United States
Environmental Protection
Agency

Air Pollution Training Institute
MD 20
Environmental Research Center
Research Triangle Park, NC 27711

EPA 450/2-81-075
October, 1981

Air

APTI
Course 423
Dispersion of Air Pollution: Theory and Model Application

Student Workbook

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Technical Content:
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R. E. Townsend

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Manpower and Technical Information Branch
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

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Introduction

The Air Pollution Training Institute has developed Course 423, Dispersion of Air Pollution—Theory and Model Application, to train meteorologists, engineers, and physical scientists responsible for measuring and evaluating meteorological factors that affect the dispersion and concentration of pollutants in the atmosphere. Meteorological factors and the role they play in the transport and dispersion of air pollution are presented. You will have an opportunity to calculate estimates of continuous-release pollutant concentrations and become familiar with meteorological instruments. Discussions will be held to enable you to evaluate air pollution control strategies and to plan and interpret surveys.

This workbook is designed to provide you with a guide to the lecture materials. Included herein are the course goal, course objectives, and chapter objectives and outlines. A study guide lists reading assignments and homework problems associated with this course. The homework problems are included in this workbook.

Table of Contents

Attachments

Course Goal and Objectives

Course Goal

The purpose of APTI Course 423, Dispersion of Air Pollution—Theory and Model Application, is to familiarize the students with the development of selected theories of dispersion, current thinking and research in dispersion modeling, and the application of dispersion and plume rise equations to actual situations.

Course Objectives

Upon completion of this course, you should be able to:

1. recall the effect that topography has on the dispersion of air pollution, the basic meteorological factors that influence air pollution dispersion, and the effect of turbulence on dispersion of air pollution.
2. solve dispersion estimate problems of air pollution transport from source to expected concentrations at receptors using the *Workbook of Atmospheric Dispersion Estimates (WADE)* by D. Bruce Turner.
3. solve plume rise estimate problems in various environmental stability situations using the methods proposed by G. A. Briggs and endorsed by the Environmental Protection Agency.
4. solve problems for comparison of differences in magnitude between sigma y and sigma z values used in air quality modeling.
5. select an air quality dispersion model to estimate the concentration values at receptor locations by using the *Guideline on Air Quality Models*; the *Workbook for Comparison of Air Quality Models*; and sufficient information about air quality models available, topography, meteorology, climatology, source emissions data, and a particular site situation.

Study Guide

Reading Assignments

The following assignments should be completed as indicated:

Prior to Arrival for Class

1. scan *Workbook of Atmospheric Dispersion Estimates* by Turner, particularly chapter 3.*
2. scan *Plume Rise* by Briggs.*
3. scan *Dispersion Estimates Suggestion* no. 2 by Turner, revised 1973 (Attachment 7-1).
4. scan *Plume Rise from Multiple Sources* by Briggs.*
5. read *Determination of Atmospheric Diffusion Parameters* by R. R. Draxler, 1977.*
6. scan *Dispersion Notes* by S. P. S. Arya.*
7. scan *Consequences of Effluent Release* by Gifford.*
8. review *Air Pollution Meteorology* by Turner, Sept. 1975.

Monday Night

1. review *Dispersion Estimates Suggestion* no. 2, revised 1973 (Attachment 7-1).
2. review precourse material by R. R. Draxler.

Tuesday Night

1. review *Guideline on Air Quality Models* EPA-450/2-78-027.
2. review *User's Guide to PTXXX Models.*

Thursday Night

1. review all materials, notes, for posttest on Friday.

Homework Problems

The following problems should be completed when indicated:

1. Problem set 1: plume rise, due Tuesday morning.
2. Problem set 2: atmospheric dispersion estimates, due Wednesday morning.

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*Found in *Selected Readings Packet* sent prior to course offering.

Chapter 1

Registration, Course Information, and Pretest

Chapter Goal

To familiarize you with the course structure and objectives, to have you meet instructors and other students, to take the pretest, and to receive pertinent logistical information.

Chapter Objectives

Upon completion of this chapter, you should be familiar with the basic content and structure of this course. There are no testable objectives for this chapter.

Chapter Outline

I. Introduction
II. Course structure and requirements
III. Registration
IV. Pretest

Chapter 2

Air Pollution Meteorology I

Chapter Goal

To familiarize you with the meteorological scales of motion, important meteorological factors that influence dispersion, and the large-scale meteorological factors that influence air pollution dispersion.

Chapter Objectives

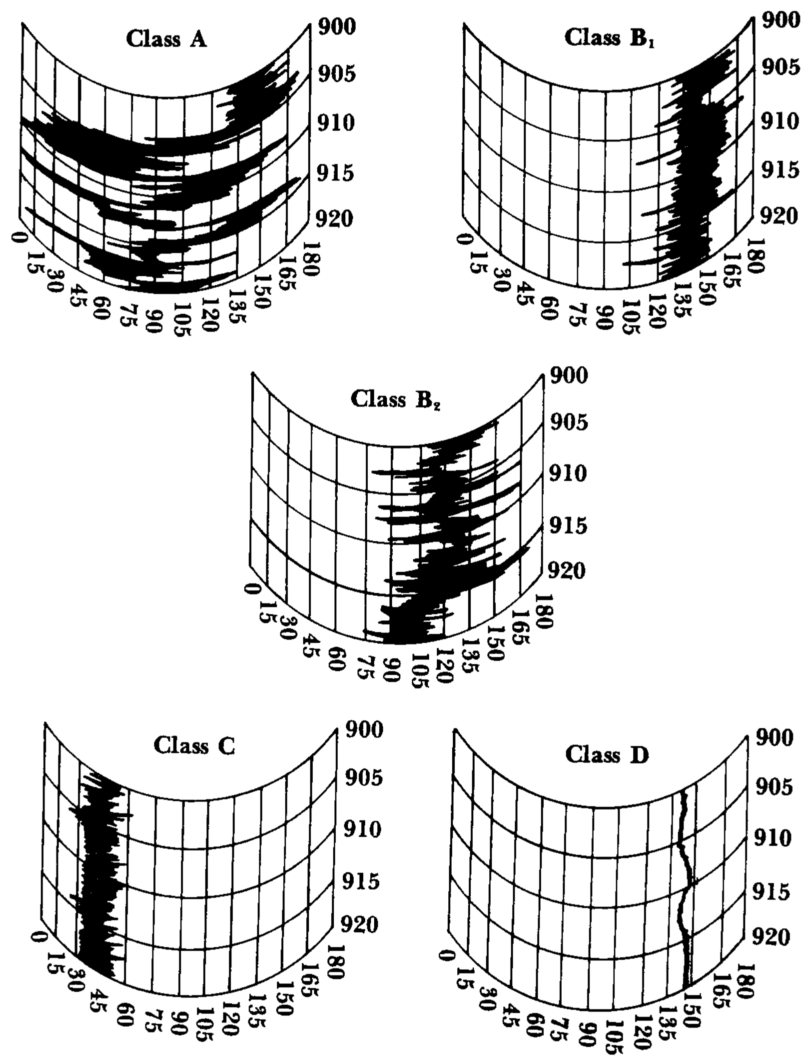
Upon completion of this chapter, you should be able to:

1. identify the meteorological scales of motion of the atmosphere and the relative distances that characterize them.
2. recall the important meteorological factors that influence dispersion.
3. recall the large-scale meteorological factors that influence air pollution dispersion.

Chapter Outline

I. Meteorological scales of motion
   A. Microscale
   B. Mesoscale
   C. Synoptic scale
   D. Macroscale
II. Meteorological factors influencing dispersion
   A. Primary
   B. Secondary
III. Large-scale meteorological factors influencing air pollution
   A. Dispersion anticyclones
   B. Frontal trapping
   C. Shoreline winds

Attachment 2-1. Brookhaven National Laboratories gustiness classifications.



Attachment 2-2. Nuclear Safety Guide #23.

Classification of atmospheric stability			
Stability classification	**Pasquill categories**	σ_θ* **(degrees)**	**Temperature change with height (°C/100 m)**
Extremely unstable	A	25.0°	< −1.9
Moderately unstable	B	20.0°	−1.9 to −1.7
Slightly unstable	C	15.0°	−1.7 to −1.5
Neutral	D	10.0°	−1.5 to −0.5
Slightly stable	E	5.0°	−0.5 to 1.5
Moderately stable	F	2.5°	1.5 to 4.0
Extremely stable	G	1.7°	>4.0

*Standard deviation of horizontal wind direction fluctuation over a period of 15 minutes to one hour. The values shown are averages for each stability classification.

Extracted from Safety Guide 23: Onsite Meteorological Programs (Nuclear Regulatory Comission).

Attachment 2-3. Oak Ridge data: Pasquill stability categories versus temperature difference* and wind speed.

Temperature gradient (°C/30.5 m)	Wind speed (m/s)				
	0-1.4	**1.5-3.1**	**3.2-4.9**	**5.0-6.7**	**6.8**
< −3.1 to −2.0	A	A-B	B	B-C	(C)
−1.9 to −1.1	A-B	B	B-C	C	C-D
−1.0 to −0.4	B	B-C	C	C-D	D
−0.3 to ±0.0	D	D	D	D	D
+0.1 to +1.1	F	E-F	E	D-E	D
+1.2 to +2.3	F-G	F	E-F	(E)	—
+2.4 to +3.5	G	F-G	F	—	—

*Temperature difference in °C per 30.5 m from 1.2 m to 41 m.

From *AEC*, Oak Ridge, TN.

Attachment 2-4. Richardson number.

$$R_i = (g/T)\frac{(\partial\theta/\partial z)}{(\partial u/\partial z)^2}$$

Where: g = gravitational constant
T = average temperature through layer of concern
$\partial\theta/\partial z$ = change of potential temperature with height
$\partial u/\partial z$ = change of wind speed with height

$0.25 < R_i$	No vertical mixing
$0 < R_i < 0.25$	Mechanical turbulence, weakened by stratification
$R_i = 0$	Mechanical turbulence only
$-0.03 < R_i < 0$	Mechanical turbulence and convection, but mixing mostly due to the former
$R_i < -0.04$	Convective mixing dominates mechanical mixing

The relative importance of heat convection and mechanical turbulence is often characterized by the Richardson number, R_i. Actually, $-R_i$ is a measure of the relative rate of conversion of convective to mechanical energy. For example, negative Richardson numbers of large magnitude indicate that convection predominates; in this situation, the winds are weak, and there is strong vertical motion. Smoke leaving a source spreads rapidly, both vertically and laterally. As the mechanical turbulence increases, the Richardson number approaches zero, and the angular dispersion decreases. Finally, as the Richardson number becomes positive, the stratification becomes stable and damps the mechanical turbulence. For Richardson numbers above 0.25 (strong inversions, weak winds), vertical mixing effectively disappears, and only horizontal eddies remain.

Chapter 3

Air Pollution Meteorology II

Chapter Goal

To familiarize you with topographical effects on air pollution, urban effects on meteorology and climate, and the meteorological situations that cause problems in making dispersion estimates.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. apply the effects of a particular topographical feature to atmospheric motion and explain the resulting effects on plume dispersion.
2. explain how urban areas modify the meteorology and climate of the urban area itself and of the surrounding area.
3. explain the dispersion of plumes for various meteorological situations.
4. describe the urban heat island effect on atmospheric circulation and temperatures.

Chapter Outline

I. Topographical influences on dispersion
   A. Plane
   B. Mountain and valley
   C. Shoreline
II. Urban effect on meteorology and climate
   A. Urban effects
   B. Effects on meteorology
   C. Effects on climate
III. Meteorological situations that cause problems in making dispersion estimates
   A. Fumigation
   B. Trapping
   C. Stability A category
   D. Flow reversal
   E. Background concentrations
   F. Elevated receptor

Attachment 3-1. Climatic changes produced by cities.

Element	Comparison with rural environs
Contaminants	
dust particles	10 times more
sulfur dioxide	5 times more
carbon dioxide	10 times more
carbon monoxide	25 times more
Radiation	
total on horizontal surface	15 to 20% less
ultraviolet, winter	30% less
ultraviolet, summer	5% less
Cloudiness	
clouds	5 to 10% more
fog, winter	100% more
fog, summer	30% more
Precipitation	
amounts	5 to 10% more
days with 0.2 inches	10% more
Temperature	
annual mean	1 to 1.5 °F more
winter minima	2 to 3.0 °F more
Relative humidity	
annual mean	6% less
winter	2% less
summer	8% less
Wind speed	
annual mean	20 to 30% less
extreme gusts	10 to 20% less
calms	5 to 20% more

Taken from *Symposium: Air Over Cities,* SEC Technical Report A62-5, Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 1961.

Chapter 4

Turbulence and Diffusion I
(video presentation)

Chapter Goal

To introduce you to the nature of wind, the importance of average wind, and the meaning and use of standard deviation of wind direction fluctuations, roughness factor, and turbulence.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. select the statement that describes the relationship of average wind to plume transport.
2. select the statement that describes the relationship of wind direction fluctuations to plume dispersion.

Chapter Outline

- I. Plume rise
  - A. Wind
  - B. Effluent temperature
  - C. Ambient temperature
- II. Transport
  - A. Weather maps
  - B. Airport observations
  - C. Special observations
- III. Diffusion
  - A. Dilution
  - B. Difficult to treat
- IV. Removal
  - A. Air chemistry
  - B. Radioactive
  - C. Washout
  - D. Rainout
  - E. Deposition

V. Wind properties
   A. Recorded by anemometer
   B. Height above ground
   C. Fluctuations
   D. Statistics of V′ and W′
   E. Standard deviations
   F. Turbulence
   G. Basic properties of heat convection
   H. Rates of mechanical turbulence to heat convection

Chapter 5

Turbulence and Diffusion II
(video presentation)

Chapter Goal

To familiarize you with the qualitative meaning of the Richardson number and its relationship to the Monin-Obukhov number; and with roughness factor and wind profiles.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. equate Richardson numbers to turbulent production.
2. use a wind profile to obtain roughness factor.

Chapter Outline

I. Richardson number
   A. Flux Richardson number
   B. Gradient Richardson number
   C. Richardson number versus atmospheric conditions
II. Monin-Obukhov number
   A. Defined in relation to Richardson number
   B. Properties
III. Mean wind described quantitatively
   A. Properties of mean wind in surface layer
   B. Validity problems
   C. Increased accuracy of wind estimation
IV. Statistics of the wind
   A. Normalized standard deviation of vertical wind speed
   B. Meaning of normalized standard deviation

Attachment 5-1. Roughness lengths for various surfaces.

Type of surface	h(cm)	z_0(cm)	Author
Fir forest	555	283.0	Baumgartner (1956)
Citrus orchard	335	198.0	Kepner et al. (1942)
Large city (Tokyo)		165.0	Yamamoto and Shimanuki (1964)
Corn *$u_{5.2}$ = 35 cm sec^{-1} $u_{5.2}$ = 198 cm sec^{-1}	300	 127.0 71.5	Wright and Lemon (1962)
Corn $u_{4.0}$ = 29 cm sec^{-1} $u_{4.0}$ = 212 cm sec^{-1}	220	 84.5 74.2	Wright and Lemon (1962)
Wheat $u_{1.7}$ = 190 cm sec^{-1} $u_{1.7}$ = 384 cm sec^{-1}	60	 23.3 22.0	Penman and Long (1960)
Grass $u_{2.0}$ = 148 cm sec^{-1} $u_{2.0}$ = 343 cm sec^{-1} $u_{2.0}$ = 622 cm sec^{-1}	60-70	 15.4 11.4 8.0	Deacon (1953)
Alfalfa brome $u_{2.2}$ = 260 cm sec^{-1} $u_{2.2}$ = 625 cm sec^{-1}	15.2	 2.72 2.45	Tanner and Pelton (1960b)
Grass	5-6 4 2-3	0.75 0.14 0.32	 Rider et al. (1963) Rider (1954)
Smooth desert		0.03	Deacon (1953)
Dry lake bed		0.003	Vehrencamp (1951)
Tarmac		0.002	Rider et al. (1963)
Smooth mud flats		0.001	Deacon (1953)

*The subscript gives the height (in meters) above the ground at which the wind speed, $\bar{u}$, is measured.

Chapter 6

Turbulence and Diffusion III (video presentation)

Chapter Goal

To familiarize you with some experimental data that is used to assess the sigma values; the relationships of the Richardson number, Monin-Obukhov length, and other sigma values.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. select the statement that describes the use of experimental data to obtain sigma values.
2. identify the terms in the Richardson number and their meaning in obtaining a representative dimensionless number.

Chapter Outline

I. Fluctuation of wind direction
   - A. Complicated
   - B. Azimuth
   - C. Weak wind, strong insolation, rapid fluctuation
   - D. Strong wind, weak insolation, little fluctuation

II. Monin-Obukhov theory
   - A. Problems
   - B. Changes
   - C. Pine Grove Mills study

III. Taylor diffusion theorem
   - A. Description
   - B. Assumptions by Taylor

IV. Treatment of dispersion in practice
   - A. Direct measurements
   - B. Estimate σ_A and σ_E

V. Graphical form of dispersion
   - A. Pasquill-Gifford categories
   - B. Assumptions

Chapter 7
Effective Stack Height and Plume Rise

Chapter Goal

To familiarize you with the method of calculating effective stack height and plume rise as suggested by Dr. Gary Briggs and endorsed by USEPA; and to compare Briggs' plume rise formula with other plume rise formulas available.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. calculate effective stack height and final plume rise, given the EPA endorsed plume rise formulas by Briggs and sufficient information about a source and atmospheric conditions.
2. calculate plume rise from formulas by Davidson-Bryant, Holland, etc., to contrast with that calculated by the Briggs method.

Chapter Outline

- I. Background
  - A. Early attempts
  - B. Contradicting formulas
- II. Behavior of plume
  - A. Aerodynamic effects
    - 1. Stack effects
    - 2. Plume rise
    - 3. Dispersion
- III. Observations
  - A. Modeling studies
  - B. Atmospheric studies
- IV. Plume rise formulas
  - A. Earlier formulas
  - B. Current formulas

Attachment 7-1. Dispersion estimate suggestion no. 2 (revised).

MODEL APPLICATION BRANCH

Subject:
Estimate of Plume Rise

It was brought to my attention last month by Mr. Marvin Green of the Department of Environmental Protection of the State of New Jersey, and by Mr. Ed Burt of the Monitoring and Data Evaluation Division, EPA that the use of the equation (12) for stable conditions results in estimates for some x in excess of the final rise. The correction of this error in calculations is the reason for this revision.

We, in the Model Application Branch, have used the equations of Briggs to estimate plume rise for several years now. Gary Briggs has revised this several times and we have tried to keep up with these revisions.

Briggs, Gary A., 1969. *Plume Rise*. USAEC Critical Review Series. TID-25075. National Technical Information Service, Springfield, Va. 22151.

Briggs, Gary A., 1971. Some Recent Analyses of Plume Rise Observation. pp. 1029-1032, in *Proceedings of the Second International Clean Air Congress*, edited by H. M. Englund and W. T. Berry. New York: Academic Press.

Briggs, Gary A., 1972. Discussion on Chimney Plumes in Neutral and Stable Surroundings. *Atmos. Environ.* 6, 507-510 (Jul 72).

The following symbols are used:

π	a constant = 3.14
g	gravitational acceleration = 9.80 m sec^{-2}
T	ambient air temperature, K
u	average wind speed at stack level, m sec^{-1}
v_s	stack gas exit velocity, m sec^{-1}
d	top inside stack diameter, m
T_s	stack gas exit temperature, K
V_f	stack gas volume flow, m^3 sec^{-1}
F	buoyancy flux parameter, m^4 sec^{-3}
x*	distance at which atmospheric turbulence begins to dominate entrainment, m
ΔH	plume rise above stack top, m
x	downwind distance from the source, m
x_f	distance downwind to final rise, m
$\partial\theta/\partial z$	vertical potential temperature gradient of atmosphere, K m^{-1}
s	restoring acceleration per unit vertical displacement for adiabatic motion in the atmosphere—a stability parameter, sec^{-2}

The following procedures are consistent with the way in which we calculate Briggs plume rise:

If T is not given, we have been using
T = 293 K (68 °F) for design calculations

$$V_f = \frac{\pi}{4} v_s d^2 = 0.785\ [v_s d^2] \qquad (1)$$

$$F = \frac{g}{\pi} V_f \left[\frac{T_s - T}{T_s}\right] = 3.12 \quad V_f \left[\frac{T_s - T}{T_s}\right] \qquad (2)$$

For unstable or neutral conditions:

$x^* = 14\ F^{5/8}$ for F less than 55 (3)

$x^* = 34\ F^{2/5}$ for F greater than or equal to 55 (4)

The distance of the final rise is: $x_f = 3.5\ x^*$ (5)

The final plume rise:

$$\Delta H = \frac{1.6\ F^{1/3}\ (3.5\ x^*)^{2/3}}{u} \qquad (6)$$

For x less than the distance of final rise:

$$\Delta H = \frac{1.6\ F^{1/3} x^{2/3}}{u} \qquad (7)$$

For stable conditions, need $\partial\theta/\partial z$

If $\partial\theta/\partial z$ is not given use:

0.02 °K m^{-1} for stability E

0.035 °K m^{-1} for stability F

$$s = g\left[\frac{\partial\theta/\partial z}{T}\right] = 9.806\left[\frac{\partial\theta/\partial z}{T}\right] \qquad (8)$$

Calculate

$$\Delta H = 2.4\left[\frac{F}{us}\right]^{1/3} \qquad (9)$$

and

$$\Delta H = \frac{5\ F^{1/4}}{s^{3/8}} \text{ (plume rise for calm conditions)} \qquad (10)$$

Use the smaller of these two ΔH's.

This is the final rise.

The distance to final rise is:

$$x_f = \frac{3.14\ u}{s^{1/2}} \qquad (11)$$

If you want to calculate rise for a downwind x less than x_f, this is given by

$$\Delta H = \frac{1.6\ F^{1/3} x^{2/3}}{u} \qquad (12)$$

which is the same equation used for unstable and neutral conditions.

Although under stable conditions the plume begins to rise according to the 2/3 power with distance, it does not continue the same rate of rise to the distance of final rise, x_f, given by equation (11). Therefore equation (12) will give a ΔH higher than the final rise at distances beyond about 2/3 x_f. It is therefore recommended that when using equation (12), the result be compared with the final rise and the smaller value used. In effect then, for determining the plume rise at a distance, x, during stable conditions, the minimum value of the three values of ΔH determined by equations (9), (10) and (12) should be used.

A FORTRAN subroutine to perform these calculations is included here in case it is of use to you. This is used by a main program by using a CALL BEHO72 statement which has all the variables included in parenthesis following the BEHO72 as it is in the subroutine statement. Note that both the final plume height, HF, and the plume height at the distance X, HX, are calculated and given as output. By having X equal 0 upon entry to the subroutine, only the final rise will be determined.

This subroutine is one of several to be put on the UNAMAP network in the near future.

I want to acknowledge Roger Thompson's valuable assistance in keeping up with plume rise developments prior to his assignment for University Training, and to Russ Lee, Marvin Green, and Ed Burt who have pointed out some recent changes.

D. Bruce Turner, NOAA
Acting Chief
Model Application Branch

S O U R C E   P R O G R A M   L I S T I N G

04/30/73

```
      SUBROUTINE BEHO72    (HF,HX,HMW,F,DELHF,DISTF,DELHX,HP,TS,VS,D,VF,KST,U,X,
      DTHDZ,
     1 T,P)
C          BEHO72   (BRIGGS EFFECTIVE HEIGHT)        OCTOBER 1972
C          D. B. TURNER. RESEARCH METEOROLOGIST* MODEL APPLICATIONS BRANCH,
C           METEOROLOGY LABORATORY, ENVIRONMENTAL PROTECTION AGENCY.
C             ROOM 316B, NCHS BUILDING, RTP. PHONE (919) 549-8411 EXT 4564
C          MAILING ADDRESS:  MTL,EPA, RESEARCH TRIANGLE PARK, NC 27711.
C            *ON ASSIGNMENT FROM NATIONAL OCEANIC AND ATMOSPHERIC
C                 ADMINISTRATION, DEPARTMENT OF COMMERCE.
C            THIS DIFFERS FROM THE AUGUST 1972 VERSION IN STATEMENT 24 + 1:
C             THE CONSTANT 2.4 PREVIOUSLY WAS 2.9, AND IN STATEMENT 27:
C             THE CONSTANT 3.14159 PREVIOUSLY WAS 2.4 .
C          THIS VERSION OF BRIGGS EFFECTIVE HEIGHT TO CALCULATE PLUME RISE
C           FROM A SINGLE SOURCE IS BASED ON:
C             1)  BRIGGS,GARY A., 1971: SOME RECENT ANALYSES OF PLUME RISE
C                  OBSERVATION. PP 1029 - 1032 IN PROCEEDINGS OF THE SECOND
C                  INTERNATIONAL CLEAN AIR CONGRESS, EDITED BY H.M. ENGLUND
C                  AND W.T. BEERY. ACADEMIC PRESS, NEW YORK.
C             2)  BRIGGS,GARY A., 1972: DISCUSSION ON CHIMNEY PLUMES IN
C                  NEUTRAL AND STABLE SURROUNDINGS. ATMOS. ENVIRON. 6, 507
C                  - 510. JULY 1972.
C          OUTPUT VARIABLES ARE....
C            HF    FINAL EFFECTIVE PLUME HEIGHT (METERS)
C            HX    EFFECTIVE PLUME HEIGHT FOR DISTANCE X (METERS)
C            HMW   HEAT OUTPUT OF SOURCE (MW)
C            F     BUOYANCY FLUX (M**4/SEC**3)
C            DELHF FINAL PLUME RISE (METERS)
C            DISTF DISTANCE OF FINAL PLUME RISE FROM SOURCE (KM)
C            DELHX PLUME RISE AT DISTANCE X (METERS)
C          INPUT VARIABLES ARE....
C            HP    PHYSICAL STACK HEIGHT (METERS)
C            TS    STACK GAS TEMPERATURE (DEG K)
C            VS    STACK GAS EXIT VELOCITY (M/SEC)
C            D     INSIDE STACK DIAMETER (METERS)
C            VF    STACK GAS VOLUMETRIC FLOW RATE (M**3/SEC)
C            KST   STABILITY (CLASS), SEE PAGE 209 OF PASQUILL,
C                   ATMOSPHERIC DISPERSION. CLASSES DEFINED BY....
C                     1 IS PASQUILL STABILITY CLASS A
C                     2 IS PASQUILL STABILITY CLASS B
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C                    3 IS PASQUILL STABILITY CLASS C
C                    4 IS PASQUILL STABILITY CLASS D
C                    5 IS PASQUILL STABILITY CLASS E
C                    6 IS PASQUILL STABILITY CLASS F
C            U     WIND SPEED (M/SEC)
C            X     DOWNWIND DISTANCE (KM)
C            DTHDZ POTENTIAL TEMPERATURE LAPSE RATE (DEG K/METER)
C            T     AMBIENT AIR TEMPERATURE (DEG K)
C            P     AMBIENT AIR PRESSURE (MB)
C         THANKS TO DALE COVENTRY FOR HIS HELPFUL DISCUSSION ON
C          PROGRAMMING PLUME RISE, TO ROGER THOMPSON FOR THE COMMENT
C          CARDS, AND TO RUSS LEE WHO REVISED THIS ACCORDING TO REFERENCE 1.
      IF(T)1,1,2                                                          2
C         T = 0. MEANS NO AMBIENT TEMPERATURE GIVEN. USE T = 293.
    1 T = 293.                                                            3
    2 IF(P)3,3,4                                                          4
C         P = 0. MEANS NO AMBIENT AIR PRESSURE GIVEN.  USE P = 960.
    3 P = 960.                                                            5
C         IF VF IS NOT GIVEN, CALCULATE IT FROM STACK DATA.
    4 IF (VF)5,5,6                                                        6
    5 VF = 0.785398*VS*D*D                                                7
C         THE CONSTANT 0.785398 = PI/4
    6 F  = 3.12139*VF*(TS-T)/TS                                           8
C         THE CONSTANT 3.12139 IS THE ACCELERATION DUE TO GRAVITY / PI
      HMW = 0.00011217*F*P                                                9
C         THE CONSTANT 0.00011217 = PI TIMES THE SPECIFIC HEAT OF AIR AT
C         CONSTANT PRESSURE (0.24 CAL/GM*DEG K) TIMES MOLECULAR WEIGHT
C         OF AIR (28.966 GM/GM.MOLE) DIVIDED BY IDEAL GAS CONSTANT
C         (0.0831 MB*M**3/GM.MOLE*DEG K) AND ACCELERATION DUE TO GRAVITY
C         (9.80616 M/SEC*SEC) AND THEN MULTIPLIED BY (4.1855E-06 MW/CAL
C         PER SEC) TO CONVERT THE ANSWER TO MEGAWATTS.
C         GO TO APPROPRIATE BRANCH FOR STABILITY CONDITION GIVEN.
C         IF UNSTABLE OR NEUTRAL GO TO 7, IF STABLE GO TO 20.
      GO TO (7,7,7,7,20,20,20),KST                                        10
C         DETERMINE APPROPRIATE FORMULA FOR CALCULATING XST, DISTANCE AT
C         WHICH TURBULENCE BEGINS TO DOMINATE.  THE FORMULA USED DEPENDS
C         UPON BUOYANCY FLUX. STATEMENTS 8 AND 9 ARE EQUATION (7).
    7 IF(F-55.)8,9,9                                                      11
    8 XST = 14.*F**0.625                                                  12
      GO TO 10                                                            13
```

```
    9 XST = 34.*F**0.4
   10 DISTF = 3.5*XST
      DELHF = 1.6*F**0.333333*DISTF**0.666667/U
      IF(X)29,29,32
C        IF X = 0.0, CALCULATE FINAL RISE ONLY, IF X IS GREATER THAN
C         0.0, CALCULATE RISE FOR DISTANCE = X ALSO.
   32 XM = 1000.*X
C        XM IS X IN METERS.
C        STATEMENT 14 IS EQUATION (6), REFERENCE 1.
   14 DELHX = 1.6*F**0.333333*XM**0.666667/U
      IF(DELHX.GT.DELHF)DELHX=DELHF
      GO TO 30
   20 IF(DTHDZ)21,21,24
C        IF DTHDZ IS NEGATIVE OR ZERO ASSIGN TO IT A VALUE OF 0.02 OR
C         0.035 IF STABILITY IS SLIGHTLY STABLE OR STABLE, RESPECTIVELY.
   21 GO TO (7,7,7,7,22,23,23),KST
   22 DTHDZ = 0.02
      GO TO 24
   23 DTHDZ = 0.035
   24 S = 9.80616*DTHDZ/T
C        THE CONSTANT 9.80615 IS THE ACCELERATION DUE TO GRAVITY.
C        S IS A STABILITY PARAMETER.
C        CALCULATE PLUME RISE ACCORDING TO EQUATION (4), REFERENCE 1.
      DHA = 2.4*(F/(U*S))**0.333333
C        CALCULATE PLUME RISE BY EQUATION (5), REFERENCE 1 FOR LIGHT
C         WIND CONDITIONS ACCORDING TO MORTON, TAYLOR, AND TURNER.
      DELHF = 5.0*F**0.25/S**0.375
      IF(DHA-DELHF)25,25,27
   25 DELHF = DHA
C         DISTANCE TO FINAL PLUME RISE IS GIVEN BY THE FOLLOWING
   27 DISTF = 3.14159*U/S**0.5
C         IF X = 0.0, CALCULATE FINAL RISE ONLY, IF X IS GREATER THAN
C          0.0, CALCULATE RISE FOR DISTANCE = X ALSO.
C         IF X IS ZERO OR LESS, GO TO 29 AND SET PLUME RISE AND DISTANCE
C          TO MAXIMUM PLUME RISE EQUAL TO ZERO.
      IF(X)29,29,33
   33 XM = 1000.*X
C         XM IS X IN METERS.
C         IF XM IS GREATER THAN THE DISTANCE TO THE POINT OF FINAL PLUME
C          RISE, SET PLUME RISE EQUAL TO FINAL PLUME RISE, OTHERWISE,
```

```
C          CALCULATE PLUME RISE FROM EQUATION (6), REFERENCE 1.
      IF (XM-DISTF)14,14,28                                              35
   28 DELHX = DELHF                                                      36
      GO TO 30                                                           37
   29 DELHX = 0.                                                         38
      HX = 0.                                                            39
      GO TO 31                                                           40
C          CALCULATE EFFECTIVE HEIGHT AT DISTANCE X.
   30 HX = HP + DELHX                                                    41
C          CALCULATE FINAL EFFECTIVE HEIGHT.
   31 HF = HP + DELHF                                                    42
      DISTF = DISTF/1000.                                                43
      RETURN                                                             44
      END                                                                45
```

87 COMMENT CARDS   1 CONTINUATION CARDS   21 NUMBERED STATEMENTS

Chapter 8

Problem Set 1: Plume Rise

Chapter Goal

To reinforce the material presented in Chapter 7.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. calculate plume rise using specific data from *Plume Rise* by Briggs and atmospheric conditions specified by the problem.
2. calculate plume rise enhancement using formulas found in *Plume Rise from Multiple Sources* by Briggs and data specified by the problem.

Attachment 8-1. Problem set 1: plume rise.

Name____________________________ Date____________________

The Tennessee Valley Authority's Colbert Power Generation Plant data may be found in *Plume Rise* by Briggs. This data will be used throughout the problem set. Calculate the quantities called for when the appropriate atmospheric conditions are given.

- Neutral and unstable, when the wind speed is 5 meters per second. Refer to Dispersion Estimate Suggestion Number 2 (revised) handout.
  1. Find x^*.
  2. Find the distance to final plume rise, x_f.
  3. Find the Δh at 800 meters downwind.
  4. Find the Δh at 1,500 meters downwind.
- Stable, when the wind speed is 2 meters per second, the temperature is 280 K, and $\partial\theta/\partial z$ is 0.02 K per meter.
  5. At what distance, x, is x equal to $\pi u/s^{1/2}$?
  6. The x in question 5 above is important to plume rise calculations. Why?
  7. Find the Δh at 800 meters downwind.
  8. Use equation for calm conditions, assuming an inversion at 500 meters, to find Δh.
- As an estimate of possible enhancement in the plume rise from the three stacks at the Colbert Power Plant, assume a spacing of 100 meters, the number of stacks is three, and use the plume rise calculated in question 4 above as Δh_1. Use the formulas found in *Plume Rise from Multiple Sources* by Briggs to calculate the spacing factor, S, the plume enhancement, E_n, and Δh_n.
  9. Find spacing factor, S.
  10. Find plume enhancement, E_n.
  11. Find Δh_n.

Chapter 9

Atmospheric Dispersion Estimates

Chapter Goal

To familiarize you with the methods of solving dispersion estimate problems found in air pollution using the *Workbook of Atmospheric Dispersion Estimates (WADE)* by D. B. Turner.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. select from the *Workbook of Atmospheric Dispersion Estimates* the appropriate formula and procedure for calculating dispersion concentrations given a specific air pollution situation with appropriate source data, atmospheric factors, and receptor locations.
2. use the graphs and tables in the *Workbook of Atmospheric Dispersion Estimates* to determine the appropriate data to use in the proper formula given the physical description and meteorological data about an air pollution problem.

Chapter Outline

I. Estimates of atmospheric dispersion
   A. Coordinate system (Figure 9-1)
   B. Dispersion equations (Figures 9-2 and 9-3)
   C. Standard deviations of wind directions
II. Effective height of emission
   A. Plume rise (Holland's equation)
   B. Estimating required stack height
   C. Effects of evaporative cooling
   D. Effect of aerodynamic downwash

III. Special topics
   A. Inversion, breakup, fumigation
   B. Plume trapping
   C. Comparisons of ground-level concentration to effective stack height concentration from elevated sources
   D. Total dosage
   E. Crosswind-integrated concentrations
   F. Sampling times
   G. Topography
   H. Area sources
IV. Example problems
V. Appendices

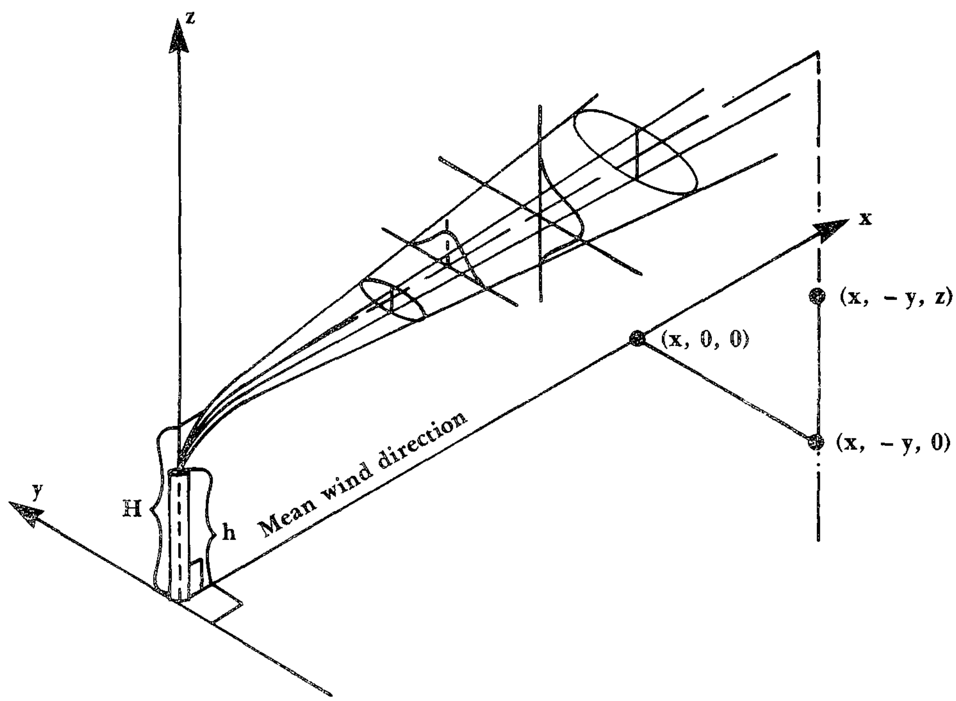

Figure 9-1. Coordinate system showing Gaussian distributions in horizontal and vertical.

$$\chi(x,y,z) = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} e^{-1/2\left[\frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2}\right]}$$

Where: $\sigma_y \sigma_z$ = standard deviation of plume width and height

Figure 9-2. Generalized Gaussian equation.

$$\begin{array}{c}\text{Downwind}\\ \text{concentration}\\ \text{(point source)}\end{array} = \frac{\text{Source emission rate}}{\pi \left[\begin{array}{c}\text{Average}\\ \text{wind}\\ \text{speed}\end{array}\right]\left[\begin{array}{c}\text{Horizontal}\\ \text{plume}\\ \text{spread}\end{array}\right]\left[\begin{array}{c}\text{Vertical}\\ \text{plume}\\ \text{spread}\end{array}\right]\left[\begin{array}{c}\text{Effective}\\ \text{emission}\\ \text{height}\end{array}\right]\left[\begin{array}{c}\text{Receptor}\\ \text{location}\\ \text{distance}\end{array}\right]}$$

$$\begin{array}{c}\text{Ground level}\\ \text{source/ground}\\ \text{level receptor}\end{array} = \frac{\text{Source emission rate}}{\pi \left[\begin{array}{c}A\\ W\\ S\end{array}\right]\left[\begin{array}{c}H\\ P\\ S\end{array}\right]\left[\begin{array}{c}V\\ P\\ S\end{array}\right]}$$

$$\begin{array}{c}\text{Elevated source/}\\ \text{ground level}\\ \text{receptor}\end{array} = \frac{\text{Source emission rate}}{\pi \left[\begin{array}{c}A\\ W\\ S\end{array}\right]\left[\begin{array}{c}H\\ P\\ S\end{array}\right]\left[\begin{array}{c}V\\ P\\ S\end{array}\right]\left[\begin{array}{c}E\\ E\\ H\end{array}\right]}$$

$$\begin{array}{c}\text{Elevated source/}\\ \text{ground level}\\ \text{receptor}\end{array} = \frac{\text{Source emission rate}}{\pi \left[\begin{array}{c}A\\ W\\ S\end{array}\right]\left[\begin{array}{c}H\\ P\\ S\end{array}\right]\left[\begin{array}{c}V\\ P\\ S\end{array}\right]\left[\begin{array}{c}E\\ E\\ H\end{array}\right]\left[\begin{array}{c}R\\ L\\ D\end{array}\right]} \text{ (not on plume centerline)}$$

Figure 9-3. Generalized Gaussian diffusion equation.

$$\begin{array}{c}\text{Downwind}\\ \text{concentration}\\ \text{(area source)}\end{array} = \frac{\text{Area source emission rate}}{\pi \left[\begin{array}{c}\text{Average}\\ \text{wind}\\ \text{speed}\end{array}\right]\left[\begin{array}{c}\text{Adjusted}\\ \text{horizon}\\ \text{plume}\\ \text{spread}\end{array}\right]\left[\begin{array}{c}\text{Vertical}\\ \text{plume}\\ \text{spread}\end{array}\right]\left[\begin{array}{c}\text{Effective}\\ \text{emission}\\ \text{height}\end{array}\right]\left[\begin{array}{c}\text{Receptor}\\ \text{location}\\ \text{distance}\end{array}\right]}$$

$$\begin{array}{c}\text{Downwind}\\ \text{concentration}\\ \text{(line source)}\end{array} = \frac{\text{Line source emission rate}}{\sqrt{2\pi} \left[\begin{array}{c}A\\ W\\ S\end{array}\right]\left[\begin{array}{c}V\\ P\\ S\end{array}\right]}$$

$$\begin{array}{c}\text{Seasonal/annual}\\ \text{average}\\ \text{concentration}\end{array} = \sum_{s=1}^{S}\sum_{n=1}^{N} \frac{[\text{Source emission rate}][\text{Frequencies of w/s, w/d, stability}]}{\sqrt{2\pi} \left[\begin{array}{c}A\\ W\\ S\end{array}\right]_N \left[\begin{array}{c}V\\ P\\ S\end{array}\right]_S \left[\begin{array}{c}\text{Downwind}\\ \text{distance}\\ \text{factor}\end{array}\right]\left[\begin{array}{c}E\\ E\\ H\end{array}\right]_S}$$

Figure 9-4. Special forms of Gaussian diffusion equation.

