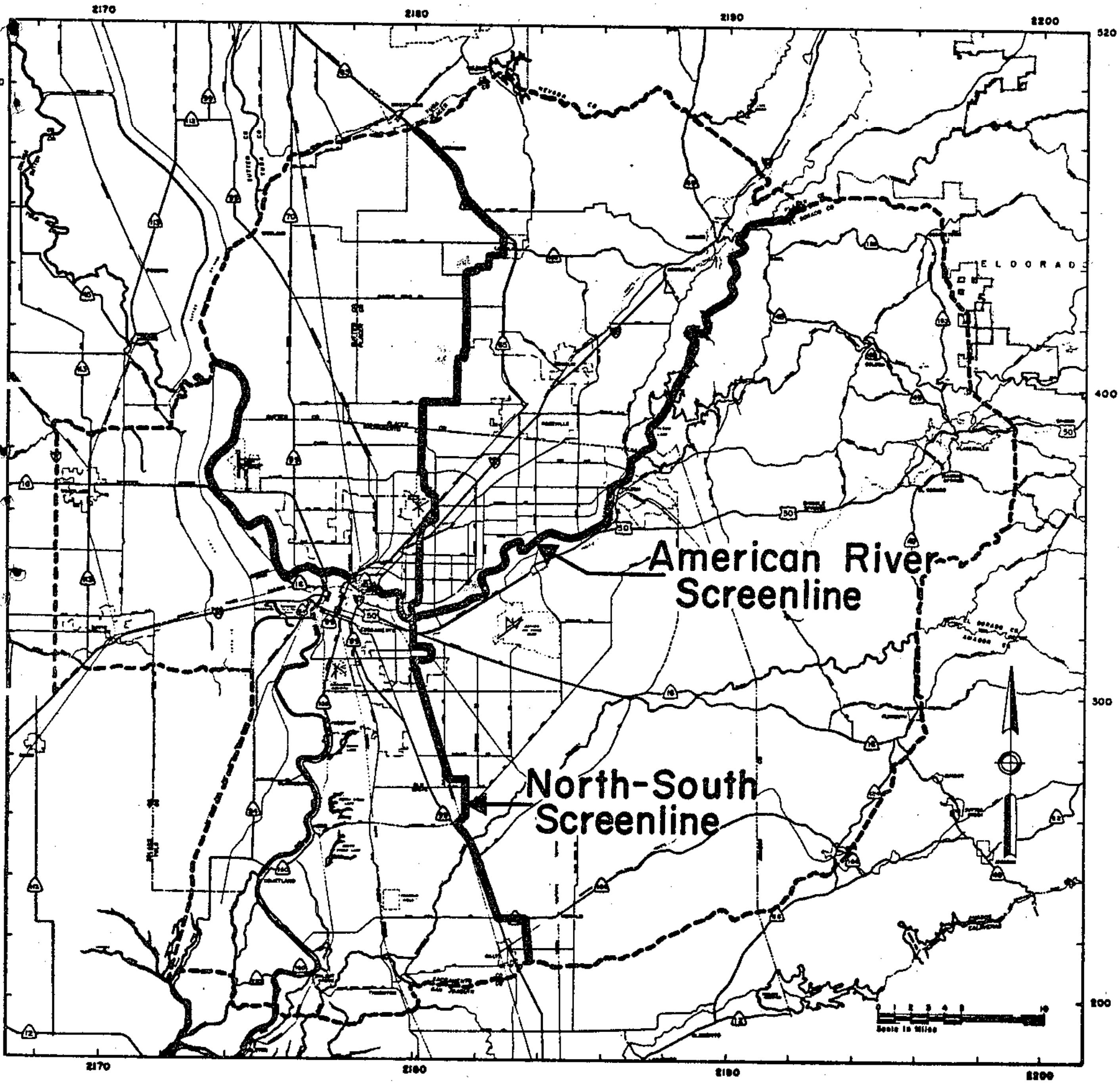


SATS ORIGIN AND DESTINATION

PERCENT OF TRIPS BY HOUR OF START (FROM TRIP REPORT)



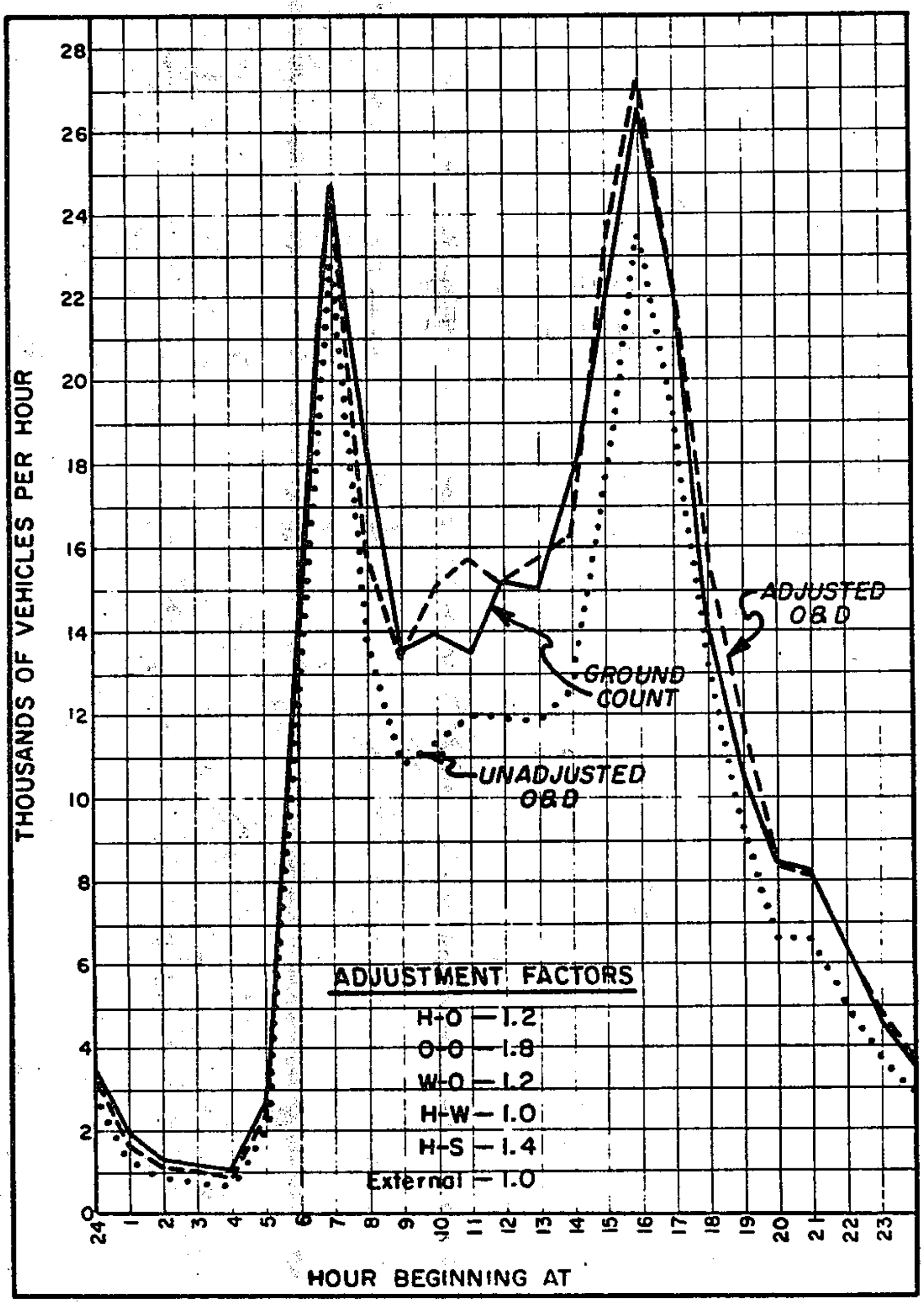
SATS MAJOR SCREENLINES



LEGEND

- INTERSTATE HIGHWAY ROUTE NUMBERS
- U.S. HIGHWAY ROUTE NUMBERS
- STATE HIGHWAY ROUTE NUMBERS
- COUNTY BOUNARIES
- SURVEY BOUNDARIES
- CALIFORNIA GRID READINGS IN 1,000's OF FEET