Attachment 9-1. Dispersion estimate suggestion no. 1, November 7, 1972 (Model Application Branch).

Subject: Estimation of 3-hour and 24-hour average concentrations

In order to obtain some degree of uniformity in performing calculations of air pollution concentrations from point sources among EPA's air pollution meteorologists, the following suggestions are made:

Calculate plume rise by using methods suggested by Briggs (1970) as modified by his discussion (1972).

Assume that estimates made using equations (excluding equation 5.12, page 38) and sigmas suggested by the *Workbook of Atmospheric Dispersion Estimates (WADE)* are valid for averaging times up to one hour.

To make an estimate of concentrations for a longer averaging time such as 3-hours or 24-hours, perform calculations for each hour of the period and average the hourly concentrations to obtain the concentration for the longer averaging time. Since interest is frequently on the maximum concentration during this period, the difficulty is in designating the location (azimuth and range) of the receptor that will receive the maximum impact from the source. If conditions are relatively stationary during this period, the mean direction and the distance of maximum for this stability and wind speed can be used for an estimate of this location. For changing conditions, calculations may need to be made at several receptors to approximate the maximum.

Because of interest in the estimation of short period maximum concentrations (3-hour to 24-hour) with a frequency of occurrence of once per year, a computational scheme was recently developed by the Model Application Branch with assistance from the Computer Techniques Group, Division of Meteorology to estimate the maximum 24-hour concentration for a year for single sources. This computational scheme can be considered a "brute force" approach as concentrations for each hour of the year 1964 (the only year that data from Asheville is readily available for 24 hours per day with wind direction to 10°) are calculated and the 24-hour concentration for each day is determined. Concentrations at 180 receptors (36 azimuths and 5 ranges) are found. An *Interim User's Guide* has been made available for this system. It is anticipated that technical review will require some modification to the calculations. Validation using air quality data near a point source is desirable, if suitable data can be found. A final *User's Guide* will be prepared and distributed by the Model Application Branch within the next several months.

Briggs, Gary A., 1971. Some Recent Analyses of Plume Rise Observations, pp. 1029-1032, in *Proceedings of the Second International Clean Air Congress*, edited by H. M. Englund and W. T. Berry, New York: Academic Press.

Briggs, Gary A., 1972. Discussion on Chimney Plumes in Neutral and Stable Surroundings, *Atmospheric Environment* 6: 507-510.

Chapter 10

Class Exercise 1
Atmospheric Dispersion Estimates: Stability and Receptor Distance

Chapter Goal

To reinforce the material presented in Chapter 9.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. work dispersion estimate problems, given adequate information about particular situations.
2. identify the different forms of the Gaussian equation and explain their application to dispersion estimate situations.

Chapter Outline

I. Examples of dispersion estimates problems
   A. Stability (Figure 10-1).
   B. Centerline concentration from an elevated source, sunny summer afternoon (Figure 10-2).
   C. Centerline concentration from ground-level source (Figure 10-3).
   D. Centerline concentration from an elevated source, cloudy day, Stability D (Figure 10-4).
   E. Off centerline concentration (Figure 10-5).

Support Material

D. B. Turner, *Workbook of Atmospheric Dispersion Estimates.*

Example Problems (Figures 10-1—10-5) Student Worksheets

Given: sunny summer afternoon

Windspeed ____________________

Insolation is____________________

Stability class is____________________

Figure 10-1. Stability: sunny summer afternoon.

Given: sunny summer afternoon

Where: $\bar{u} = 4$ m/s
elevated source
$H = 20$ m
$Q = 100$ g/s

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp^{-1/2}\left[\frac{H^2}{\sigma_y^2}\right] \exp^{-1/2}\left[\frac{y^2}{\sigma_z^2}\right]$$

Receptor distance	**200 m**	**1000 m**
Stability =		
$Q =$		
$\bar{u} =$		
$\sigma_y =$		
$\sigma_z =$		
$H =$		
$y =$		
$\exp^{-1/2}\left[\frac{H^2}{\sigma_z^2}\right] =$		
$\exp^{-1/2}\left[\frac{y^2}{\sigma_y^2}\right] =$		
$\chi =$		

Figure 10-2. Receptor distance: sunny summer afternoon.

Given: clear night

Where: $\bar{u} = 2$ m/s
ground-level source
$Q = 100$ g/s

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp^{-1/2}\left[\frac{H^2}{\sigma_y^2}\right] \exp^{-1/2}\left[\frac{y^2}{\sigma_z^2}\right]$$

Receptor distance	200 m	1000 m
Stability =		
$Q =$		
$\bar{u} =$		
$\sigma_y =$		
$\sigma_z =$		
$H =$		
$y =$		
$\exp^{-1/2}\left[\frac{H^2}{\sigma_z^2}\right] =$		
$\exp^{-1/2}\left[\frac{y^2}{\sigma_y^2}\right] =$		
$\chi =$		

Figure 10-3. Receptor distance: clear night.

Given: stability "D"

Where: $\bar{u} = 4$ m/s
elevated source
$H = 20$ m
$Q = 100$ g/s

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp^{-1/2}\left[\frac{H^2}{\sigma_y^2}\right] \exp^{-1/2}\left[\frac{y^2}{\sigma_z^2}\right]$$

Receptor distance	200 m	1000 m
Stability =		
$Q =$		
$\bar{u} =$		
$\sigma_y =$		
$\sigma_z =$		
$H =$		
$y =$		
$\exp^{-1/2}\left[\frac{H^2}{\sigma_z^2}\right] =$		
$\exp^{-1/2}\left[\frac{y^2}{\sigma_y^2}\right] =$		
$\chi =$		

Figure 10-4. Receptor distance: stability "D".

Given: stability "B"

Where: $\bar{u} = 4$ m/s
ground-level source
concentration 50 meters off centerline
$Q = 100$ g/s

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp^{-1/2}\left[\frac{H^2}{\sigma_y^2}\right] \exp^{-1/2}\left[\frac{y^2}{\sigma_z^2}\right]$$

Receptor distance	200 m	1000 m
Stability =		
$Q =$		
$\bar{u} =$		
$\sigma_y =$		
$\sigma_z =$		
$H =$		
$y =$		
$\exp^{-1/2}\left[\frac{H^2}{\sigma_z^2}\right] =$		
$\exp^{-1/2}\left[\frac{y^2}{\sigma_y^2}\right] =$		
$\chi =$		

Figure 10-5. Receptor distance: stability "B".

Chapter 11

Atmospheric Dispersion Parameters in Gaussian Plume Modeling I and II

Chapter Goal

To familiarize you with a few of the important atmospheric dispersion parameters used in Gaussian plume modeling techniques. Emphasized are their development and their similarities and differences.

Chapter Objective

Upon completion of this chapter, you should be able to:

1. calculate the Richardson number, Slade's sigma θ, Smith's P, and sigma y given sufficient meteorological data at a particular location.

Chapter Outline

I. Theoretical basis of the Gaussian plume modeling and dispersion parameters
   A. Conservation of mass—diffusion equation
   B. Gradient transport theories
   C. Statistical theories of diffusion
   D. Lagrangian similarity theories
   E. Contemporary numerical models of dispersion
II. Experimental evaluations of stability and dispersion parameters
   A. Stability parameters and typing schemes
   B. Diffusion measurement techniques
   C. Plume diffusion experiments
   D. Empirical sigma schemes
   E. Accuracy of dispersion estimates

Chapter 12

Problem Set 2: Atmospheric Dispersion Estimates

Chapter Goal

To reinforce the material presented in Chapters 9 and 10.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. work dispersion estimate problems given adequate information about particular situations.
2. identify the different forms of the Gaussian equation and explain their applications to dispersion estimate situations.

Support Material

D. B. Turner, *Workbook of Atmospheric Dispersion Estimates*.

Attachment 12-1. Problem set 2: dispersion estimates.

Name ______________________ Date ____________

1. A source emits 100 grams per second of effluent into the atmosphere with an effective stack height of 100 meters. A subsidence inversion at 500 meters above the surface limits vertical dispersion. The wind speed is 4 meters per second and the stability class is B. What is the ground-level, centerline concentration at 500 meters downwind from the source? At a distance of 5 kilometers downwind, how many times higher is the ground-level, centerline concentration with the inversion than the concentration at the same receptor, if there was no limit to vertical mixing?
2. A proposed source is to emit 72 grams per second of SO_2 from a stack 30 meters high with a diameter of 1.5 meters. The effluent gases are emitted at a temperature of 394 K with an exit velocity of 13 meters per second. Assume the design ambient air temperature is 20°C. Use stability class A and Briggs' plume rise formulas to determine the critical wind speed for the stability class. Use Figure 12-1 and a downwind distance of 200 meters.

$\bar{u}$ (m/s)	Δh (m)	H (m)	$\frac{\chi \bar{u}}{Q}$ (/m²)	$\frac{Q}{\bar{u}}$ (g/m)	χ (g/m³)
1.0					
1.5					
2.0					
2.5					
3.0					

Figure 12-1. Maximum concentration versus wind speed.

3. The particle counts shown in Figure 12-2 were observed at sampling stations 400 meters apart. The relationship of the stations to plume center line is shown in Figure 12-3. What is the effective σ_y for this sample run? Use the graph paper provided to solve this problem.

Sampling station	Left side	Centerline	Right side
1	157	210	182
2	96		110
3	18		22
4	14		18

Figure 12-2. Station sampling data.

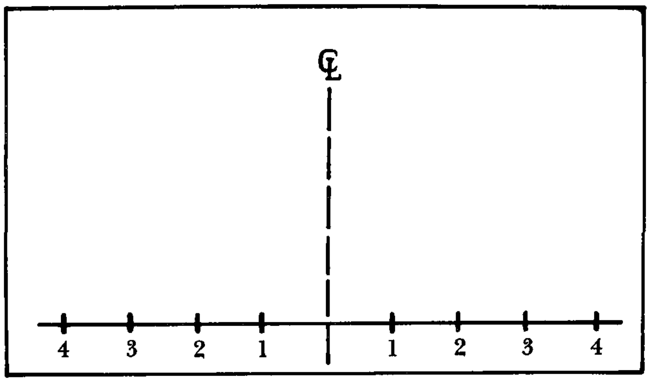

Figure 12-3. Plotting scheme for data.

4. An inventory of emissions has been made in an urban area by square areas, 1524 meters on a side. The emissions from one such area are estimated to be 6 grams per second for the entire area. The effective stack height of the sources within each area is assumed to be 20 meters. The wind is from the south at 2.5 meters per second on a thinly overcast night. If the source areas have the configuration shown below, what is the percentage contribution of emissions from area A to the center point of area D? Also assume that the emissions from areas A and C are equal.

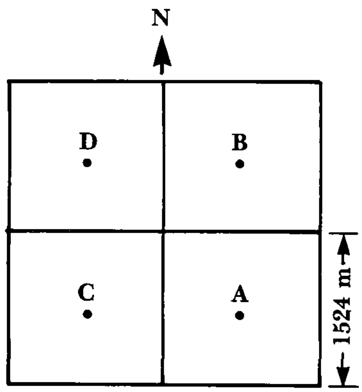

Figure 12-4. Area source illustration.

5. An apartment building is located at the sampling point 300 meters downwind from an expressway. The expressway runs north-south and the wind is from the west at 4 meters per second. It is 5:30 in the afternoon on an overcast day. The measured traffic flow is 8,000 vehicles per hour during this rush hour and the average vehicle speed is 40 miles per hour. At this speed the average vehicle is expected to emit 0.02 grams per second of total hydrocarbons. How much lower, in percent, will the hydrocarbon concentration be on the top of the building as compared with the concentration estimated at ground level? Assume a standard floor to be 3½ meters in height.

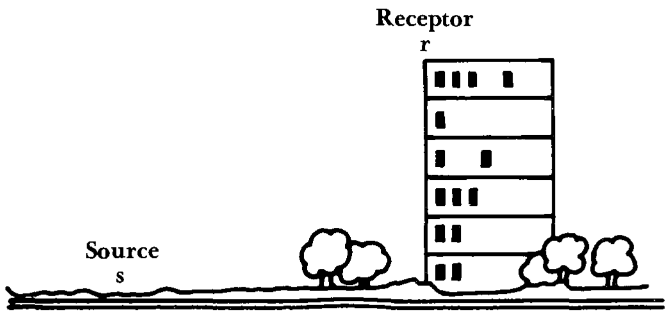

Figure 12-5. Source/receptor relationship.

Chapter 13
Air Quality Models on UNAMAP

Chapter Goal

To familiarize you with the air quality models that are currently available on the computerized UNAMAP series.

Chapter Objectives

Upon completion of this chapter, you should be able to:
1. recall the method of determining plume rise for each of the models available on UNAMAP.
2. recall the method of determining plume dispersion used in each of the air quality models available on UNAMAP.
3. recognize the limitations of each of the air quality models available on UNAMAP.
4. interpret data obtained from use of each of the air quality models available on UNAMAP.

Chapter Outline

I. Series Three models
   A. APRAC—1A
   B. CDM
   C. CDMQC
   D. CRSTER
   E. HIWAY
   F. PAL
   G. PTDIS
   H. PTMAX
   I. PTMPT
   J. ISC
   K. RAM
   L. VALLEY

II. Types of algorithms
   A. Size of computer core required
   B. Character of model
   C. Receptor/source oriented
   D. Factors required by algorithm

III. Computer algorithms for handling input parameters
   A. Plume rise
   B. Plume dispersion
   C. Atmospheric stability
   D. Mixing height
   E. Wind speed and direction
IV. Discussion of models on UNAMAP
   A. APRAC—1A
   B. CDM
   C. CDMQC
   D. HIWAY
   E. PTXXX
V. UNAMAP air quality model outlook

Support Material

D. B. Turner, *User's Guide to PTXXX Air Quality Models: PTMAX, PTDIS, PTMTP.*

Attachment 13-1. A partial model listing of UNAMAP.

1. Busse, A. D. and Zimmerman, J. R. *User's Guide for the Climatological Dispersion Model,* USEPA, EPA-R4-73-024, Research Triangle Park, NC, 1973. 144 pages.
2. Zimmerman, J. R. and Thompson, R. S. *User's Guide for HIWAY, a Highway Air Pollution Model,* USEPA, EPA-650/4-74-008, Research Triangle Park, NC, 1972. 74 pages.
3. Mancuso, R. L. and Ludwig, F. L. *User's Manual for the APRAC-1A Urban Diffusion Model Computer Program,* USEPA, EPA-650/3-73-001, Research Triangle Park, NC, 1972. 111 pages. (Available from NTIS as publication PB213091.)
4. Turner, D. B. and Busse, A. D. *User's Guides for PTXXX Point Source Dispersion Programs* (draft), USEPA, Research Triangle Park, NC, 1973. 29 pages.
5. Petersen, W. B. *User's Guide for PAL, a Gaussian-Plume Algorithm for Point, Area, and Line Sources,* USEPA, EPA-600/4-78-013, Research Triangle Park, NC, 1978. 63 pages.
6. Brubaker, K. L. et al. *Addendum to User's Guide for Climatological Disperison Model,* USEPA, EPA-450/3-77-015, Research Triangle Park, NC, 1977. 134 pages.

(Guldberg talks about the balance.)

Chapter 14

Introduction to the Guideline on Air Quality Models

Chapter Goal

The purpose of this chapter is to familiarize you with the *Guideline on Air Quality Models*, EPA 450/2-78-027, and the air quality models recommended by the Guideline for use in air pollution dispersion modeling.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. recall the models that are recommended for use in air quality modeling.
2. recall the uses of the *Guideline* as it applies to new source reviews, prevention of significant deterioration, and control strategies.

Chapter Outline

I. Atmospheric dispersion modeling
   - A. Important in new source reviews, control strategy analysis, and prevention of significant deterioration
   - B. Mathematical set of equations
   - C. Predictive tool

II. *Guideline on Air Quality Models*
   - A. Origin
   - B. General description
   - C. Status and uses
   - D. Recommended modeling procedures

III. *Workbook for Comparisons of Air Quality Models*
   - A. Purpose
   - B. Principal contents
   - C. Use (practical)

Table 14-1. Models applicable to specific pollutants, sources, and averaging times.

Point sources SO_2 and PM	Multi-sources SO_2 and PM	Multi-sources SO_2 and PM	NO_2	O_X	CO
All averaging times	Annual average	Short-term averages	Annual average	1-hour average	1- and 8-hour averages
CRSTER RAM PTXXX models ISC VALLEY	AQDM TCM CDM/CDMQC Rollback	Rollback TEM RAM CDMQC AQDM	Rollback CDM	EKMA Rollback	Rollback HIWAY PAL Holzworth APRAC-1A APRAC 2

Attachment 14-1. Modeling bibliography.

CRSTER	*User's Manual for the Single Source (CRSTER) Model*, EPA-450/2-77-013, July 1977.
	Addendum to the User's Manual for the Single Source (CRSTER) Model, November 1979.
	User Information for the Modified CRSTER Program, USEPA Region IV, Atlanta, Ga.
	Guideline on Air Quality Models (revised), October 1980.
EKMA/OZIPP	*Guideline for the Interpretation of the Ozone Air Quality Standard*, EPA-450/4-79-003, January 1979.
	Uses, Limitations, and Technical Basis of Procedures for Quantifying Relationships Between Photochemical Oxidants and Precursors, EPA-450/2-77-021a and b, November 1977 and February 1978.
	User's Manual for Kinetics Model and Ozone Isopleth Plotting Package, EPA-600/8-78-014a, July 1978.
ISC	*Industrial Source Complex (ISC) Dispersion Model User's Guide*, Volumes I and II, EPA-450/4-79-030 and 031, December 1979.
	Addendum to the ISC Model User's Guide, 1980.
MOBILE1	User's Guide to MOBILE1: Mobile Source Emissions Model, EPA-400/9-78-007, August 1978.
	Mobile Source Emissions Factors, EPA-400/9-78-005, March 1978.
	Guidelines for Air Quality Maintenance Planning and Analysis, Volume 9 (revised): Evaluating Indirect Sources, EPA-450/4-78-001, September 1978.
MPTER	User's Guide for MPTER, EPA-600/8-80-016, April 1980.
PBLSQ	Guidelines for Lead Implementation Plans, EPA-450/2-78-038, August 1978.
RAM	User's Guide for RAM, Volumes I and II, EPA-600/8-78-016a and b, November 1978.
	Auer, A., "Correlation of Land Use and Cover with Meteorological Anomalies," *Journal of Applied Meteorology, 17*: 636-643, 1978.
VALLEY	VALLEY Model User's Guide, EPA-450/2-77-018, 1977.
	Addendum to the VALLEY Model User's Guide, October 1979.
	Workshop on Atmospheric Dispersion Models in Complex Terrain, EPA-600/9-79-041, November 1979.

Chapter 15

Elements and Applications of the Single Source (CRSTER) Model

Chapter Goal

To familiarize students with the Single Source model presently available on the UNAMAP computer package.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. describe the application of the Single Source model to a given source and surrounding terrain features.
2. describe the accuracy of the Single Source model under given source-receptor conditions.

Chapter Outline

Follows *Modeling Notes (CRSTER)*.

Support Material

Peter Guldberg, *Modeling Notes, Elements and Applications of the Single Source (CRSTER) Model.*

Attachment 15-1. Hourly surface observation station listing 9-24-80.

NO.	NAME	ST	BEG	END	REMARKS
11641	SAN JUAN/IS VERDE/PR		01/01/78	12/31/78	LIBRARY
11641	SAN JUAN/IS VERDE/PR		01/01/77		ROUTINE
26451	ANCHORAGE	AK	01/01/65	10/31/77	LIBRARY
26411	FAIRBANKS	AK	01/01/74	12/31/74	LIBRARY
26411	FAIRBANKS	AK	01/01/77		ROUTINE
25309	JUNEAU	AK	01/01/74	12/31/74	IN LIBRARY
24523	KENAI/MUNI	AK	01/01/74	12/31/78	>IN EDIT
25501	KODIAK	AK	01/01/65	02/28/72	LIBRARY
13876	BIRMINGHAM	AL	01/01/78	12/31/78	W03475
13876	BIRMINGHAM	AL	01/01/65	12/31/65	LIBRARY
13876	BIRMINGHAM	AL	01/01/79	12/31/79	>IN KEY ENTRY
03856	HUNTSVILLE	AL	01/01/70	12/31/74	LIBRARY
13894	MOBILE/BATES	AL	01/01/78	12/31/78	W03475
13894	MOBILE/BATES	AL	01/01/71	12/31/75	LIBRARY
93855	MOBILE/BATES	AL	01/01/79	12/31/79	IN KEY ENTRY
13895	MONTGOMERY/DANNELLY	AL	01/01/70	12/31/76	LIBRARY
13895	MONTGOMERY/DANNELLY	AL	01/01/77		ROUTINE
93992	ELDORADO/GOODWIN	AR	01/01/77	12/31/77	C1144
93993	FAYETTEVILLE/DRAKE FIELD	AR	01/01/74	12/31/78	IN EDIT
13963	LITTLE ROCK/ADAMS	AR	01/01/73	12/31/77	LIBRARY
23183	PHOENIX/SKY HARBOR	AZ	01/01/77		ROUTINE
23194	WINSLOW	AZ	01/01/68	12/31/68	LIBRARY
93193	FRESNO SIR TERM/HAMMER	CA	01/01/77		ROUTINE
23174	LOS ANGELES	CA	01/01/65	12/31/76	LIBRARY
23174	LOS ANGELES	CA	01/01/77		ROUTINE
03102	ONTARIO/INTL	CA	01/01/74	12/31/78	IN EDIT
93225	SACRAMENTO/METRO	CA	01/01/74	12/31/78	IN EDIT
23188	SAN DIEGO/LINDBERGH	CA	01/01/74	12/31/74	LIBRARY
23234	SAN FRANCISCO	CA	01/01/74	12/31/74	LIBRARY
23234	SAN FRANCISCO	CA	01/01/65	06/30/69	LIBRARY
23190	SANTA BARBARA/MUNI	CA	01/01/74	12/31/78	IN EDIT
23237	STOCKTON/MET	CA	10/01/75	03/31/77	LIBRARY
93214	VANDENBERG AFB	CA	01/01/79	12/31/79	IN DPS
23062	DENVER/STAPLETON	CO	03/01/65	12/31/65	LIBRARY
23062	DENVER/STAPLETON	CO	11/01/67	06/31/69	LIBRARY
23066	GRAND JUNCTION/WALKER	CO	01/01/77		ROUTINE
93058	PUEBLO/MEMORIAL	CO	01/01/73	12/31/74	LIBRARY
94702	BRIDGEPORT	CT	01/01/65	02/28/65	LIBRARY
94702	BRIDGEPORT	CT	06/01/80	08/31/80	PROCESS ROUTINELY
94702	BRIDGEPORT	CT	01/01/70	12/31/74	LIBRARY
54729	DANBURY	CT	06/01/80	08/31/80	PROCESS ROUTINELY
14750	HARTFORD/BRADLEY	CT	01/01/70	12/31/74	LIBRARY
94772	NEW HAVEN	CT	06/01/80	08/31/80	PROCESS ROUTINELY
93738	WASHINGTON/DULLES	DC	06/01/80	08/31/80	PROCESS ROUTINELY
13743	WASHINGTON/NATIONAL	DC	06/01/80	08/31/80	PROCESS ROUTINELY
13743	WASHINGTON/NATIONAL	DC	01/01/65	12/31/74	LIBRARY
13889	JACKSONVILLE	FL	01/01/70	12/31/74	ON LIBRARY

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13889 JACKSONVILLE	FL	01/01/65	12/31/65	LIBRARY
12839 MIAMI	FL	01/01/77		ROUTINE
12839 MIAMI	FL	01/01/70	12/31/76	LIBRARY
12839 MIAMI	FL	01/01/78	12/31/79	IN KEY ENTR
Y				
12815 ORLANDO	FL	02/01/74	12/31/78	W03489
03855 PENSACOLA	FL	01/01/78	12/31/78	W03475
93805 TALLAHASSEE	FL	01/01/77		ROUTINE
12842 TAMPA	FL	01/01/79	12/31/79	IN KEY ENTR
Y				
12842 TAMPA	FL	01/01/78	12/31/78	W03475
12842 TAMPA	FL	01/01/70	12/31/75	LIBRARY
12844 WEST PALM BEACH	FL	10/01/75	03/31/77	LIBRARY
13874 ATLANTA	GA	01/01/74	12/31/78	W03472
13874 ATLANTA	GA	01/01/70	12/31/73	LIBRARY
13874 ATLANTA	GA	01/01/65	06/30/69	LIBRARY
03820 AUGUSTA	GA	01/01/74	12/31/78	W03489
03813 MACON	GA	01/01/74	12/31/78	W03472
03822 SAVANNAH	GA	01/01/78	12/31/78	W03475
03822 SAVANNAH	GA	01/01/79	12/31/79	IN KEY ENTR
Y				
93845 VALDOSTA	GA	01/01/72	12/31/76	SELECTED EL
EMENT ONLY				
22521 HONOLULU/JOHN ROGERS	HI	01/01/77		ROUTINE
14931 BURLINGTON	IA	01/01/75	12/31/79	IN KEY ENTR
Y				
14990 CEDAR RAPIDS	IA	01/01/75	04/25/75	W03847
14990 CEDAR RAPIDS	IA	04/26/75	12/31/79	W03847
14933 DES MOINES	IA	01/01/75	12/31/79	W03848
94908 DUBUQUE	IA	01/01/75	12/31/79	IN KEY ENTR
Y				
14940 MASON CITY	IA	01/01/75	12/31/79	W03848
14950 OTTOMAWA	IA	01/01/75	12/31/79	W03848
14943 SIOUX CITY	IA	01/01/75	12/31/79	W03848
94910 WATERLOO	IA	01/01/75	12/31/79	W03847
24131 BOISE	ID	01/01/74	12/31/76	LIBRARY
24131 BOISE	ID	01/01/66	12/31/66	LIBRARY
24131 BOISE	ID	01/01/77		ROUTINE
24156 POCATELLO	ID	01/01/74	12/31/74	LIBRARY
14819 CHICAGO/MIDWAY	IL	01/01/65	12/31/77	LIBRARY
94846 CHICAGO/OHARE	IL	09/01/65	03/31/66	LIBRARY
94846 CHICAGO/OHARE	IL	11/01/67	06/30/69	LIBRARY
14923 MOLINE/QUADACITY	IL	01/01/73	12/31/77	LIBRARY
14923 MOLINE/QUADACITY	IL	01/01/78	12/31/79	IN KEY ENTR
Y				
14842 PEORIA/GREATER PEORIA	IL	01/01/70	12/31/77	LIBRARY
94822 ROCKFORD/GRTR ROCKFORD	IL	01/01/73	12/31/77	LIBRARY
93822 SPRINGFIELD/CAPITAL	IL	01/01/73	12/31/77	LIBRARY
93817 EVANSVILLE/DRESS	IN	01/01/78	12/31/78	COMPLETED
93817 EVANSVILLE/DRESS	IN	01/01/70	12/31/77	LIBRARY
93817 EVANSVILLE/DRESS	IN	01/01/79	12/31/79	EDIT
14827 FT WAYNE/BAER	IN	01/01/73	12/31/77	LIBRARY
93819 INDIANAPOLIS/WEIR COOK	IN	01/01/77		ROUTINE
93819 INDIANAPOLIS/WEIR COOK	IN	01/01/72	12/3176	LIBRARY
14848 SOUTH BEND/ST JOE	IN	01/01/73	12/31/77	LIBRARY
93823 TERRE HAUTE/HULMAN	IN	01/01/73	06/30/74	LIBRARY
93823 TERRE HAUTE/HULMAN	IN	08/01/74	12/31/78	LIBRARY
13985 DODGE CITY	KS	01/01/71	12/31/71	LIBRARY
13985 DODGE CITY	KS	01/01/77		ROUTINE
13985 DODGE CITY	KS	01/01/75	12/31/76	IN KEY ENTR

Y				
13994 ST LOUIS/LAMBERT	MO	01/01/72	12/31/77	LIBRARY
13994 ST LOUIS/LAMBERT	MO	01/01/65	12/31/65	LIBRARY
03940 JACKSON/THOMPSON	MS	01/01/77	12/31/78	W03472
03940 JACKSON/THOMPSON	MS	01/01/76	12/31/76	LIBRARY
03940 JACKSON/THOMPSON	MS	01/01/74	12/31/75	W03472
03940 JACKSON/THOMPSON	MS	08/01/72	12/31/73	LIBRARY
13865 MERIDIAN	MS	01/01/74	12/31/78	W03472
24143 GREAT FALLS	MT	01/01/77		ROUTINE
14942 OMAHA/EPPLEY	NB	01/01/77	12/31/78	LIBRARY
14942 OMAHA/EPPLEY	NB	01/01/66	12/31/66	LIBRARY
13881 CHARLOTTE	NC	01/01/79	12/31/79	IN KEY ENTR
Y				
13881 CHARLOTTE	NC	01/01/74	12/31/78	W03489
13723 GREENSBORO/GSO-HI	NC	01/01/74	12/31/78	W03472
13723 GREENSBORO/GSO-HI	NC	01/01/70	12/31/74	LIBRARY
13722 RALEIGH	NC	01/01/74	12/31/78	W03489
13722 RALEIGH/RALEIGH-DURHAM	NC	01/01/72	12/31/73	LIBRARY
13722 RALEIGH/RALEIGH-DURHAM	NC	01/01/65	12/31/65	LIBRARY
24011 BISMARCK	ND	01/01/70	12/31/70	LIBRARY
24011 BISMARCK	ND	01/01/77	12/31/78	LIBRARY
14914 FARGO	ND	01/01/73	12/31/77	CI144
14916 GRAND FORKS/INTL	ND	01/01/74	12/31/78	IN EDIT
14942 OMAHA	NE	01/01/75	12/31/76	IN KEY ENTR
Y				
14942 OMAHA	NE	01/01/77		ROUTINE
14745 CONCORD	NH	06/01/80	08/31/80	PROCESS ROU
TINELY				
94741 PETERBORO	NJ	06/01/80	08/31/80	PROCESS ROU
TINELY				
54730 MORRISTOWN	NJ	06/01/80	08/31/80	PROCESS ROU
TINELY				
14734 NEWARK	NJ	01/01/65	06/30/67	LIBRARY
14734 NEWARK	NJ	06/01/80	08/31/80	PROCESS ROU
TINELY				
14734 NEWARK	NJ	01/01/70	12/31/76	LIBRARY
23050 ALBUQUERQUE/SUNPT-KIRT	NM	01/01/77		ROUTINE
23050 ALBUQUERQUE/SUNPT-KIRT	NM	01/01/73	12/31/76	LIBRARY
04781 ISLIP/MACARTHUR	NU	01/01/74	12/31/78	IN EDIT
03160 DESERT ROCK	NV	05/01/78	12/31/78	LIBRARY
23154 ELY/YELLAND	NV	01/01/77		ROUTINE
23169 LAS VEGAS/MCCARIAN	NV	01/01/77		ROUTINE
14735 ALBANY	NY	11/01/67	12/31/74	LIBRARY
14733 BUFFALO	NY	01/01/65	07/31/66	LIBRARY
14733 BUFFALO	NY	01/01/73	12/31/77	CI144
14733 BUFFALO	NY	01/01/70	12/31/74	LIBRARY
14705 FARMINGDALE	NY	06/01/80	08/31/80	PROCESS ROU
TINELY				
04781 ISLIP	NY	06/01/80	08/31/80	PROCESS ROU
TINELY				
94789 NEW YORK/FT TOTTEN	NY	11/01/67	06/30/69	
94789 NEW YORK/FT TOTTEN	NY	01/01/65	02/28/65	
94789 NEW YORK/FT TOTTEN	NY	01/01/70	12/31/70	
94789 NEW YORK/FT TOTTEN	NY	01/01/66	03/31/66	
94789 NEW YORK/JFK	NY	01/01/74	12/31/78	AWAITING KE
YING				
94789 NEW YORK/KENNEDY	NY	06/01/80	08/31/80	PROCESS ROU
TINELY				
14732 NEW YORK/LAGUARDIA	NY	06/01/80	08/31/80	PROCESS ROU

Y

13994 TOPEKA	KS	01/01/75	12/31/79	IN KEY ENTRY
03928 WICHITA	KS	01/01/75	12/31/79	IN KEY ENTRY
93814 COVINGTON/GTR CINN	KY	01/01/73	12/31/77	LIBRARY
93814 COVINGTON/GTR CINN	KY	01/01/65	12/31/65	LIBRARY
93820 LEXINGTON	KY	01/01/74	06/08/77	W03489
93820 LEXINGTON	KY	06/08/77	12/31/78	W03490
93821 LOUISVILLE/STANDIFORD	KY	01/01/79	12/31/79	IN KEY ENTRY
93821 LOUISVILLE/STANDIFORD	KY	01/01/78	12/31/78	W03475
93821 LOUISVILLE/STANDIFORD	KY	01/01/70	12/31/77	LIBRARY
13935 ALEXANDRIA/ESLER	LA	08/01/72	07/31/74	LIBRARY
13935 ALEXANDRIA/ESLER	LA	01/01/76	12/31/76	LIBRARY
13076 LAFAYETTE/REGIONAL	LA	01/01/74	12/31/78	IN EDIT
03937 LAKE CHARLES	LA	01/01/77		ROUTINE
03937 LAKE CHARLES	LA	01/01/66	12/31/66	LIBRARY
12916 NEW ORLEANS/MOISANT	LA	01/01/68	06/30/68	LIBRARY
13957 SHREVEPORT	LA	01/01/70	12/31/74	CI144
14739 BOSTON/LOGAN	MA	01/01/77		ROUTINE
14739 BOSTON/LOGAN	MA	01/01/69	12/31/76	LIBRARY
14739 BOSTON/LOGAN	MA	06/01/80	08/31/80	PROCESS ROUTINELY
93721 BALTIMORE/FRIENDSHIP	MD	09/01/65	03/31/66	LIBRARY
93721 BALTIMORE/FRIENDSHIP	MD	06/01/80	08/31/80	PROCESS ROUTINELY
93721 BALTIMORE/FRIENDSHIP	MD	11/01/67	06/30/69	LIBRARY
24011 BISMARCK	MD	01/01/77		ROUTINE
14914 FARGO/HECTOR	MD	01/01/73	12/31/77	CI144
93720 SALISBURY/WICOMICO CO	MD	01/01/68	12/31/72	LIBRARY
14605 AUGUSTA/AUGUSTA STATE	ME	01/01/74	12/31/78	IN EDIT
14607 CARIBOU	ME	01/01/77		ROUTINE
94849 ALPEN/PHELPS COLLINS	MI	01/01/73	12/31/77	CI144
94847 DETROIT/METROPOLITAN	MI	01/01/73	05/31/73	LIBRARY
94847 DETROIT/METROPOLITAN	MI	01/01/65	12/31/68	LIBRARY
94847 DETROIT/METROPOLITAN	MI	07/01/73	12/31/77	LIBRARY
14826 FLINT/BISHOP	MI	01/01/70	12/31/77	LIBRARY
94860 GRAND RAPIDS/KENT CO	MI	01/01/75	12/31/77	LIBRARY
94860 GRAND RAPIDS/KENT CO	MI	01/01/73	12/31/77	CI144
94814 HOUGHTON LAKE/ROSCOMMON	MI	01/01/73	12/31/76	CI144
14836 LANSING/CAPITAL CITY	MI	01/01/73	12/31/77	LIBRARY
14840 MUSKEGON CO	MI	01/01/73	12/31/77	LIBRARY
14845 SAGINAW/TRI-CITY	MI	01/01/74	12/31/78	IN EDIT
14847 SAULT STE MARIE	MI	01/01/73	12/31/77	CI144
14913 DULUTH	MN	01/01/73	12/31/77	CI144
94931 HIBBING/CHISHOLM	MN	01/01/72	12/31/75	LIBRARY
14918 INTERNATIONAL FALLS	MN	01/01/73	12/31/77	LIBRARY
14922 MINNEAPOLIS/ST PAUL	MN	01/01/70	12/31/77	LIBRARY
14925 ROCHESTER	MN	01/01/73	12/31/77	CI144
03945 COLUMBIA REG/FRM	MO	01/01/77		ROUTINE
03947 KANSAS CITY(AIRPORT)	MO	01/01/75	12/31/79	IN KEY ENTRY
13988 KANSAS CITY(DOWNTOWN)	MO	01/01/75	12/31/79	IN KEY ENTRY
13995 SPRINGFIELD	MO	01/01/75	12/31/79	IN KEY ENTR

TIMELY					
14732	NEW YORK/LAGUARDIA	NY	10/01/75	12/31/77	
14757	POUGHKEEPSIE/DUTCHESS	NY	01/01/77	12/31/77	CI144
14757	POUGHKEEPSIE/DUTCHESS CO	NY	01/01/74	12/31/78	IN EDIT
14768	ROCHESTER/MONROE CO	NY	10/01/75	03/31/77	
04741	SCHENECTADY CO	NY	01/01/76	12/31/77	CI144
94745	WHITE PLAINS	NY	06/01/80	08/31/80	PROCESS ROU
TIMELY					
94745	WHITE PLAINS/WCHSTR	NY	01/01/74	12/31/78	IN EDIT
14895	AKRON/AKRON CANTON	OH	01/01/73	12/31/77	
93814	CINCINNATI	OH	01/01/78	12/31/78	W03475
14820	CLEVELAND/HOPKINS	OH	01/01/69	12/31/77	
14821	COLUMBUS/PORT COLUMBUS	OH	01/01/73	12/31/77	
93815	DAYTON	OH	01/01/80		ROUTINE
93815	DAYTON	OH	01/01/80	12/31/80	W/ROUTINE W
ORK					
93815	DAYTON/JM COX DAY	OH	01/01/70	12/31/77	
14891	MANFIELD/LAHM	OH	01/01/73	12/31/77	CI144
94830	TOLEDO	OH	01/01/73	12/31/77	
14852	YOUNGSTOWN	OH	01/01/73	12/31/73	
14852	YOUNGSTOWN	OH	01/01/73	12/31/77	CI144
13968	TULSA	OK	01/01/73	12/31/73	
94224	ASTORIA/CLATSOP CO	OR	01/01/74	12/31/74	
24221	EUGENE/MAHLON SWEET	OR	01/01/74	12/31/74	
24225	MEDFORD	OR	01/01/77		ROUTINE
24225	MEDFORD/JACKSON CITY	OR	01/01/74	12/31/74	
24225	MEDFORD/JACKSON CITY	OR	01/01/77	12/31/78	
24225	MEDFORD/JACKSON CITY	OR	01/01/66	12/31/66	
24229	PORTLAND	OR	10/01/69	02/28/70	
24229	PORTLAND	OR	01/01/74	12/31/74	
24230	REDMON/ROBERTS	OR	01/01/74	12/31/74	
24232	SALEM/MCMARY	OR	01/01/74	12/31/74	
14860	ERIE	PA	01/01/73	12/31/77	CI144
13739	PHILADELPHIA	PA	01/01/77	12/31/77	DIP
13739	PHILADELPHIA	PA	01/01/78	12/31/78	CI144
13739	PHILADELPHIA	PA	01/01/65	03/31/72	
13739	PHILADELPHIA	PA	05/01/72	12/31/76	
13739	PHILADELPHIA	PA	01/01/74	12/31/78	
13739	PHILADELPHIA	PA	01/01/79	12/31/79	KEY ENTRY
13739	PHILADELPHIA	PA	01/01/80		ROUTINE
94823	PITTSBURGH	PA	01/01/77		ROUTINE
94823	PITTSBURGH/GTR PITTSBGH	PA	01/01/70	12/31/78	
14765	PROVIDENCE/FRANCIS/GREEN	RI	01/01/70	12/31/74	
13880	CHARLESTON	SC	01/01/70	12/31/74	
13880	CHARLESTON	SC	01/01/79	12/31/79	IN KEY ENTR
Y					
13880	CHARLESTON	SC	01/01/78	12/31/78	W03475
13883	COLUMBIA	SC	01/01/74	12/31/78	W03489
Y					
14944	SIOUX FALLS	SD	01/01/75	12/31/79	IN KEY ENTR
Y					
13877	BRISTOL/TRI CITY	TN	01/01/68	12/31/74	
13882	CHATTANOOGA	TN	01/01/70	12/31/74	
13882	CHATTANOOGA	TN	01/01/78	12/31/78	W03475
93850	CHATTANOOGA	TN	01/01/79	12/31/79	IN KEY ENTR
Y					
13891	KNOXVILLE	TN	01/01/70	12/31/74	
13893	MEMPHIS	TN	01/01/72	12/31/76	
13893	MEMPHIS	TN	01/01/79	12/31/79	IN KEY ENTR

Y				
13893 MEMPHIS	TN	01/01/78	12/31/78	W03475
13897 NASHVILLE	TN	01/01/77	12/31/77	ROUTINE
13897 NASHVILLE	TN	01/01/78	12/31/78	W03475
13897 NASHVILLE	TN	01/01/79	12/31/79	IN KEY ENTR
Y				
13897 NASHVILLE/MET	TN	01/01/70	12/31/78	
23047 AMARILLO/ENGLISH	TX	01/01/68	12/31/68	
12919 BROWNSVILLE	TX	01/01/77		ROUTINE
12919 BROWNSVILLE/RIO GRAND	TX	01/01/77	12/31/78	
13960 DALLAS/LOVE FIELD	TX	01/01/74	12/31/78	IN EDIT
23044 EL PASO	TX	01/01/77		ROUTINE
23044 EL PASO	TX	06/01/76	12/31/78	
23044 EL PASO	TX	01/01/67	12/31/67	
03927 FT WORTH/REGIONAL	TX	01/01/75	12/31/75	
12918 HOUSTON/HOBBY	TX	08/01/75	08/31/75	
12918 HOUSTON/HOBBY	TX	10/01/75	12/31/77	
12918 HOUSTON/HOBBY FIELD	TX	01/01/74	12/31/78	IN EDIT
23023 MIDLAND	TX	01/01/77		ROUTINE
23023 MIDLAND/SLOAN	TX	01/01/77	12/31/78	
12921 SAN ANTONIO	TX	01/01/67	06/30/69	
24127 SALT LAKE CITY	UT	01/01/65	12/31/78	
24127 SALT LAKE CITY	UT	01/01/65	12/31/78	ON LIBRARY
REEL				
24127 SALT LAKE CITY	UT	01/01/77		ROUTINE
13737 NORFOLK	VA	01/01/78	12/31/78	CI144
13737 NORFOLK REG	VA	01/01/70	12/31/74	
13740 RICHMOND	VA	01/01/78	12/31/78	CI144
13740 RICHMOND/BYRD	VA	01/01/77	12/31/77	CI144
13740 RICHMOND/BYRD	VA	01/01/69	12/31/69	
93734 STERLING	VA	01/01/77		ROUTINE
93738 WASHINGTON DC/DULLES	VA	01/01/77	12/31/78	
93738 WASHINGTON DC/DULLES	VA	01/01/68	12/31/72	
14742 BURLINGTON	VT	01/01/66	12/31/66	
14742 BURLINGTON	VT	06/01/76	12/31/78	
14742 BURLINGTON	VT	01/01/80		ROUTINE
24227 OLYMPIA	WA	01/01/74	12/31/74	
94240 QUILLAYUTE	WA	01/01/74	12/31/74	
24233 SEATTLE-TACOMA	WA	01/01/77		ROUTINE
24233 SEATTLE/TACOMA	WA	01/01/72	12/31/72	
24233 SEATTLE/TACOMA	WA	01/01/65	12/31/69	
24233 SEATTLE/TACOMA	WA	01/01/74	12/31/78	
24157 SPOKANE	WA	01/01/74	12/31/74	
24160 WALLA WALLA/CITY-CNTY	WA	01/01/74	12/31/78	IN EDIT
24243 YAKIMA	WA	01/01/77	12/31/77	TO BE REQUE
STED				
24243 YAKIMA	WA	01/01/74	12/31/74	
14991 EAU CLAIRE	WI	01/01/73	12/31/77	CI144
14898 GREEN BAY	WI	01/01/73	12/31/77	CI144
14920 LA CROSSE	WI	01/01/73	12/31/77	CI144
14920 LACROSSE	WI	01/01/78	12/31/79	IN KEY ENTR
Y				
14837 MADISON	WI	01/01/77		ROUTINE
14837 MADISON/TRUAX	WI	01/01/73	12/31/78	
14839 MILWAUKEE/MITCHEL	WI	01/01/70	12/31/74	
14839 MILWAUKEE/MITCHEL	WI	01/01/76	12/31/77	
14839 MILWAUKEE/MITCHEL	WI	01/01/73	12/31/77	CI144
14897 WAUSAU	WI	01/01/73	12/31/77	

03872	BECKLEY/RALEIGH	WV	01/01/68	12/01/72	
93818	HUNTINGTON	WV	01/01/78	12/31/78	W03475
03860	HUNTINGTON	WV	01/01/78	12/31/78	REQUESTED
03860	HUNTINGTON/TRI STATE	WV	01/01/70	12/31/74	
03860	HUNTINGTON/TRI STATE	WV	01/01/73	12/31/77	C1144
13736	MORGANTOWN/MUNI-HARD FLO	WV	01/01/74	12/31/78	IN EDIT
03804	PARKERSBURG	WV	01/01/73	12/31/77	C1144
24089	CASPER	WY	01/01/74	12/31/74	
24018	CHEYENNE	WY	01/01/74	12/31/74	
24021	LANDER	WY	01/01/77		ROUTINE
24021	LANDER/HUNT	WY	01/01/77	12/31/78	
24062	WORLAND	WY	01/01/79	12/31/79	IN KEY ENTR

Y

EOF:317

MODELING NOTES
by Peter H. Guldberg

Elements and Applications of the Single Source (CRSTER) Model

POINT SOURCE MODELS FOR SO_2, TSP, CO, AND NO_2*
APPLICABLE TO ALL AVERAGING TIMES

RECOMMENDED MODELS

1. SINGLE SOURCE (CRSTER) MODEL
2. UNAMAP MODELS (PTMAX, PTDIS)
3. TURNERS WORKBOOK, ETC.

*All pollutants assumed to be nonreactive in the atmosphere

EPA GUIDELINE ON AIR QUALITY MODELS

- REQUIREMENTS FOR CONCENTRATION ESTIMATES
- AIR QUALITY MODELS
  - Suitability
  - Classes of models
  - Recommended models
  - Special situations
- DATA REQUIREMENTS
  - Emissions source data
  - Meteorological data
  - Receptor sites
  - Background air quality
- MODEL VALIDATION/CALIBRATION

SINGLE SOURCE MODEL APPLICATIONS

- STACK DESIGN STUDIES
- NEW SOURCE REVIEW - P.S.D.
- MONITORING NETWORK DESIGN
- CONTROL STRATEGY EVALUATION FOR SIPs
- REGULATORY VARIANCE EVALUATION
- COAL CONVERSION STUDIES
- SIP REVISIONS

SINGLE SOURCE MODEL CONCEPTS

- INPUT DATA REQUIREMENTS
  - SOURCE DATA - Multiple elevated stacks at single plant location
  - SITE DATA - 180 receptors, uneven terrain
  - METEOROLOGICAL DATA - Hourly wind speed and direction, stability, mixing height, and temperature
- MODEL COMPONENTS
  - PLUME RISE MODEL - Briggs for hot, buoyant plumes
  - DIFFUSION MODEL - Gaussian plume modified for limited mixing heights, with P-G dispersion coefficients
- OUTPUT DATA PRODUCED
  - POLLUTANT CONCENTRATIONS FOR SPECIFIC AVERAGING TIMES (NAAQS) AND RECEPTOR SITES

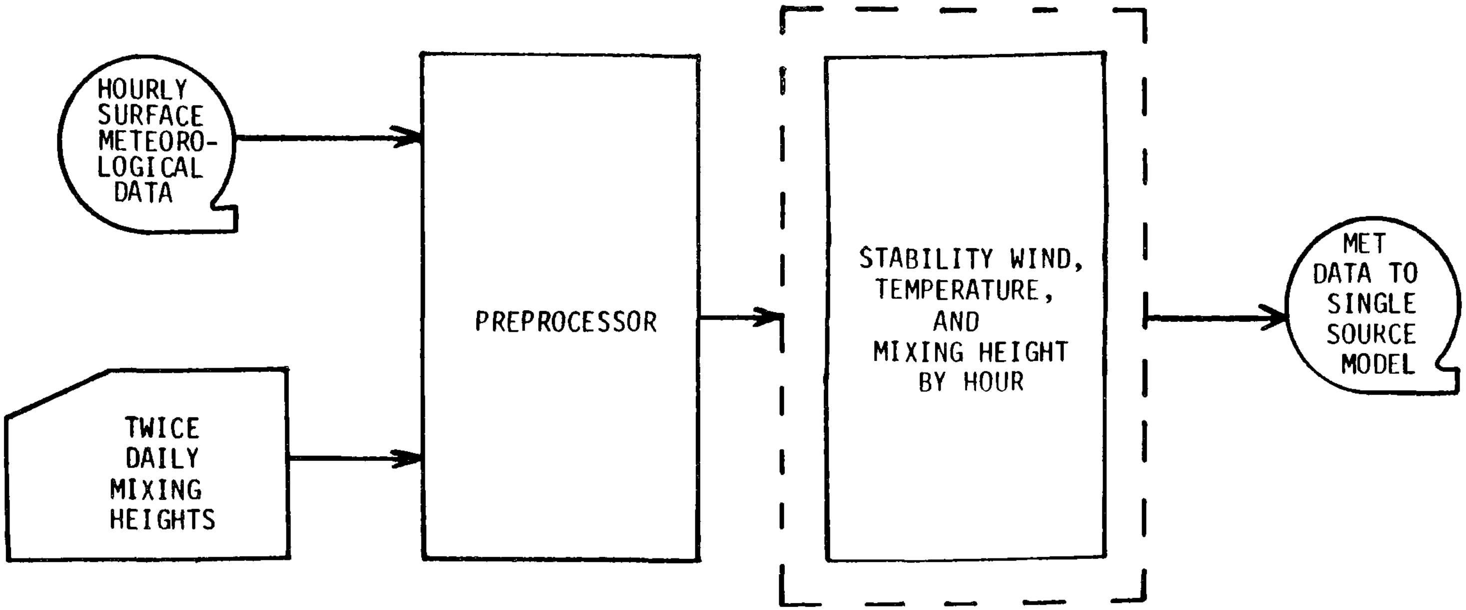


FIGURE 1-1

SCHEMATIC OF METEOROLOGICAL DATA PREPROCESSOR

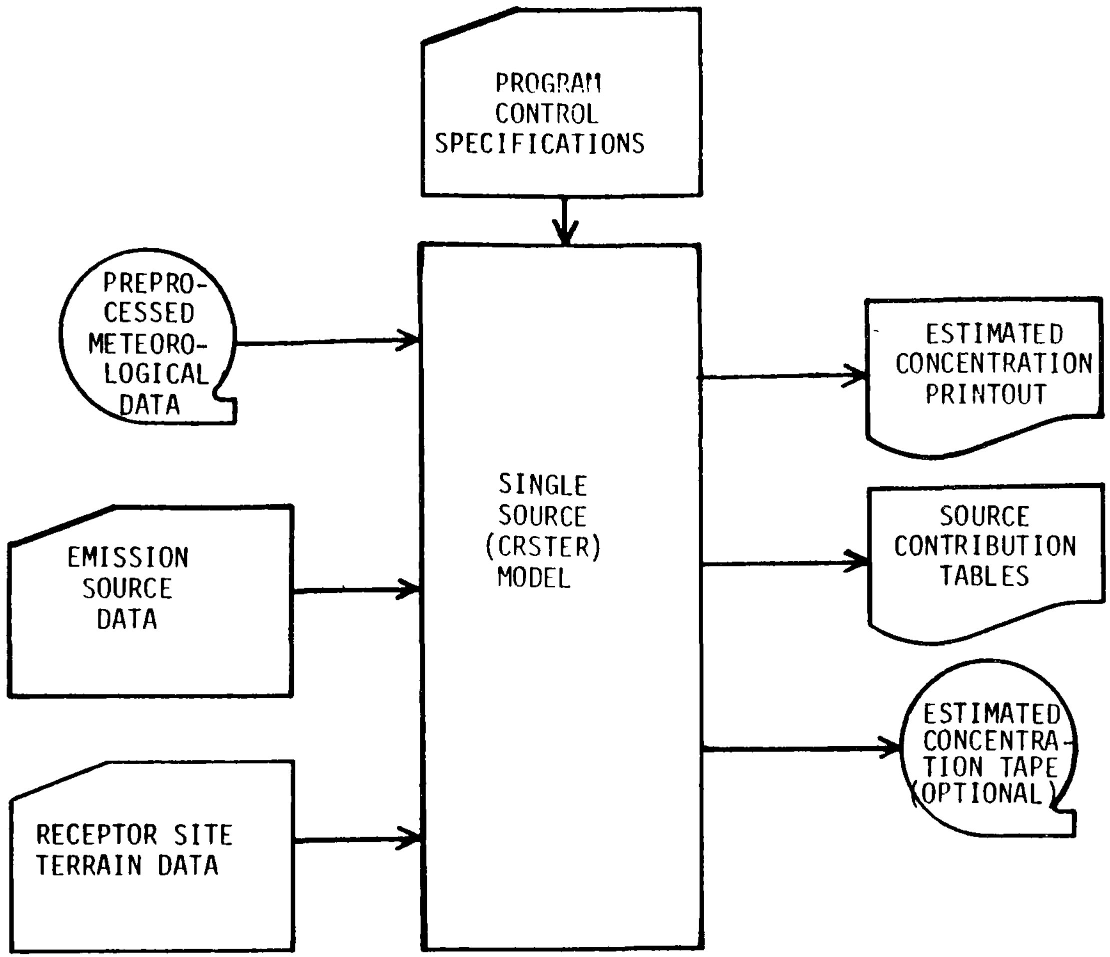


FIGURE 1-2

SCHEMATIC OF THE SINGLE SOURCE (CRSTER) MODEL

SINGLE SOURCE MODEL ASSUMPTIONS

- STEADY-STATE CONDITIONS

  CONTINUOUS, UNIFORM EMISSION RATE

  REPRESENTATIVE HOURLY MEAN WIND VELOCITY

  HOMOGENEOUS HORIZONTAL WIND FIELD

  VERTICAL WIND SHEAR

  - Direction, no
  - Speed, yes

  INFINITE PLUME

  NO PLUME HISTORY

- POLLUTANT CHARACTERISTICS

  NO CHEMICAL REACTIONS

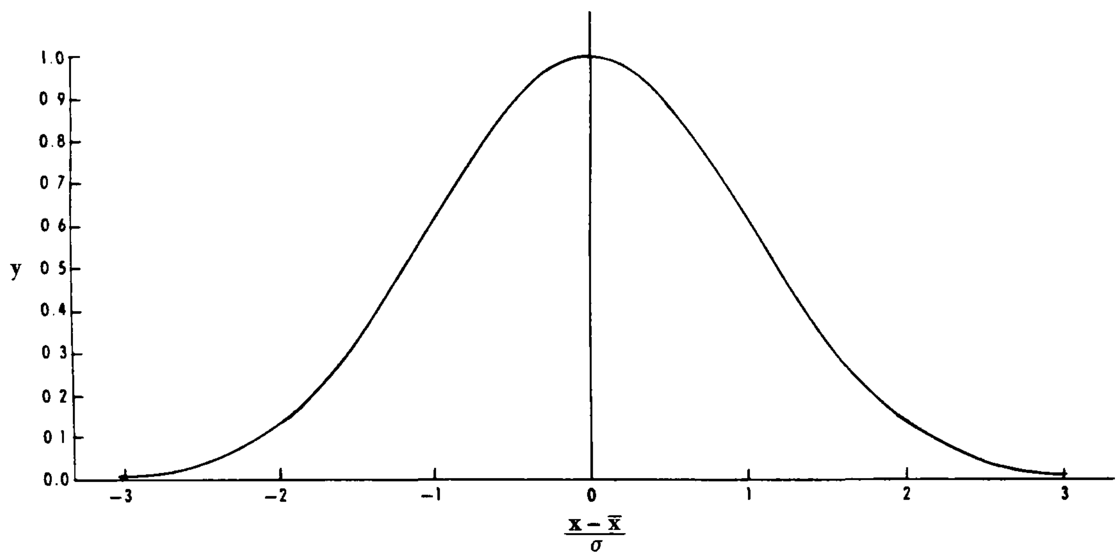
  NO DEPOSITION

  NO RAINOUT

  COMPLETE REFLECTION AT GROUND

- GAUSSIAN DISTRIBUTION

  PLUME CONCENTRATION IN HORIZONTAL AND VERTICAL DIRECTIONS DESCRIBED BY EMPIRICAL DISPERSION PARAMETERS DEPENDENT ON ATMOSPHERIC STABILITY



The Gaussian distribution curve.

THE GAUSSIAN PLUME EQUATION

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

(x,y)	= RECEPTOR COORDINATES	(m)
χ	= GROUND-LEVEL CONCENTRATION	(g/m^3)
Q	= EMISSION RATE	(g/s)
H	= EFFECTIVE STACK HEIGHT	(m)
u	= MEAN WIND SPEED	(m/s)
$\sigma_y\ \sigma_z$	= DISPERSION COEFFICIENTS	(m)

SINGLE SOURCE MODEL ASSUMPTIONS

- WIND SPEED AT STACK HEIGHT

  $$u = u_0 \, (h/7)^p$$

- EFFECTIVE STACK HEIGHT

  $$H = h + \Delta h$$

- LIMITED MIXING

  Plume Trapping

  Plume Lofting

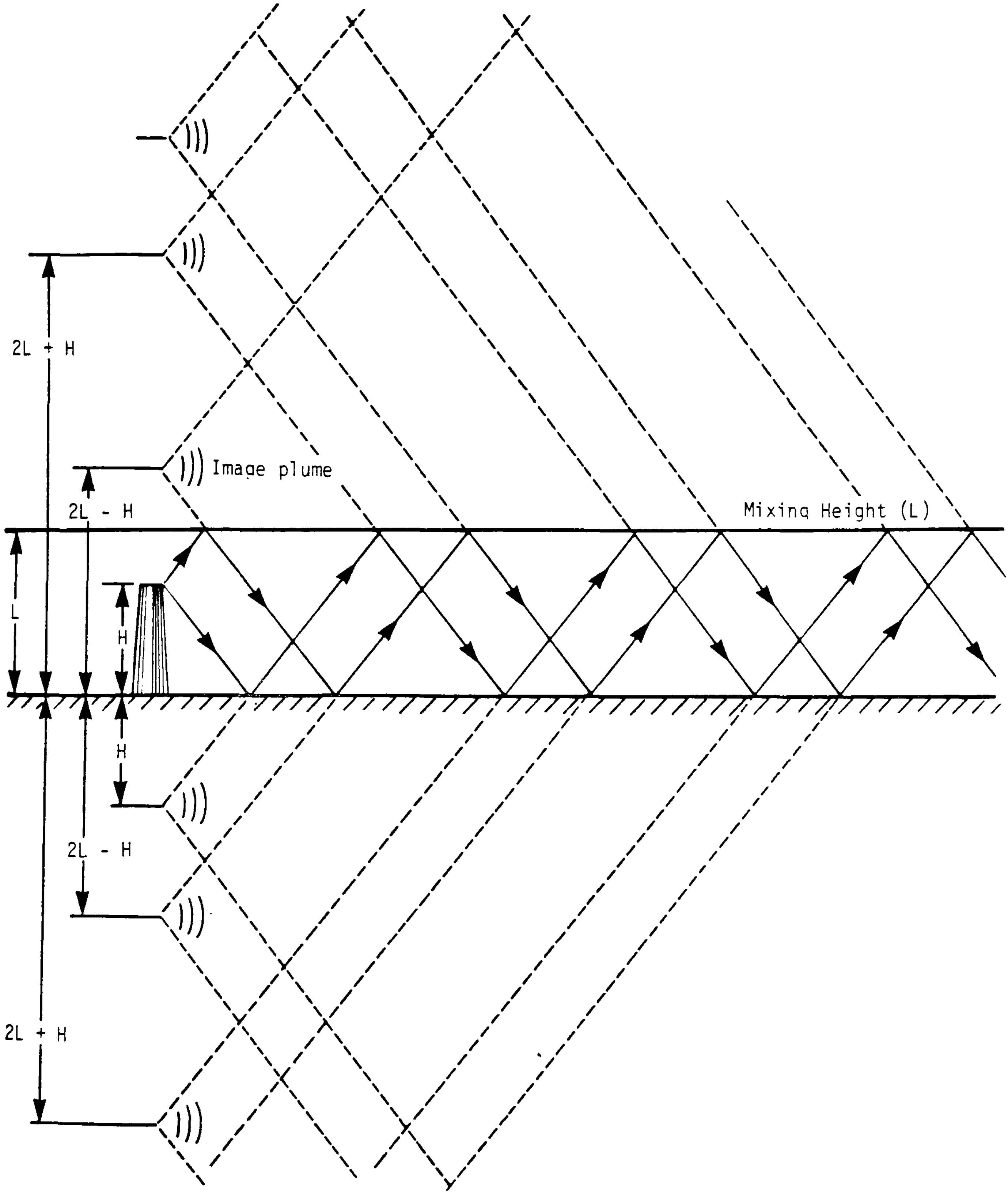


Figure 2-1

The method of multiple plume images used to simulate plume reflections in the single source model

TABLE 2-3

MODIFIED GAUSSIAN PLUME EQUATIONS USED IN THE SINGLE SOURCE (CRSTER) MODEL

If $H \le L$ and $\sigma_z \le 1.6L$	$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \sum_{N=-\infty\ (-k)}^{+\infty\ (+k)} \exp\left[-\frac{1}{2}\left(\frac{H+2NL}{\sigma_z}\right)^2\right]$	(2-11)
If $H \le L$ and $\sigma_z > 1.6L$	$\chi = \frac{Q}{\sqrt{2\pi}\, \sigma_z L u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$	(2-12)
If $H > L$	$\chi = 0$	(2-13)

SINGLE SOURCE MODEL ASSUMPTIONS

- RECEPTOR NETWORK

  Randomized flow vector for wind

  Maximum widths of plume impact

  Off-centerline distance approximation

- URBAN/RURAL CONSIDERATIONS

  Atmospheric stability limited to P-G "D"

  Separate mixing heights

- DETERMINING HOURLY MIXING HEIGHTS (PREPROCESSOR)

  Twice daily estimates of mixing height

  Interpolated using time of sunrise, sunset, and hourly stability

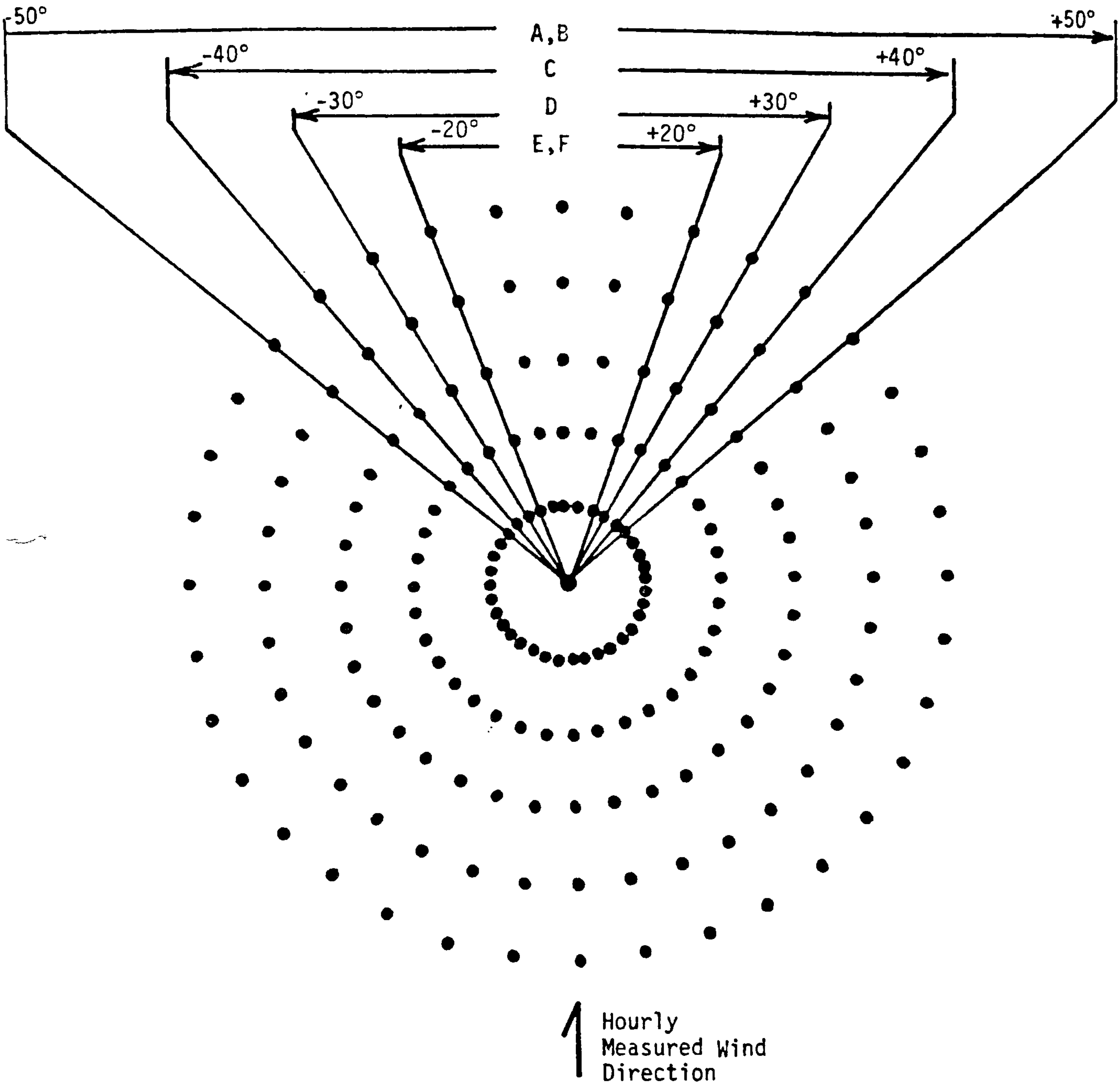


FIGURE 2-2

EXAMPLE OF RECEPTOR NETWORK USED IN THE SINGLE SOURCE (CRSTER) MODEL FOR A SOUTH WIND AND FOR EACH STABILITY CLASS

SINGLE SOURCE MODEL ASSUMPTIONS

- DETERMINING HOURLY STABILITY (PREPROCESSOR)

  Pasquill-Gifford Categories (A-F and "-")

  Solar insolation determined by Turner method using cloud cover, ceiling height, and solar elevation

- TERRAIN CONSIDERATIONS

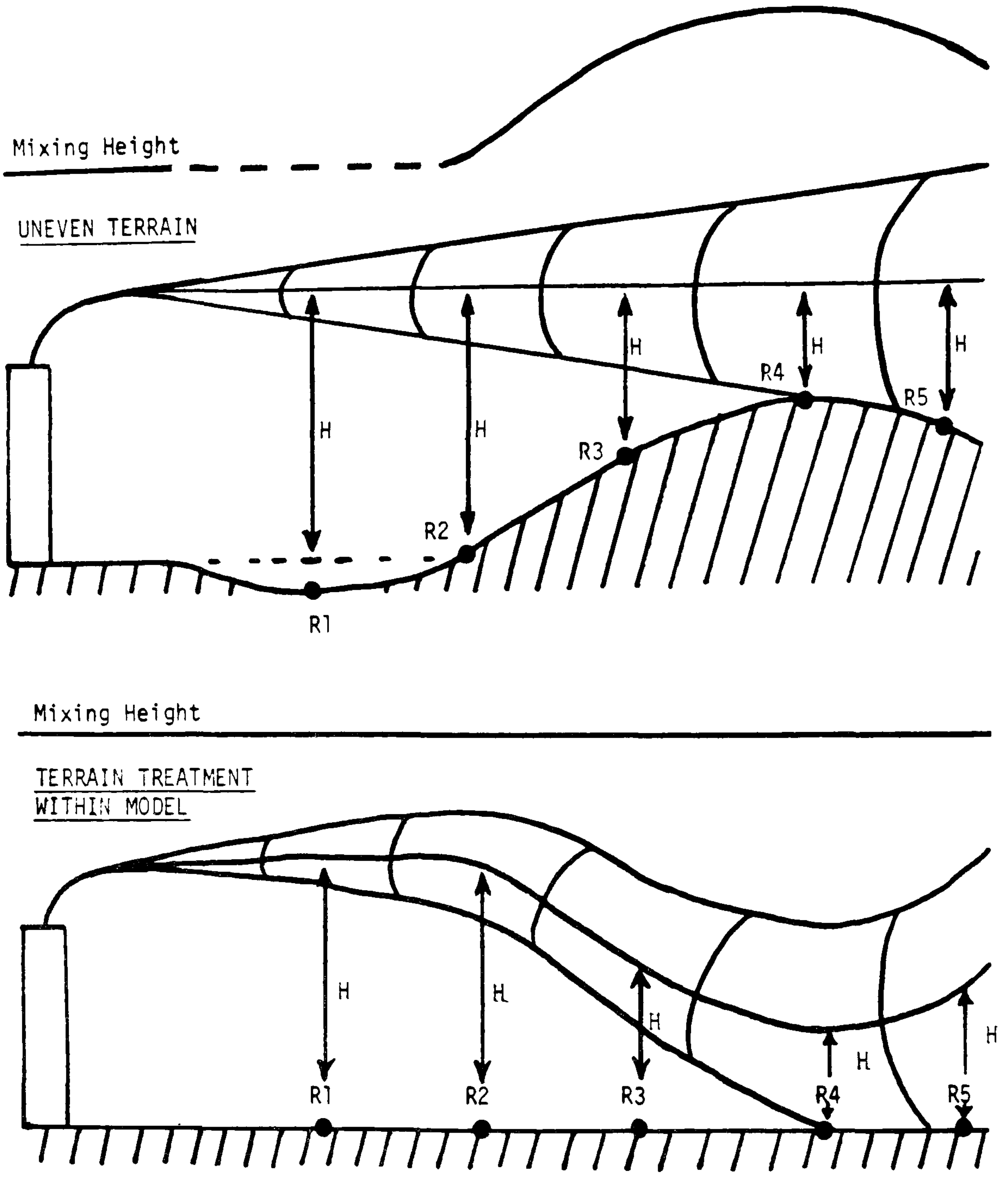
  Plume height correction for uneven terrain

  No plume impaction allowed

  Plant base elevation is lower limit on receptor elevation

  Mixing height follows terrain

  Receptors not floating in air, no "Z" term in Gaussian plume equation



Note: R1-R5 are receptor points at 5 ring distances.

FIGURE 2-4

ILLUSTRATION OF THE METHOD FOR TERRAIN ADJUSTMENT
IN THE SINGLE SOURCE (CRSTER) MODEL

HOW DO YOU USE THE SINGLE SOURCE MODEL?

- GATHER METEOROLOGICAL DATA
- RUN PREPROCESSOR COMPUTER PROGRAM
- GATHER SOURCE AND RECEPTOR SITE DATA
- RUN SINGLE SOURCE MODEL COMPUTER PROGRAM
- INTERPRET RESULTS

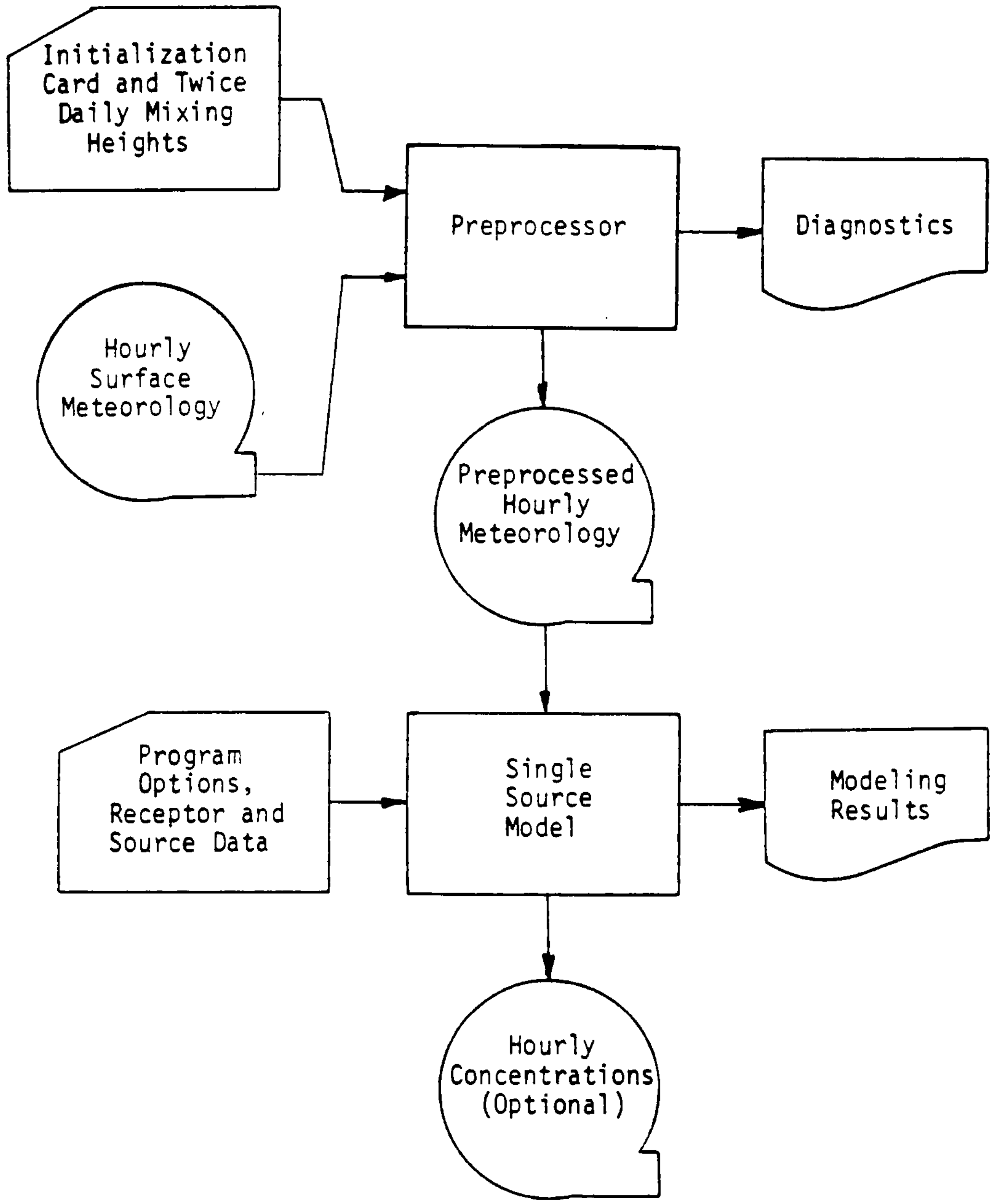


FIGURE 4-1

PROCEDURE FOR USING THE SINGLE SOURCE (CRSTER) MODEL

STEPS TO USE THE SINGLE SOURCE MODEL

- SELECT SURFACE AND UPPER AIR OBSERVATION STATIONS (NWS) FOR METEOROLOGICAL DATA FROM TD 1440 SURVEY
- SELECT THE YEAR OF ANALYSIS
- ORDER METEOROLOGICAL DATA FROM NCC
    - Hourly surface data, mag tape in 144 format
    - Twice daily mixing heights, tabular form
- PUNCH MIXING HEIGHT CARDS
- CHECK FOR MISSING DATA, MANUALLY OR BY PROGRAM
    - Preprocessor does some checking for missing surface data only
- RUN PREPROCESSOR COMPUTER PROGRAM
- OBTAIN MAG TAPE OF HOURLY PREPROCESSED METEOROLOGICAL DATA AND DIAGNOSTICS

STEPS TO USE THE SINGLE SOURCE MODEL

- SELECT PROGRAM OPTIONS
  - Rural or urban mode?
  - Output tape of concentrations?
  - Flat or uneven terrain?
  - Which days will be run?
  - Monthly source parameters?
  - Source contribution output?
  - Variable averaging period?
- COLLECT EMISSIONS SOURCE DATA
  - Plant elevation
  - Stack parameters, for each stack

    emission rate
    gas velocity
    gas temperature
    stack exit diameter
    stack height
- COLLECT RECEPTOR SITE DATA
  - Select ring distances - use PTMAX (UNAMAP)
  - Determine terrain elevations
  - Source contribution receptor data (optional)
- PUNCH OPTIONS, EMISSIONS AND SITE DATA ON CARDS
- INPUT PREPROCESSOR MAG TAPE
- RUN SINGLE SOURCE MODEL COMPUTER PROGRAM

SINGLE SOURCE MODEL OUTPUT

- PRINTOUT-CARD INPUT DATA LISTING
- PRINTOUT-METEOROLOGICAL DATA
- PRINTOUT-MODELING RESULTS
  - STANDARD RUN OR SOURCE-CONTRIBUTION RUN
- OUTPUT MAG TAPE (OPTIONAL) - EVERY 1-HOUR, 24-HOUR AND ANNUAL AVERAGE CONCENTRATION CALCULATED AT EACH OF 180 RECEPTOR POINTS
- DIAGNOSTICS

CRITERIA FOR SPECIFYING SIP EMISSION LIMITS

- ANNUAL AVERAGE = THE HIGHEST CONCENTRATION
- 24, 8, 3, AND 1 HOUR AVERAGES = THE HIGHEST OF THE SECOND-HIGHEST CONCENTRATIONS

EXAMPLE

DAY #	RECEPTORS # 1	# 2	# 3
1	345	320	336
2	420	400	298
3	317	469	400

WHICH 24-HOUR SO_2 CONCENTRATION DO YOU USE TO DETERMINE COMPLIANCE WITH NAAQS?