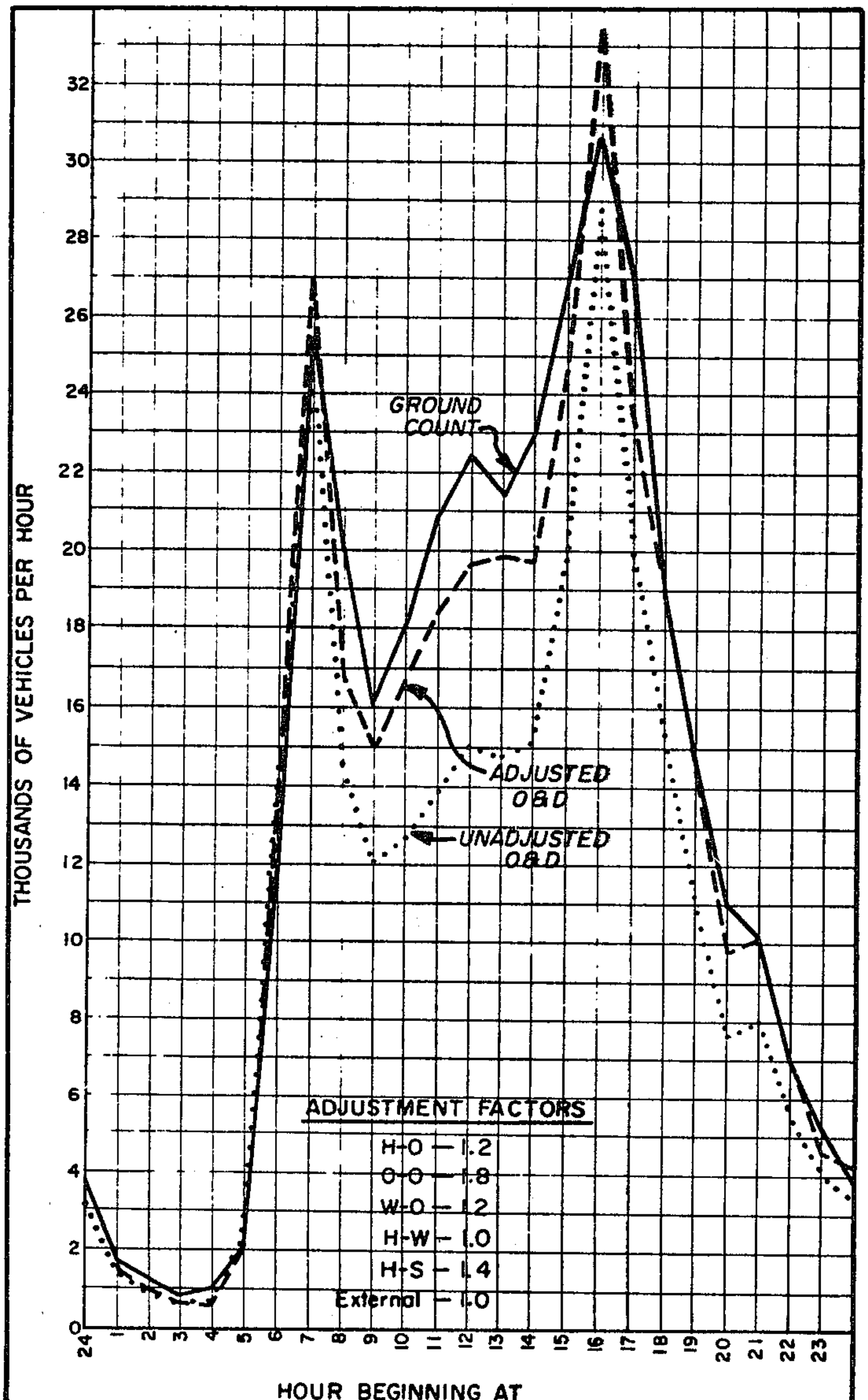
AMERICAN RIVER SCREENLINE
ADJUSTED AND UNADJUSTED HOURLY VOLUMES



UNADJUSTED O & D TRIPS = 85% OF 1968-69 ADT

ADJUSTED O & D TRIPS = 102% OF 1968-69 ADT

NORTH-SOUTH SCREENLINE
ADJUSTED AND UNADJUSTED HOURLY VOLUMES



UNADJUSTED O & D TRIPS = 77% OF 1968-69 ADT
ADJUSTED O & D TRIPS = 94% OF 1968-69 ADT

IV VEHICLE EMISSIONS MODEL

LINK EMISSIONS

ZONAL EMISSIONS

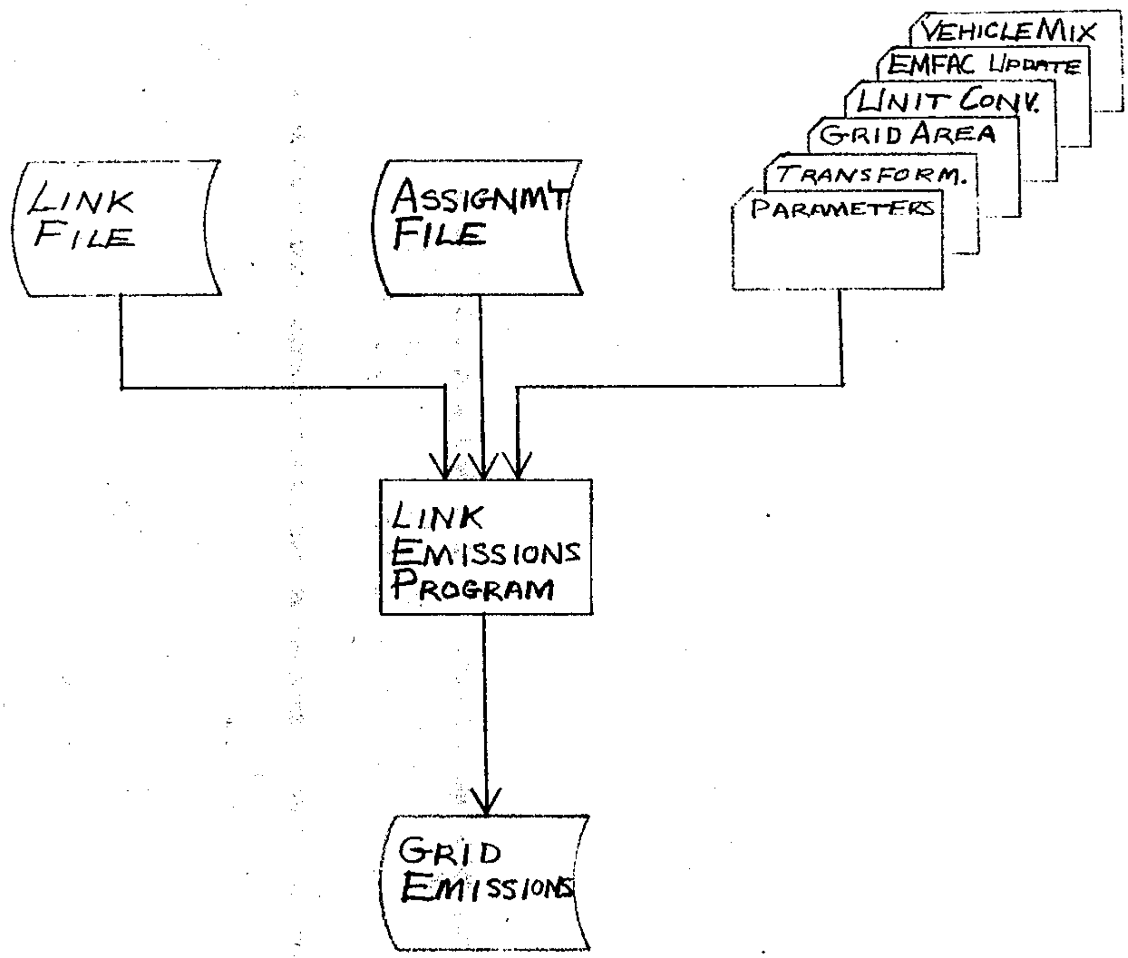
GRID EMISSIONS

SOURCES OF VEHICULAR EMISSIONS

THE PURPOSE FOR MAKING A TRIP DETERMINES

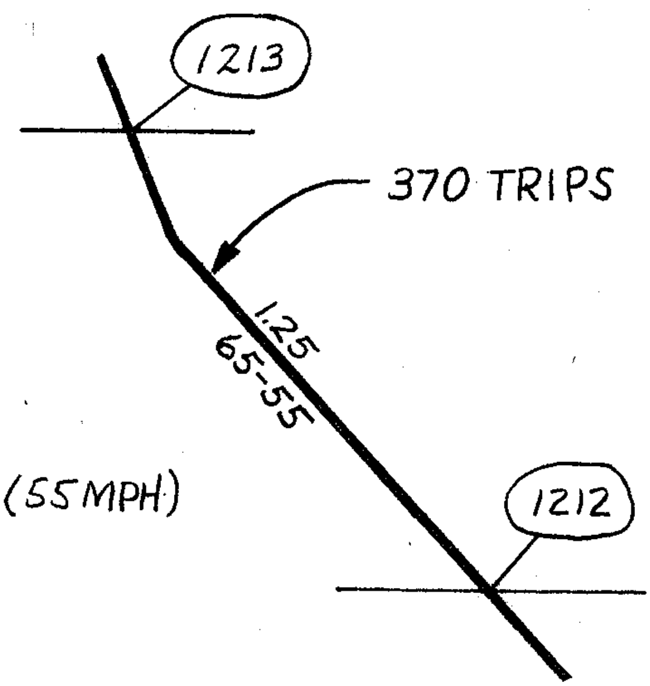
- WHEN IT IS LIKELY TO HAPPEN - TEMPORALLY
- WHAT TYPE OF VEHICLE WILL BE USED
- WHETHER IT WILL BE EXPOSED TO PEAK PERIOD CONGESTION
- WHETHER IT WILL HAVE A COLD START
- HOW LONG IT WILL REMAIN AT THE DESTINATION

FLOWCHART OF LINK EMISSIONS MODEL



LINK, ASSIGNMENT AND TRIP PURPOSE INFORMATION IS USED TO COMPUTE LINK EMISSIONS (Q)

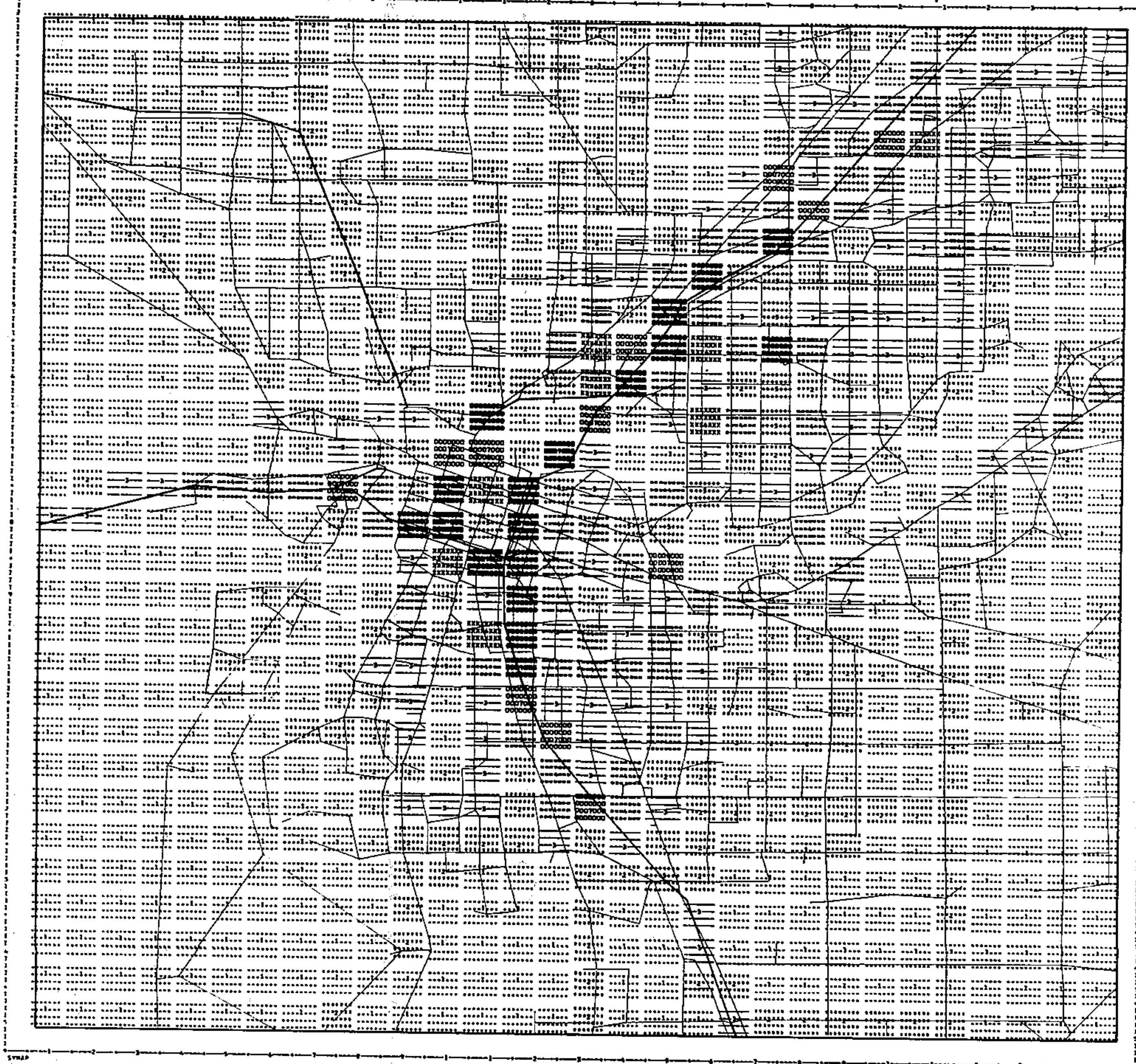
Q = TRIPS
× MILES
× EMFAC (SPEED)



EXAMPLE:

Q = 370
X 1.25
X EMFAC(55MPH)

CARBON MONOXIDE VEHICULAR EMISSIONS (TONS/DAY)



EMISSION LEVEL KEY

LEVEL	1	2	3	4	5	6	7	8	9	10
SYMBOL										
FREQUENCY	433	219	98	56	26	8	12	8	8	2
MINIMUM	0.0	0.10	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00
MAXIMUM	0.10	0.50	1.00	1.50	2.00	2.50	3.00	4.00	5.00	55.00

DATA VALUE EXTREMES ARE 0.0–6.49 TONS/SQ. KM.

SATS 1969 NETWORK PLOT

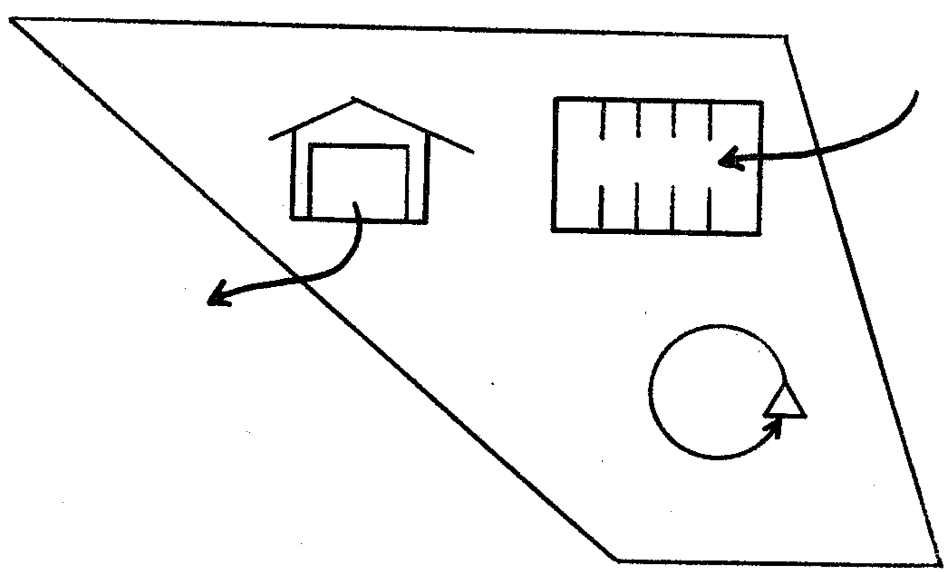
AIR QUALITY 1"= 4000'