STANDARD MODEL RUN CONCENTRATION OUTPUT

- BASIC CALCULATION IS FOR 1-HOUR
- AVERAGED TO 3, 24-HOUR, AND ANNUAL TIME PERIODS
  - Variable averaging period = 2, 4, 6, 8, or 12 hours
- DISCRETE, NONOVERLAPPING TIME PERIODS
  - 24 1-hour concentrations: 0000-0100, 0100-0200, ...
  - 8 3-hour concentrations: 0000-0300, 0300-0600, ...
  - 1 24-hour concentration : 0000-2400

CONCENTRATION OUTPUT FOR EACH AVERAGING PERIOD

- Table of highest concentration at each of 180 receptors
- Maximum highest concentration at any receptor
- Table of 2nd-highest concentration at each of 180 receptors
- Maximum 2nd-highest concentration at any receptor
- Table of 50 highest concentrations at any receptor

OUTPUT DATA FOR AN EXAMPLE STANDARD RUN OF THE SINGLE SOURCE (CRSTER) MODEL

```
PLANT NAME:  EXAMPLE RUN                POLLUTANT: SO2        EMISSION UNITS: GM/SEC     AIR QUALITY UNITS: GM/M**3
THIS IS A SINGLE SOURCE (CRSTER) MODEL EXAMPLE RUN.
THIS RUN ILLUSTRATES THE USE OF THE FOLLOWING OPTIONS:
*         STANDARD MODEL RUN
*         DAILY MET PRINTOUT
*         RUN FOR TWENTY DAYS
*         UNEVEN RECEPTOR TERRAIN
*         NO HOURLY OUTPUT TAPE
*         RURAL MIXING HEIGHTS
*         VARIABLE AVERAGING TIME
*         MONTHLY VARIATIONS OF Q,V AND T.
CINCINNATI SURFACE
DAYTON UPPER AIR

             MET FILE      REQUESTED
            STN NO. YR    STN NO. YR
 SURFACE     93814  64     93814  64
 UPPER AIR   93815  64     93815  64
PLANT LOCATION: RURAL
NO TAPE OUTPUT
Q VALUES REQUIRE MONTHLY INPUT
V VALUES REQUIRE MONTHLY INPUT
T VALUES REQUIRE MONTHLY INPUT

DAY-- 0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0
      0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0
      0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 1 1 1 1 1 1  1 1 1 1 0 0 0 0 0 1  1 1 1 1 1 1 1 1 1 0
      0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0
      0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0
      0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0
      0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0
      0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0

* * * * * * * * * * * * * * * * * * * * N O T E * * * * * * * * * * * * * * * * * * * *

        ALL TABLES, INCLUDING SOURCE CONTRIBUTION, THAT CONTAIN "ANNUAL" IN THE HEADING ARE BASED ONLY ON THOSE DAYS

        MARKED BY "1" IN THE ABOVE TABLE
```

RING DISTANCES(KM)= .90 1.50 2.00 3.80 6.20

PLANT ELEVATION (FEET ABOVE SEA LEVEL)-- 492.0

PLANT ELEVATION (METERS ABOVE SEA LEVEL)-- 150.0

RECEPTOR ELEVATIONS (FEET ABOVE SEA LEVEL)

DIRECTION	RING#1	RING#2	RING#3	RING#4	RING#5
1	540.0	500.0	470.0	510.0	460.0
2	550.0	550.0	575.0	660.0	460.0
3	525.0	615.0	625.0	710.0	460.0
4	490.0	720.0	640.0	720.0	540.0
5	490.0	680.0	650.0	455.0	500.0
6	480.0	550.0	580.0	490.0	480.0
7	470.0	480.0	455.0	470.0	720.0
8	470.0	455.0	455.0	720.0	720.0
9	455.0	455.0	480.0	720.0	720.0
10	455.0	455.0	610.0	720.0	720.0
11	455.0	610.0	720.0	720.0	720.0
12	455.0	660.0	660.0	720.0	720.0
13	520.0	590.0	590.0	720.0	720.0
14	610.0	720.0	720.0	720.0	720.0
15	700.0	560.0	560.0	720.0	720.0
16	700.0	530.0	540.0	720.0	720.0
17	600.0	720.0	550.0	720.0	720.0
18	510.0	650.0	580.0	720.0	720.0
19	470.0	470.0	650.0	720.0	700.0
20	455.0	600.0	670.0	610.0	720.0
21	455.0	720.0	720.0	590.0	720.0
22	455.0	700.0	720.0	610.0	520.0
23	455.0	455.0	495.0	460.0	455.0
24	460.0	455.0	455.0	460.0	460.0
25	460.0	460.0	470.0	480.0	560.0
26	470.0	460.0	460.0	460.0	720.0
27	480.0	460.0	455.0	460.0	510.0
28	500.0	465.0	455.0	470.0	455.0
29	530.0	475.0	460.0	480.0	470.0
30	610.0	460.0	460.0	490.0	520.0
31	720.0	460.0	470.0	490.0	550.0
32	675.0	460.0	470.0	480.0	720.0
33	630.0	470.0	470.0	470.0	650.0
34	590.0	460.0	470.0	470.0	620.0
35	560.0	460.0	470.0	480.0	600.0
36	540.0	460.0	470.0	480.0	480.0

RECEPTOR ELEVATIONS (METERS ABOVE SEA LEVEL)

DIRECTION	RING#1	RING#2	RING#3	RING#4	RING#5
1	164.6	152.4	143.3	155.4	140.2
2	167.6	167.6	175.3	201.2	140.2
3	160.0	187.5	190.5	216.4	140.2
4	149.4	219.5	195.1	219.5	164.6
5	149.4	207.3	198.1	138.7	152.4
6	146.3	167.6	176.8	149.4	146.3
7	143.3	146.3	138.7	143.3	219.5
8	143.3	138.7	138.7	219.5	219.5
9	138.7	138.7	146.3	219.5	219.5
10	138.7	138.7	185.9	219.5	219.5
11	138.7	185.9	219.5	219.5	219.5
12	138.7	201.2	201.2	219.5	219.5
13	158.5	179.8	179.8	219.5	219.5
14	185.9	219.5	219.5	219.5	219.5
15	213.4	170.7	170.7	219.5	219.5
16	213.4	161.5	164.6	219.5	219.5
17	182.9	219.5	167.6	219.5	219.5
18	155.4	198.1	176.8	219.5	219.5
19	143.3	143.3	198.1	219.5	213.4
20	138.7	182.9	204.2	185.9	219.5
21	138.7	219.5	219.5	179.8	219.5
22	138.7	213.4	219.5	185.9	158.5
23	138.7	138.7	150.9	140.2	138.7
24	140.2	138.7	138.7	140.2	140.2
25	140.2	140.2	143.3	146.3	170.7
26	143.3	140.2	140.2	140.2	219.5
27	146.3	140.2	138.7	140.2	155.4
28	152.4	141.7	138.7	143.3	138.7
29	161.5	144.8	140.2	146.3	143.3
30	185.9	140.2	140.2	149.4	158.5
31	219.5	140.2	143.3	149.4	167.6
32	205.7	140.2	143.3	146.3	219.5
33	192.0	143.3	143.3	143.3	198.1
34	179.8	140.2	143.3	143.3	189.0
35	170.7	140.2	143.3	146.3	182.9
36	164.6	140.2	143.3	146.3	146.3

STACK # 1-- STACK 1
STACK # 2-- STACK 2
STACK # 3-- STACK 3
STACK # 4-- STACK 4

RECEPTOR ELEVATION LESS THAN PLANT ELEVATION - - - RECEPTOR ELEVATION SET TO PLANT ELEVATION - 80 TIMES

STACK	MONTH	EMISSION RATE (GMS/SEC)	HEIGHT (METERS)	DIAMETER (METERS)	EXIT VELOCITY (M/SEC)	TEMP (DEG.K)	VOLUMETRIC FLOW (M**3/SEC)
1	JAN	36.2200	83.20	3.05	19.42	428.00	532.74
	FEB	36.2200	83.20	3.05	19.42	428.00	532.74
	MAR	36.2200	83.20	3.05	19.42	428.00	532.74
	APR	36.2200	83.20	3.05	19.42	428.00	532.74
	MAY	36.2200	83.20	3.05	19.42	428.00	532.74
	JUN	36.2200	83.20	3.05	19.42	428.00	532.74
	JUL	36.2200	83.20	3.05	19.42	428.00	532.74
	AUG	36.2200	83.20	3.05	19.42	428.00	532.74
	SEP	36.2200	83.20	3.05	19.42	428.00	532.74
	OCT	36.2200	83.20	3.05	19.42	428.00	532.74
	NOV	36.2200	83.20	3.05	19.42	428.00	532.74
	DEC	36.2200	83.20	3.05	19.42	428.00	532.74
2	JAN	1395.2000	70.70	3.96	28.19	462.00	773.32
	FEB	1395.2000	70.70	3.96	28.19	462.00	773.32
	MAR	1395.2000	70.70	3.96	28.19	462.00	773.32
	APR	1395.2000	70.70	3.96	28.19	462.00	773.32
	MAY	1395.2000	70.70	3.96	28.19	462.00	773.32
	JUN	1395.2000	70.70	3.96	28.19	462.00	773.32
	JUL	1395.2000	70.70	3.96	28.19	462.00	773.32
	AUG	1395.2000	70.70	3.96	28.19	462.00	773.32
	SEP	1395.2000	70.70	3.96	28.19	462.00	773.32
	OCT	1395.2000	70.70	3.96	28.19	462.00	773.32
	NOV	1395.2000	70.70	3.96	28.19	462.00	773.32
	DEC	1395.2000	70.70	3.96	28.19	462.00	773.32
3	JAN	1086.1000	114.30	3.35	28.77	415.00	789.23
	FEB	1086.1000	114.30	3.35	28.77	415.00	789.23
	MAR	1086.1000	114.30	3.35	28.77	415.00	789.23
	APR	1086.1000	114.30	3.35	28.77	415.00	789.23
	MAY	1086.1000	114.30	3.35	28.77	415.00	789.23
	JUN	1086.1000	114.30	3.35	28.77	415.00	789.23
	JUL	1086.1000	114.30	3.35	28.77	415.00	789.23
	AUG	1086.1000	114.30	3.35	28.77	415.00	789.23
	SEP	1086.1000	114.30	3.35	28.77	415.00	789.23
	OCT	1086.1000	114.30	3.35	28.77	415.00	789.23
	NOV	1086.1000	114.30	3.35	28.77	415.00	789.23
	DEC	1086.1000	114.30	3.35	28.77	415.00	789.23

STACK	MONTH	EMISSION RATE (GMS/SEC)	HEIGHT (METERS)	DIAMETER (METERS)	EXIT VELOCITY (M/SEC)	TEMP (DEG.K)	VOLUMETRIC FLOW (M**3/SEC)
4	JAN	3434.8000	243.80	5.91	33.83	405.00	928.04
	FEB	3434.8000	243.80	5.91	33.83	405.00	928.04
	MAR	3434.8000	243.80	5.91	33.83	405.00	928.04
	APR	3434.8000	243.80	5.91	33.83	405.00	928.04
	MAY	3434.8000	243.80	5.91	33.83	405.00	928.04
	JUN	3434.8000	243.80	5.91	33.83	405.00	928.04
	JUL	3434.8000	243.80	5.91	33.83	405.00	928.04
	AUG	3434.8000	243.80	5.91	33.83	405.00	928.04
	SEP	3434.8000	243.80	5.91	33.83	405.00	928.04
	OCT	3434.8000	243.80	5.91	33.83	405.00	928.04
	NOV	3434.8000	243.80	5.91	33.83	405.00	928.04
	DEC	3434.8000	243.80	5.91	33.83	405.00	928.04

```
JYR=64 IMO= 5 JDAY=125.
ISTAB=  6    6    6    6    6    5    4    3    3    2    2    1    2    1    2    2    3    3    4    5    6    7    7    7
AWS=  2.1  2.6  2.1  2.1  2.1  2.6  1.5  3.1  4.1  3.6  3.1  2.6  3.6  2.1  3.6  2.6  3.1  3.1  2.6  2.1  1.5  1.0  1.0  1.0
TEMP= 289. 288. 287. 286. 286. 286. 287. 290. 292. 294. 297. 299. 299. 299. 300. 299. 300. 299. 298. 294. 291. 289. 287. 288.
AFV=  270. 320. 330. 330.  10. 350.  50.  20.  20.  30.  20. 320. 340. 350. 340. 360. 340. 330. 330. 330. 350.  10. 340. 340.
AFVR= 267. 322. 335. 331.   8. 354.  53.  24.  23.  29.  23. 320. 343. 351. 345.   4. 340. 327. 333. 327. 349.  12. 344. 338.
HLH1= 2010. 2032. 2054. 2077. 2099.   86.  362.  639.  915. 1192. 1468. 1745.
      2021. 2298. 2298. 2298. 2298. 2298. 2298. 2294. 2287. 2279. 2271. 2264.
HLH2=  264.  264.  264.  264.  264.  340.  585.  829. 1074. 1319. 1564. 1808.
      2053. 2298. 2298. 2298. 2298. 2298. 2298. 2048. 1563. 1079.  595.  111.
```

		MAX HOURLY				MAX 24-HOUR		
DAY	RATIO	CONCENTRATION	DIRECTION	DISTANCE(KM)	HOUR	CONCENTRATION	DIRECTION	DISTANCE(KM)
125	18.457	2.426167-03	32	.90	12	1.314483-04	2	3.80

```
JYR=64 IMO= 5 JDAY=126.
ISTAB=  7    6    6    5    6    5    4    3    3    2    2    2    2    2    3    3    3    3    3    4    5    5    6    6
AWS=  1.0  3.1  2.6  2.6  1.0  2.1  1.5  1.0  3.1  3.1  2.6  3.6  3.1  4.6  3.6  4.1  4.1  2.1  1.5  2.1  2.6  2.1  1.0  2.6
TEMP= 286. 289. 289. 288. 289. 289. 290. 291. 293. 296. 297. 300. 300. 300. 300. 301. 300. 299. 298. 298. 295. 293. 290. 290.
AFV=  340. 320. 330. 330. 330. 330. 360. 360.  40.  40.  10.  20.  30.  30.  20.  40.  30. 360. 320. 330. 320. 360. 360. 320.
AFVR= 345. 322. 327. 333. 330. 328.   2.   5.  37.  42.  12.  19.  34.  30.  18.  43.  32.   1. 324. 333. 318.   1.   1. 318.
HLH1= 2256. 2249. 2241. 2234. 2226.   85.  344.  603.  862. 1122. 1381. 1640.
      1899. 2158. 2158. 2158. 2158. 2158. 2158. 2141. 2106. 2071. 2037. 2002.
HLH2=  111.  111.  111.  111.  111.  192.  438.  683.  929. 1175. 1421. 1666.
      1912. 2158. 2158. 2158. 2158. 2158. 2158. 2141. 1489. 1043.  597.  151.
```

		MAX HOURLY				MAX 24-HOUR		
DAY	RATIO	CONCENTRATION	DIRECTION	DISTANCE(KM)	HOUR	CONCENTRATION	DIRECTION	DISTANCE(KM)
126	7.380	1.399798-03	3	2.00	14	1.896704-04	4	3.80

```
JYR=64 IMO= 5 JDAY=127.
ISTAB=  6    7    6    7    6    5    4    3    4    4    4    3    3    3    4    4    4    3    4    5    4    5    5    5
AWS=  2.6  1.5  2.1  1.0  1.0  2.1  2.6  3.6  6.7  7.7  7.2  6.7  7.2  7.2  6.2  6.2  6.7  3.1  3.1  2.6  3.6  2.6  2.1  2.6
TEMP= 291. 290. 289. 288. 289. 288. 290. 292. 295. 297. 299. 300. 300. 300. 301. 300. 300. 299. 298. 295. 295. 293. 293. 294.
AFV=  330.  20.  30.  30.  10.  10.  10.  20.  30.  40.  40.  30.  40.  20.  50.  30.  30.  20.  10. 360. 360.  50.  30.  10.
AFVR= 334.  18.  32.  31.  13.   7.  15.  22.  26.  44.  38.  26.  37.  24.  49.  26.  28.  19.   6. 359.   1.  48.  26.  13.
HLH1= 1967. 1933. 1898. 1863. 1829.   63.  245.  426.  608.  790.  971. 1153.
```

PLANT NAME: EXAMPLE RUN POLLUTANT: SO2 EMISSION UNITS: GM/SEC AIR QUALITY UNITS: GM/M**3

YEARLY MAXIMUM 24-HOUR CONC= 2.4790-04 DIRECTION= 4 DISTANCE= 3.8 KM DAY=129

HIGHEST 24-HOUR CONCENTRATION AT EACH RECEPTOR

RANGE / DIR	.9 KM	1.5 KM	2.0 KM	3.8 KM	6.2 KM
1	2.2800-05 (125)	3.9212-05 (125)	5.6554-05 (126)	7.1670-05 (126)	4.5615-05 (126)
2	1.4440-05 (126)	8.5751-05 (126)	1.2960-04 (126)	1.4925-04 (127)	8.7575-05 (127)
3	1.6584-05 (126)	1.4062-04 (126)	1.8687-04 (126)	1.8588-04 (127)	8.5478-05 (126)
4	3.4162-05 (142)	2.0398-04 (145)	1.7518-04 (126)	2.4790-04 (129)	1.0550-04 (126)
5	4.1920-05 (142)	1.6454-04 (145)	1.5672-04 (145)	7.9902-05 (144)	7.9473-05 (145)
6	2.5603-05 (142)	7.4144-05 (143)	9.6394-05 (143)	6.4913-05 (143)	4.1824-05 (130)
7	7.9046-06 (142)	5.8683-05 (140)	9.0559-05 (140)	1.3873-04 (140)	2.3068-04 (140)
8	1.5662-06 (143)	1.7020-05 (131)	3.9138-05 (131)	1.3706-04 (134)	1.2452-04 (134)
9	7.3962-07 (131)	2.2067-05 (131)	5.0687-05 (131)	1.1575-04 (131)	7.6599-05 (134)
10	1.5423-06 (131)	2.2844-05 (131)	8.4294-05 (130)	1.6547-04 (131)	1.2286-04 (131)
11	1.2737-06 (142)	4.3707-05 (148)	9.9419-05 (148)	8.1471-05 (145)	7.0885-05 (145)
12	1.0331-05 (142)	5.2522-05 (148)	7.7432-05 (148)	1.1373-04 (148)	8.4023-05 (148)
13	4.7104-05 (142)	5.0333-05 (142)	4.5560-05 (142)	9.5443-05 (148)	7.7519-05 (148)
14	1.1597-04 (142)	1.3149-04 (142)	1.1212-04 (142)	8.6899-05 (148)	5.8097-05 (148)
15	1.5121-04 (142)	1.6583-04 (142)	1.3441-04 (142)	1.2135-04 (148)	1.0295-04 (148)
16	9.4427-05 (142)	1.0734-04 (142)	8.4606-05 (142)	4.4713-05 (142)	2.7208-05 (142)
17	2.7646-05 (142)	3.4915-05 (142)	2.5181-05 (142)	1.0888-05 (142)	6.0128-06 (145)
18	4.3213-06 (142)	5.3873-06 (142)	4.1854-06 (141)	4.4424-05 (141)	4.6923-05 (141)
19	2.4246-06 (146)	1.7659-05 (141)	8.6886-05 (141)	8.7217-05 (141)	5.4395-05 (141)
20	1.5021-05 (146)	9.5324-05 (141)	1.9818-04 (141)	1.6738-04 (141)	1.6212-04 (141)
21	4.7899-05 (146)	1.2591-04 (141)	1.7206-04 (141)	1.4434-04 (141)	1.3248-04 (141)
22	7.7230-05 (146)	1.0227-04 (141)	1.6812-04 (141)	1.5710-04 (141)	9.2942-05 (141)
23	6.3289-05 (146)	5.3935-05 (146)	5.5828-05 (146)	5.6739-05 (146)	4.3760-05 (146)
24	7.5912-05 (143)	5.3310-05 (143)	6.1957-05 (146)	7.9974-05 (146)	6.0074-05 (146)
25	7.5912-05 (143)	7.8007-05 (146)	1.1736-04 (146)	1.1729-04 (146)	7.6257-05 (146)
26	3.8834-05 (143)	9.6434-05 (146)	1.4285-04 (146)	1.3251-04 (146)	9.4739-05 (142)
27	1.0042-05 (143)	4.7195-05 (146)	6.6347-05 (146)	5.4728-05 (146)	5.1655-05 (132)
28	1.3282-06 (143)	7.8668-06 (146)	1.2778-05 (146)	2.9697-05 (142)	2.5437-05 (142)
29	3.9901-06 (125)	1.8769-06 (125)	7.2069-06 (132)	3.3604-05 (132)	3.9109-05 (132)
30	2.4067-05 (125)	1.2875-05 (125)	1.8690-05 (132)	7.4832-05 (132)	8.6754-05 (132)
31	7.5737-05 (125)	4.1048-05 (125)	2.8000-05 (125)	7.5309-05 (132)	8.2911-05 (132)
32	1.0525-04 (125)	6.3211-05 (125)	4.6699-05 (125)	4.1212-05 (132)	7.8095-05 (126)
33	9.2649-05 (125)	6.8800-05 (125)	5.9804-05 (125)	5.8412-05 (125)	6.7342-05 (125)
34	8.7913-05 (125)	1.0519-04 (125)	1.1185-04 (125)	1.0654-04 (125)	7.9498-05 (125)
35	8.7191-05 (125)	1.1510-04 (125)	1.1232-04 (125)	8.6773-05 (125)	5.0092-05 (125)
36	5.7601-05 (125)	7.0879-05 (125)	6.8347-05 (125)	7.1527-05 (143)	7.0908-05 (143)

PLANT NAME: EXAMPLE RUN POLLUTANT: SO2 EMISSION UNITS: GM/SEC AIR QUALITY UNITS: GM/M**3

YEARLY SECOND MAXIMUM 24-HOUR CONC= 1.8967-04 DIRECTION= 4 DISTANCE= 3.8 KM DAY=126

SECOND HIGHEST 24-HOUR CONCENTRATION AT EACH RECEPTOR

RANGE DIR	.9 KM	1.5 KM	2.0 KM	3.8 KM	6.2 KM
1	4.6927-06 (126)	3.6403-05 (126)	4.5701-05 (125)	4.5998-05 (125)	4.2805-05 (143)
2	9.2047-06 (125)	5.9081-05 (125)	1.0155-04 (125)	1.3360-04 (126)	7.8626-05 (125)
3	1.4855-05 (142)	9.0950-05 (127)	1.2061-04 (127)	1.8509-04 (129)	6.6402-05 (127)
4	7.2971-06 (126)	1.7461-04 (126)	1.2001-04 (145)	1.8967-04 (126)	8.9402-05 (129)
5	5.8437-06 (145)	1.0791-04 (142)	1.0451-04 (144)	5.9550-05 (145)	7.8592-05 (144)
6	7.4737-06 (143)	6.2490-05 (142)	4.9984-05 (140)	4.0594-05 (130)	4.1647-05 (140)
7	6.0150-06 (143)	5.2282-05 (143)	7.0462-05 (143)	1.0184-04 (131)	1.8459-04 (130)
8	1.2533-06 (142)	1.3434-05 (140)	2.4112-05 (140)	1.0780-04 (131)	7.2466-05 (131)
9	1.0246-07 (143)	2.4817-06 (130)	6.3474-06 (130)	6.9236-05 (140)	6.9389-05 (131)
10	7.0201-07 (130)	1.9422-05 (130)	8.2972-05 (131)	1.1084-04 (130)	6.8646-05 (130)
11	7.7295-07 (131)	3.7597-05 (130)	7.1757-05 (130)	7.6372-05 (148)	5.0526-05 (148)
12	2.0607-07 (148)	9.9267-06 (142)	1.3549-05 (130)	4.0905-05 (130)	3.2021-05 (130)
13	1.8114-07 (148)	1.0870-05 (148)	2.5336-05 (148)	5.1375-05 (142)	3.7030-05 (142)
14	3.6291-06 (148)	7.8798-05 (148)	9.7135-05 (148)	8.3178-05 (142)	5.6670-05 (142)
15	7.1001-06 (148)	1.4262-05 (148)	3.1861-05 (148)	7.9655-05 (142)	5.1593-05 (142)
16	9.8925-07 (148)	2.3678-06 (148)	7.0826-06 (148)	1.7320-05 (148)	1.0783-05 (148)
17	9.5202-09 (146)	7.5014-07 (145)	1.0755-07 (148)	6.3757-06 (145)	5.5228-06 (142)
18	2.0384-07 (146)	4.8522-06 (141)	3.4470-06 (142)	3.3564-05 (146)	3.6865-05 (148)
19	5.3060-07 (141)	1.1864-06 (146)	1.6503-06 (146)	3.6028-05 (146)	3.8804-05 (146)
20	8.6307-07 (141)	9.6605-06 (146)	5.9978-06 (146)	8.1893-06 (149)	5.4565-05 (149)
21	1.2595-06 (143)	3.6338-05 (146)	2.4682-05 (146)	1.2916-05 (146)	5.6766-05 (149)
22	9.7489-06 (143)	6.3892-05 (146)	4.6318-05 (146)	2.6291-05 (146)	1.6932-05 (146)
23	3.8147-05 (143)	2.4659-05 (143)	2.8550-05 (141)	3.8236-05 (141)	3.6957-05 (141)
24	2.8802-05 (146)	4.4817-05 (146)	3.5737-05 (142)	3.6384-05 (142)	2.9196-05 (142)
25	1.2749-05 (146)	5.3353-05 (143)	3.7459-05 (142)	3.4797-05 (142)	4.9306-05 (142)
26	9.9013-06 (146)	2.4679-05 (143)	1.7080-05 (142)	1.9361-05 (142)	7.8335-05 (146)
27	5.0798-06 (146)	6.9585-06 (142)	1.1234-05 (142)	4.0548-05 (132)	3.6452-05 (142)
28	1.0804-06 (146)	3.3507-06 (142)	1.0327-05 (142)	2.5871-05 (146)	2.5432-05 (132)
29	8.9815-08 (143)	1.6517-06 (132)	4.2019-06 (146)	2.3691-05 (146)	2.7115-05 (146)
30	3.9366-07 (132)	3.7728-06 (132)	8.0572-06 (125)	1.9823-05 (146)	3.0511-05 (146)
31	1.5981-06 (132)	2.9271-06 (132)	1.8025-05 (132)	1.4932-05 (125)	1.2273-05 (146)
32	3.2444-07 (142)	1.5083-06 (142)	7.0647-06 (132)	3.6244-05 (125)	7.5410-05 (132)
33	1.0780-06 (142)	9.4672-06 (142)	2.2932-05 (142)	3.7767-05 (142)	3.2220-05 (143)
34	1.0585-06 (142)	1.3552-05 (142)	3.3933-05 (142)	5.5882-05 (142)	3.7267-05 (142)
35	7.7780-07 (143)	1.1397-05 (143)	2.5571-05 (143)	3.7279-05 (143)	2.6430-05 (143)
36	9.1389-07 (143)	1.4293-05 (143)	3.4389-05 (143)	5.7805-05 (125)	3.4652-05 (126)

PLANT NAME: EXAMPLE RUN   POLLUTANT: SO2   EMISSION UNITS: GM/SEC   AIR QUALITY UNITS: GM/M**3

MAXIMUM DAILY CONCENTRATIONS

DAY	24-HOUR CONCENTRATION	DIRECTION	DISTANCE
129	2.4790-04	4	3.80
140	2.3068-04	7	6.20
145	2.0398-04	4	1.50
141	1.9818-04	20	2.00
126	1.8967-04	4	3.80
127	1.8588-04	3	3.80
130	1.8459-04	7	6.20
128	1.7147-04	4	3.80
142	1.6583-04	15	1.50
131	1.6547-04	10	3.80
134	1.5318-04	7	6.20
146	1.4285-04	26	2.00
125	1.3145-04	2	3.80
144	1.2320-04	4	3.80
148	1.2135-04	15	3.80
143	9.6394-05	6	2.00
147	9.1085-05	3	3.80
132	8.6754-05	30	6.20
133	8.5918-05	7	6.20
149	5.6766-05	21	6.20

SINGLE SOURCE MODEL LIMITATIONS

- STEADY-STATE ASSUMPTIONS
  - Continuous uniform emission rate
  - Homogeneous horizontal wind field
  - Hourly mean wind vector
  - No directional wind shear in vertical
  - Constant eddy diffusivities
  - No plume history
  - No deposition or reaction
- TERRAIN ADJUSTMENT
- MIXING HEIGHT
- CALM WINDS
  - 1.0 meters/second limit
  - Use of previous hour's direction
- AERODYNAMIC EFFECTS
- STACK SEPARATION
- PLUME RISE

Chapter 16

Elements of the Expected Exceedance (EXEX) Method

Chapter Goal

To familiarize you with the method of determining the number of times the National Ambient Air Quality Standard will be exceeded (using statistical methods) for SO_2.

Chapter Objective

Upon completion of this chapter, you should be able to:

1. explain the procedure used to determine the expected number of exceedances of the SO_2 standard.

Chapter Outline

Follows *Modeling Notes (EXEX)*.

Support Material

Peter Guldberg, *Modeling Notes, Elements of the Expected Exceedance Method (EXEX)*.

MODELING NOTES
by Peter H. Guldberg

Elements of the Expected Exceedance (EXEX) Method

EXPECTED EXCEEDANCES METHOD (EXEX)

APPLIES ONLY TO COAL FIRED BOILERS

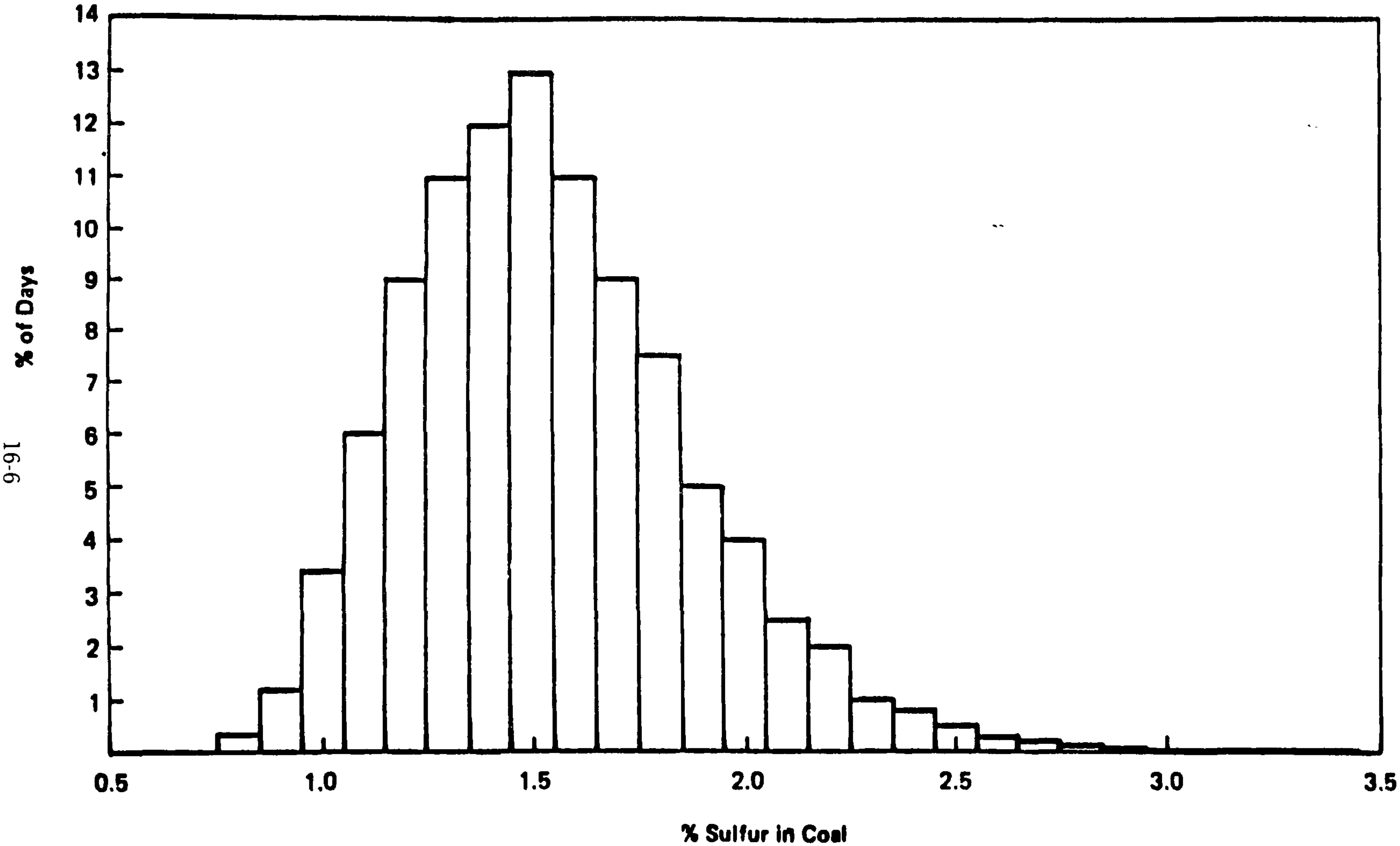
EPA MEMO 12-6-79 OUTLINES EXEX

FEDERAL REGISTER NOTICE 2-14-80 LISTS CONDITIONS FOR USE:

(1) 5 YEARS OF MET DATA

(2) COAL WASHING IF SULFUR IS HIGH

(3) CONTINUOUS SAMPLING OF STACK SO_2 OR COAL PILE



% of Days
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0.5
1.0
1.5
2.0
2.5
3.0
3.5
% Sulfur in Coal

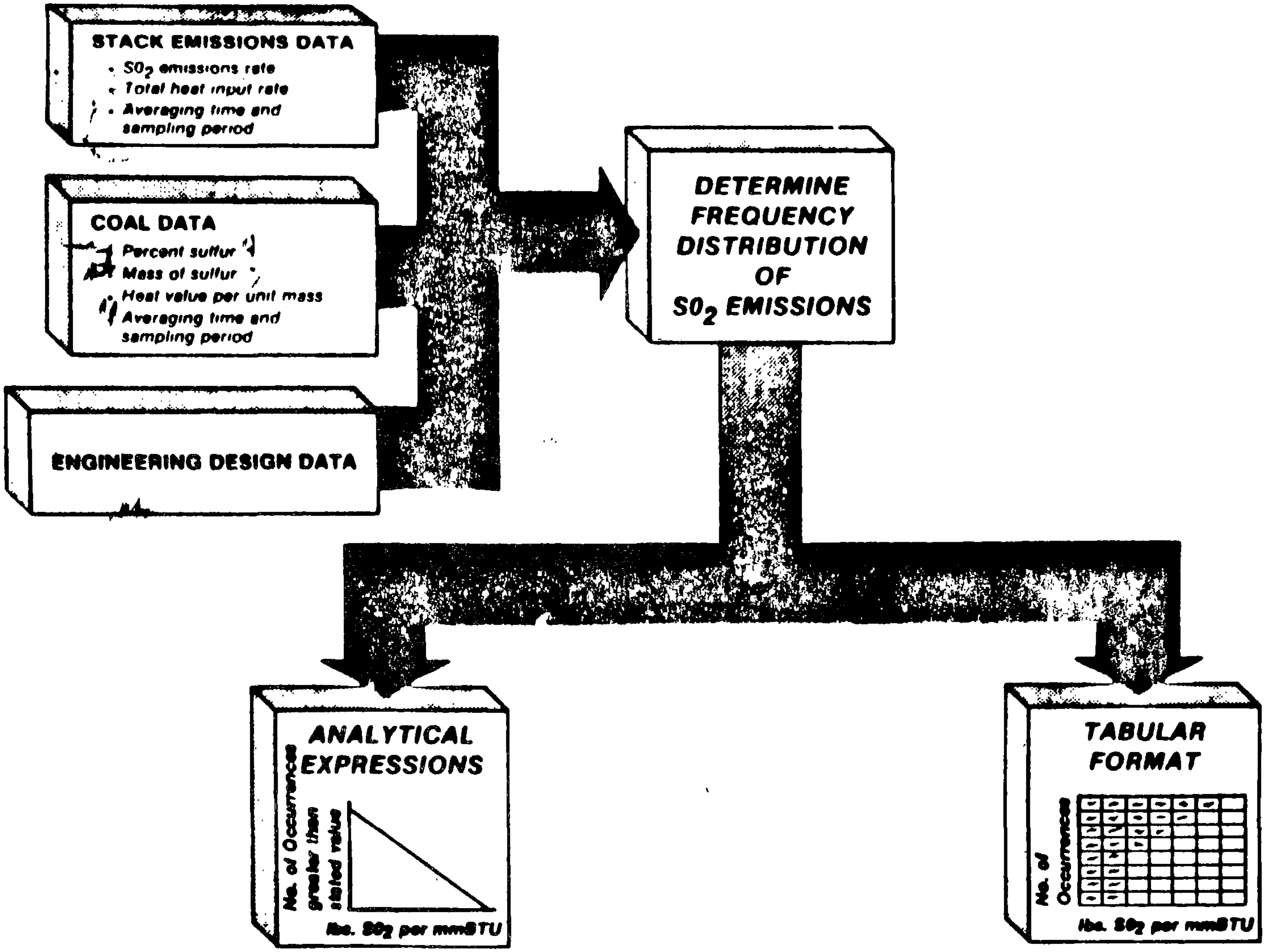


FIGURE 3. ELEMENTS OF THE SIMPLIFIED EXEX METHOD

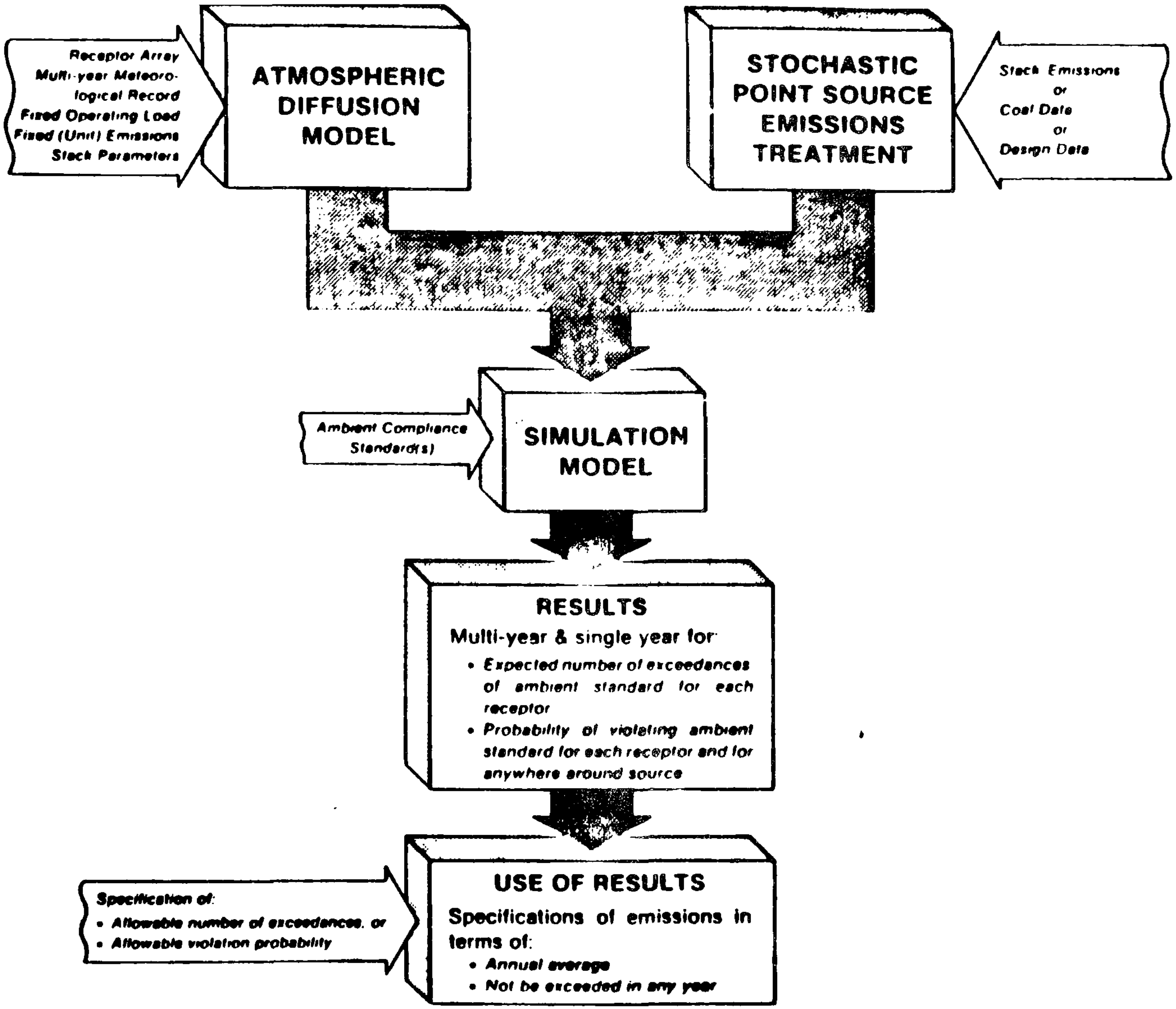


FIGURE 1. ELEMENTS OF THE SIMPLIFIED EXEX METHOD

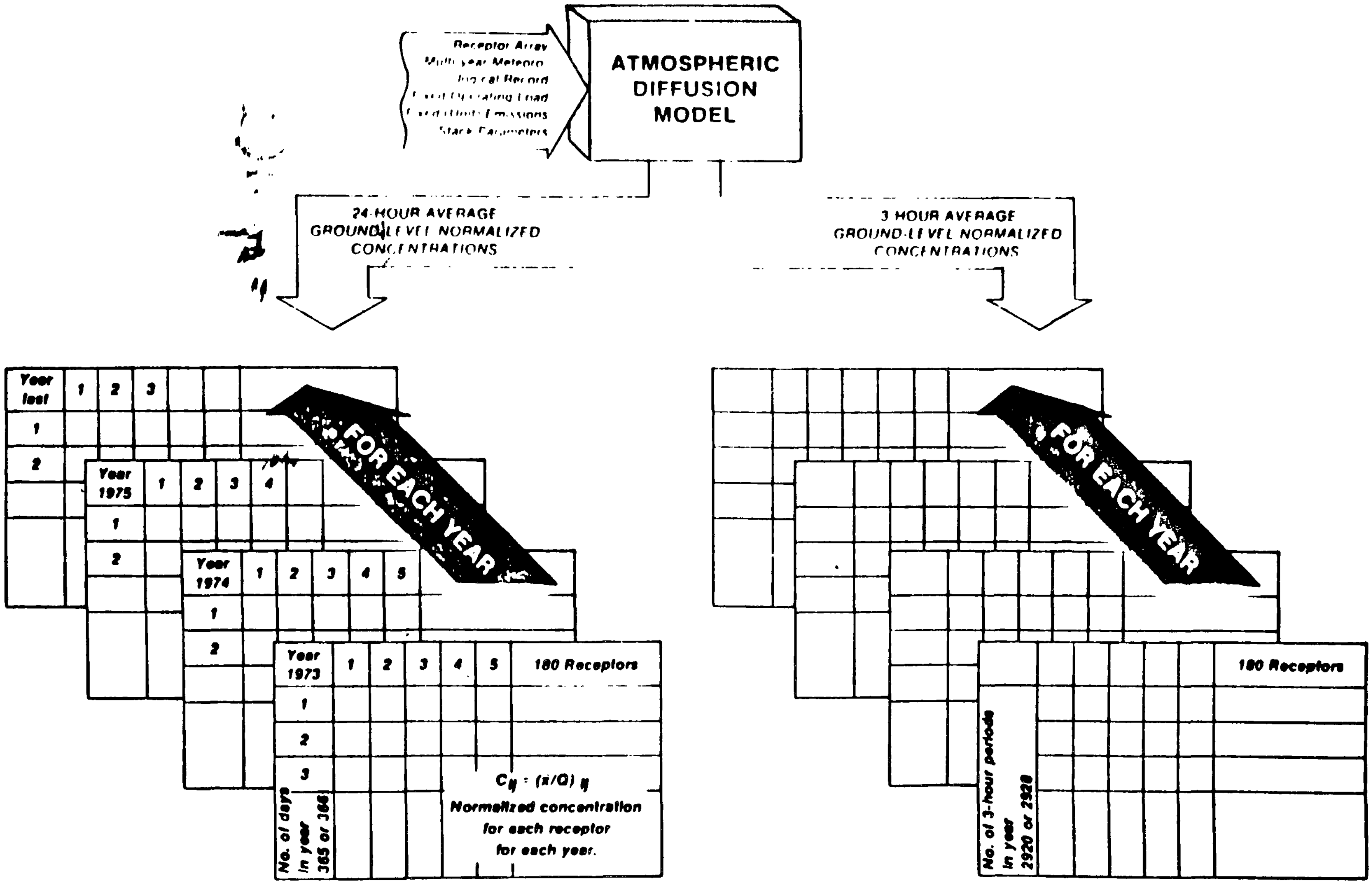


FIGURE 2. ATMOSPHERIC DIFFUSION MODEL

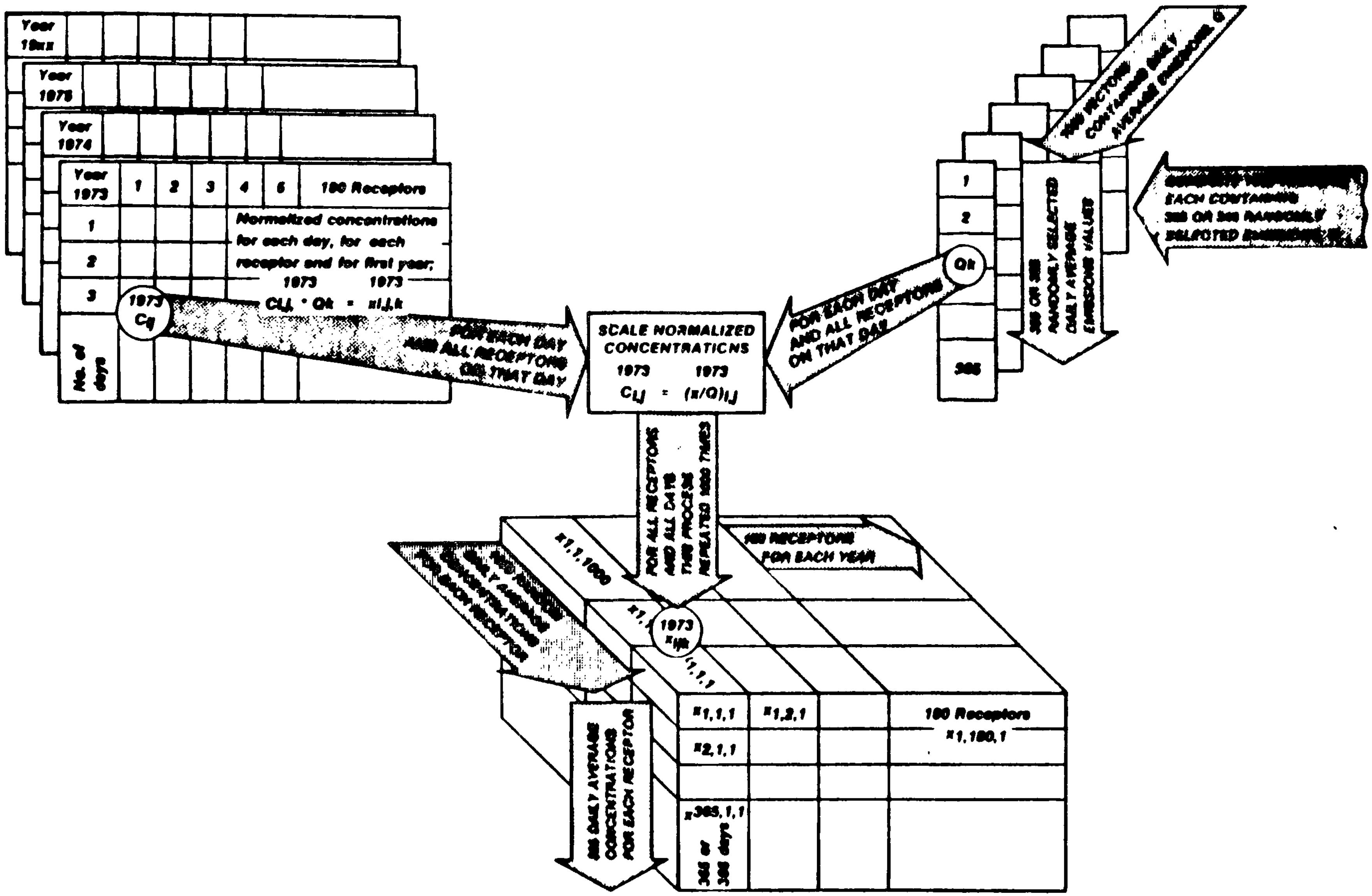


FIGURE 4. SIMULATION MODEL

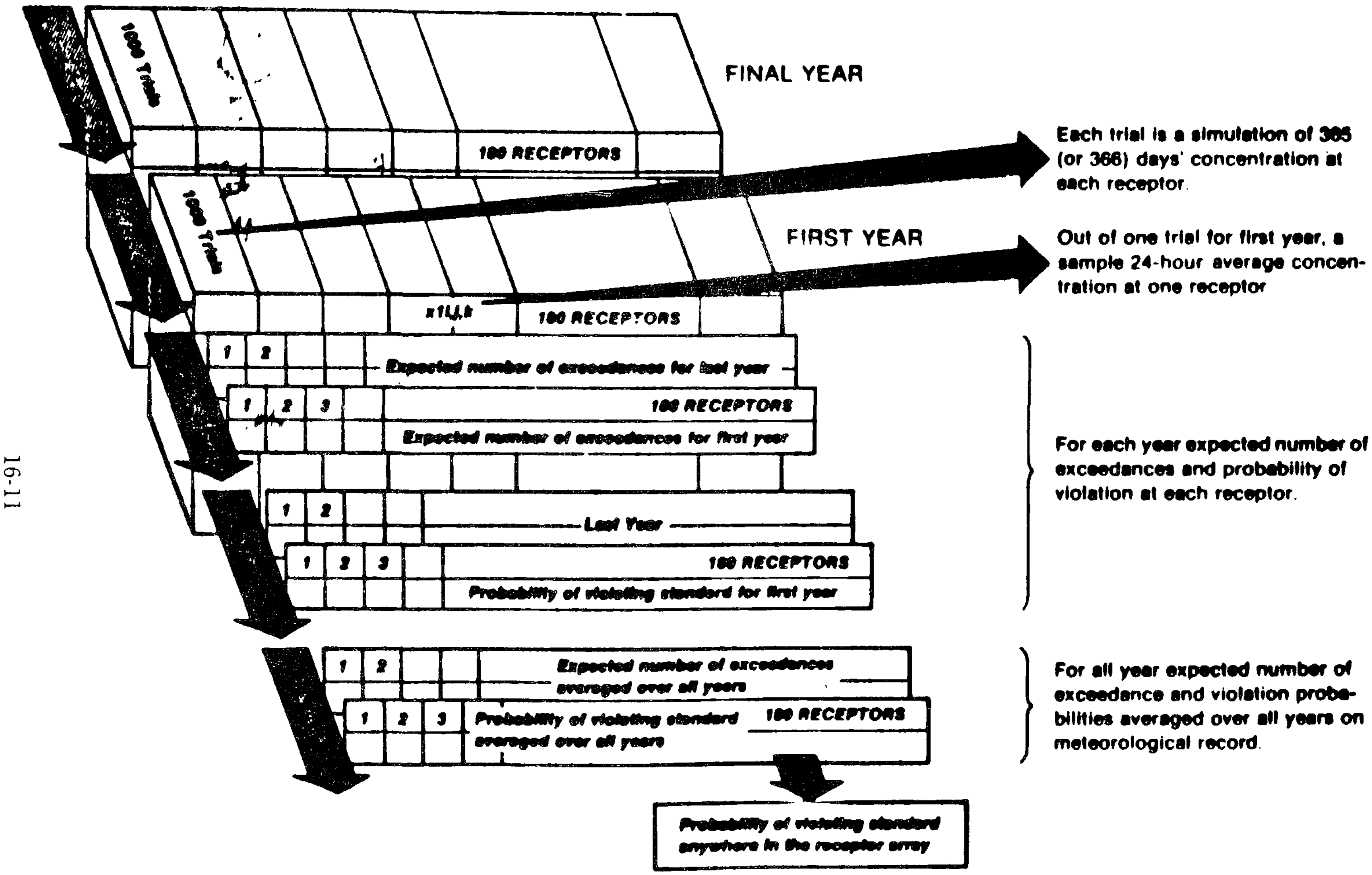
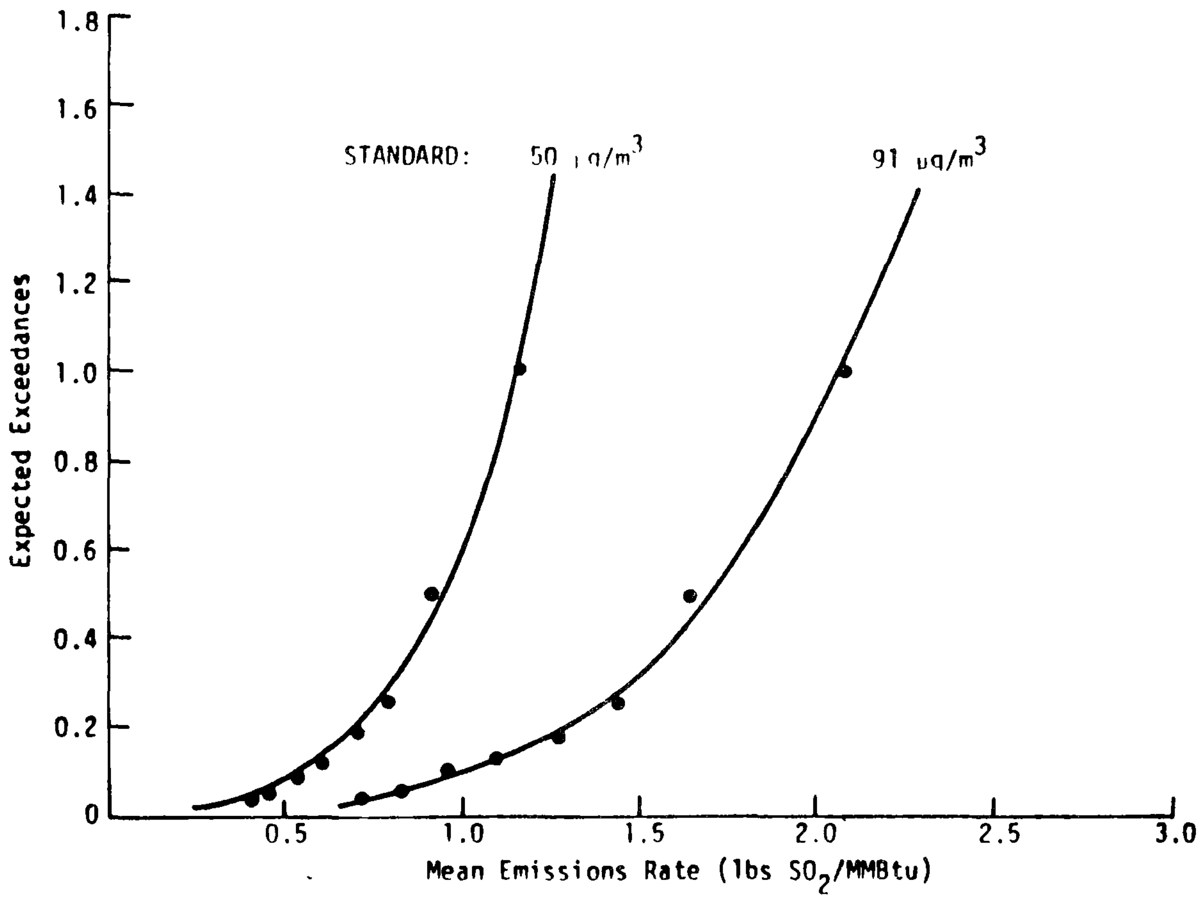
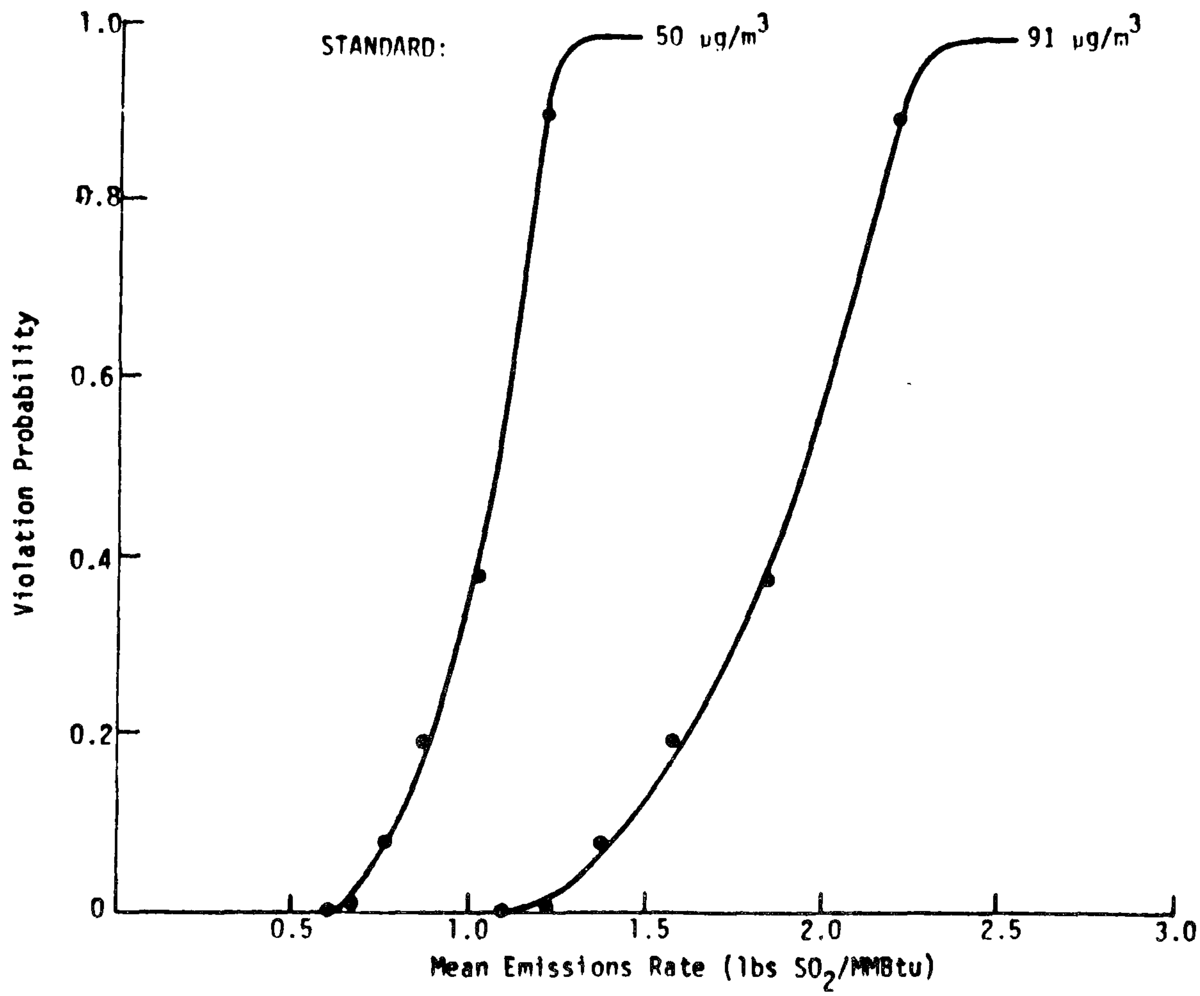


FIGURE 5. ANALYSIS EXCEEDANCES AND VIOLATIONS FROM EXEX METHODOLOGY



(c) GSD of SO_2 Emissions Distribution: 1.4--Scrubbed Plant

FIGURE 7 (Continued)



(b) GSD of SO_2 Emissions Distribution: 1.2--Scrubbed Plant

FIGURE 8 (Continued)

Chapter 17

Elements and Applications of the Industrial Source Complex (ISC) Model

Chapter Goal

To familiarize you with the Industrial Source Complex (ISC) model presently available on UNAMAP.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. describe the application of the Industrial Source Complex model to a given source and surrounding terrain features.
2. describe the accuracy of the Industrial Source Complex model under given source-receptor conditions.

Chapter Outline

Follows *Modeling Notes (ISC)*.

Support Material

Peter Guldberg, *Modeling Notes, Elements and Application of the Industrial Source Complex (ISC) Model.*

MODELING NOTES
by Peter H. Guldberg

Elements and Applications of the Industrial Source (ISC) Model

INDUSTRIAL SOURCE COMPLEX (ISC) MODEL

- COMPLEX MODEL FOR INDUSTRIAL COMPLEXES OFFERING NUMEROUS SPECIAL FEATURES
- TWO COMPUTER PROGRAMS
  - ISCST: EXTENSION OF CRSTER
  - ISCLT: EXTENSION OF CDM, AQDM
- RUN COSTS APPROXIMATELY 1/3¢ PER SOURCE/RECEPTOR/DAY FOR ISCST, $5.00 TOTAL FOR ISCLT
- CODE AND USER'S MANUAL AVAILABLE

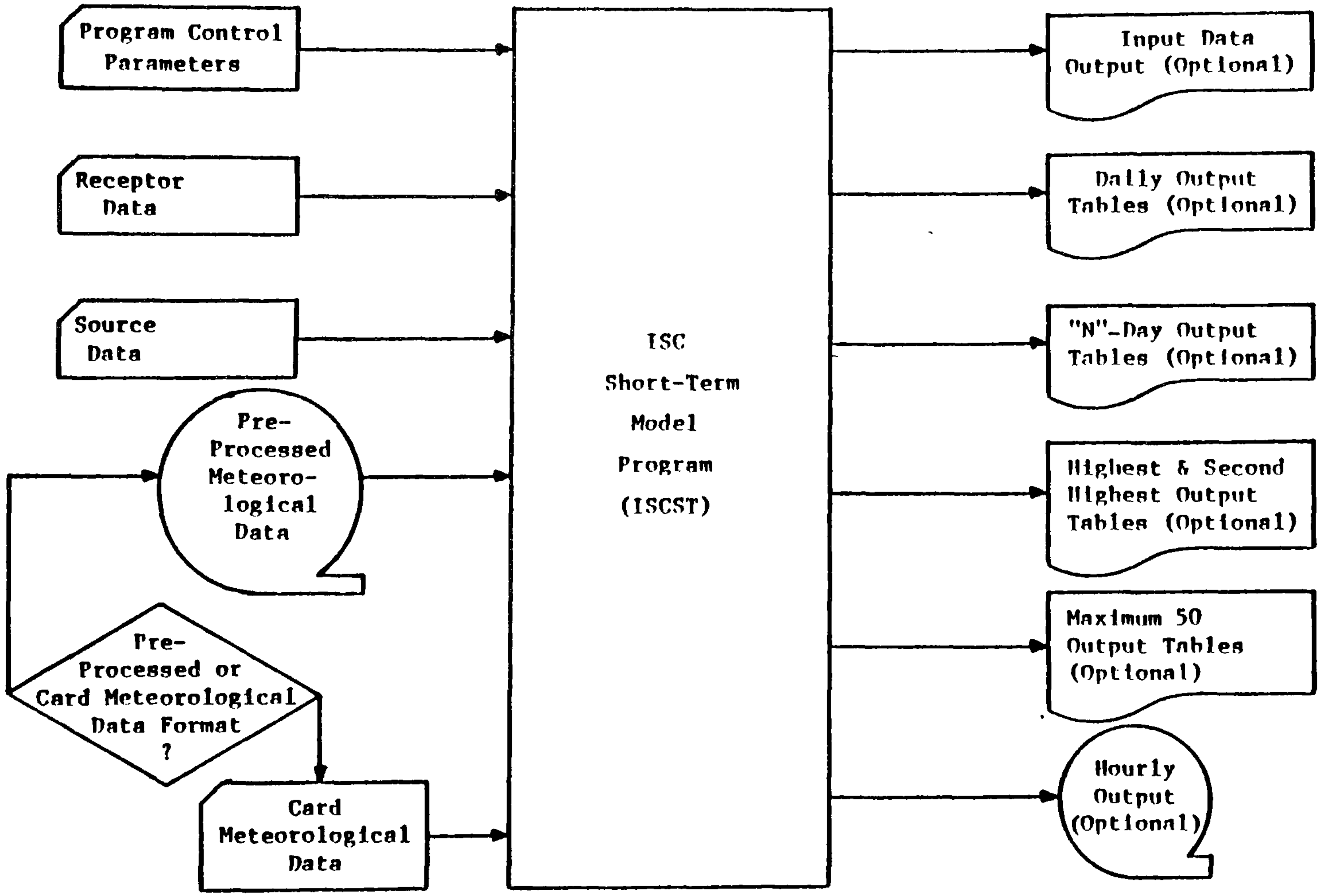


FIGURE 1-1. Schematic diagram of the ISC Model short-term computer program ISCST.

HIGH
24-HR
SGROUP8 1

*** -- HYPOTHETICAL POTASH PROCESSING PLANT - CONCENTRATION -- ***

* HIGHEST 24-HOUR AVERAGE CONCENTRATION (MICROGRAMS/CUBIC METER) *
* FROM SOURCES: 1,
* FOR THE RECEPTOR GRID *

* MAXIMUM VALUE EQUALS 29257.33984 AND OCCURRED AT (.0, -200.0) *

y-axis / (meters) /	x-axis (meters) -800.0	-600.0	-400.0	-200.0	.0
3000.0 /	.02187 (187, 1)	.00103 (187, 1)	.00002 (187, 1)	.00140 (289, 1)	.39458 (289, 1)
2000.0 /	3.64513 (205, 1)	.23969 (187, 1)	.00440 (187, 1)	.00018 (289, 1)	1.03276 (289, 1)
1500.0 /	118.39290 (305, 1)	6.56493 (205, 1)	.17455 (187, 1)	.00037 (187, 1)	2.02372 (289, 1)
1250.0 /	329.68170 (305, 1)	53.75400 (205, 1)	1.50348 (187, 1)	.00314 (187, 1)	3.07055 (289, 1)
1000.0 /	103.86832 (305, 1)	427.40199 (305, 1)	15.05959 (187, 1)	.04380 (187, 1)	5.07164 (289, 1)
800.0 /	107.80086 (187, 1)	331.47763 (305, 1)	188.70668 (305, 1)	.57678 (187, 1)	8.50962 (289, 1)
600.0 /	1164.95976 (187, 1)	192.61037 (187, 1)	999.93413 (305, 1)	12.40346 (187, 1)	16.37711 (289, 1)
400.0 /	2586.00357 (305, 1)	3429.66122 (187, 1)	431.43685 (187, 1)	596.57519 (305, 1)	40.20404 (289, 1)
200.0 /	3417.10876 (262, 1)	5034.82111 (305, 1)	8261.22119 (305, 1)	1618.61168 (187, 1)	159.62988 (289, 1)
.0 /	2113.19528 (262, 1)	3410.68469 (262, 1)	6411.06494 (262, 1)	14624.32703 (262, 1)	.00000 (0, 0)
-200.0 /	16.72914 (262, 1)	.65443 (262, 1)	.00080 (187, 1)	.00000 (337, 1)	29257.33984 (337, 1)
-400.0 /	.00006 (187, 1)	.00000 (187, 1)	.00000 (337, 1)	.08076 (337, 1)	12556.48901 (337, 1)
-600.0 /	.00000 (187, 1)	.00000 (337, 1)	.00000 (337, 1)	41.96467 (337, 1)	6761.63867 (337, 1)
-800.0 /	.00000 (337, 1)	.00000 (337, 1)	.00620 (337, 1)	250.86494 (337, 1)	4217.97260 (337, 1)
-1000.0 /	.00000 (337, 1)	.00000 (337, 1)	.71882 (337, 1)	442.10267 (337, 1)	2898.65292 (337, 1)
-1250.0 /	.00000 (337, 1)	.00420 (337, 1)	13.46043 (337, 1)	557.08878 (337, 1)	2017.04434 (337, 1)
-1500.0 /	.00006 (337, 1)	.24976 (337, 1)	54.82790 (337, 1)	589.01745 (337, 1)	1501.84814 (337, 1)
-2000.0 /	.12187 (337, 1)	12.00114 (337, 1)	160.56051 (337, 1)	549.62419 (337, 1)	949.64354 (337, 1)
-3000.0 /	20.03640 (337, 1)	98.79222 (337, 1)	227.32941 (337, 1)	396.21886 (337, 1)	513.20028 (337, 1)

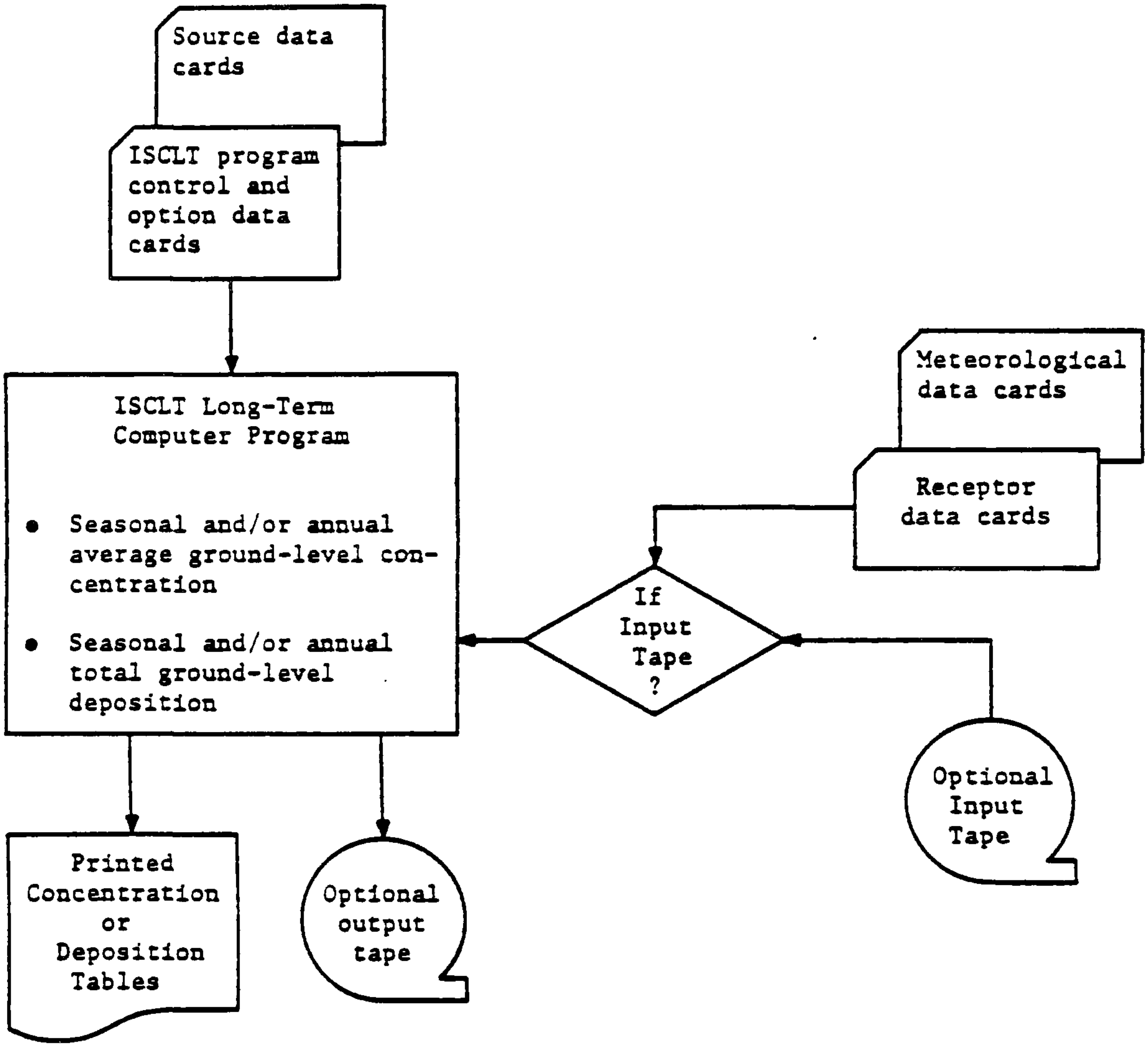


FIGURE 1-2. Schematic diagram of the ISC Model long-term computer program ISCLT.

A COMPARISON OF EPA'S ISCST AND CRSTER MODELS

Item	Similarities/Differences
Averaging Times	Same, except ISC allows N-day averages also
Multiple Source, Treatment	ISC allows for spatial separation, CRSTER does not
Plume Rise	ISC calculates plume rise as a function of distance and includes both momentum and buoyancy effects, CRSTER uses only the final rise due to buoyancy alone. ISC uses default β_2 value of 0.60 while CRSTER uses 0.66
Downwash	ISC allows for stack tip (Briggs) or building wake effects (Huber and Snyder), CRSTER makes no adjustments
Terrain Adjustment	Same
Atmospheric Decay	ISC calculates time dependent decay rate, CRSTER has no decay term
Particulate Settling and Deposition	ISC allows user to specify particle size dependent effects, CRSTER makes no adjustments. ISC also calculates deposition mass as option, CRSTER does not
Source Input Data	ISC allows at least 100 of any combination of point, area, and volume sources, CRSTER can handle only point sources and up to 19 of these
Output Tables	Same, except ISC offers more variety of output data, e.g. definition of source groups, deposition mass, as well as concentrations
Meteorological Input Data	Same, except ISC allows user to input values of the wind-profile exponents and vertical potential temperature gradients
Rural Dispersion Coefficients	Same
Urban Dispersion Coefficients	ISC in Urban1 mode is the same as CRSTER in urban mode. ISC in Urban2 mode is new.
Receptor Coordinate System	Same, except ISC allows rectangular coordinates as an option. ISC allows at least 400 receptors CRSTER has 180. There is a tradeoff between the maximum number of sources and receptors in ISC as the limitation is on program core requirements

A COMPARISON OF EPA'S ISCST AND CRSTER MODELS

(Continued)

Item	Similarities/Differences
Emissions Input	ISC allows variations by month, hour, season and hour, or wind speed and stability; CRSTER only allows variations by month. ISC allows the users to apply scalars to one or several sources, CRSTER variations apply to all sources
Source Contributions	ISC disallows contributions when source-receptor distances are 100 meters, CRSTER does not
Crosswind Distance	ISC calculates exactly, CRSTER approximates with arc length
Plume Trapping, Lofting	Same

Table 3-1. Meteorological data input options for ISCST.

Input of hourly data by preprocessed data tape or card deck
Site-specific wind-profile exponents
Site-specific vertical potential temperature gradients
Rural Mode or Urban Mode 1 or 2
Entrainment coefficients other than the Briggs (1975) coefficients
Final or distance dependent plume rise
Wind system measurement height other than 10 meters

Table 2-2. Default values for the wind-profile exponents and vertical potential temperature gradients.