SEPT. 1974

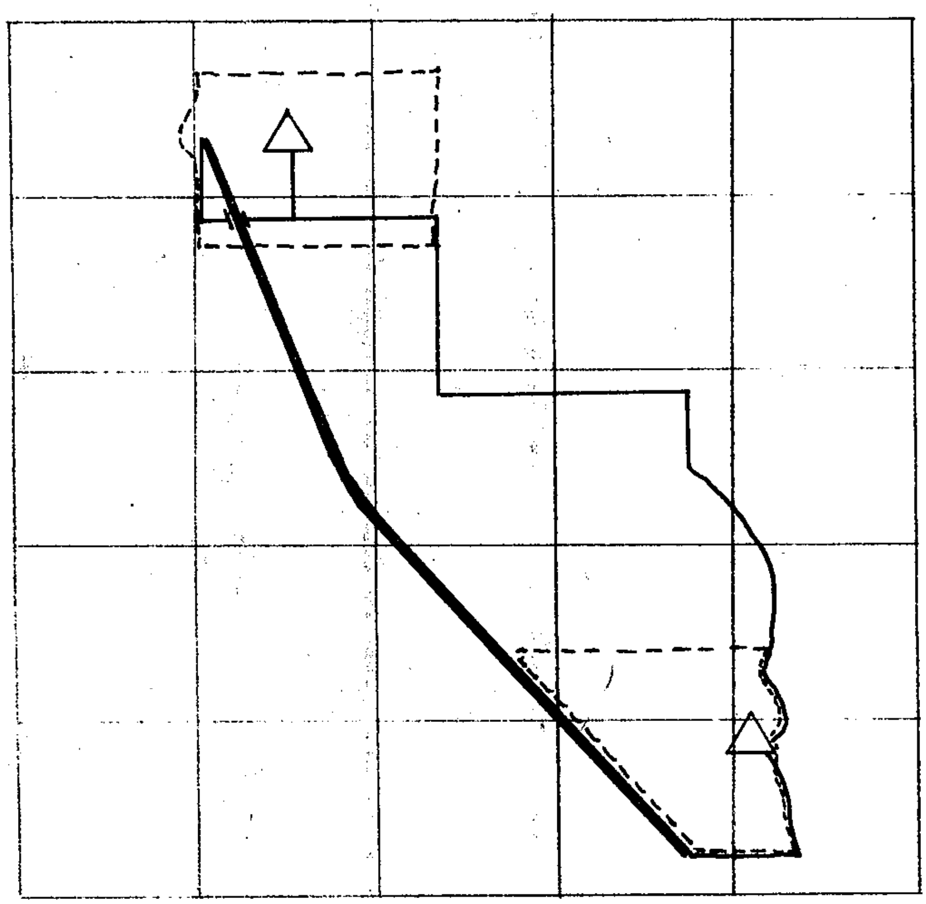
TAPE REEL NO. IS 011406

ZONAL EMISSIONS TO INCLUDE

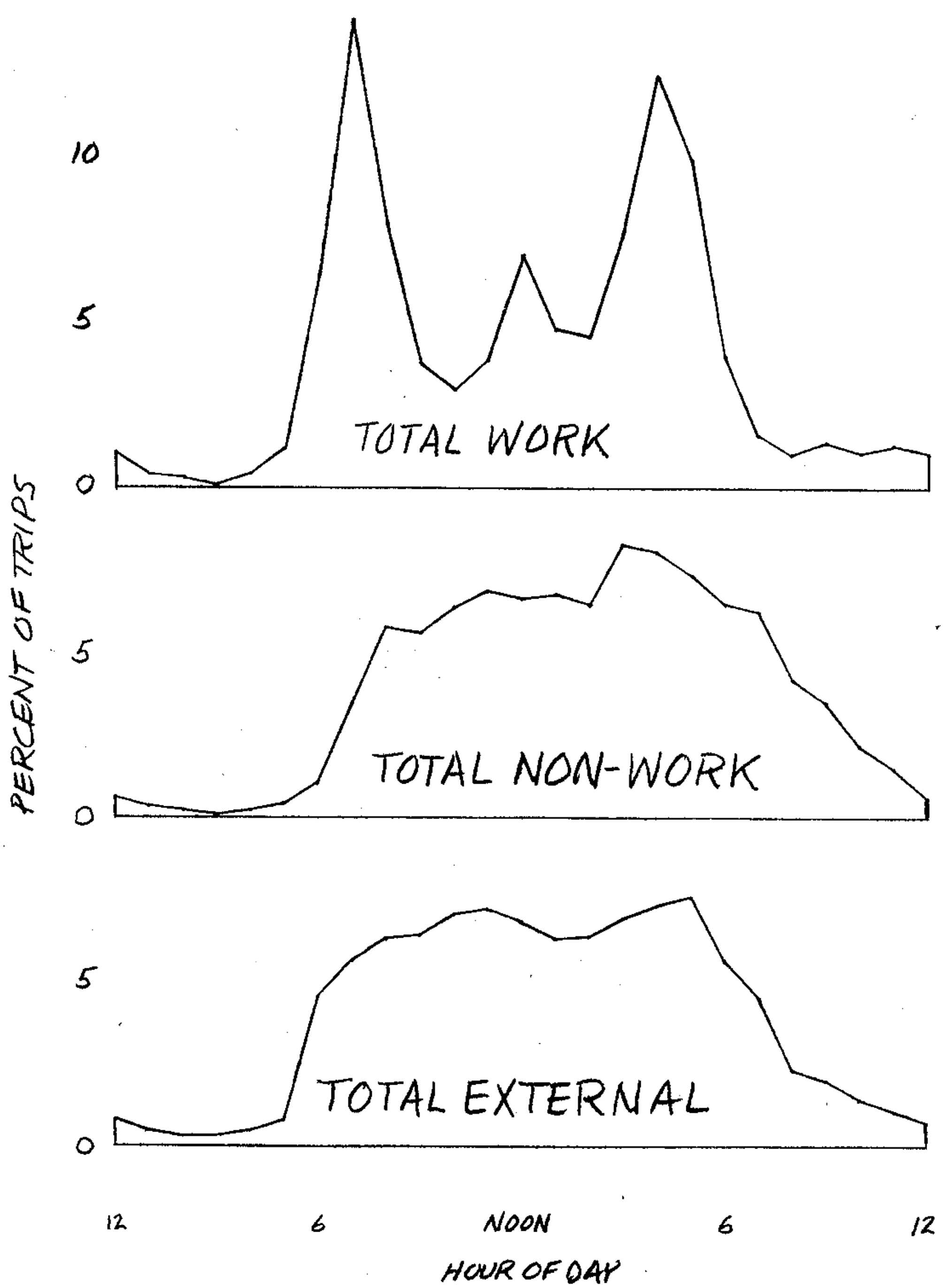
- COLD STARTS
- SOAKS
- INTRAZONAL TRIPS



LINK & ZONAL EMISSIONS ARE ACCUMULATED INTO GRID CELLS



SATS TEMPORAL DISTRIBUTION OF TRIPS AND EMISSIONS (FOR SAI MODEL)



V TRIP ESTIMATION MODEL

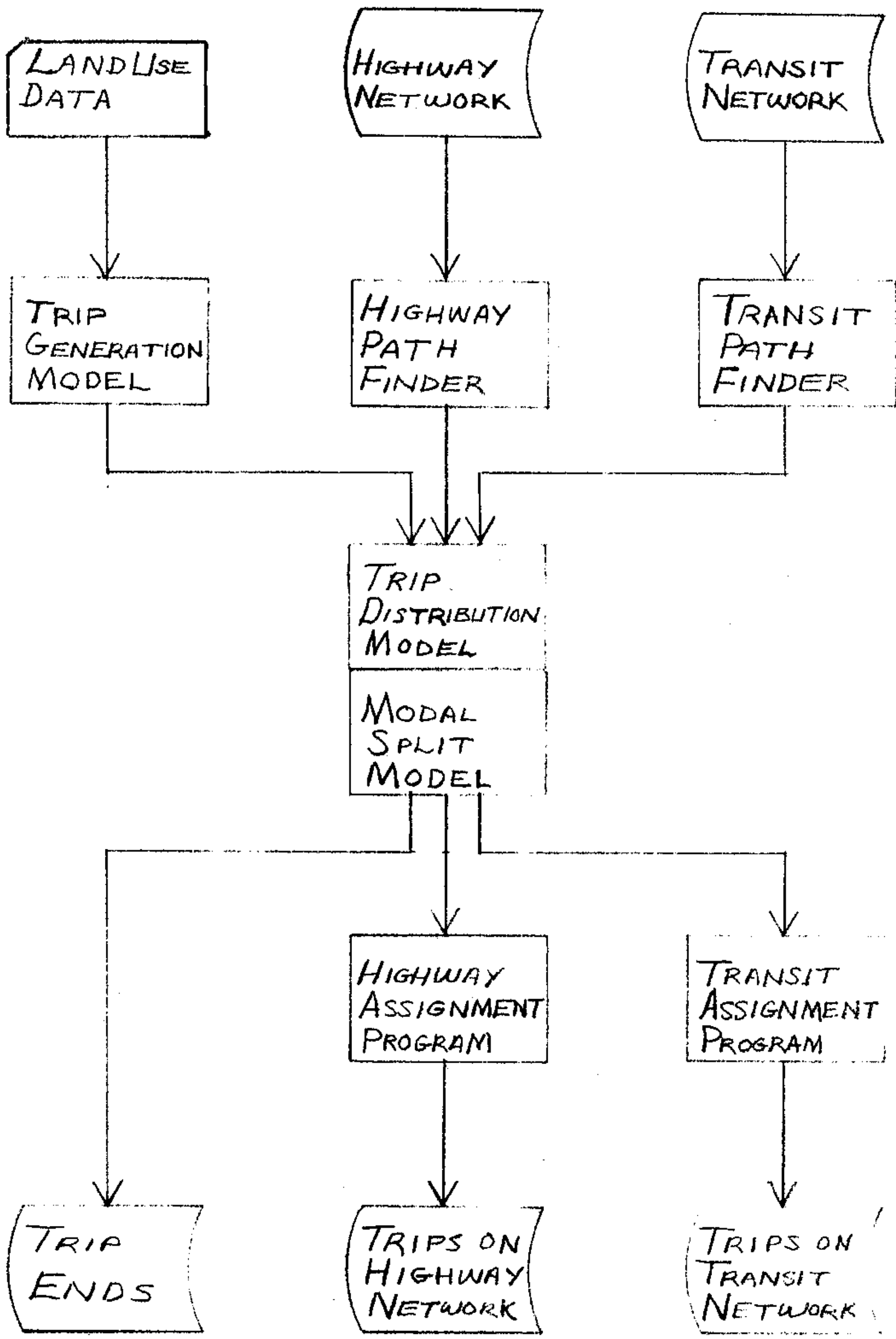
TRAVEL FORECASTING FROM LAND USE PATTERNS AND TRANSPORTATION CONFIGURATIONS:

TRIP GENERATION

TRIP DISTRIBUTION

MODAL SPLIT

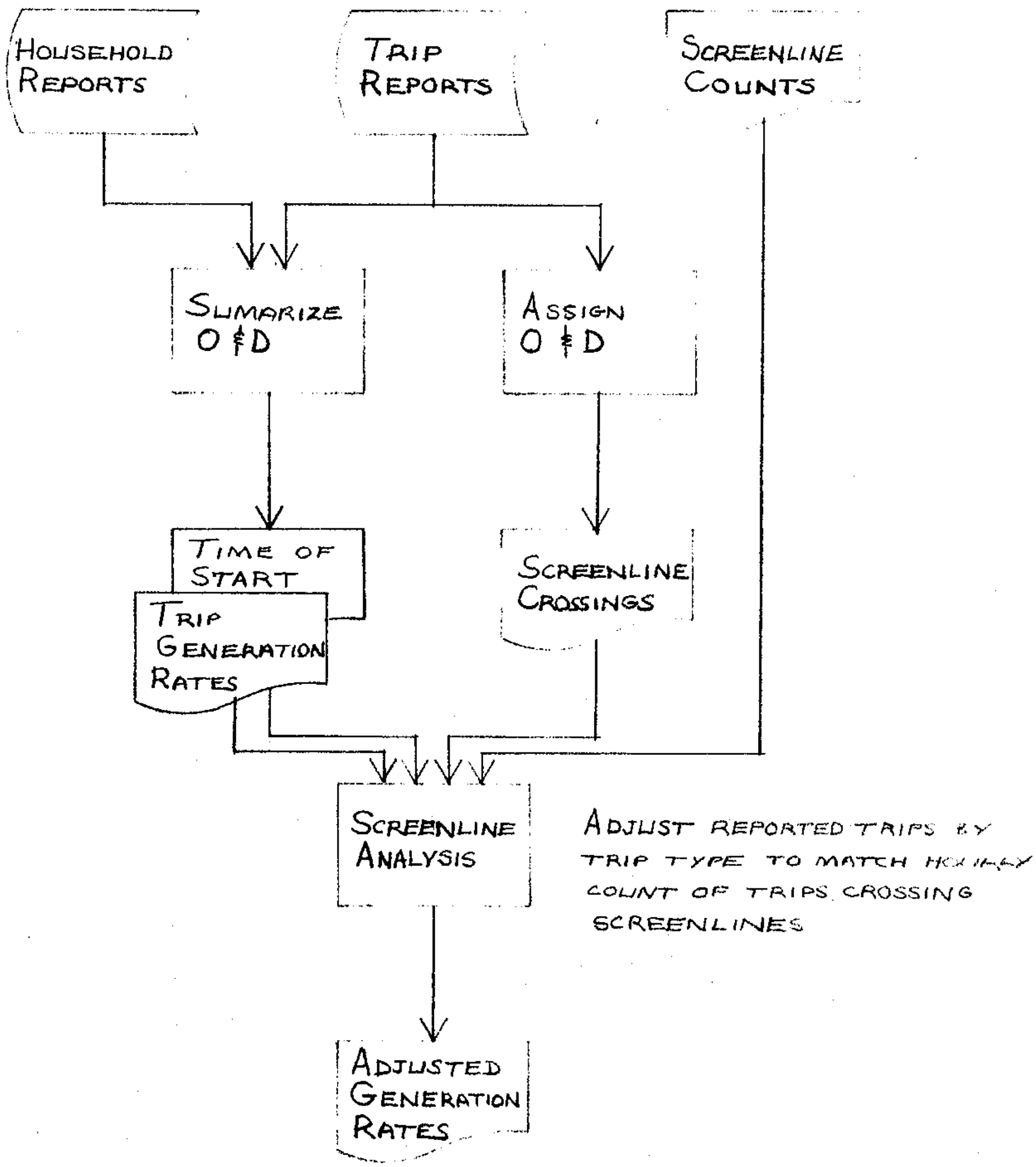
FLOWCHART FOR TRAVEL FORECASTING MODELS



TRIP GENERATION

- CROSS CLASSIFICATION MODEL
  - HOUSEHOLDS AND VEHICLES TABLE
  - TRIP TABLE
  - TRIP RATE TABLE
- VEHICLE ESTIMATING EQUATIONS
  - EQUATIONS
  - CURVES

DEVELOPMENT OF TRIP GENERATION RATES



CROSS CLASSIFICATION MODEL
HOUSEHOLDS VEHICLES AND TRIPS
TABLE

SATS 1968 PERSON TRIP MODEL — JANUARY 28, 1974

TRIP GENERATION RATES (MOTORCYCLE AND WALKING 1ST TRIP TO WORK EXCLUDED)

FWY070 FACTORS= 1.2(TT1)+1.8(TT2)+1.2(TT3)+1.0(TT4)+1.4(TT5) — COMPILED JUNE 70

	HOUSING UNITS	VEHICLES	HOME-OTHER	OTHER-OTHER	OTHER-WORK	HOME-WORK	HOME-SHOP	TOTAL
SINGLE								
0	20720	0	11640	3312	360	2860	3780	21952
1	59660	59660	205920	107100	23880	76660	88480	502040
2+	109760	254800	577752	338544	94632	240060	213080	1464068
TOTAL	190140	314460	795312	448956	118872	319580	305340	1988060
MULTIPLE								
0	17480	0	9240	3600	480	2860	3360	19540
1	33920	33920	78000	63324	15048	42820	33824	233016
2+	17640	38380	62040	52056	15216	34880	24500	188692
TOTAL	69040	72300	149280	118980	30744	80560	61684	441248
GROUP								
0	8800	0	2208	1188	96	240	616	4348
1	3100	3100	4992	2592	288	500	1764	10136
2+	320	800	504	396	576	220	224	1920
TOTAL	12220	3900	7704	4176	960	960	2604	16404
MUL +GRP								
0	26280	0	11448	4788	576	3100	3976	23888
1	37020	37020	82992	65916	15336	43320	35588	243152
2+	17960	39180	62544	52452	15792	35100	24724	190612
TOTAL	81260	76200	156984	123156	31704	81520	64288	457652
SING+MUL								
0	38200	0	20880	6912	840	5720	7140	41492
1	93580	93580	283920	170424	38928	119480	122304	735056
2+	127400	293180	639792	390600	109848	274940	237580	1652760
TOTAL	259180	386760	944592	567936	149616	400140	367024	2429308
TOTAL								
0	47000	0	23088	8100	936	5960	7756	45840
1	96680	96680	288912	173016	39216	119980	124068	745192
2+	127720	293980	640296	390996	110424	275160	237804	1654680
TOTAL	271400	390660	952296	572112	150576	401100	369628	2445712

SOURCE TAB: 451000

MULTIPLES = MULTIPLES + TRAILERS

SINGLES = SINGLES

THE TRIP RATE TABLE IS CALCULATED FROM THE
HOUSEHOLDS AND VEHICLES TABLE AND THE TRIP TABLE

SATS 1968 PERSON TRIP MODEL — JANUARY 28, 1974

TRIP GENERATION RATES (MOTORCYCLE AND WALKING 1ST TRIP TO WORK EXCLUDED)

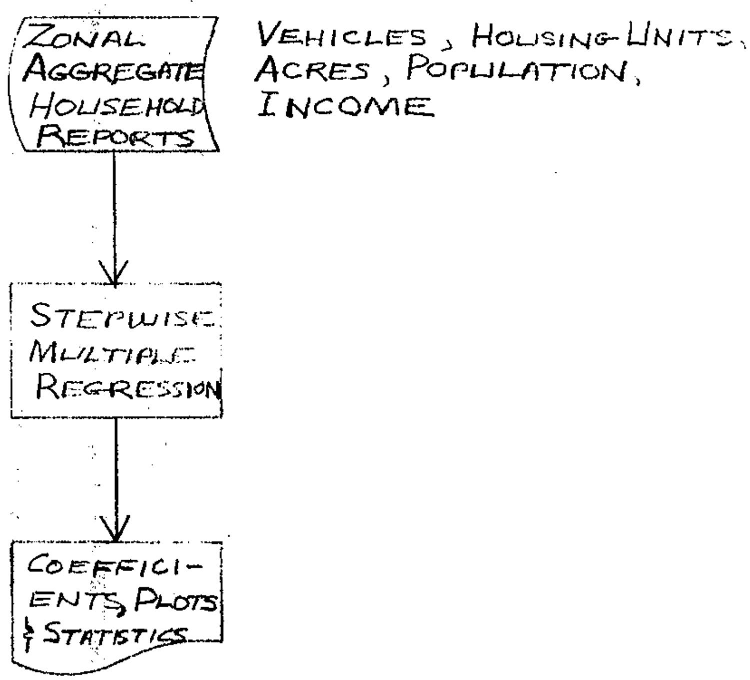
FACTORS= 1.2(TT1),1.8(TT2),1.2(TT3),1.0(TT4),1.4(TT5)

TRIPS PER VEHICLE	HOME-OTHER	OTHER-OTHER	OTHER-WORK	HOME-WORK	HOME-SHOP	TOTAL
1 VEHICLE						
•SINGLE	3.452	1.795	0.400	1.285	1.483	8.415
MULTIPLE	2.300	1.867	0.444	1.262	0.997	6.870
GROUP	1.610	0.836	0.093	0.161	0.569	3.270
SING + MUL	3.034	1.821	0.416	1.277	1.307	7.855
•MUL + GRP	2.242	1.781	0.414	1.170	0.961	6.568
TOTAL	2.988	1.790	0.406	1.241	1.283	7.708
2+ VEHICLES						
•SINGLE	2.267	1.329	0.371	0.942	0.836	5.746
MULTIPLE	1.616	1.356	0.396	0.909	0.638	4.916
GROUP	0.630	0.495	0.720	0.275	0.280	2.400
SING + MUL	2.182	1.332	0.375	0.938	0.810	5.637
•MUL + GRP	1.596	1.339	0.403	0.896	0.631	4.865
TOTAL	2.178	1.330	0.376	0.936	0.809	5.629
TOTAL VEHICLES						
SINGLE	2.529	1.428	0.378	1.016	0.971	6.322
MULTIPLE	2.065	1.646	0.425	1.114	0.853	6.103
GROUP	1.975	1.071	0.246	0.246	0.668	4.206
SING + MUL	2.442	1.468	0.387	1.035	0.949	6.281
MUL + GRP	2.060	1.616	0.416	1.070	0.844	6.006
TOTAL	2.438	1.464	0.385	1.027	0.946	6.260
TRIPS PER ZERO VEHICLE UNIT						
•SINGLE	0.562	0.160	0.017	0.138	0.182	1.059
MULTIPLE	0.529	0.206	0.027	0.164	0.192	1.118
GROUP	0.251	0.135	0.011	0.027	0.070	0.494
SING + MUL	0.547	0.181	0.022	0.150	0.187	1.086
•MUL + GRP	0.436	0.182	0.022	0.118	0.151	0.909
TOTAL	0.491	0.172	0.020	0.127	0.165	0.975

SOURCE TAB: 451000
MULTIPLES = MULTIPLES + TRAILERS
SINGLES = SINGLES

-399-

DEVELOPMENT OF VEHICLE ESTIMATING EQUATIONS



VEHICLE ESTIMATING EQUATIONS SPLIT THE HOUSEHOLDS AND VEHICLES IN EACH ZONE INTO THE SIX CLASSES USED FOR TRIP GENERATION

$$R_1 = \frac{\text{VEHICLES}}{\text{HOUSING UNITS}}$$

$$= -.23901 + .51900\left(\frac{HST}{HTT}\right) + .47571\left[\text{LOGN}\left(1+\frac{MI}{1000}\right)\right] - .08204\left[\text{LOGN}\left(\frac{HTT}{A}\right)\right] + .34180\left[\text{LOGN}\left(\frac{POP}{HTT}\right)\right]$$

$$R_2 = \frac{\text{ZERO VEHICLE HOUSING UNITS}}{\text{HOUSING UNITS}}$$

$$= .18438 + .87178\left(\frac{1}{MI/1000}\right) - .12052\left[\text{LOGN}\left(\frac{POP}{HTT}\right)\right] - .10569\left(\frac{HST}{HTT}\right) + .01094\left(\frac{HTT}{A}\right)$$

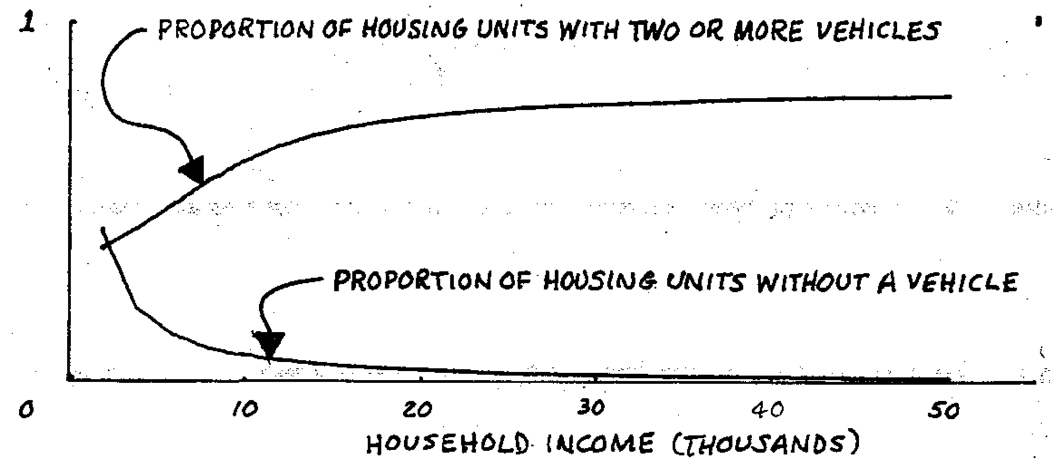
$$R_3 = \frac{\text{HOUSING UNITS WITH 2+ VEHICLES}}{\text{HOUSING UNITS WITH VEHICLES}}$$