Pasquill Stability Category	Wind-Profile Exponent p	Vertical Potential Temperature Gradient (°K/m)
A	0.10	0.000
B	0.15	0.000
C	0.20	0.000
D	0.25	0.000
E	0.30	0.020
F	0.30	0.035

Table 2-3. Pasquill-Gifford dispersion coefficients used by the ISC model in the rural and urban modes.

Actual Pasquill Stability Category*	Pasquill Stability Category for the σ_y, σ_z Values Used in ISC Model Calculations		
	Rural Mode	Urban Mode 1	Urban Mode 2
A	A	A	A
B	B	B	A
C	C	C	B
D	D	D	C
E	E	D	D
F	F	D	D

*The ISCST program redefines extremely stable G stability as very stable F stability.

Table 4-1. Meteorological data input options for ISCLT.

Input of all meteorological data by card deck or by magnetic tape inventory previously generated by ISCLT
STAR summaries with five or six Pasquill stability categories
Site-specific mixing heights
Site-specific ambient air temperatures
Site-specific wind-profile exponents
Site-specific vertical potential temperature gradients
Rural Mode or Urban Mode 1 or 2
Entrainment coefficients other than the Briggs (1975) coefficients
Final or distance dependent plume rise
Wind system measurement height other than 10 meters

AMBIENT TEMPERATURE

STABILITY	SUGGESTED VALUE
A, B, C	AVERAGE DAILY MAXIMUM FOR EACH SEASON
D	AVERAGE FOR EACH SEASON
E, F	AVERAGE DAILY MINIMUM FOR EACH SEASON

MIXING HEIGHTS

A	1.5 TIMES MEAN AFTERNOON HEIGHT
B, C	MEAN AFTERNOON HEIGHT
D	AVERAGE OF MEAN MORNING AND AFTERNOON HEIGHTS
E, F	MEAN MORNING HEIGHT

ISC DISPERSION MODEL FEATURES

ST	LT	
X		SOURCE INPUT - CONSTANT OR VARY BY MONTH, HOUR, SEASON AND HOUR, OR WIND SPEED AND STABILITY
	X	SOURCE INPUT - CONSTANT OR VARY BY SEASON, OR WIND SPEED, OR WIND SPEED AND STABILITY
X	X	SOURCE TYPES - AT LEAST 100 OF ANY COMBINATION OF POINT, AREA,
X	X	RECEPTORS - ARTESIAN OR POLAR
X	X	TERRAIN EFFECTS - SAME AS CRSTER
X	X	DOWNWASH - STACK TIP OR BUILDING WAKES
X	X	ATMOSPHERIC DECAY
X	X	PARTICULATE SETTLING AND DEPOSITION
X	X	CONCENTRATIONS OR DEPOSITION AMOUNTS
X		AVERAGING TIMES - 1, 2, 3, 4, 6, 8, 12, 24 HOURS AND N DAYS
	X	AVERAGING TIMES - SEASON OR YEAR
X	X	OUTPUT - TAPE OR PRINTOUT
X	X	FINAL OR TRANSITIONAL PLUME RISE

SOURCE COMBINATION GROUPS

MAXIMUM 150 GROUPS OF ANY SET OF POINT, AREA, AND VOLUME SOURCES

EXAMPLES

GROUP 1	=	1-100	ALL SOURCES
GROUP 2	=	1	POWER PLANT A
GROUP 3	=	2	POWER PLANT B
GROUP 4	=	3-20	XYZ CHEMICAL COMPANY COMPLEX
GROUP 5	=	1-59	ALL SOURCES IN STATE A
GROUP 6	=	60-100	ALL SOURCES IN STATE B

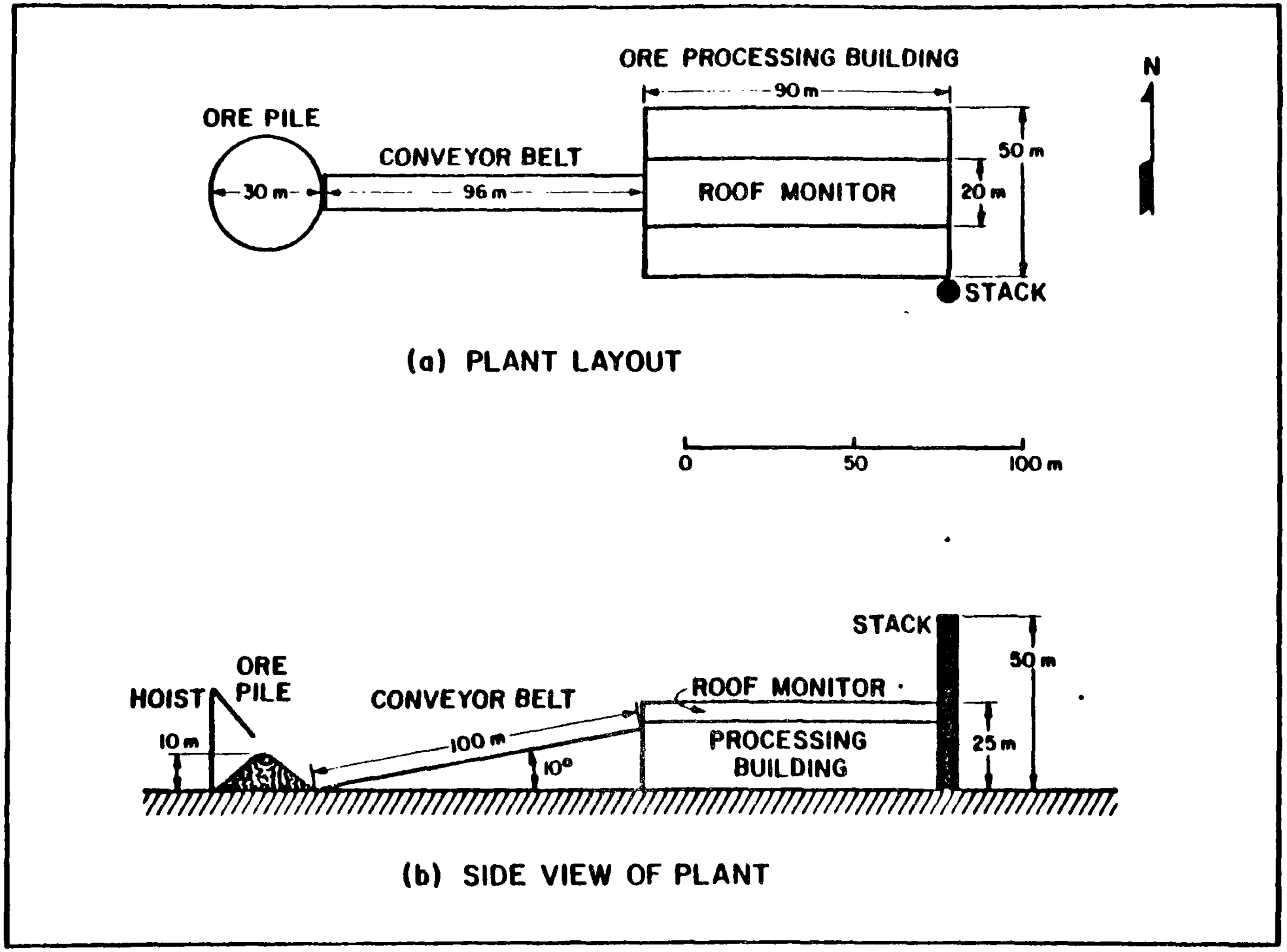


FIGURE 2-11. Plant layout and side view of a hypothetical potash processing plant.

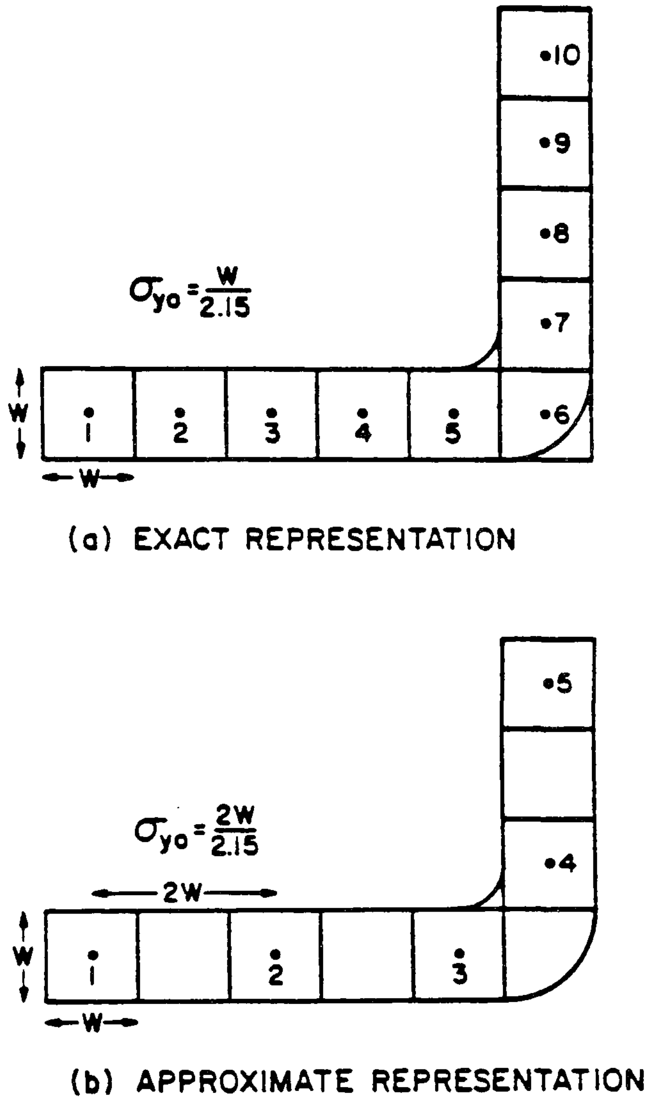


FIGURE 2-10. Exact and approximate representations of a line source by multiple volume sources.

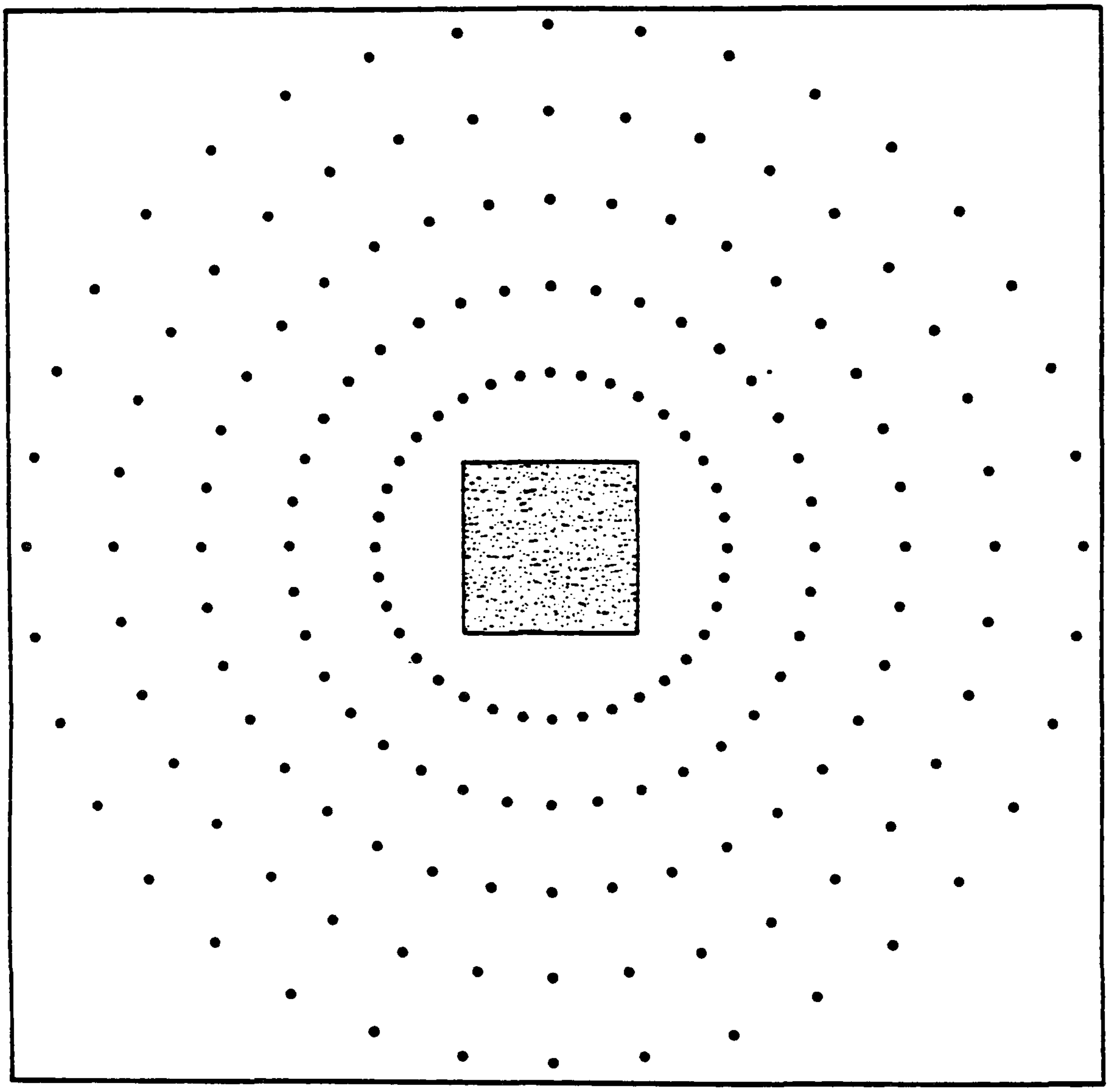


FIGURE 2-2. Example of a polar receptor grid. The stippled area shows the property of a hypothetical industrial source complex.

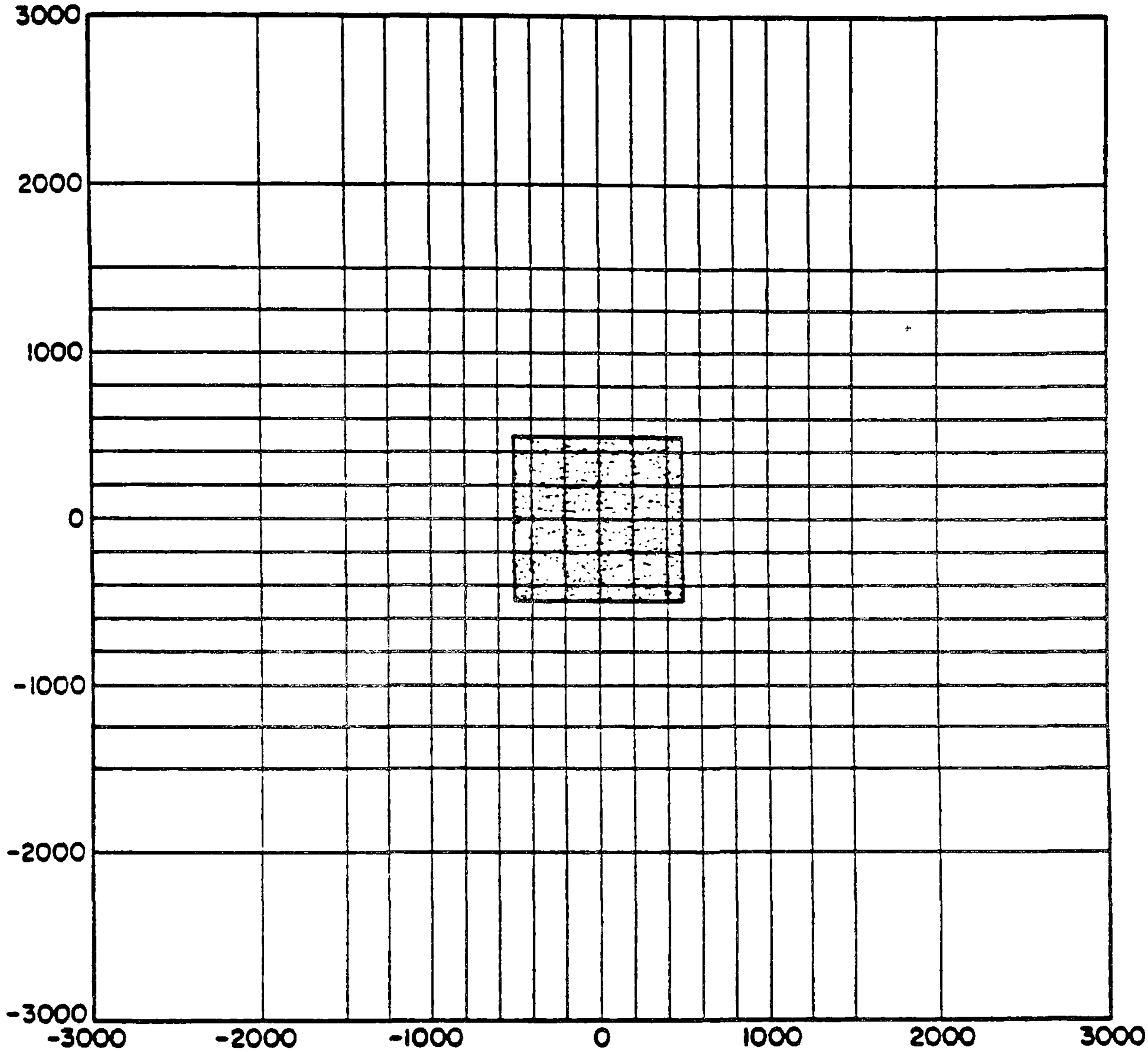


FIGURE 2-3. Example of an irregularly-spaced Cartesian receptor grid. The stippled area shows the property of a hypothetical industrial source complex.

Table 2-12. Particle-size distribution, gravitational settling velocities and surface reflection coefficients for particulate emissions from the ore pile and conveyor belt.

Particle Size Category (μ)	Mass Mean Diameter (μ)	Mass Fraction ϕ_n	Settling Velocity V_{sn} (m/sec)	Reflection Coefficient γ_n
0 - 10	6.30	0.10	0.001	1.00
10 - 20	15.54	0.40	0.007	0.82
20 - 30	25.33	0.28	0.019	0.72
30 - 40	35.24	0.12	0.037	0.65
40 - 50	45.18	0.06	0.061	0.59
50 - 65	17.82	0.04	0.099	0.50

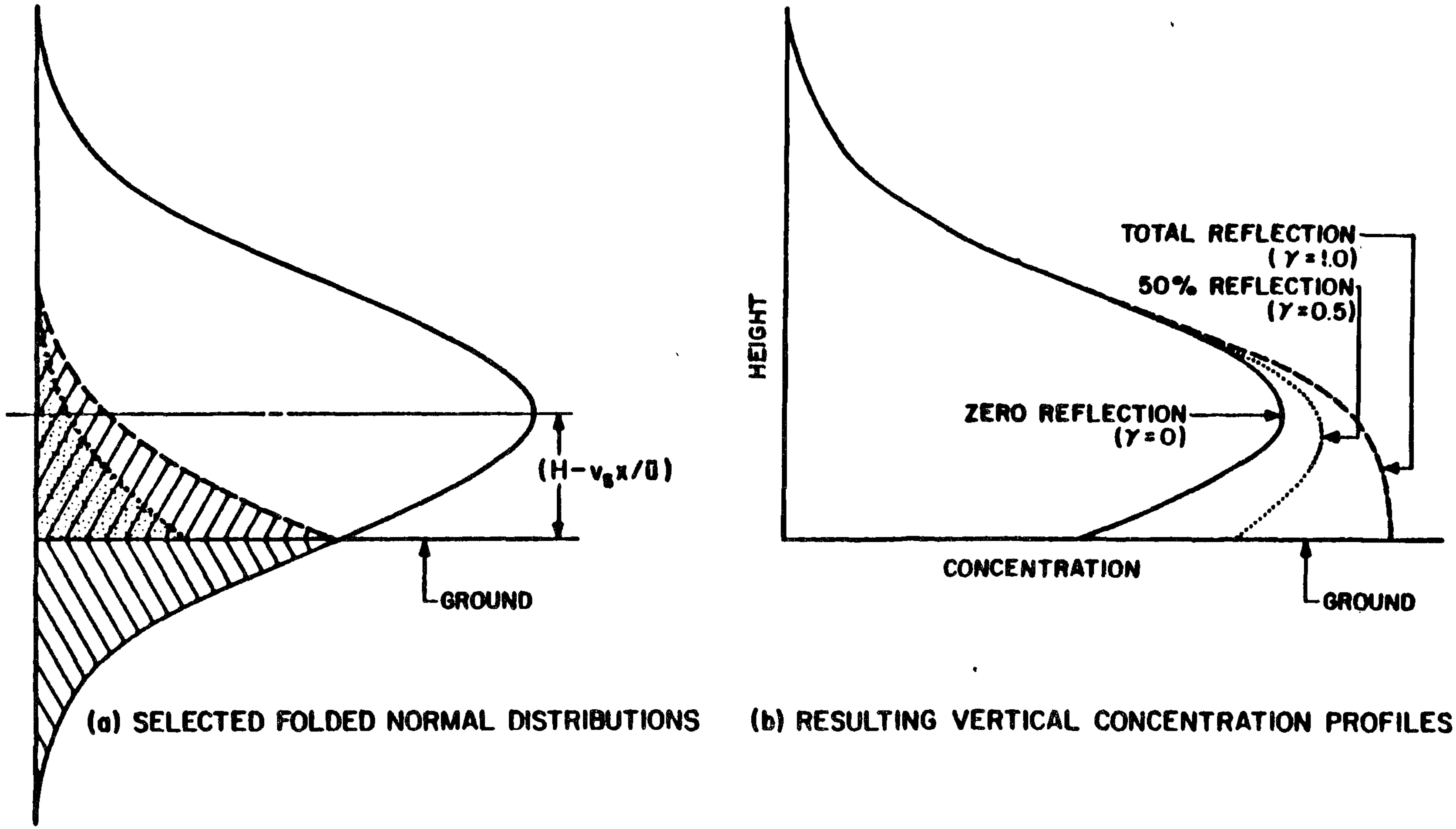


FIGURE 2-7. Illustration of vertical concentration profiles for reflection coefficients of 0, 0.5 and 1.0.

Chapter 18

Elements and Applications of the Multiple Source (RAM) Model

Chapter Goal

To familiarize students with the elements and applications of the Multiple Source (RAM) model that is currently available on the UNAMAP computer package.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. describe the application of the Multiple Source model to a given source and surrounding terrain features.
2. describe the accuracy of the Multiple Source model under given source-receptor conditions.

Lesson Outline

Follows *Modeling Notes (RAM)*.

Support Material

Peter Guldberg, *Modeling Notes, Elements and Applications of the Multiple Source (RAM) Model.*

MODELING NOTES
by Peter H. Guldberg

Elements and Applications of the Multiple Source (RAM) Model

MULTIPLE SOURCE (RAM) MODEL

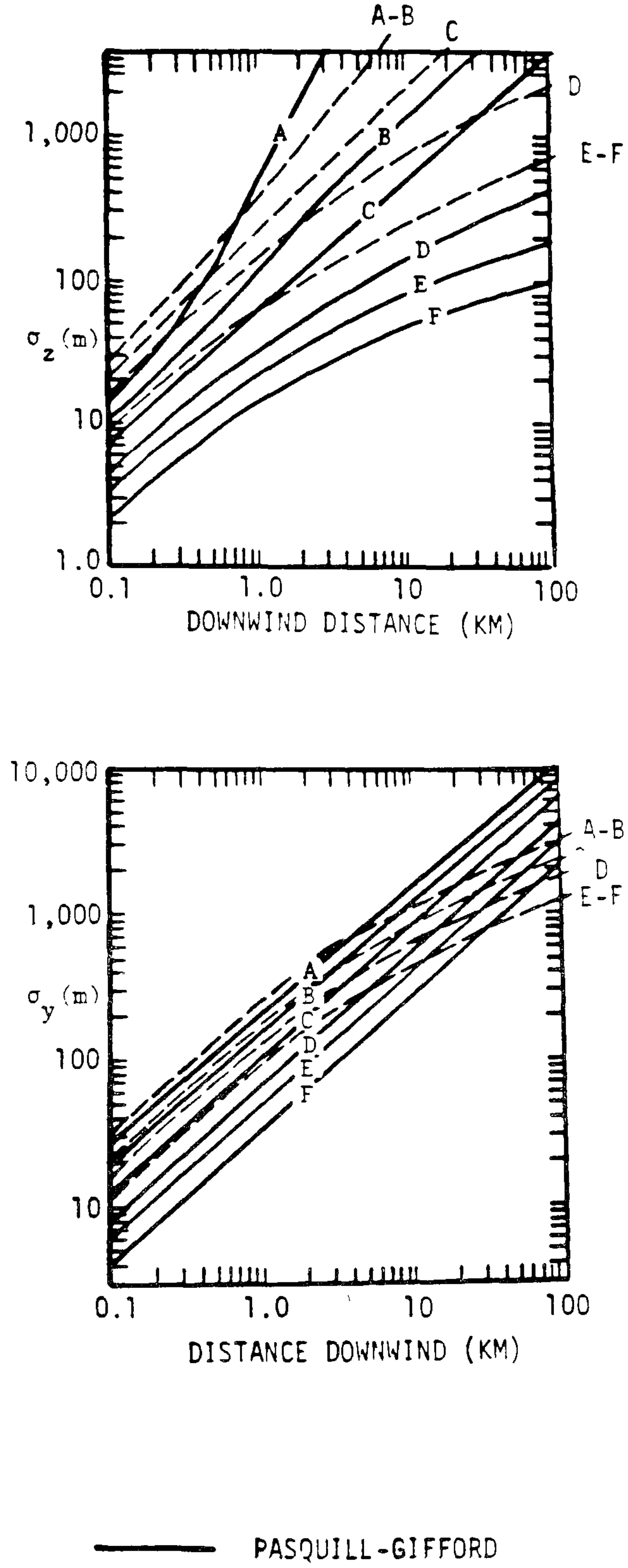
- MULTIPLE SOURCE MODEL FOR SHORT-TERM CONCENTRATIONS
- EIGHT (8) COMPUTER PROGRAMS

RAMQ	RAM
RAMMET	RAMR
RAMBLK	RAMF
CUMF	RAMFR

- RUN COST APPROXIMATELY 1/3¢ PER SOURCE/RECEPTOR/DAY
- CODE ON UNAMAP AVAILABLE FROM NTIS, $350.00
- TWO (2) VOLUME USER'S MANUAL

RAM DISPERSION COEFFICIENTS

	PASQUILL-GIFFORD	MCELROY-POOLER
Based on measurements in	Gently rolling rural terrain	St. Louis urban area
Roughness (Z_0)	3-30 centimeters	100 centimeters
Named Regime	Rural	Urban



A-B
C
D
E-F
A
B
C
D
E
F
1,000
100
10
1.0
σ_z (m)
0.1
1.0
10
100
DOWNWIND DISTANCE (KM)
10,000
1,000
100
10
σ_y (m)
A-B
D
E-F
A
B
C
D
E
F
0.1
1.0
10
100
DISTANCE DOWNWIND (KM)
PASQUILL-GIFFORD
MCELROY-POOLER

FACTORS IN SELECTING URBAN VS RURAL

- URBAN CORE POPULATION AND DENSITY
- SOURCE HEIGHT
- RECEPTOR LOCATION

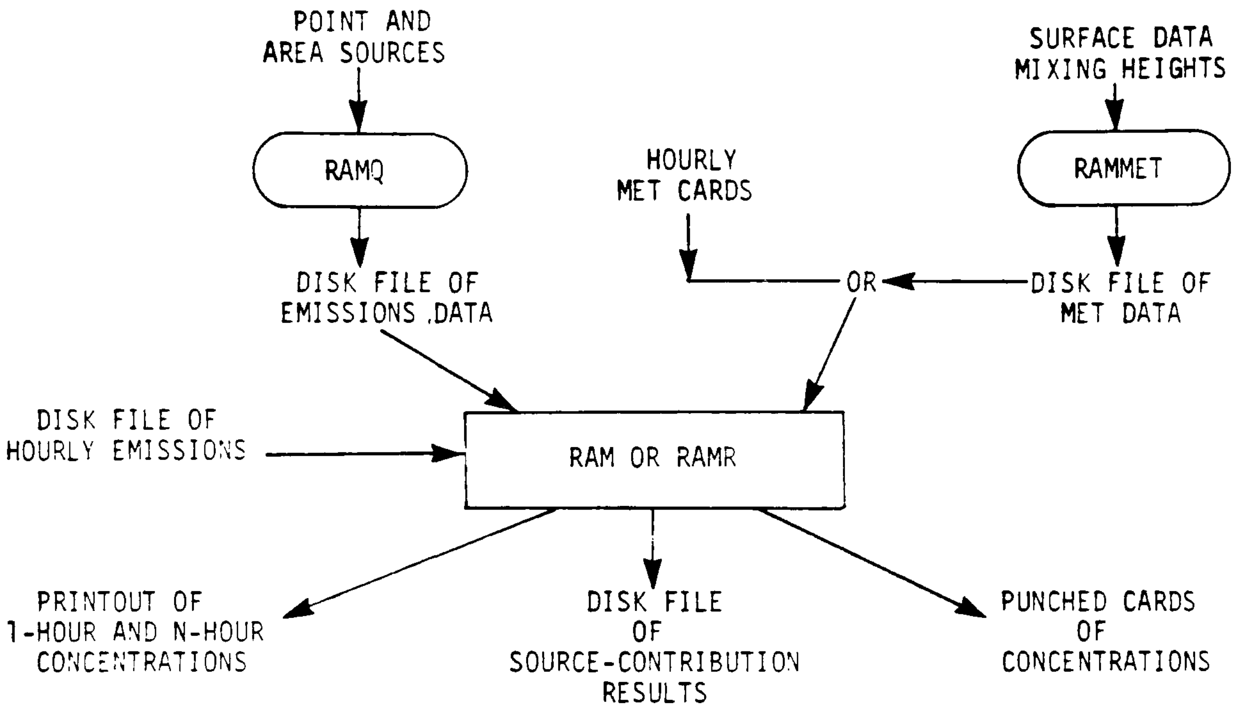
SUMMARY OF RAM MODEL CAPABILITIES

Item	Comment
Averaging Times	1, 2, 3, 4, 6, 8, 12, or 24 hours
Plume Rise	Transitional and final rise, momentum and buoyancy effects, stack downwash
Terrain Adjustment	None
Atmospheric Decay	Exponential half-life
Rural Dispersion Rates	Same as CRSTER
Urban Dispersion Rates	McElroy-Pooler
Meteorological Input Data	Same as CRSTER; card input also available
Plume Trapping, Lofting	Same as CRSTER except no upper boundry exists in stable conditions
Sources	Maximum 250 point sources and 100 area sources at arbitary locations
	Area sources can be one of 3 heights
	Program identifies most significant sources
	Constant emissions or hourly values
Receptors	3 types: arbitary, program selected maximum, and honeycomb grid. One elevation height above ground available
Output	Extensive source-contribution tables and cumulative frequency distributions for 24-hour concentrations. No second highest determinations

RAM PROGRAM MODULES

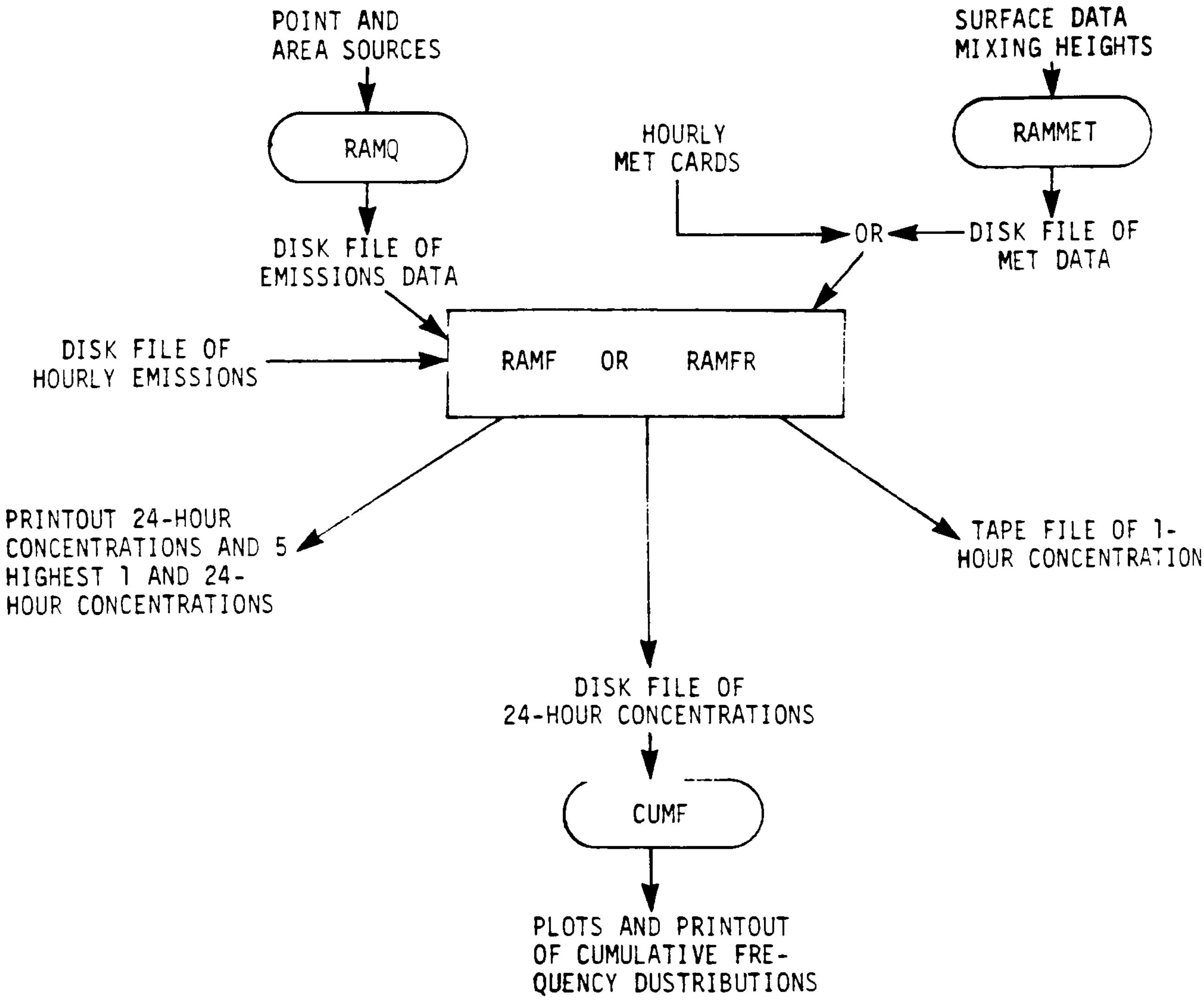
RAMMET	-	SAME AS CRSTER PREPROCESSOR
RAMQ	-	PROCESSES EMISSIONS DATA AND RANKS SOURCES BY SIGNIFICANCE OF IMPACTS
RAMBLK	-	BLOCK DATA
CUMF	-	PLOTS AND PRINTS CUMULATIVE FREQUENCY DISTRIBUTIONS OF 24-HOUR CONCENTRATIONS

	NORMAL RUN	FREQUENCY DISTRIBUTION RUN
URBAN SIGMAS	RAM	RAMF
RURAL SIGMAS	RAMR	RAMFR


POINT AND
AREA SOURCES
RAMQ
DISK FILE OF
EMISSIONS DATA
HOURLY
MET CARDS
SURFACE DATA
MIXING HEIGHTS
RAMMET
OR
DISK FILE OF
MET DATA
DISK FILE OF
HOURLY EMISSIONS
RAM OR RAMR
PRINTOUT OF
1-HOUR AND N-HOUR
CONCENTRATIONS
DISK FILE
OF
SOURCE-CONTRIBUTION
RESULTS
PUNCHED CARDS
OF
CONCENTRATIONS

RAM/RAMR OPTIONS

1 POINT SOURCE INPUT?
2 AREA SOURCE INPUT?
3 SPECIFIED RECEPTORS?
4 SIGNIFICANT POINT RECEPTORS?
5 SIGNIFICANT AREA RECEPTORS?
6 HONEYCOMB GRID OF RECEPTORS?
7 HOURLY CONCENTRATION OUTPUT?
8 SOURCE-CONTRIBUTIONS TO DISK?
9 HOURLY SUMMARIES ONLY?
10 PUNCH CARDS FOR ISOPLETHS?
11 INPUT MET DATA ON CARDS?
12 SPECIFY SIGNIFICANT SOURCE NUMBERS?
13 READ HOURLY EMISSIONS?


POINT AND
AREA SOURCES
RAMQ
DISK FILE OF
EMISSIONS DATA
HOURLY
MET CARDS
SURFACE DATA
MIXING HEIGHTS
RAMMET
OR
DISK FILE OF
MET DATA
DISK FILE OF
HOURLY EMISSIONS
RAMF OR RAMFR
PRINTOUT 24-HOUR
CONCENTRATIONS AND 5
HIGHEST 1 AND 24-
HOUR CONCENTRATIONS
TAPE FILE OF 1-
HOUR CONCENTRATION
DISK FILE OF
24-HOUR CONCENTRATIONS
CUMF
PLOTS AND PRINTOUT
OF CUMULATIVE FRE-
QUENCY DUSTRIBUTIONS

RAM PRINTOUT

N=24-HOURS

HOUR 1	1-HOUR SIGNIFICANT POINT CONTRIBUTIONS
	1-HOUR SIGNIFICANT AREA CONTRIBUTIONS
	1-HOUR SUMMARY TABLE
HOUR 2	(REPEAT)
	⋮
HOUR 24	(REPEAT)
	24-HOUR SIGNIFICANT POINT CONTRIBUTIONS
	24-HOUR SIGNIFICANT AREA CONTRIBUTIONS
	24-HOUR SUMMARY TABLE

```
RUN BY: ED KRENSHAW, AIR & HAZARDOUS MATER. DIV., REGION XV,EPA(1 JAN 78)
EMISSIONS: TEST CITY,  1973
SFC MET. DATA: TEST CITY 1973 ;  UPPER AIR: TEST CITY 1973

INPUT MET DATA   73/   1
HOUR    THETA     SPEED    MIXING      TEMP       STABILITY
        (DEG)     (M/S)    HEIGHT(M)  (DEG-K)     CLASS

  1     33.00      6.17     429.11    269.82        4
  2     23.00      4.63     401.70    271.48        4

RESULTANT MET CONDITIONS

 WIND DIRECTION=  28.71              RESULTANT WIND SPEED=    5.38
 AVERAGE WIND SPEED=   5.40          AVERAGE TEMP= 270.65
 WIND PERSISTENCE=  .996             MODAL STABILITY= 4
```

SIGNIFICANT POINT RECEPTORS

RECEPTOR #	EAST	NORTH	PREDICTED MAX CONC. (MICROGRAMS/M**3)	MAX. DIST (KM)	EFF. HT (M)	U(PHY HT) (M/SEC)
3 P 7	564.43	4407.01	39.39	.902	156.385	8.026
4 P 7	564.16	4406.52		1.804	156.385	8.026
5 P 5	579.45	4403.16	839.47	.166	32.007	6.281
6 P 5	579.40	4403.07		.331	32.007	6.281
7 P 8	577.38	4401.21	448.58	.249	47.506	6.890
8 P 8	577.30	4401.08		.499	47.506	6.890
9 P 9	576.67	4400.55	619.39	.276	52.296	4.753
10 P 9	576.59	4400.40		.551	52.296	4.753
11 P 11	582.94	4400.80	427.63	.187	35.952	6.263
12 P 11	582.89	4400.70		.374	35.952	6.263

SIGNIFICANT AREA SOURCE RECEPTORS

RECEPTOR #	EAST	NORTH
13 A 4	578.42	4399.94
14 A 3	576.43	4399.95
15 A 5	578.43	4401.96
16 A 9	578.43	4405.95
17 A 2	574.43	4399.96
18 A 10	580.41	4405.92
19 A 8	574.43	4405.96
20 A 7	570.87	4403.94
21 A 13	582.41	4403.92
22 A 12	580.41	4403.92

RUN BY: ED KRENSHAW, AIR & HAZARDOUS MATER. DIV., REGION XV,EPA(JAN 78)
EMISSIONS: TEST CITY, 1973
SFC MET. DATA: TEST CITY 1973 ; UPPER AIR: TEST CITY 1973

CONTRIBUTION(MICROGRAMS/M**3) FROM SIGNIFICANT POINT SOURCES 73/ 1 : HOUR 1

RANK	1	2	3	4	5	TOTAL SIGNIF POINT	TOTAL ALL POINT SOURCES
SOURCE #	7	5	8	9	11		
RECEP #							
1	.000	.000	.000	.000	.000	.000	.000
2	.000	.000	.000	.000	.000	.000	.000
3	35.799	.000	.000	.000	.000	35.799	35.799
4	18.203	.000	.000	.000	.000	18.203	18.203
5	.000	723.757	.000	.000	.000	723.757	723.757
6	.000	368.049	.000	.000	.000	368.049	368.049
7	.000	.357	431.406	.000	.000	431.762	432.202
8	.000	.464	204.270	.000	.000	204.734	205.191
9	.000	.137	7.947	701.982	.000	710.066	712.682
10	.000	.181	9.385	281.595	.000	291.161	293.761
11	.000	.000	.000	.000	433.349	433.349	433.349
12	.000	.000	.000	.000	194.826	194.826	194.826
13	.000	.084	.000	.000	.000	.084	.084
14	.000	.536	13.504	35.822	.000	49.862	51.679
15	.000	7.980	.000	.000	.000	7.980	7.980
16	.000	.000	.000	.000	.000	.000	.754
17	.000	.000	.000	.000	.000	.000	13.839
18	.000	.000	.000	.000	.000	.000	.000
19	.000	.000	.000	.000	.000	.000	.563
20	.000	.000	.000	.000	.000	.000	.000
21	.000	.000	.000	.000	.000	.000	.000
22	.000	.000	.000	.000	.000	.000	.000
23	.000	.000	.000	.000	.000	.000	26.205
24	.000	.000	.000	.000	.000	.000	8.605
25	.000	.000	.000	.000	.000	.000	.000
26	.000	.000	.000	.000	.000	.000	.021
27	.000	.000	.000	.000	.000	.000	19.452
28	.000	.000	.000	.000	.000	.000	9.412
29	.000	.000	.000	.000	.000	.000	29.518
30	.000	.000	.000	.000	.000	.000	.003
31	.000	.000	.000	.000	.000	.000	7.218
32	.000	.000	.000	.000	.000	.000	10.968
33	.000	.000	.000	.000	.000	.000	45.548
34	.000	.000	.000	.000	.000	.000	.820
35	.000	.000	.000	.000	.000	.000	.000
36	.000	.000	.000	.000	.000	.000	12.956
37	.000	.000	.000	.000	.000	.000	.000
38	.000	.000	.000	.000	.000	.000	.000
39	.000	.000	.000	.000	.000	.000	.942
40	.000	.000	.000	.000	.000	.000	15.210
41	.000	.000	.000	.000	.000	.000	.000

RUN BY: ED KRENSHAW, AIR & HAZARDOUS MATER. DIV., REGION XV,EPA(1 JAN 78)
EMISSIONS: TEST CITY, 1973
SFC MET. DATA: TEST CITY 1973 ; UPPER AIR: TEST CITY 1973

SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 73/ 1 : HOUR 1

HOUR	THETA (DEG)	SPEED (M/S)	MIXING HEIGHT(M)	TEMP (K)	STABILITY CLASS
1	33.00	6.17	429.11	249.82	4

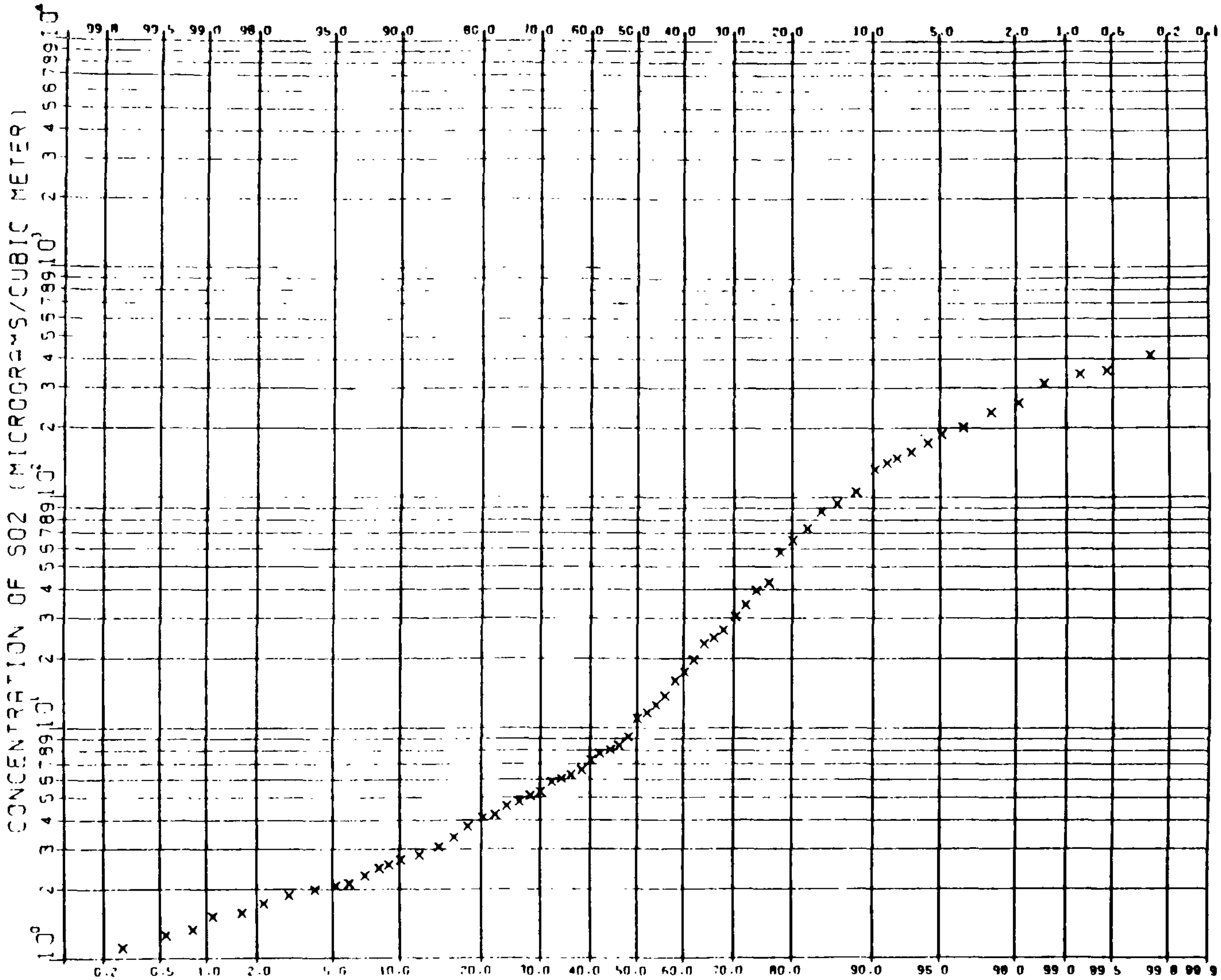
AREA HTS: 11., 14., 19.; SEPARATION HTS: 12., 16.

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 I 0	566.00	4405.00	.0000	.0000	.0000	.0000	.0000	41
2 I 0	564.00	4401.50	.0000	.0000	.0000	.0000	.0000	40
3 P 7	564.43	4407.01	35.7987	35.7987	.0000	.0000	35.7987	11
4 P 7	564.16	4406.52	18.2026	18.2026	.0000	.0000	18.2026	15
5 P 5	579.45	4403.16	723.7571	723.7571	1.4215	1.4667	725.2238	1
6 P 5	579.40	4403.07	368.0487	368.0487	1.4465	1.4929	369.5415	5
7 P 8	577.38	4401.21	431.7621	432.2024	2.7281	2.7281	434.9305	3
8 P 8	577.30	4401.08	204.7343	205.1913	2.8280	2.8280	208.0193	7
9 P 9	576.67	4400.55	710.0658	712.6823	2.9602	2.9602	715.6425	2
10 P 9	576.59	4400.40	291.1613	293.7612	3.0427	3.0427	296.8038	6
11 P 11	582.94	4400.80	433.3493	433.3493	.0000	.0483	433.3975	4
12 P 11	582.89	4400.70	194.8263	194.8263	.0000	.0445	194.8708	8
13 A 4	578.42	4399.94	.0837	.0837	3.2543	3.4000	3.4837	24
14 A 3	576.43	4399.95	49.8623	51.6786	3.0888	3.0888	54.7674	9
15 A 5	576.43	4401.96	7.9795	7.9803	1.7745	1.8009	9.7811	21
16 A 9	578.43	4405.95	.0000	.7536	1.1665	1.1665	1.9200	25
17 A 2	574.43	4399.96	.0000	13.8389	1.6338	1.6338	15.4727	17
18 A 10	580.41	4405.92	.0000	.0000	.8464	.8464	.8464	29
19 A 8	574.43	4405.96	.0000	.5625	1.0529	1.0529	1.6154	26
20 A 7	570.87	4403.94	.0000	.0000	.4950	.5121	.5121	33
21 A 13	582.41	4403.92	.0000	.0000	.5493	.6120	.6120	31
22 A 12	580.41	4403.92	.0000	.0000	.5444	.6414	.6414	30
23 H 0	572.00	4400.87	.0000	26.2047	.1834	.3421	26.5468	13
24 H 0	574.00	4400.87	.0000	8.6046	1.2702	1.2702	9.8749	20
25 H 0	580.00	4400.87	.0000	.0000	.2272	.3489	.3489	37
26 H 0	571.00	4402.60	.0000	.0214	.3706	.4890	.5104	34
27 H 0	573.00	4402.60	.0000	19.4521	.2353	.3536	19.8057	14
28 H 0	575.00	4402.60	.0000	9.4123	.1610	.1610	9.5734	22
29 H 0	577.00	4402.60	.0000	29.5180	.3822	.3822	29.9002	12
30 H 0	572.00	4404.33	.0000	.0026	.5696	.5696	.5724	32
31 H 0	574.00	4404.33	.0000	7.2180	.2753	.2753	7.4933	23
32 H 0	576.00	4404.33	.0000	10.9682	.1248	.1248	11.0931	19
33 H 0	578.00	4404.33	.0000	45.5482	.4121	.4121	45.9603	10
34 H 0	571.00	4406.06	.0000	.8200	.3788	.3788	1.1988	27
35 H 0	573.00	4406.06	.0000	.0001	.4319	.4319	.4320	36
36 H 0	577.00	4406.06	.0000	12.9563	.0959	.0959	13.0522	18
37 H 0	572.00	4407.79	.0000	.0000	.1342	.1342	.1342	39
38 H 0	574.00	4407.79	.0000	.0000	.4364	.4364	.4364	35
39 H 0	576.00	4407.79	.0000	.9420	.0000	.0000	.9420	28
40 H 0	578.00	4407.79	.0000	15.2102	.4971	.4971	15.7073	16
41 H 0	580.00	4407.79	.0000	.0000	.2645	.2645	.2645	38

RUN BY: ED KRENSHAW, AIR & HAZARDOUS MATER. DIV., REGION XV (ACT JAN 78)
EMISSIONS: TEST CITY, 1973
SFC MET. DATA: TEST CITY 1973 ; UPPER AIR: TEST CITY 1973

2-HOUR AVERAGE SO2 SUMMARY CONCENTRATION TABLE(MICROGRAMS/M**3) 73/ 1 START HOUR: 1

RECEPTOR NO.	EAST	NORTH	TOTAL FROM SIGNIF POINT SOURCES	TOTAL FROM ALL POINT SOURCES	TOTAL FROM SIGNIF AREA SOURCES	TOTAL FROM ALL AREA SOURCES	TOTAL FROM ALL SOURCES	CONCENTRATION RANK
1 I 0	566.00	4405.00	.0000	.0000	.0000	.0000	.0000	41
2 I 0	564.00	4401.50	.0013	.0013	.0000	.0000	.0013	40
3 P 7	564.43	4407.01	32.5148	32.5148	.0000	.0000	32.5148	11
4 P 7	564.16	4406.52	18.4737	18.4737	.0000	.0000	18.4737	15
5 P 5	579.45	4403.16	704.3478	704.3489	1.6611	1.6837	706.0326	1
6 P 5	579.40	4403.07	392.9166	392.9184	1.6936	1.7168	394.6352	5
7 P 8	577.38	4401.21	415.6223	433.9664	2.9728	2.9728	436.9392	3
8 P 8	577.30	4401.08	216.8572	235.3004	3.0843	3.0843	238.3847	7
9 P 9	576.67	4400.55	641.0958	661.2062	3.2274	3.2274	664.4337	2
10 P 9	576.59	4400.40	292.9232	312.7181	3.3120	3.3120	316.0301	6
11 P 11	582.94	4400.60	413.7422	413.7422	.0000	.1091	413.8514	4
12 P 11	582.89	4400.70	206.3210	206.3210	.0000	.1069	206.4279	8
13 A 4	578.42	4399.94	2.9785	2.9683	4.1139	4.1933	7.1616	24
14 A 3	576.43	4399.95	78.4472	97.5496	3.3706	3.3706	100.9202	9
15 A 5	578.43	4401.96	4.2674	5.7926	1.9783	1.9914	7.7841	23
16 A 9	578.43	4405.95	.0000	4.7655	1.3397	1.3397	6.1052	25
17 A 2	574.43	4399.96	.0000	18.0500	1.6149	1.6149	19.6649	14
18 A 10	580.41	4405.92	.0000	.0000	.9617	.9617	.9617	28
19 A 8	574.43	4405.96	.0000	.2813	1.2067	1.2067	1.4880	27
20 A 7	570.87	4403.94	.0000	.0336	.5670	.5843	.6179	31
21 A 13	562.41	4403.92	.0000	.0000	.6292	.7362	.7362	30
22 A 12	580.41	4403.92	.0000	.0000	.7640	.8303	.8303	29
23 M 0	572.00	4400.87	.0000	13.1975	.3962	.5671	13.7646	17
24 M 0	574.00	4400.87	.0000	11.6752	1.3131	1.3131	12.9883	18
25 M 0	580.00	4400.87	.0000	.0000	.2447	.4113	.4113	37
26 M 0	571.00	4402.60	.0000	.0110	.3562	.5002	.5112	33
27 M 0	573.00	4402.60	.0000	9.7772	.3962	.5322	10.3094	20
28 M 0	575.00	4402.60	.0000	8.9824	.0805	.0805	9.0629	21
29 M 0	577.00	4402.60	.0000	26.0166	.4567	.4567	26.4733	13
30 M 0	572.00	4404.33	.0000	.0014	.6026	.6026	.6040	32
31 M 0	574.00	4404.33	.0000	3.6096	.3848	.3848	3.9944	26
32 M 0	576.00	4404.33	.0000	12.4064	.0624	.0624	12.4688	19
33 M 0	578.00	4404.33	.0000	34.0503	.4876	.4876	34.5379	10
34 M 0	571.00	4406.06	.0000	7.7681	.4289	.4289	8.1970	22
35 M 0	573.00	4406.06	.0000	.0001	.4554	.4554	.4555	36
36 M 0	577.00	4406.06	.0000	18.4134	.0479	.0479	18.4613	16
37 M 0	572.00	4407.79	.0000	.0000	.1466	.1466	.1466	39
38 M 0	574.00	4407.79	.0000	.0000	.4812	.4812	.4812	34
39 M 0	576.00	4407.79	.0000	.4711	.0000	.0000	.4711	35
40 M 0	578.00	4407.79	.0000	29.2430	.5482	.5482	29.7912	12
41 M 0	580.00	4407.79	.0000	.0007	.2859	.2859	.2865	38



CUMULATIVE FREQUENCY DISTRIBUTION OF ESTIMATED 24-HOUR SULFUR DIOXIDE.

RECEPTOR NO.4 LOCATED AT: (576.79,4400.56)

RUN BY: ED KRENSHAW, AIR & HAZARDOUS MATER. DIV., REGION XV,EPA(1 JAN 78)

EMISSIONS: TEST CITY, 1973

SFC MET. DATA: TEST CITY 1973 ; UPPER AIR: TEST CITY 1973

Chapter 19

Elements and Applications of the Complex Terrain (VALLEY) Model

Chapter Goal

To familiarize you with the complex terrain (VALLEY) model that is currently available on the UNAMAP computer package.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. describe the application of the Complex Terrain model to a given source and surrounding terrain features.
2. describe the accuracy of the Complex terrain model under given source-receptor conditions.

Chapter Outline

Follows *Modeling Notes (VALLEY)*.

Support Material

Peter Guldberg, *Modeling Notes, Elements and Applications of the Complex Terrain (VALLEY) Model.*

Attachment 19-1. VALLEY model estimate of χ 24-hour maximum short-cut method (Ed Burt).

GENERAL FORM:

$$\chi_{Valley,\ 24\text{-}hr} = (aX^b) * \left[\text{half-life factor}\right] * \left[\text{plume deflection factor}\right] * \left[\frac{6\text{-hour}}{24\text{-hr}}\right] * \left[\chi_{℄}^{*}\right] * \left[\text{Standard Conditions}^{**}\right]$$

(aX^b): from graph, X in meters

half-life factor: $e^{\left[-0.693X/(3600*I*u)\right]}$ — X in meters; I in hours; u in meters/second (2.5)

plume deflection factor: $\left[\frac{401-D}{400}\right]$, $1 \leq D \leq 401m$; D= 1 for nonstable

$\chi_{℄}^{*}$: from fig 3-5 Turner's WADE (stability F) $\chi_{℄\,1\text{-}hr} = \chi\frac{u}{Q}\frac{Q}{u}$

Standard Conditions: $\frac{T_a}{298}\ \frac{1013.25}{P_a}$ — °K & mb

---

EXAMPLE: Make an estimate of maximum $\chi_{24\text{-hour}}$ concentration at a site 40 meters above plume height (at stability F, u = 2.5 meters/second, T_a = 283°K, P = 850mb), and 6400 meters from source. Half-life = 3-hours. Q = 10^3 g/s.

From WADE, $\chi\frac{u}{Q}$ = $4.5*10^{-5}$ meters^{-2} (use H = 10 meters)

$\therefore \chi_{℄\,1\text{-}hr}$ = $1.8*10^{-2}$ grams/meter^3 , and

$$\chi_{24\text{-}hr\ max} \doteq (0.18)(0.85)(0.9)(6/24)(1.8*10^{-2}*10^{6})(1.13)$$
$$\doteq \underline{700\ \mu g/m^3}$$

Valley Model

SHORTCUT TO VALLEY MODEL ESTIMATE OF $\chi_{24\text{-hour}}$

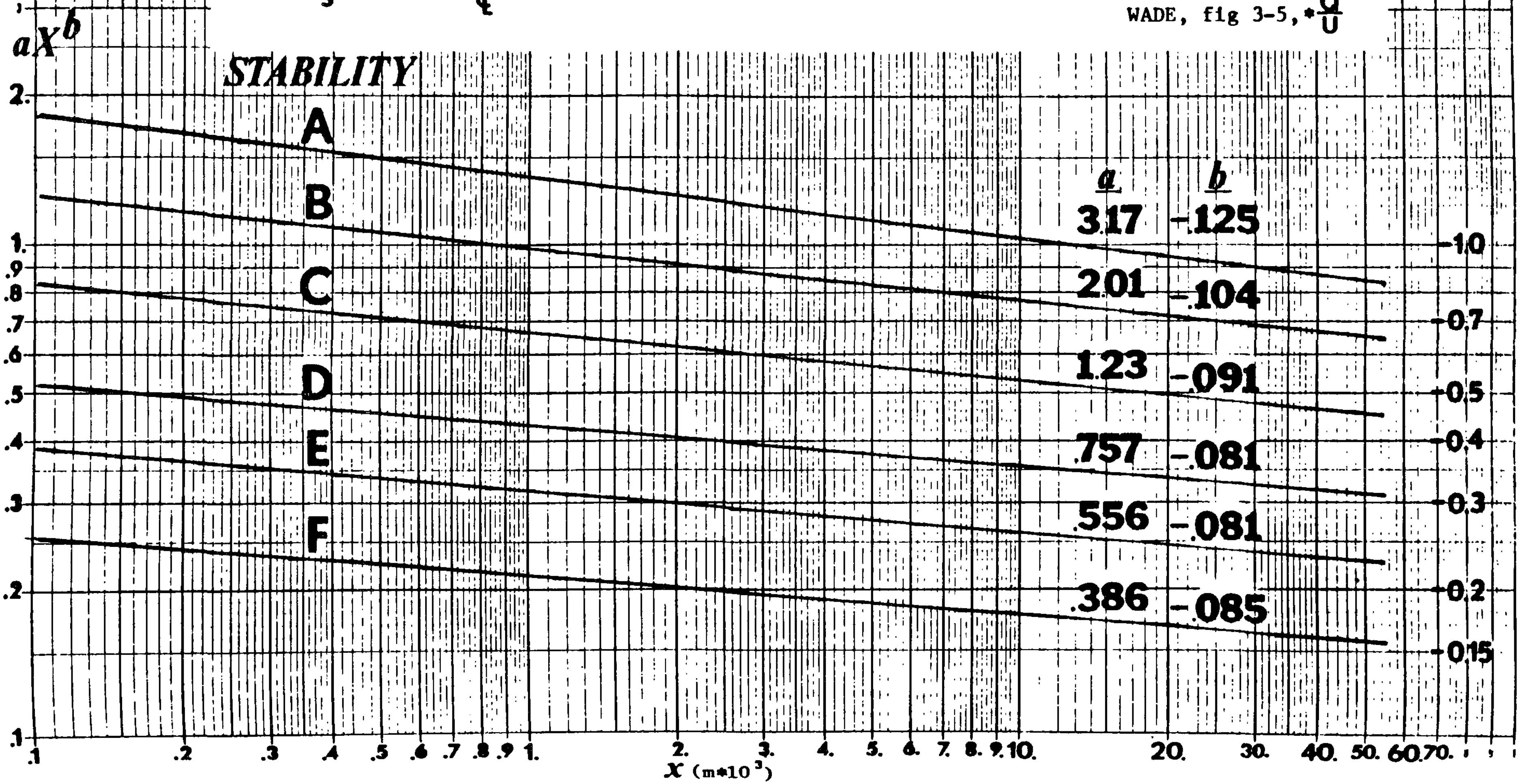
$$\chi_{\text{Valley, 24-hr}} = (aX^b) * \left[\begin{matrix}\text{half-life}\\ \text{factor}\end{matrix}\right] * \left[\begin{matrix}\text{plume deflec-}\\ \text{tion factor}\end{matrix}\right] * \left[\frac{\text{6-hour}}{\text{24-hr}}\right] * \left[\chi_{℄}^{\star}\right] * \left[\begin{matrix}\text{Standard}^{\star\star}\\ \text{Conditions}\end{matrix}\right]$$

; wind directly from source to receptor; use plume height as adjusted for terrain to read $\chi_{℄}$.

$$\bar{\chi}_S = (aX^b) * \chi_{℄} \; ; \; S = 22.5° \; , \; t \approx 1 \text{ hour.}$$

★★unity for ppm.

★from Turner's WADE, fig 3-5, $* \frac{Q}{U}$



MODELING NOTES
by Peter H. Guldberg

Elements and Applications of the Complex Terrain (VALLEY) Model

VALLEY MODEL

PROVIDES ESTIMATE OF MAXIMUM 24-HOUR POLLUTANT CONCENTRATION IN COMPLEX TERRAIN

ASSUMES WORST CASE OCCURS FOR PLUME IMPINGEMENT UNDER STABLE CONDITIONS

FIELD DATA INDICATE A COMMON WORST CASE IS CLASS F, 2.5 m/s, 6 HOURS PERSISTENCE OF WIND IN A 22 1/2° SECTOR

NOT DESIGNED FOR:

- -- CURVING PLUMES
- -- UNSTABLE CONDITIONS
- -- DOWNWASH
- -- CALMS
- -- FUMIGATION

EPA POLICY ON COMPLEX TERRAIN

INSUFFICIENT EMPIRICAL DATA EXIST TO SPECIFY GENERALLY APPLICABLE COMPLEX TERRAIN MODELS

SCREENING TECHNIQUES:

- -- VALLE[illegible] [illegible]R STABLE CONDITIONS
- -- CRAMER FOR UNSTABLE CONDITIONS

IF POTENTIAL PROBLEM IS INDICATED:

- -- SOURCE DEVELOPS ON-SITE DATA BASE
- -- APPLY REFINED MODEL

EPA INITIATING 5-YEAR PLAN IN FY 80 TO DEVELOP AND TEST COMPREHENSIVE COMPLEX TERRAIN MODELS

VALLEY MODEL CAPABILITIES

- MULTIPLE SOURCES, UP TO 50 POINT OR A EA
- STAR INPUT DATA
- POLLUTANT HALF-LIFE
- CONCENTRATION UNITS
- URBAN/RURAL OPTION
- LIMITED MIXING
- LONG-TERM/24-HOUR OPTION
- 112 FIXED RECEPTORS
- TERRAIN ADJUSTMENT

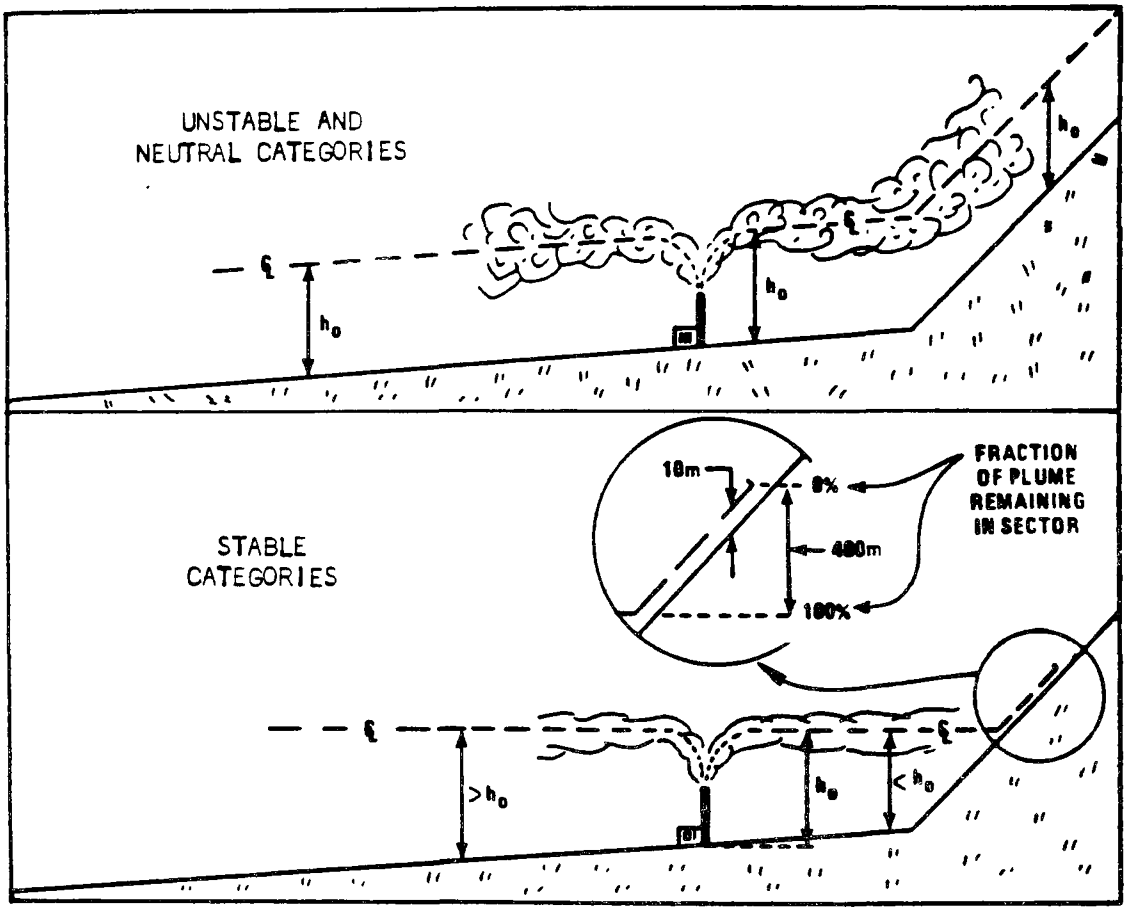
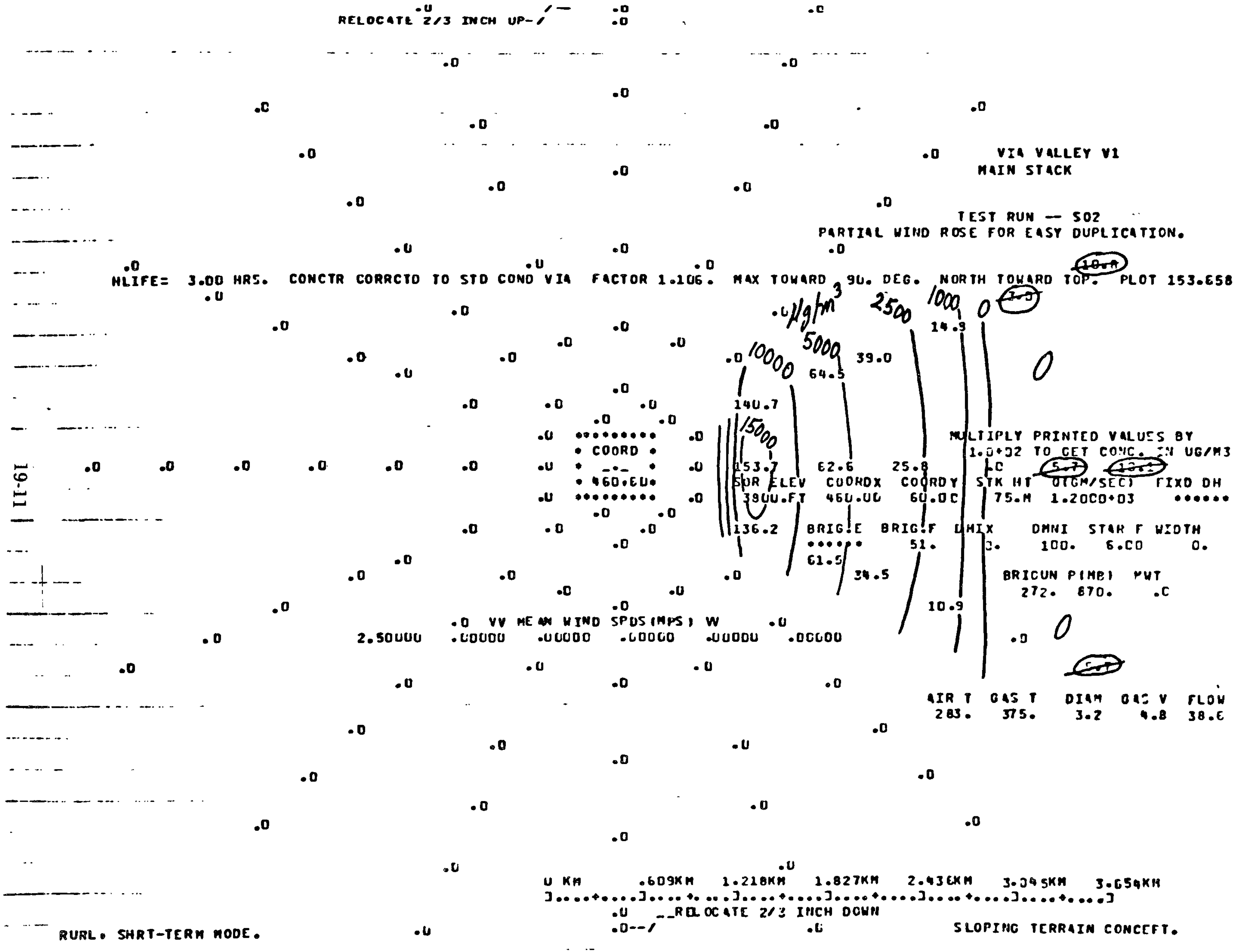
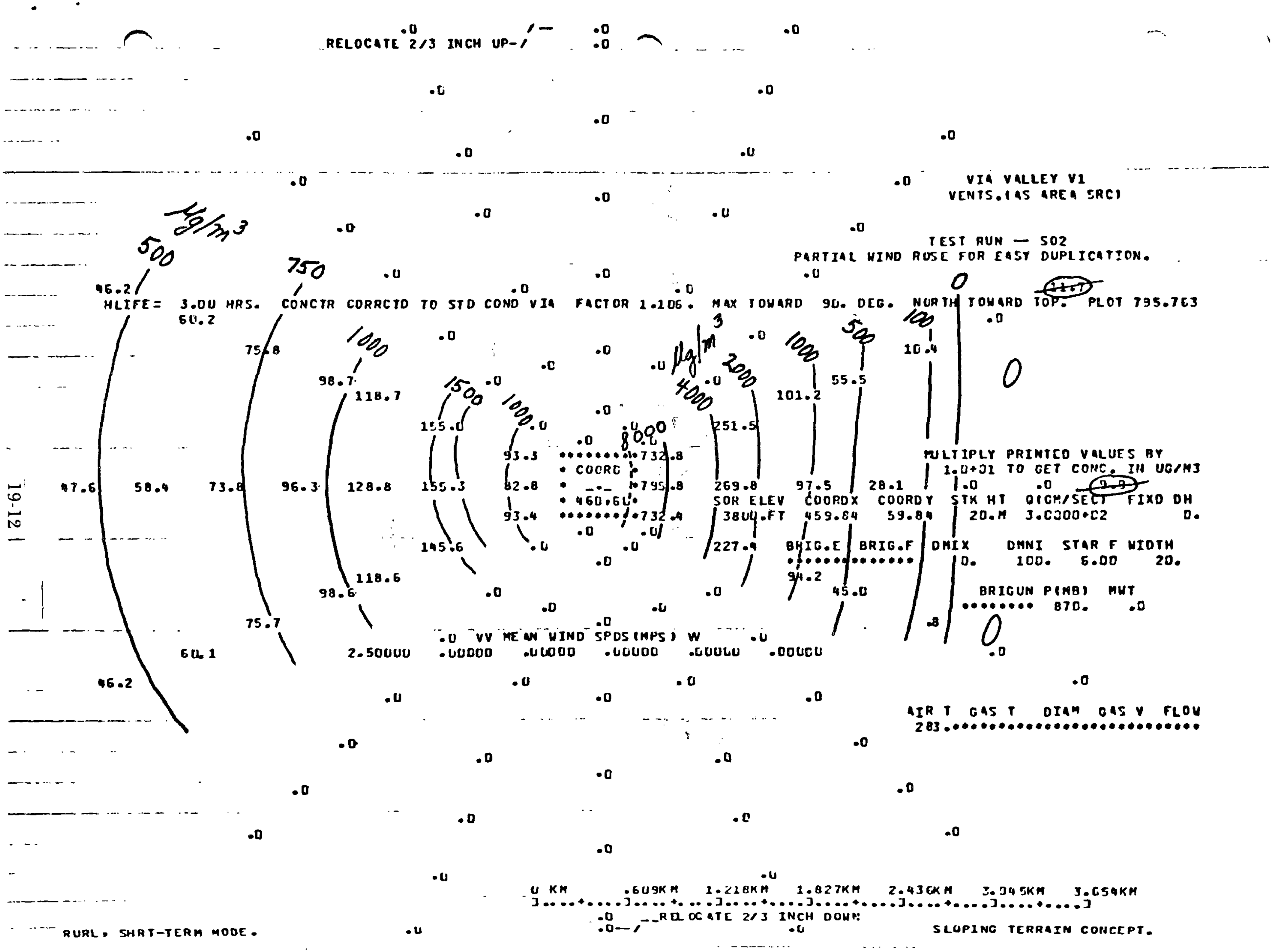


Figure 2-1. Depiction of Plume Height in Complex Terrain, as in the Valley Model. h_o is the Height of the Plume at Final Rise Above Ground for the Unstable and Neutral Cases and Above Stack Base for the Stable Cases. Plumes are Shown for Flows Toward and Away from Elevated Terrain.