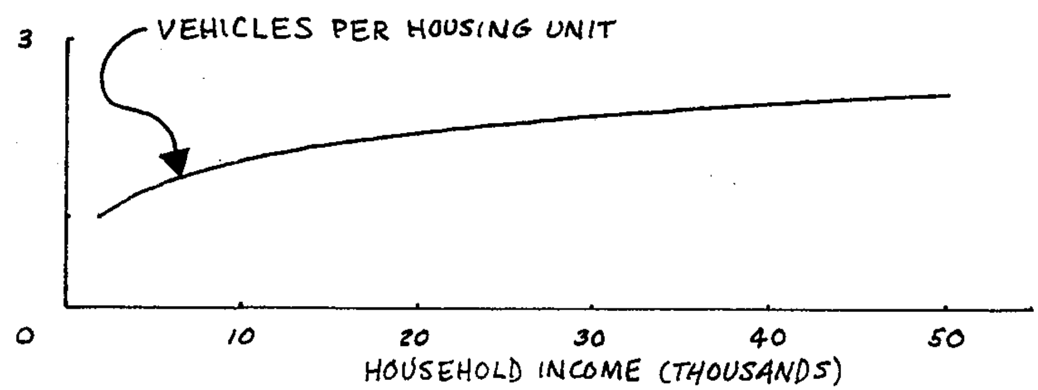
$$= .10314 + .27131\left(\frac{HST}{HTT}\right) + .21118\ \text{ARCTAN}\left[.16\left(\frac{MI}{1000} - 6\right)\right] + .18591\left(\frac{1}{1+\frac{HTT}{A}}\right) + .03487\left(\frac{POP}{HTT}\right)$$

WHERE: HST = SINGLE HOUSING UNITS
HTT = TOTAL HOUSING UNITS
MI = ZONAL MEDIAN INCOME
A = ACRES
POP = POPULATION
LOGN = NATURAL LOGARITHM

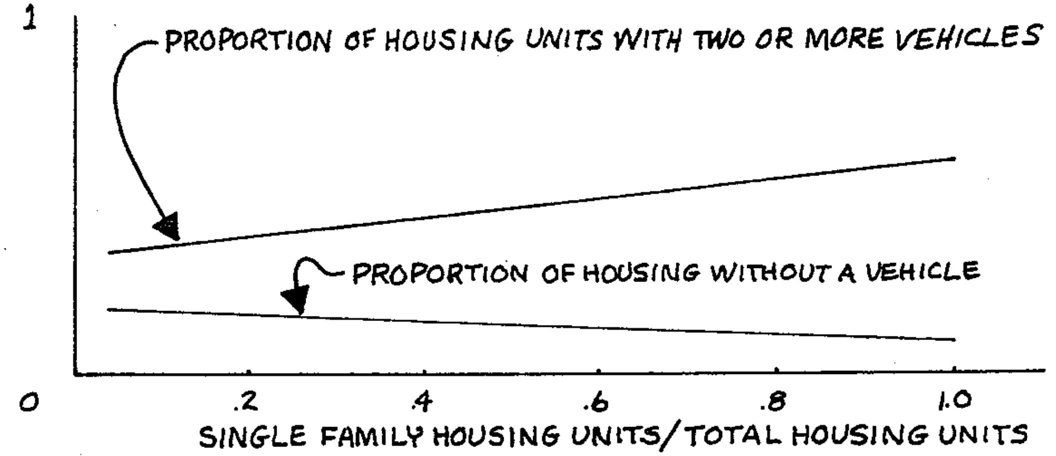
THE EQUATIONS CAN BE PLOTTED AS FOLLOWS:

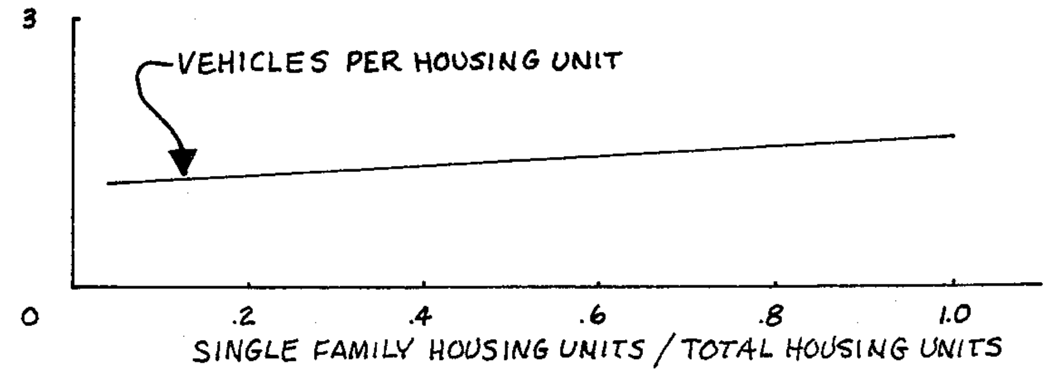
RELATION OF VEHICLE OWNERSHIP TO ZONAL MEDIAN INCOME



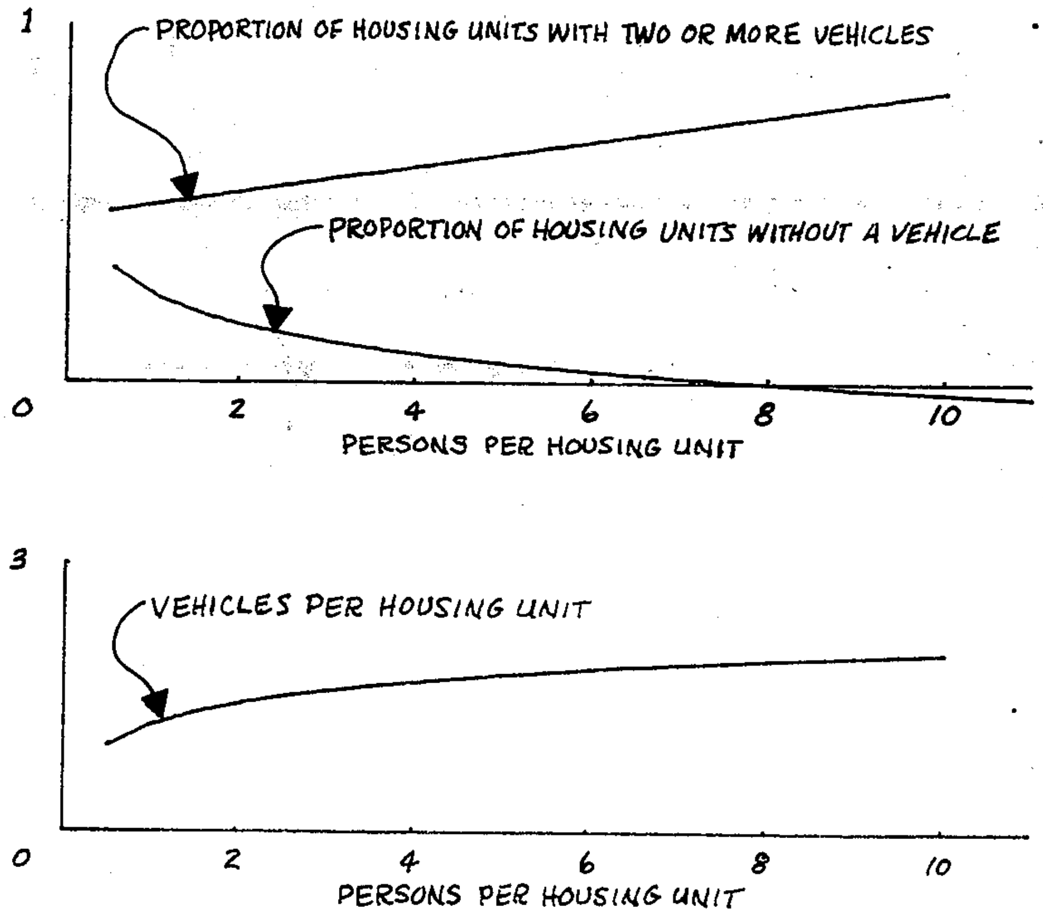


RELATION OF VEHICLE OWNERSHIP TO THE PROPORTION OF SINGLE FAMILY HOUSING UNITS

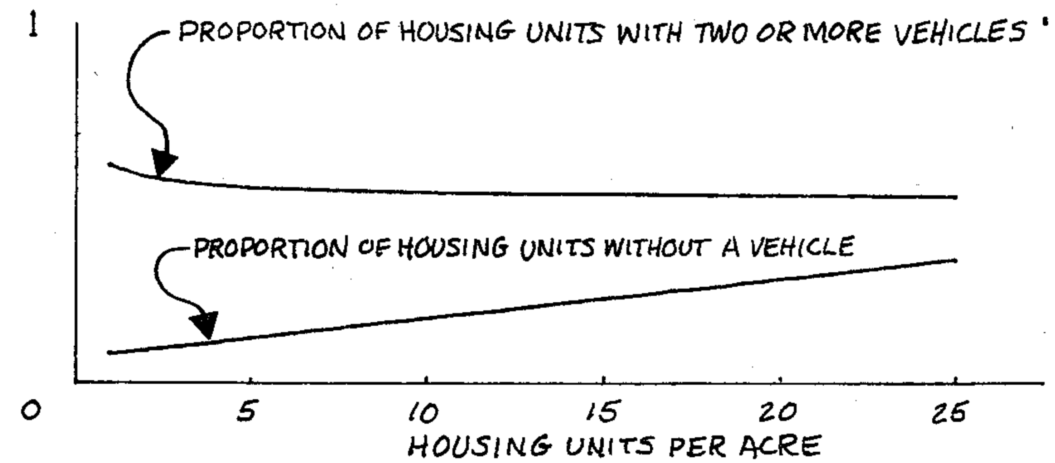


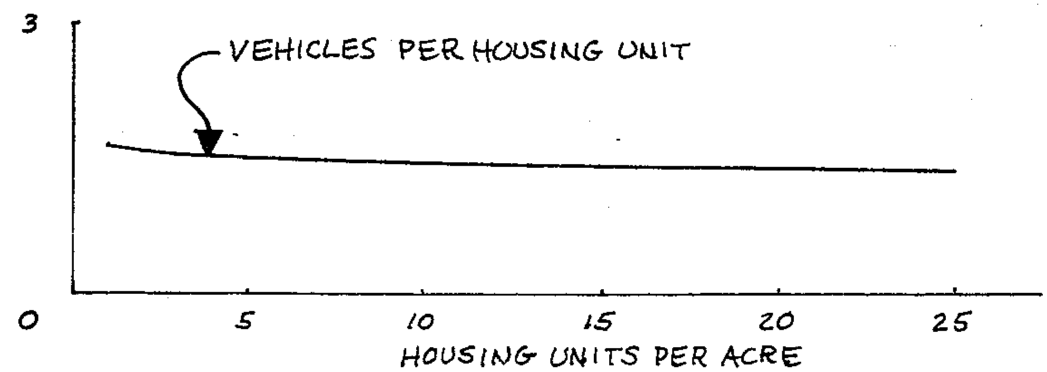


RELATION OF VEHICLE OWNERSHIP TO PERSONS PER HOUSING UNIT



RELATION OF VEHICLE OWNERSHIP TO HOUSING UNITS PER ACRE





TRIP DISTRIBUTION

- GRAVITY MODEL FORMULA
- MODEL CALIBRATION
  - ATTRACTION AND PRODUCTION EQUATIONS
  - TRIP TIME FREQUENCY DISTRIBUTIONS
  - TRAVEL TIME FACTORS

GRAVITY MODEL FORMULA

$$T_{ij} = P_i \frac{A_j F(t_{ij})}{\sum_{j=1}^{n} A_j F(t_{ij})}$$

WHERE:

T_{ij} = TRIPS BETWEEN ZONE i AND ZONE j (FOR ASSIGNMENT)

P_i = TRIPS PRODUCED IN ZONE i

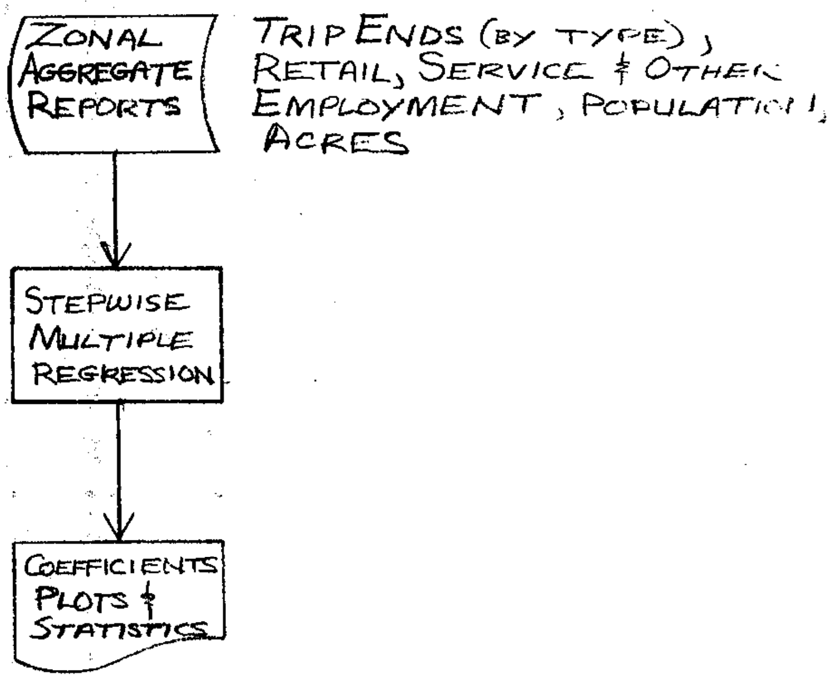
A_j = TRIP ATTRACTION FACTOR, ZONE j

t_{ij} = TRAVEL TIME BETWEEN ZONES i AND j

$F(t_{ij})$ = TRAVEL TIME FACTOR FOR t_{ij}

n = TOTAL NUMBER OF ZONES

DEVELOPMENT OF PRODUCTION AND ATTRACTION EQUATIONS



ATTRACTION AND PRODUCTION EQUATIONS

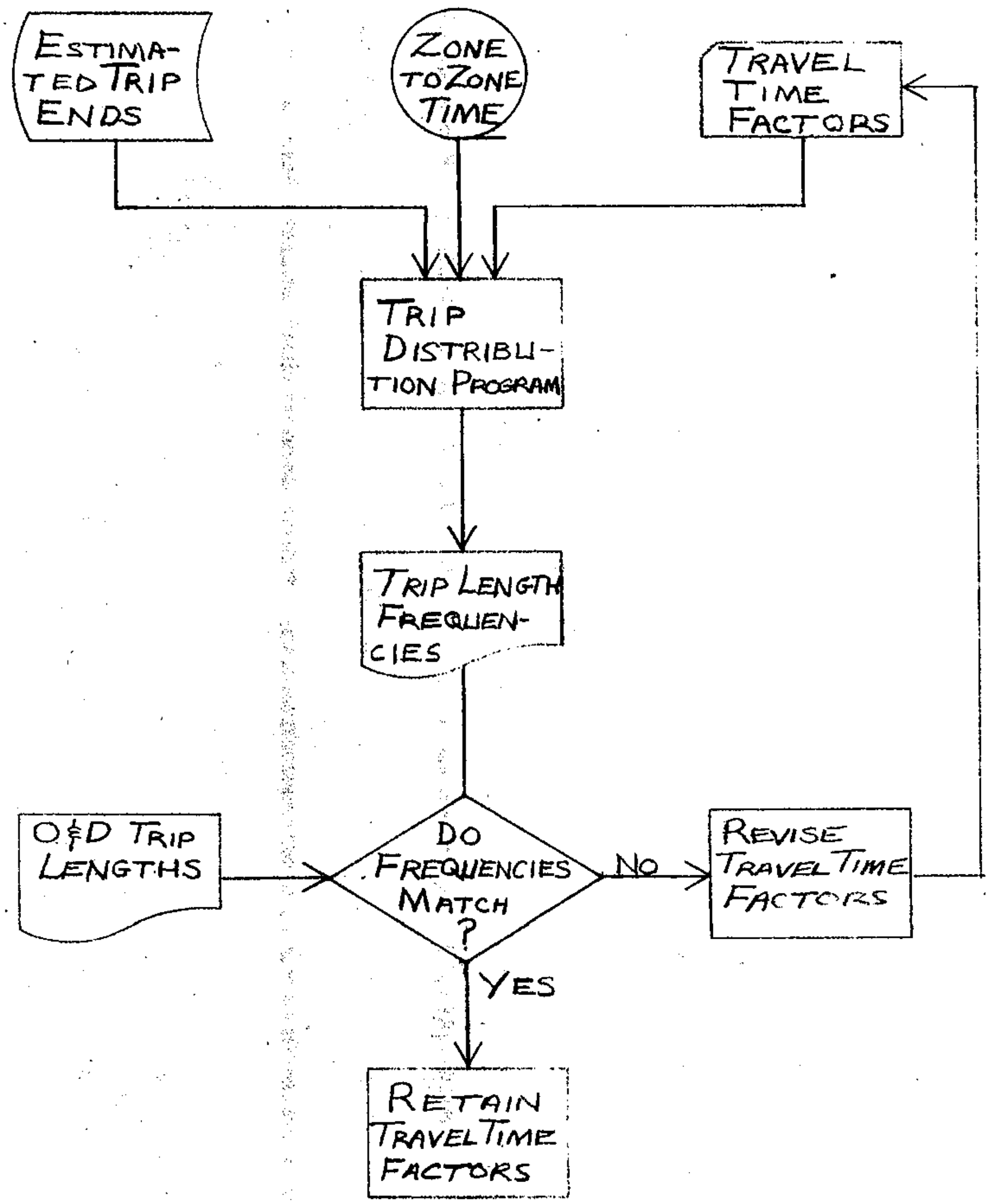
ATTRACTION:

$$\text{H-O} = 146 + 3.9\ \text{RETAIL} + 0.35\ \text{NONRETAIL} + 0.66\ \text{POPULATION}$$
$$\text{O-O} = 3.87 + 217.3\left(\sqrt{\text{RETAIL} + 49} - 7\right) + 0.214\ \text{POPULATION}$$
$$\text{O-W} = -33.2 + 27.5\left(\sqrt{\text{NON-RETAIL} + 64} - 8\right) + 0.83\ \text{RETAIL}$$
$$\text{H-W} = 34.3 + 1.40\ \text{TOTAL EMPLOYMENT}$$
$$\text{H-S} = -11.0 + 10.87\ \text{RETAIL} / \left(1 + \tfrac{1}{20}\ \text{TOTAL EMPLOYMENT/ACRE}\right)$$

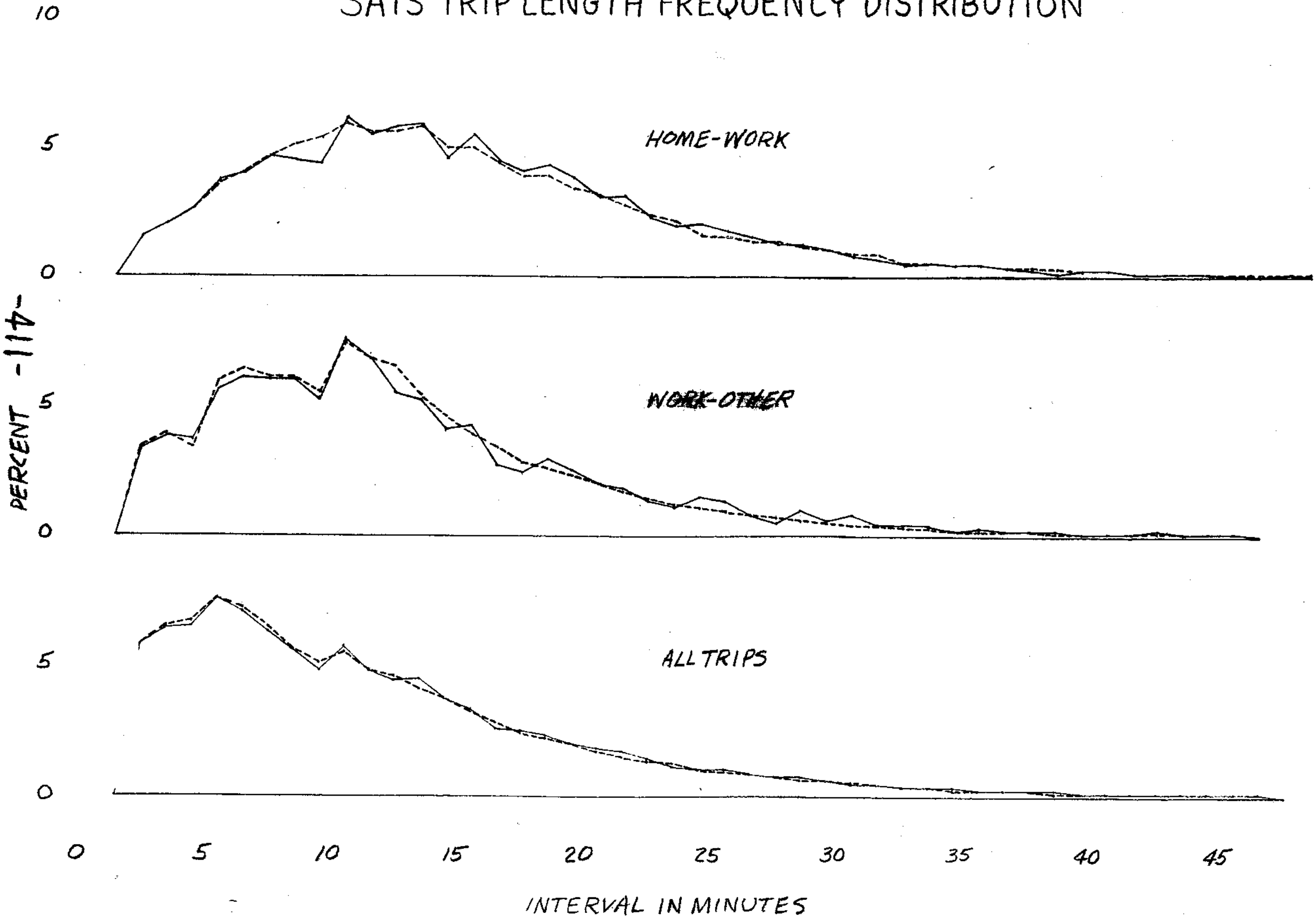
PRODUCTION (NON-HOME BASED)

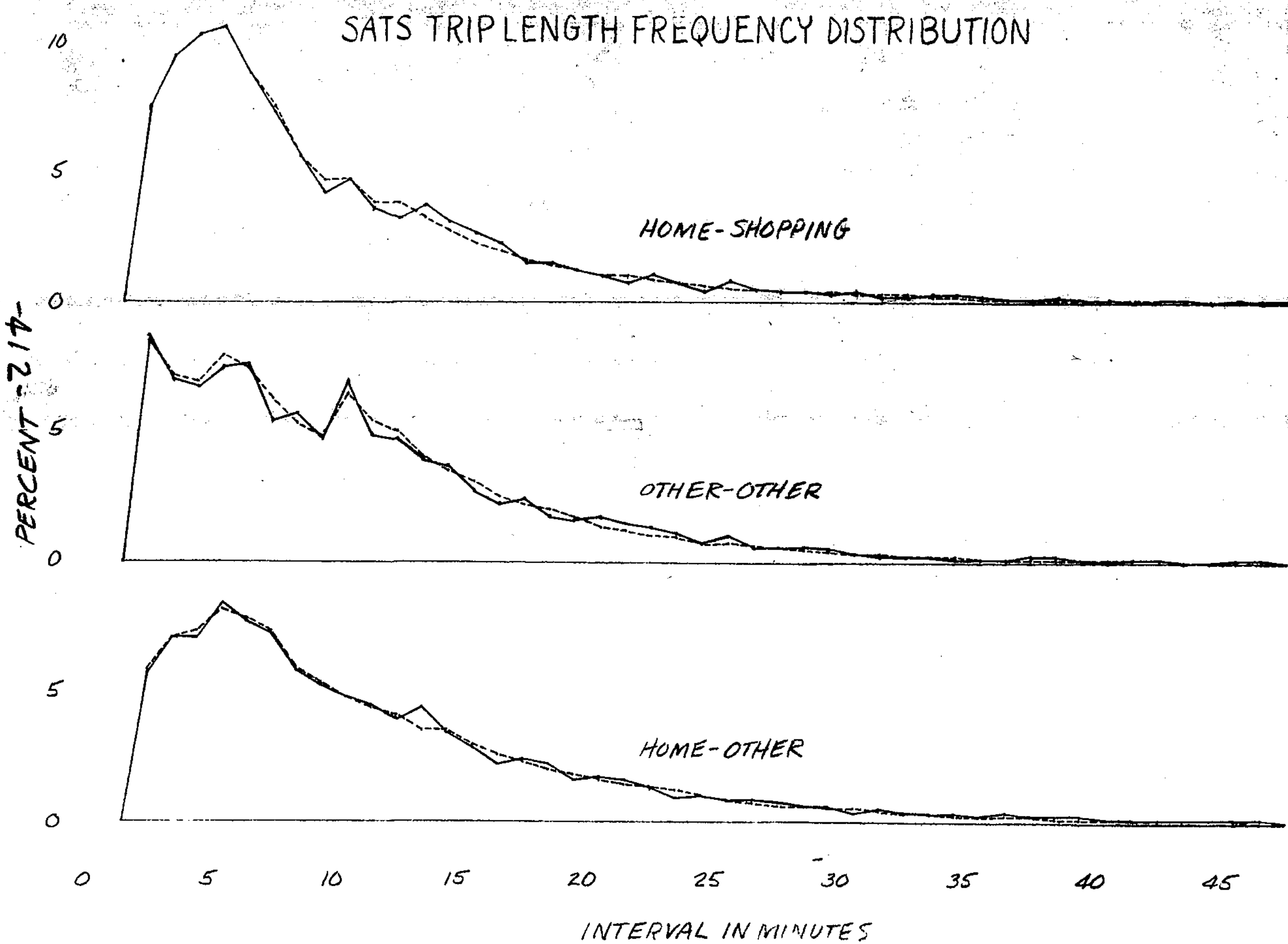
$$\text{O-O} = -0.4 + 225.8\left(\sqrt{\text{RETAIL} + 64} - 8\right) + 0.137\ \text{NON-RETAIL} + 0.195\ \text{POPULATION}$$
$$\text{O-W} = -2.1 + 65.9\left(\sqrt{\text{RETAIL} + 64} - 8\right) + 0.060\ \text{NON-RETAIL} + 0.032\ \text{POPULATION}$$

DEVELOPMENT OF TRAVEL TIME FACTORS

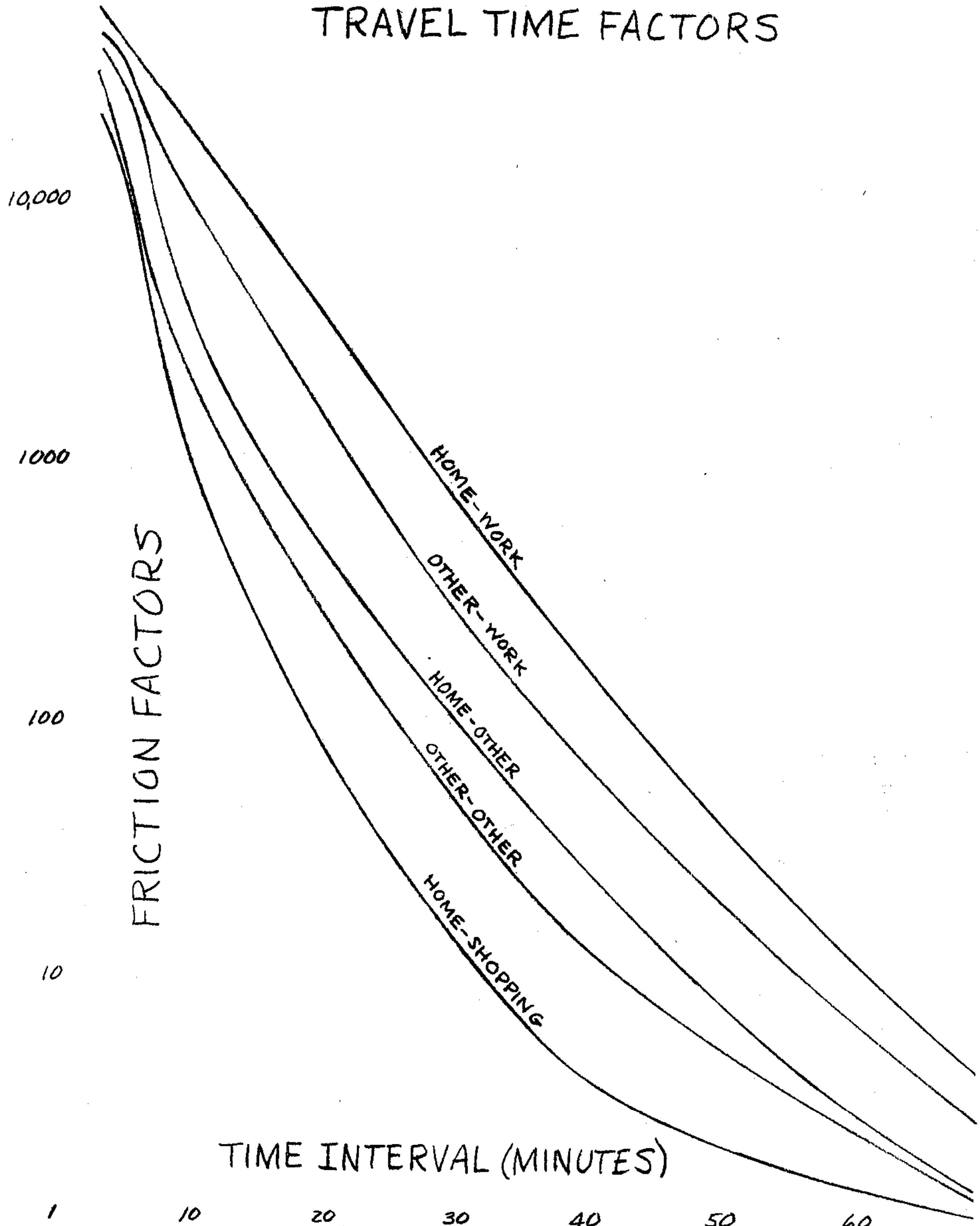


SATS TRIP LENGTH FREQUENCY DISTRIBUTION




SATS TRIP LENGTH FREQUENCY DISTRIBUTION
HOME-SHOPPING
OTHER-OTHER
HOME-OTHER
PERCENT
10
5
0
5
0
5
0
0
5
10
15
20
25
30
35
40
45
INTERVAL IN MINUTES

TRAVEL TIME FACTORS



MODAL SPLIT MODELS

N-DIMENSIONAL LOGIT (PM & M)

SAN DIEGO & SACRAMENTO

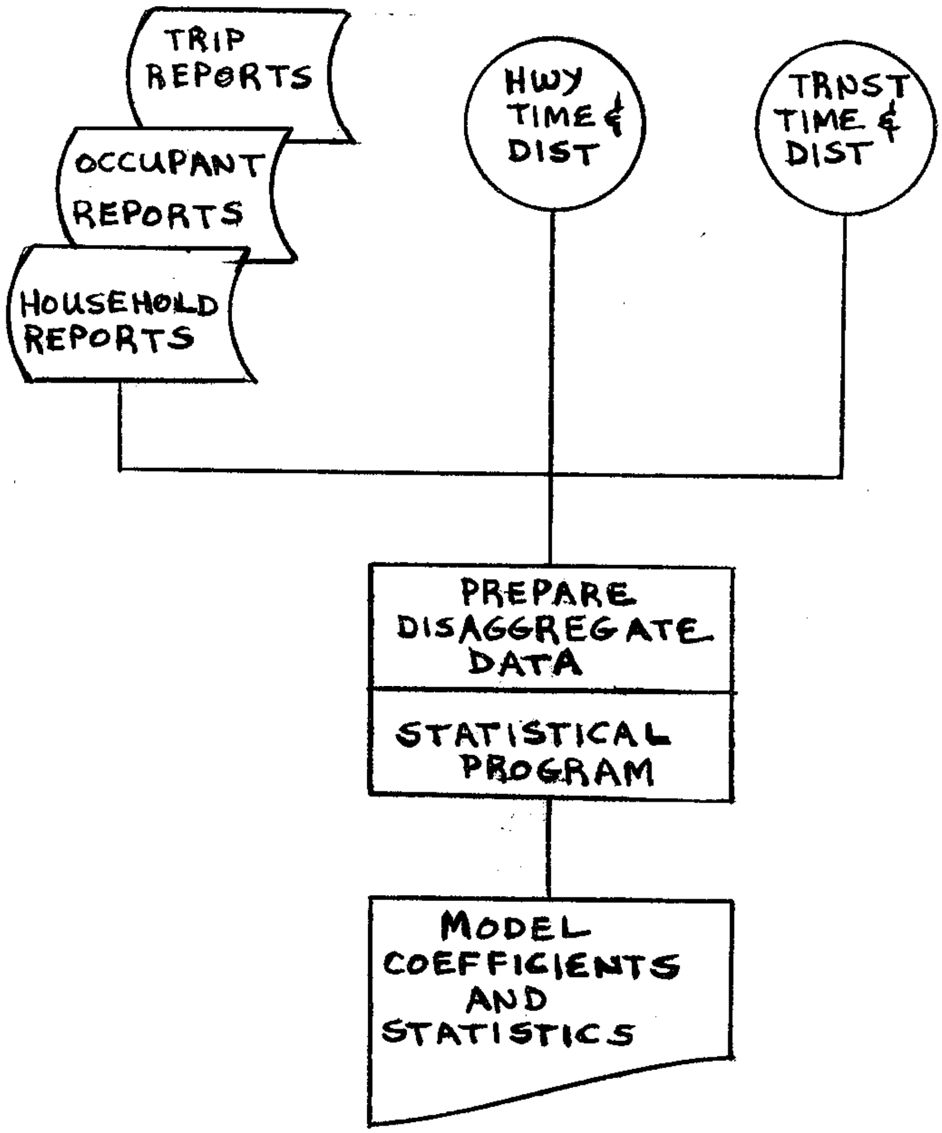
DISUTILITY (AMV)

LOS ANGELES & FRESNO

DODOTRANS (MIT)

LOS ANGELES & STATEWIDE

DEVELOPMENT OF MODAL SPLIT MODEL



SECTION 14

ENERGY REQUIREMENTS FOR TRANSPORTATION SYSTEMS

TRANSPORTATION ENERGY

The National Environmental Policy Act of 1969 (NEPA) and the State Environmental Quality Act of 1970 (CEQA) require detailed environmental impact statements (EIS) for transportation projects. In addition, The National Environmental Coordination Act of 1974 and California State Assembly Bill 1575 of May 1974 require that a detailed energy analysis be included in the EIS to determine the energy impact of proposed transportation projects.

This interim procedure is a first step toward development of a procedural manual which will enable the user to apply "energy factors" to such things as material construction, construction processes, maintenance processes, and operational processes. Here, we will consider only propulsion energy of the automobile and heavy duty vehicle. Figure 14-1 shows two curves developed by FHWA* which estimate automobile fuel consumption on freeways and on arterial streets for various speeds. The curves represent a composite automobile mix of 58%, 30%, and 12% for standard, compact, and subcompact autos, respectively, for the base year of 1974. There has been much speculation on what fuel economies may be attainable within the next 20 years. There has been much evidence developed which indicates that a 40% improvement in model year mileage between 1974 and 1980 is feasible. In addition, it appears that the fuel economy may double between 1974 (12.5 miles per gal) and 1995. Table 14-1 gives correction factors which may be applied(multiplied) to Figure 14-1 (base year 1974) to give the composite mileage for any given year up through 1995 at any given speed.

Figure 14-2 shows a fuel consumption curve developed by FHWA for a 25 ton diesel truck. Correction factors for converting diesel fuel economy to gasoline fuel economy (equivalent BTU basis) are given in table 14-2. The gasoline fuel economy may be found by multiplying these factors times the given fuel economy in figure 14-2. It is felt that little or no improvement in HDV fuel economy will be accomplished in the next 20 years; therefore, the fuel economies given in figure 14-2 will not change over the next 20 years.

In summary, total gallons of fuel consumed on a project life basis is estimated by the following:

1. Determine traffic volume, route speeds and temporal distribution of build vs. no-build conditions for both LDV and HDV
2. Divide the number of miles traveled by the fuel economy for each speed and for each year of a 20 year project life. Appropriate correction factors from table 14-1 for each year LDV estimates must be applied. Correction factors from table 14-2 must be multiplied times the fuel economy shown in figure 14-2 for gasoline HDV estimates.

* Bloom, Kent, TRANS-Urban Computer Model (OPGAS), Federal Highway Administration, U. S. Dept. of Transportation, Washington, D.C. 1973

FIGURE 14-1

1974 COMPOSITE AUTO FUEL ECONOMY

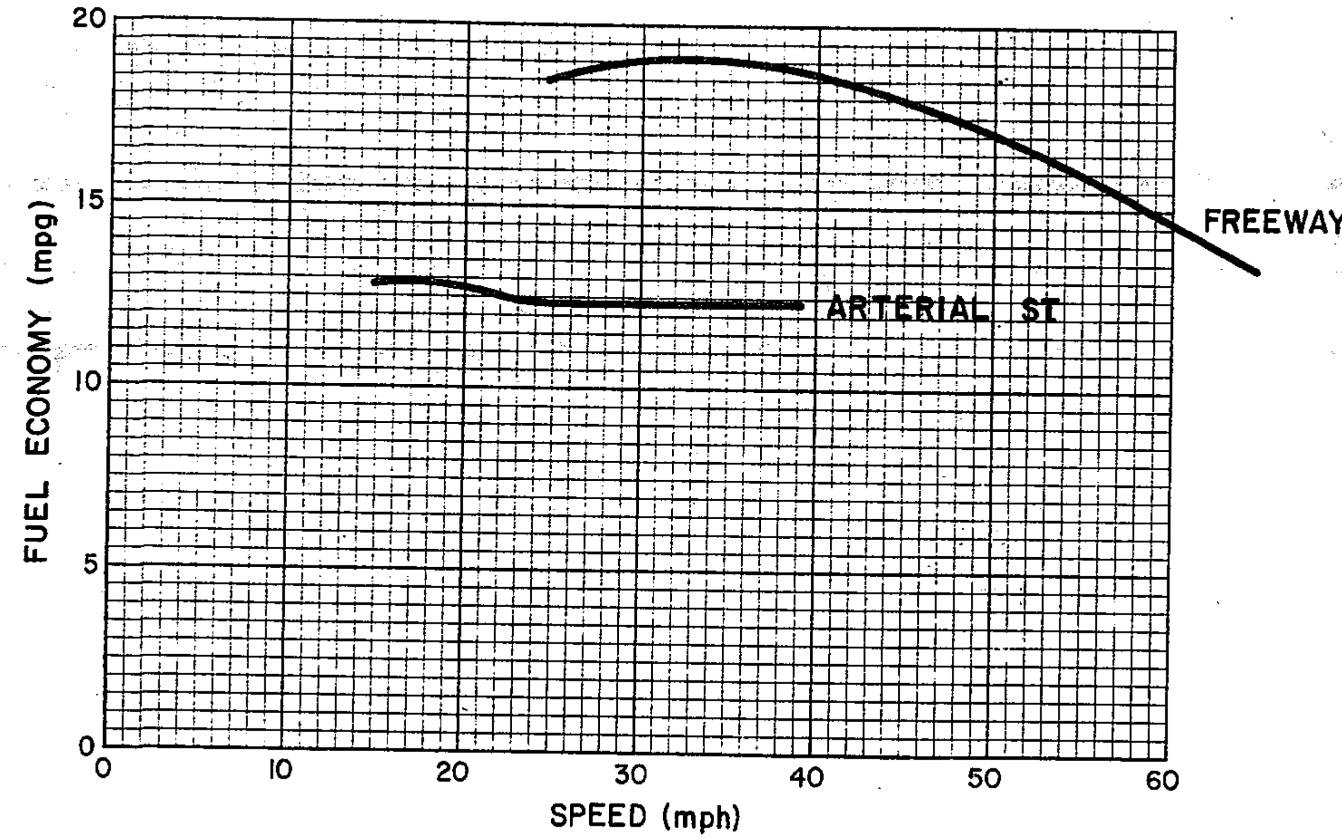


TABLE 14-1

LDV COMPOSITE CALIFORNIA MILEAGE

Year	Model mpg	Composite mpg @ 25 mph	74 Base Factor
1974	12.5	12.7	1.00
1975	14.6	13.0	1.02
1976	15.2	13.4	1.06
1977	15.75	14.0	1.10
1978	16.35	14.5	1.14
1979	16.9	15.0	1.18
1980	17.5	15.6	1.23
1981	18.1	16.2	1.28
1982	18.75	16.7	1.31
1983	19.35	17.4	1.37
1984	20.00	18.1	1.43
1985	20.6	18.7	1.47
1986	21.3	19.3	1.52
1987	22.05	20.0	1.57
1988	22.75	20.6	1.62
1989	23.5	21.3	1.68
1990	24.2	22.0	1.73
1991	24.9	22.7	1.79
1992	25.65	23.4	1.84
1993	26.35	24.1	1.90
1994	27.10	24.9	1.96
1995	27.80	25.6	2.02

FIGURE 14-2

COMPOSITE DIESEL HDV TRUCK FUEL ECONOMY

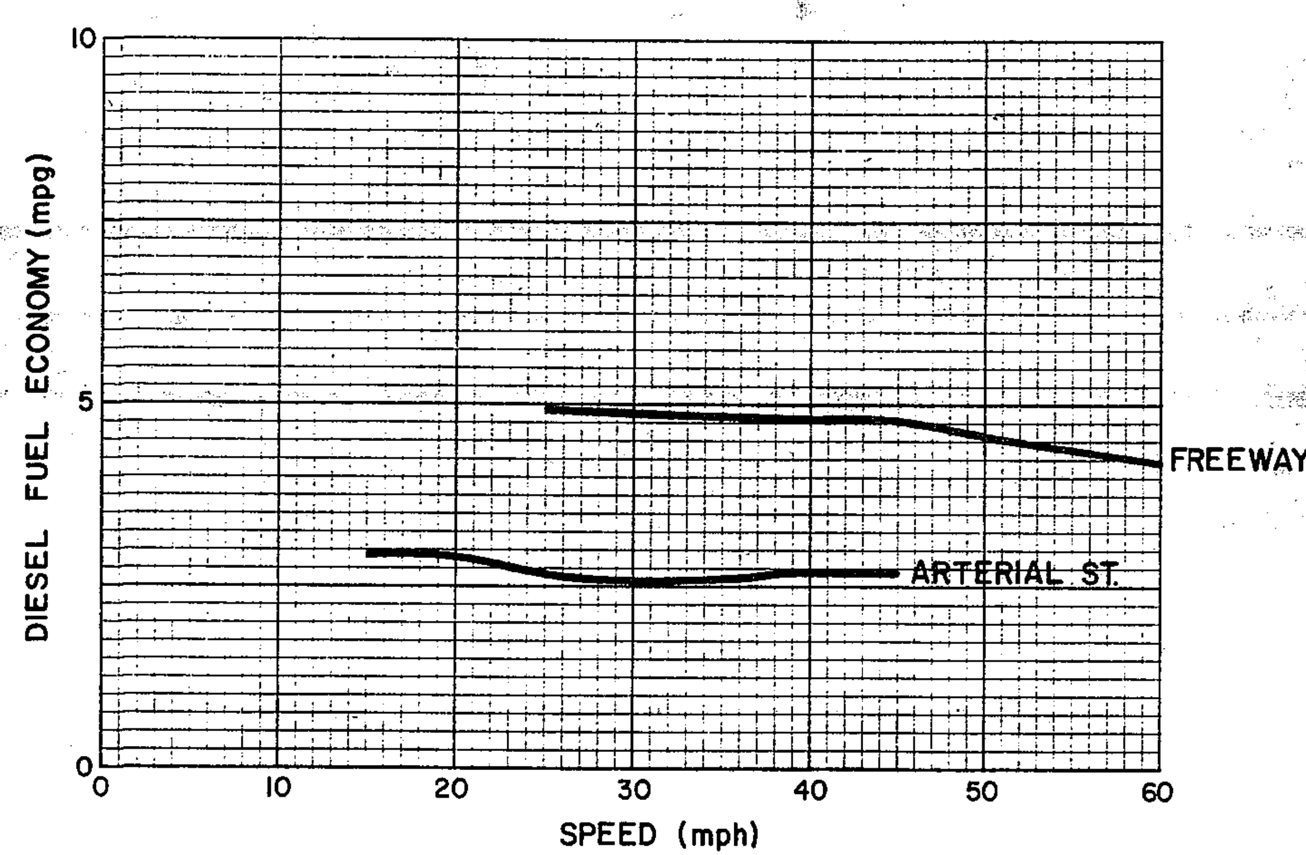


TABLE 14-2

FACTORS TO CONVERT DIESEL TRUCK FUEL ECONOMY (mpg) TO GAS TRUCK FUEL ECONOMY

Speed (mph)	Factor
10	1.10
20	0.71
30	0.63
40	0.67
50	0.69

SECTION 15

CONSTRUCTION POLLUTION

SECTION 15

CONSTRUCTION POLLUTION

I. What are primary reasons for concern about construction pollution problems?

A. We must meet all Federal, State and local APCD rules and regulations. Excessive dust could exceed standards for suspended particulate matter and Ringlemann No. among other things.

B. The Caltrans Standard Specifications specifically call for the use of water or dust palliatives to eliminate any dust nuisance. Also the Standard Specifications require that all air quality regualtions and laws be obeyed.

C. Prevention of property damage, environmental damage and lawsuits.

II. Control Techniques

A. Watering - most common, but not necessarily the cheapest or most effective. Watering must be nearly continuous, but cannot be applied at excessive rates - soil must be kept damp, but free of mud and puddles. Mud will track onto surrounding streets and when it dries it greatly expands the dust emitting area. Thus, watering should be continued over weekends and holidays - lots of water on dry soil Monday morning results in surface mud and dry dust below. In some soils, watering can provide some dust control even after the soil dries, since a thin, stabilizing crust is formed. This is quickly broken down by traffic though.

B. Chemical treatments - there are more than 100 types of treatments on the market, ranging from ligmin-sulfonate and CaCl to asphaltic emulsions and latex. Some chemicals like CaCl are useful in retaining moisture in the soil. They require occasional watering. The most effective technique is to apply an asphalt emulsion or even temporary paving where haul roads are concerned. Since labor is so expensive, continual operation of water trucks will often be less attractive economically than emulsion or even paving. The most effective means of controlling fugitive dust from aggregate stockpile is to apply water which contains dissolved chemical stabilizers. This still allows for good aggregate workability, and H_2O is retained much longer in the fines.

C. Wind erosion protection - This includes the use of windbreaks or even the planting of temporary ground cover. Sand (snow fences) barriers are sometimes useful. In jobs where large cuts or fills may stand unpaved for one or more years, planting can be worthwhile.

III. Air Pollution From Construction as Part of Air Quality Report

A. This aspect is often not dealt with in any great detail by A. Q. Report Writers.

B. Any job which involves much clearing, earthwork or hauling, the fugitive dust problem should be investigated.

C. Some key points:

1. Meteorology - W/S, W/D, precipitation. Strong winds, low precipitation or low precipitation immediately prior to job can result in high potential for construction pollution.

2. Location of receptors - Here you're not just looking at "sensitive" receptors everyone is bothered by airborne dirt. If there are any receptors who will be adversily affected to any significant degree, there could be problems. Naturally, wind direction is all-important when it comes to who gets blasted. And unlike gaseous pollutants, most dust goes only one way in the long run - down. And since vertical dispersion is generally poor, dust doesn't dilute too well with distance. Dust can affect receptors 1000's of yards away under adverse conditions.

3. Soil Particle Size Distribution. This must be considered also. The more fines, the worse the dust problem will generally be. Smaller particles are more easily suspended, rise higher, travel farther and settle slower. In the case of nearly uniform grain size sand such as at Monterey, it takes a lot of wind to pick it up (25-30 mph) and there is an abrupt threshold either its all airborne or its on the ground. Once the wind drops below threshold it all falls.

4. As part of the field survey, aerometric measurements should be taken in the vicinity of grading, operations, haul roads, stockpiles, etc., both before and during construction to get a comparison. Measurements should include W/S and W/D (MWS) and particulate concentrations, using Hi-Volume samplers. It would be useful to measure downwind particulate concentration. This will provide information for estimating how far from the project excessive concentrations will exist vs. distance from the source. In most cases it would only be practical to measure "before and during" construction in the vicinity of receptors which appear vulnerable.

IV. Present Status of Research

A. Research Project: "Measurement and Control of Air Pollution Produced by Highway Construction Operations and Related Industries".

Purpose:

1. Measure the concentration and particle size distribution of particulate matter which becomes airborne during highway construction operations and certain related activities (excluding batch planting and other stationary point sources). Concentration and particle size of particulate matter will be correlated with such factors as temporal-spatial distribution, soil gradation, meteorology, ground cover, source type and design

(cut, fill, haul road, stockpiles, etc.), control techniques, and land use (urban, rural, ect.). Impacts on surrounding area will also be evaluated to some extent, including possible property damage erosion, maintenance problems, etc.

2. Conduct a literature search to evaluate the state-of-the-art in dust control techniques as well as dust emission factors, impacts of construction - generated particulates and the like.

3. Recommend special precautions and control techniques to be observed or used during construction operations. The effectiveness of these techniques and their relative advantages and disadvantages will be dealt with.

HOMEWORK PROBLEMS

Problem No. 1: Rural Area With Neutral Conditions.

Given: Same conditions as in Example 3 of lecture notes except that the land use is a reasonal green agricultural area (alfalfa).

Find: Calculate vertical diffusivities from 25 m to base of inversion.

Problem No. 2: Light Residential Area With Stable Conditions

Given: Assume that for light residential area the Turner Stability Class is F. The wind speed is measured 10 m above the canopy and is 1 m/sec. The average height of the canopy is 7.2 m(24 feet). The height of the base of the elevated inversion is 1000 m.

Find: Calculate vertical diffusivities for heights of 10, 15, and 20 m.