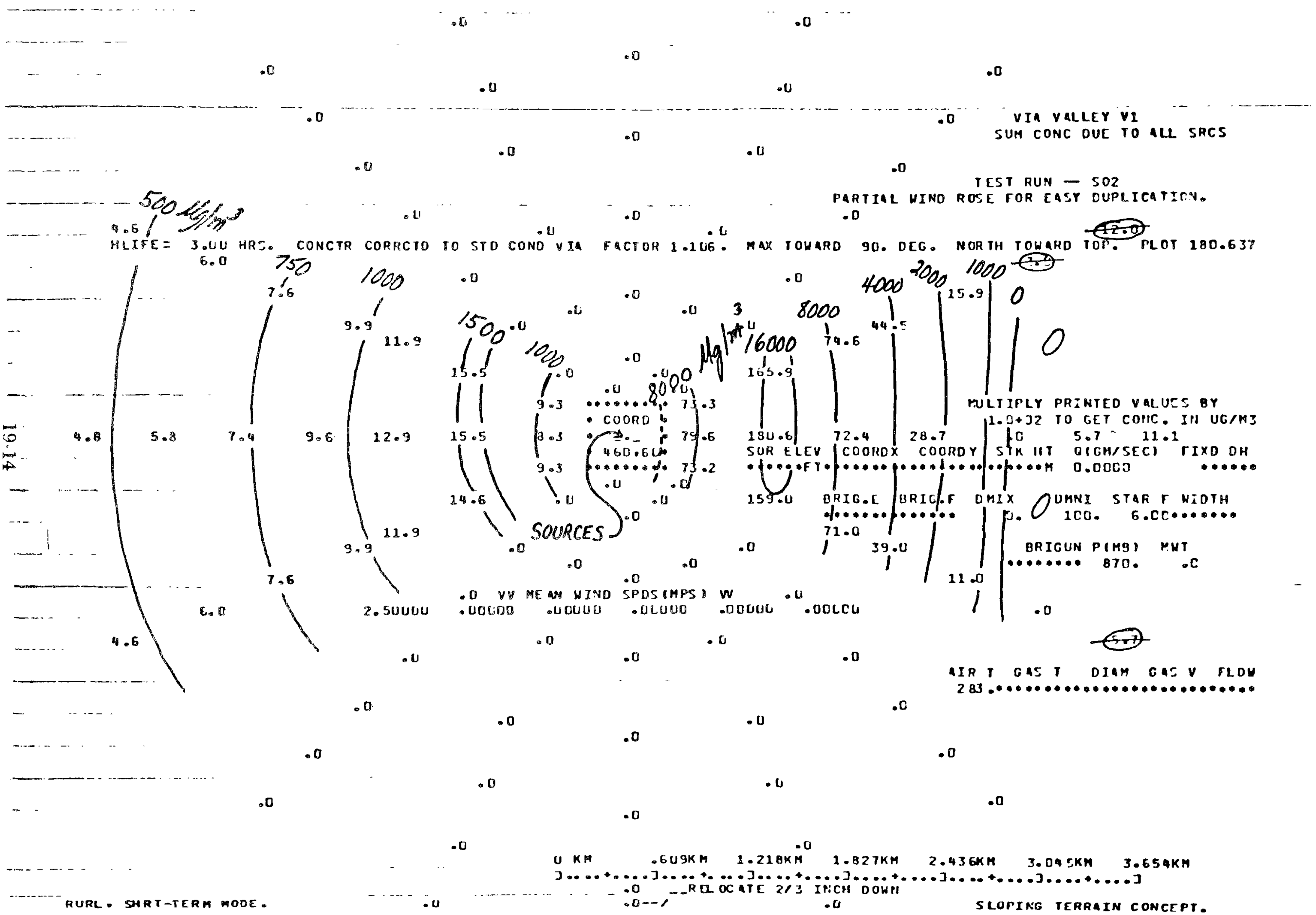

RELOCATE 2/3 INCH UP-/
VIA VALLEY V1
MAIN STACK
TEST RUN — SO2
PARTIAL WIND ROSE FOR EASY DUPLICATION.
HLIFE= 3.00 HRS. CONCTR CORRCTD TO STD COND VIA FACTOR 1.106. MAX TOWARD 90. DEG. NORTH TOWARD TOP. PLOT 153.658
µg/m3
2500
1000
0
5000
10000
15000
14.3
39.0
64.5
140.7
153.7
62.6
25.8
136.2
61.5
34.5
10.9
MULTIPLY PRINTED VALUES BY
1.0+02 TO GET CONC. IN UG/M3
COORD
460.60
SOR ELEV COORDX COORDY STK HT Q(GM/SEC) FIXD DH
3800.FT 460.00 60.00 75.M 1.2000+03 ******
BRIG.E BRIG.F UMIX OMNI STAR F WIDTH
****** 51. 0. 100. 6.00 0.
BRICUN P(MB) PWT
272. 870. .C
VV MEAN WIND SPDS(MPS) W
2.50000 .00000 .00000 .00000 .00000 .00000
AIR T GAS T DIAM GAS V FLOW
283. 375. 3.2 4.8 38.6
0 KM .609KM 1.218KM 1.827KM 2.436KM 3.045KM 3.654KM
__RELOCATE 2/3 INCH DOWN
RURL. SHRT-TERM MODE.
SLOPING TERRAIN CONCEPT.


RELOCATE 2/3 INCH UP
VIA VALLEY V1
VENTS.(AS AREA SRC)
TEST RUN — 502
PARTIAL WIND ROSE FOR EASY DUPLICATION.
HLIFE= 3.00 HRS. CONCTR CORRCTD TO STD COND VIA FACTOR 1.106. MAX TOWARD 90. DEG. NORTH TOWARD TOP. PLOT 795.763
μg/m3
MULTIPLY PRINTED VALUES BY 1.0+01 TO GET CONC. IN UG/M3
COORD
SOR ELEV COORDX COORDY STK HT Q(GM/SEC) FIXD DH
3800.FT 459.84 59.84 20.M 3.0000+02 0.
BRIG.E BRIG.F DMIX DMNI STAR F WIDTH
0. 100. 6.00 20.
BRIGUN P(MB) MWT
870.
VV MEAN WIND SPDS(MPS) W
2.50000 .00000 .00000 .00000 .00000 .00000
AIR T GAS T DIAM GAS V FLOW
283
0 KM .609KM 1.218KM 1.827KM 2.436KM 3.045KM 3.654KM
RELOCATE 2/3 INCH DOWN
RURL. SHRT-TERM MODE.
SLOPING TERRAIN CONCEPT.

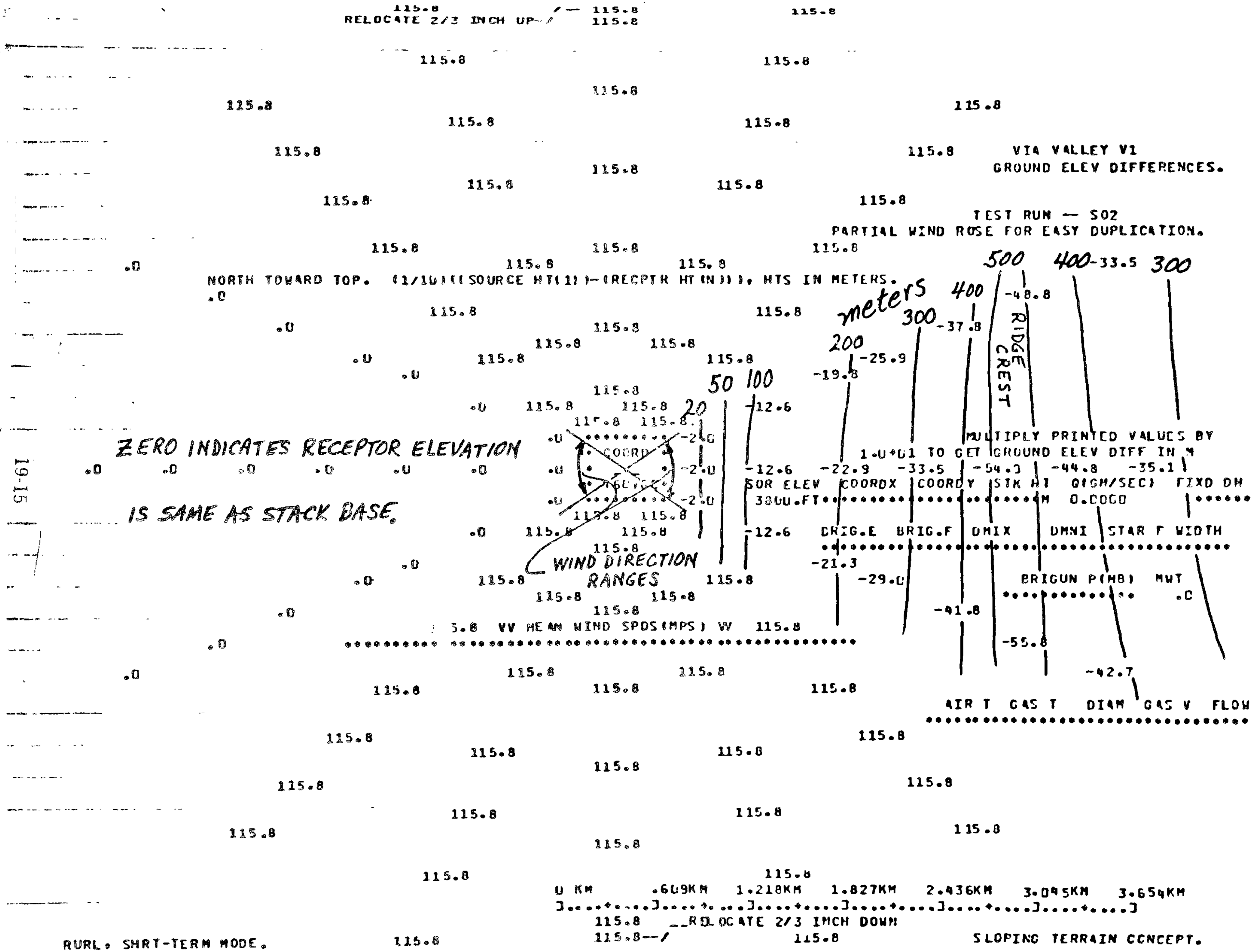
TEST RUN -- SO2 PARTIAL WIND ROSE FOR EASY DUPLICATION.

SOURCE DATA. PLOT 180.637

SOURCE NAME	COORDX	COORDY	STK HT	EMISS RATE	FIXD DH	SOR W	SOR H	BRIGUN	BRIGE	BRIGF	AIR T	GAS T	DIAM	GAS
1 MAIN STACK	460.00	60.00	75.	1.2000+03	*********	0.	3800.	272.	*******	51.	283.	375.	3.2	4.8
2 VENTS.(AS AREA SRC)	459.84	59.84	20.	3.0000+02	0.	20.	3800.	********	********	********	283.	****	*****	*****



VIA VALLEY V1
SUM CONC DUE TO ALL SRCS
TEST RUN — SO2
PARTIAL WIND ROSE FOR EASY DUPLICATION.
HLIFE= 3.00 HRS. CONCTR CORRCTD TO STD COND VIA FACTOR 1.106. MAX TOWARD 90. DEG. NORTH TOWARD TOP. PLOT 180.637
MULTIPLY PRINTED VALUES BY 1.0+02 TO GET CONC. IN UG/M3
SOR ELEV COORDX COORDY STK HT Q(GM/SEC) FIXD DH
BRIG.L BRIG.F DMIX OMNI STAR F WIDTH
BRIGUN P(MB) MWT
AIR T GAS T DIAM GAS V FLOW
VV MEAN WIND SPDS(MPS) W
COORD
0 KM .609KM 1.218KM 1.827KM 2.436KM 3.045KM 3.654KM
RELOCATE 2/3 INCH DOWN
RURL. SHRT-TERM MODE.
SLOPING TERRAIN CONCEPT.
500 Ug/m3
750
1000
1500
8000
Ug/m3
16000
4000
2000
SOURCES



RELOCATE 2/3 INCH UP
VIA VALLEY V1
GROUND ELEV DIFFERENCES.
TEST RUN — S02
PARTIAL WIND ROSE FOR EASY DUPLICATION.
NORTH TOWARD TOP. (1/10)((SOURCE HT(1))-(RECPTR HT(N))), HTS IN METERS.
ZERO INDICATES RECEPTOR ELEVATION
IS SAME AS STACK BASE.
WIND DIRECTION RANGES
meters
20
50
100
200
300
400
500
400
300
RIDGE CREST
-48.8
-37.8
-33.5
-25.9
-19.8
-12.6
-21.3
-29.0
-41.8
-55.8
-42.7
MULTIPLY PRINTED VALUES BY
1.0+01 TO GET GROUND ELEV DIFF IN M
-22.9 -33.5 -54.3 -44.8 -35.1
SOR ELEV COORDX COORDY STK HT Q(GM/SEC) FIXD DM
3800.FT M 0.0000
ORIG.E ORIG.F DMIX DMNI STAR F WIDTH
ORIGUN P(MB) MWT
.0
5.8 VV MEAN WIND SPDS(MPS) W 115.8
AIR T GAS T DIAM GAS V FLOW
115.8
.0
0 KM .609KM 1.218KM 1.827KM 2.436KM 3.045KM 3.654KM
RELOCATE 2/3 INCH DOWN
RURL. SHRT-TERM MODE.
SLOPING TERRAIN CONCEPT.

Chapter 20

Elements and Applications of the Ozone Isopleth (EKMA/OZIPP)

Chapter Goal

To familiarize you with the Ozone Isopleth (EKMA/OZIPP) model that is currently available for use and is endorsed by the Environmental Protection Agency.

Chapter Objectives

Upon completion of this chapter, you should be able to:

1. describe the application of the Ozone Isopleth model to a given source and surrounding terrain features.
2. describe the accuracy of the Ozone Isopleth model under given source-receptor conditions.

Chapter Outline

Follows *Modeling Notes (EKMA/OZIPP).*

Support Material

Peter Guldberg, *Modeling Notes, Elements and Applications of the Ozone Isopleth (EKMA/OZIPP) Model.*

MODELING NOTES
by Peter H. Guldberg

Elements and Applications of the Ozone Isopleth (EKMA/OZIPP) Model

REVISIONS TO PHOTOCHEMICAL OXIDANTS NAAQS

1. RAISE STANDARD TO 120 PPB
2. CHANGE TO OZONE
3. CHANGE MONITORING CALIBRATION PROCEDURE
4. CHANGE TO STATISTICAL FORM
5. TREATMENT OF MISSING DATA
6. CHANGES TO CONTROL STRATEGY DEVELOPMENT PROCEDURES

BY DEFINITION:

The ozone NAAQS is attained "When the expected number of days per calendar year with maximum hourly average concentrations above 120 PPB is equal to or less than one".

TECHNIQUES FOR OZONE SIP DEVELOPMENT

1. PHOTOCHEMICAL DISPERSION MODELS
2. EMPIRICAL KINETICS MODELING APPROACH (EKMA)
3. STATISTICAL AND EMPIRICAL MODELS
4. MODIFIED LINEAR ROLLBACK

MODIFIED LINEAR ROLLBACK

$$R = \frac{O_3 - A(T_0 - 40) - 120}{O_3 - AT_0}$$

O_3 = DESIGN VALUE OF OZONE
T_0 = CURRENT OZONE TRANSPORT
A = ADDITIVITY FRACTION

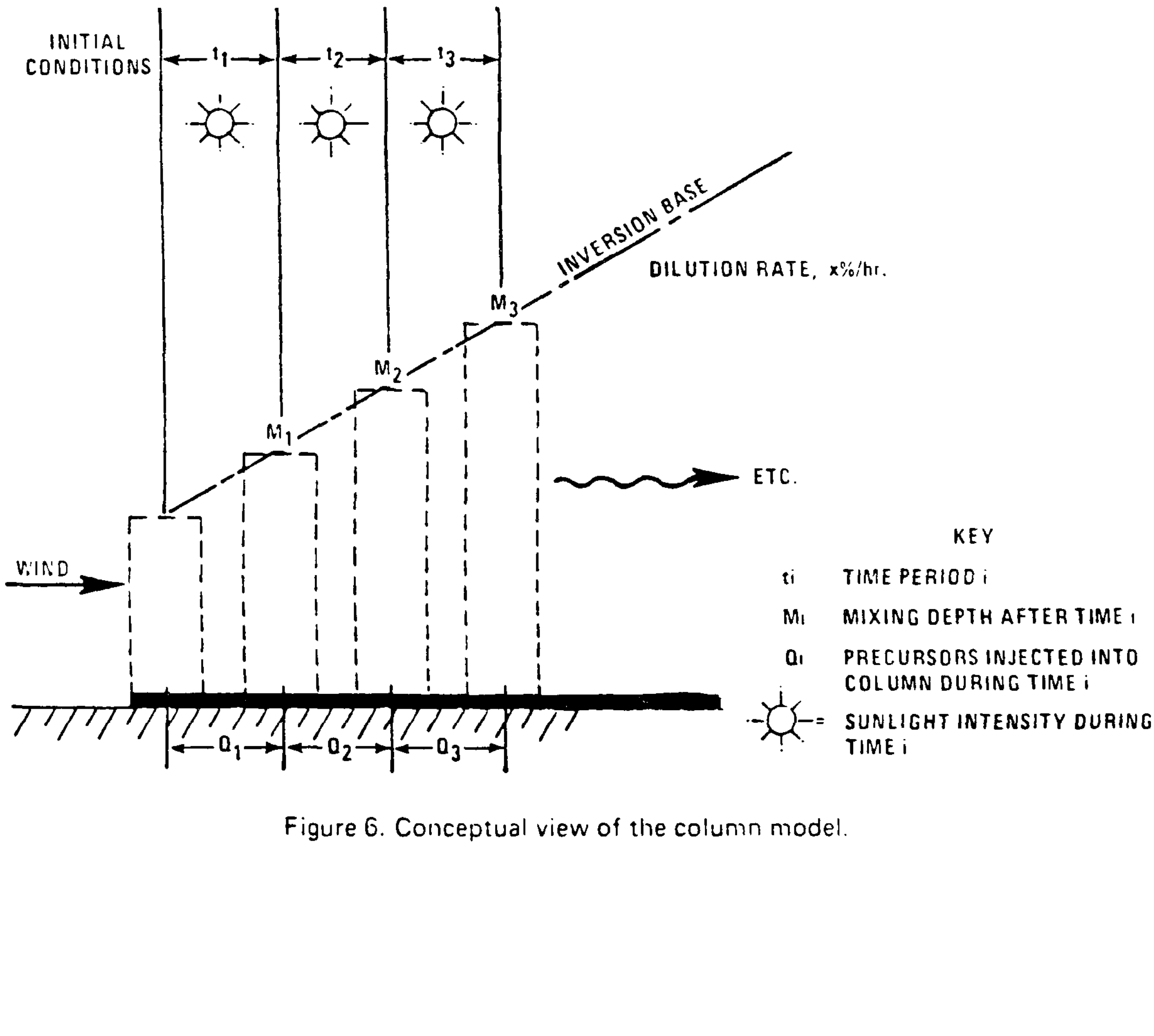


Figure 6. Conceptual view of the column model.

EKMA ISOPLETHS

STANDARD	CITY SPECIFIC
HAND APPLICATION	OZIPP COMPUTER PROGRAM
FIXED SET OF ASSUMPTIONS	LOCAL CONDITIONS INPUT
PREDICTS CHANGES IN O_3 ONLY	PREDICTS ABSOLUTE CONCENTRATIONS AND CHANGES IN O_3

INPUTS -

DESIGN O_3

MEDIAN 6-9 am
NMHC/NO_x RATIO

DESIGN O_3 = 0.280 PPM

MEDIAN RATIO = 6

STARTING POINT COORDINATES ARE: NMHC = 0.86 PPM
NO_x = 0.146 PPM

QUESTION 1: What NMHC reduction will reduce O_3 to 0.120 PPM?

R = 0.86 - 0.4/ 0.86 = 53%

QUESTION 2: If NO_x is reduced 50%, what NMHC reduction is needed?

R = 0.86 - 0.26/ 0.86 = 70%

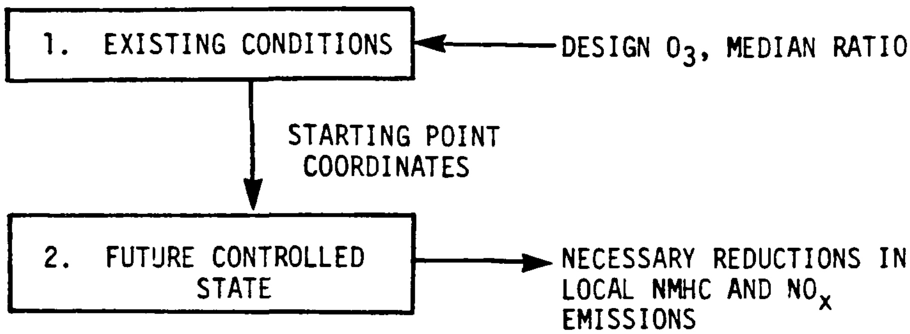
OZONE ISOPLETH PLOTTING PACKAGE (OZIPP)

NTIS: PB 287-768. COST: $250.00

INPUTS:

- LIGHT INTENSITY- LATITUDE, LONGITUDE, DAY
- MIXING HEIGHT- DIURNAL VARIATION
- NMHC AND NO_x EMISSIONS AFTER 8 am
- NMHC REACTIVITY
- ALDEHYDE FRACTION OF NMHC
- NO_2 FRACTION OF NO_x
- TRANSPORT OF NMHC, NO_2, AND O_3 INTO URBAN AREA, BOTH ALOFT AND AT THE SURFACE

USE OF CITY SPECIFIC ISOPLETHS



Chapter 21

Elements and Applications of Mobile Source Model (Mobile1)

Chapter Goal

To familiarize you with the Mobile Source (MOBILE1) procedure.

Chapter Objective

Upon completion of this chapter, you should be able to:

1. explain the procedure used to determine the percentage amount of hydrocarbon emissions from all types of vehicles.

Chapter Outline

Follows *Modeling Notes (MOBILE1)*.

Support Material

Peter Guldberg, *Modeling Notes, Mobile Source Emissions (MOBILE1) Model.*

MODELING NOTES
by Peter H. Guldberg

Mobile Source Emissions (MOBILE1) Model

MOBILE SOURCE EMISSIONS MODEL

MOBILE1 Program and User's Guide	Currently Available
MOBILE2 Program and User's Guide	Available November 1980

Contact: EPA Office of Mobile Source Control
2565 Plymouth Road
Ann Arbor, Michigan 48105
(313) 668-4306

REQUIRED INPUT FOR EACH SCENARIO

1. Region
2. Calendar Year
3. Average Vehicle Speed
4. Ambient Temperature
5. % Cold Start VMT
6. % Hot Start VMT

EMISSION PARAMETERS

3 REGIONS	LOW ALTITUDE CALIFORNIA HIGH ALTITUDE (>4,000 FT)
6 VEHICLE TYPES	LDV LDT1 LDT2 HDG HDD MC
3 POLLUTANTS	HC CO NO_X

CALENDAR YEARS 1970-1999

OPTIONAL INPUTS AND DEFAULT VALUES

VMT Mix By Vehicle Type	National Avg.
Vehicle Distribution By Age	National Avg.
Inspection/Maintenance	None
Air Conditioning	None
Humidity	75 Grains/Lb
Idle Emissions	None
HC Emissions	Total

NATIONWIDE AVERAGE

COLD/HOT START MIX FOR MOTOR VEHICLES

Vehicles Cold Start Mode	20.58%
Vehicles Hot Start Mode	27.28%
Vehicles Hot Stabilized Mode	52.14%
Total	100.00%

[illegible]RMONT MIX (1979 & 1982)- VEL=32.0,TEMP=20

* TOTAL HC EMISSION FACTORS INCLUDE EVAP. HC EMISSION FACTORS

		VEH. TYPE:	LDV	LDT1	LDT2	HDG	HDD	MC
CAL. YEAR: 1979	TEMP: 20.0(F)		0.811/	0.144/	0.013/	0.023/	0.009/	0.0
REGION: 49-STATE	32.0:32.0/32.0/32.0 MPH (32.0)					20.0/	20.0/	20.0

COMPOSITE EMISSION FACTORS (GM/MILE)

	LDV	LDT1	LDT2	HDG	HDD	MC	ALL MODES
TOTAL HC:	5.46	6.39	9.77	15.93	3.17	8.74	5.87
EXHAUST CO:	53.18	59.83	71.32	168.83	17.59	32.68	56.71
EXHAUST NOX:	3.19	3.29	5.95	11.66	18.35	0.21	3.57

		VEH. TYPE:	LDV	LDT1	LDT2	HDG	HDD	MC
CAL. YEAR: 1982	TEMP: 20.0(F)		0.811/	0.144/	0.013/	0.023/	0.009/	0.0
REGION: 49-STATE	32.0:32.0/32.0/32.0 MPH (32.0)					20.0/	20.0/	20.0

COMPOSITE EMISSION FACTORS (GM/MILE)

	LDV	LDT1	LDT2	HDG	HDD	C	ALL MODES
TOTAL HC:	3.56	5.08	7.57	11.73	2.95	5.94	4.02
EXHAUST CO:	36.65	57.63	65.71	177.39	16.31	23.88	43.10
EXHAUST NOX:	2.57	2.88	4.64	11.12	17.78	0.47	2.97

NATIONWIDE AVERAGE

MOTOR VEHICLE MIX BY TYPE

Vehicle Type	Percentage of VMT
Light-Duty Vehicles (LDV)	80.3%
Light-Duty Gasoline Trucks	
0-6000 lb GVW1/ (LDT1)	5.8%
Over 6000 lb GVW (LDT2)	5.8%
Heavy-Duty gasoline Trucks (HDG)	4.5%
Heavy-Duty Diesel Trucks (HDD)	3.1%
Motorcycles (MC)	0.5%
Total	100.0%

1/ Gross vehicle weight.

REVISED INSTRUCTIONS FOR VOLUME 9, WORKSHEET 2

Step	Instruction
5	Enter "freeflow" emissions (g/m) from MOBILE1 run using cruise speed on line 4. Note MOBILE1 emissions (g/mile) must be multiplied by a conversion factor of 0.0006214.
17a	First, calculate a correction factor C_t as the composite emission rate (g/mile) predicted by MOBILE1 for study area conditions using a speed of 5 mph, divided by 188.8 g/mile (the emission rate at 5 mph for the standard conditions given in the Guideline). Multiply this C_t times line 16.
17b	Multiply line 5 by the sum of each approach of line 6.9, divide by line 6.5.
17c	Subtract 17b from 17a and enter on line 17.
18	Multiply line 5 by line 2, divide by 3600. Enter this as the adjusted free-flow emission rate.

```
BURLINGTON WOODS-VEL=38.0,TEMP=33 F

  *   TOTAL HC EMISSION FACTORS INCLUDE EVAP. HC EMISSION FACTORS
--------------------------------------------------------------------------------
                                VEH. TYPE:  LDV    LDT1   LDT2   HDG    HDD    MC
 CAL. YEAR: 1980      TEMP: 33.0(F)          0.803/0.058/0.058/0.045/0.031/0.005
 REGION: 49-STATE     38.0:38.0/38.0/38.0 MPH (38.0)       20.6/ 27.3/ 20.6
  LDV I/M PROGRAM STARTING IN 1982, STRINGENCY LEVEL 20%, MECH. TRAINING: YES
  I/M PROG. BENEFITS APPLY ONLY TO MODEL YEARS 1951 THROUGH 1999

                         COMPOSITE EMISSION FACTORS (GM/MILE)
                LDV       LDT1      LDT2      HDG       HDD       MC      ALL MODES
EXHAUST  CO:  36.59     44.77     54.56    152.66     14.33     22.71       42.57
--------------------------------------------------------------------------------
                                VEH. TYPE:  LDV    LDT1   LDT2   HDG    HDD    MC
 CAL. YEAR: 1982      TEMP: 33.0(F)          0.803/0.058/0.058/0.045/0.031/0.005
 REGION: 49-STATE     38.0:38.0/38.0/38.0 MPH (38.0)       20.6/ 27.3/ 20.6
  LDV I/M PROGRAM STARTING IN 1982, STRINGENCY LEVEL 20%, MECH. TRAINING: YES
  I/M PROG. BENEFITS APPLY ONLY TO MODEL YEARS 1951 THROUGH 1999

                         COMPOSITE EMISSION FACTORS (GM/MILE)
                LDV       LDT1      LDT2      HDG       HDD       MC      ALL MODES
EXHAUST  CO:  27.86     43.19     51.22    160.27     13.60     18.09       35.57
--------------------------------------------------------------------------------
                                VEH. TYPE:  LDV    LDT1   LDT2   HDG    HDD    MC
 CAL. YEAR: 1987      TEMP: 33.0(F)          0.803/0.058/0.058/0.045/0.031/0.005
 REGION: 49-STATE     38.0:38.0/38.0/38.0 MPH (38.0)       20.6/ 27.3/ 20.6
  LDV I/M PROGRAM STARTING IN 1982, STRINGENCY LEVEL 20%, MECH. TRAINING: YES
  I/M PROG. BENEFITS APPLY ONLY TO MODEL YEARS 1951 THROUGH 1999

                         COMPOSITE EMISSION FACTORS (GM/MILE)
                LDV       LDT1      LDT2      HDG       HDD       MC      ALL MODES
EXHAUST  CO:   7.59     29.70     36.09    110.77     12.94      5.71       15.32
--------------------------------------------------------------------------------
```

Chapter 22

Shoreline Fumigation Model

Chapter Goal

To familiarize you with the Shoreline Fumigation model developed by Walter Lyons and Henry Cole, and to familiarize you with the techniques used to predict concentrations along the interface of land and water.

Chapter Objective

Upon completion of this chapter, you should be able to:

1. use the Lyons and Cole techniques of modeling plume behavior along the interface of land and water to predict concentrations of pollutants.

Chapter Outline

Follows *Modeling Notes, Shoreline Fumigation Model.*

Support Material

Walter Lyons and Henry Cole, *Modeling Notes, Shoreline Fumigation Model with Appendix.*

MODELING NOTES
by Henry S. Cole

Shoreline Fumigation Model
With Appendices 1-3

Lyons and Cole Shoreline Fumigation Model

DISCUSSION OF THE MODEL

Transparency, page 39, Lyon's EPA report

I. The dispersion for the shoreline fumigation case is divided into 3 parts:

Zone 1 - The plume is initially emitted into stable air. The dispersion is gaussian in both the vertical and crosswind directions. Plume does not impact the surface.

Zone 2 - Fumigation occurs. Enhanced horizontal (gaussian) dispersion is due to mixing in the turbulent zone. In the vertical, the dispersion is gaussian above the lid, uniform below. Contains maximum ground-level concentration.

Zone 3 - The entire plume is engulfed in the turbulent layer. The distribution is gaussian in the horizontal, using coefficients of dispersion for unstable air. Note the use of a virtual point source. Also note that the use of σ_y based on distance to the actual source would greatly overestimate the plume spread.

THE FUMIGATION ZONE

Predicting the maximum ground-level concentration

1. Locating X_b and X_e , a desk calculator method:

A. You first need to know the effective plume height, ie, you can use Briggs for stable.

B. Plot either the measured TIBL (top of internal boundry layer) on a graph or illustrate with a parabolic TIBL model.

$$L = mx^{\frac{1}{2}}$$

C. On the same graph or on an overlay plot H_e .

D. Plot as a function of x:

$H + 2.15\sigma_z$ and $H - 2.15\sigma_z$ for stable air. It is convenient to have them plotted in advance.

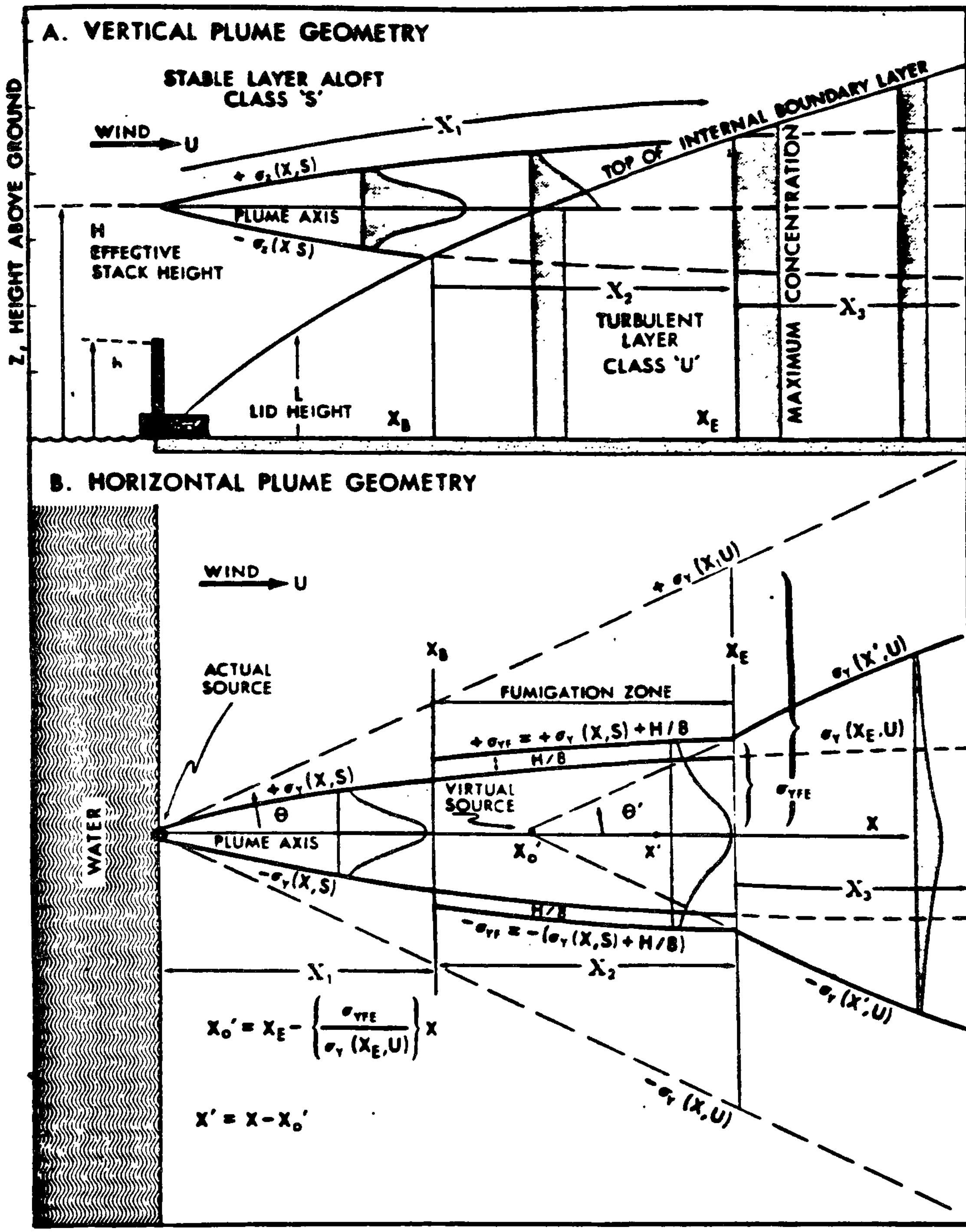


Figure 1 (a) Schematic of plume geometry in vertical (XZ) plane used in modeling continuous fumigation, (b) horizontal (XY) plume geometry used in the Lyons and Cole continuous fumigation model.

2. The equation for the fumigation zone, ie, $X_b < X < X_e$. Z is homogeneous for $0 < Z < L$.

Consider the Y = 0 line:

$$X(x,0,0) = \frac{QX10^6}{\sqrt{2\pi}\ \sigma_{yf}\ \bar{u}\ L} \int_{-\infty}^{P} I dp$$

where, Q = source in grams per second

L = lid height, which varies as a function of x, (meters)

$\bar{u}$ = mean wind speed in meters per second

σ_{yf} = stable dispersion coefficient, adjusted for added turbulence in the fumigation zone. Function of x.

$$\sigma_{yf} = \sigma_y + H_e /8 \quad \text{(in meters)}$$

$$\int_{-\infty}^{P} I dp = \text{the integral of the normal distribution curve}$$

$$= \int_{-\infty}^{P} (2\pi)^{-\frac{1}{2}} \exp(-p^2/2) dp$$

$$\text{where } p = \left[L(x) - H_e\right] / \sigma_z$$

3. Handling the I term, the physical interpretation:

The integral I represents the portion of the plume that is mixing downward in the turbulent air below the lid. In the case shown to the right, most of the plume remains above the lid.

$p = -1$

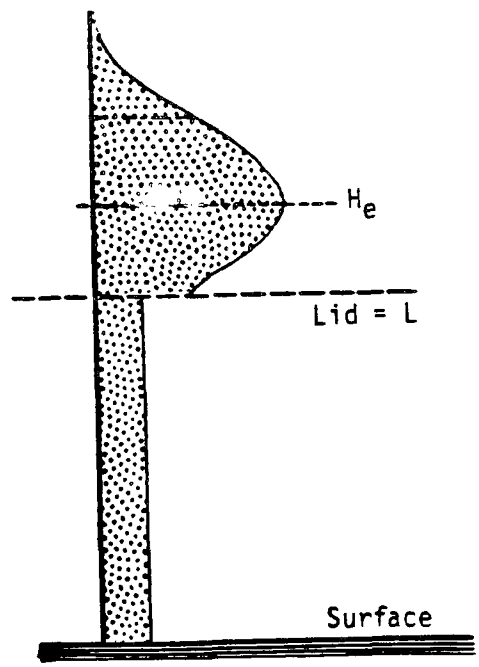


Figure 2 Physical interpretation

The integral can be solved by referring to a normal probability function table. Find p = -1 by looking up 1:

$$F(1) = 0.8413 \qquad \text{(See Appendix 3)}$$

for a -1 use $1 - F(1) = 0.1587$, ie, at this distance downwind approximately 16% of the plume is mixed downward.

4. EXAMPLE:

Given: $Q = 10^9$ grams per second

$H_e = 330$ meters

$L = f(x)$ [illegible]$^{1/2}$ (assumed)

$\bar{u} = 5$ meters per second

stabilities : stable marine air = F

unstable air within TIBL = B

nonvarying portion of the equation:

$$\frac{Q X 10^6}{\sqrt{2\pi}\ \bar{u}} = \frac{10^9 \times 10^6}{\sqrt{2\pi}\ 5} = 7.98 X 10^7$$

variable portion of the equation:

$$\frac{\int_{-\infty}^{p} I dp}{\sigma_{yf}\ L}$$

zone: $X_b < X < X_e$

Note that all of these terms increase with increasing values of x.

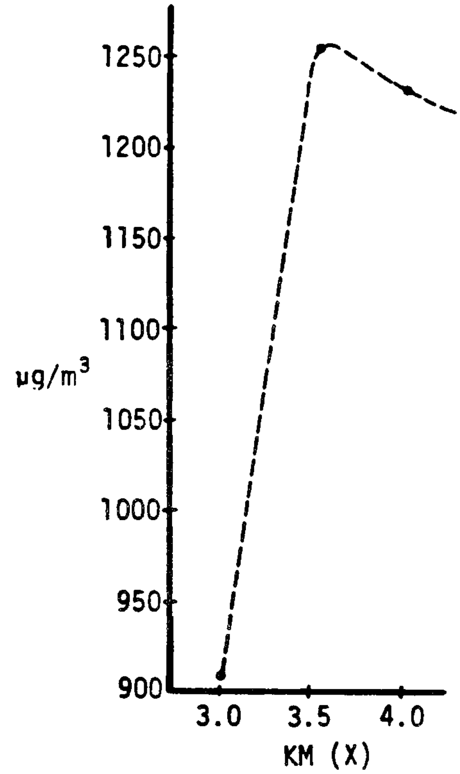


Figure 3 Example problem plot

The maximum occurs between X_p and X_e .

In the example shown $X_p = 3$ kilometers and $X_e = 4.5$ kilometers

Calculate values for 3, 3.5, 4, and 4.5 kilometers. Put on a graph.

Calculations for Z = 0, and Y = 0.

At a distance of 3 kilometers:

L = 330 meters

H_e = 330 meters

p = 0

σ_y (f) = 92 meters

σ_{yf} = 92 + 41.25 = 133 meters

$$\int_{-\infty}^{p} I dp = 0.5$$

$$\therefore X_{3KM} = \frac{7.98X10^7 \ X \ 0.5}{133 \ X \ 330} = 909.1 \ \mu grams \ per \ meter^3$$

At a distance of 3.5 kilometers:

L = 360 meters

H_e = 330 meters

σ_z = 28 meters

σ_y = 110 meters

p = 360 - 330/28 = 30/28 = 1.07

$$\int_{-\infty}^{p} I dp = 0.8577$$

σ_{yf} = 110 + 41 = 151

$$\therefore X_{3.5KM} = \frac{7.98X10^7 \ X \ 0.8577}{151 \ X \ 360} = 1259 \ \mu grams \ per \ meter^3$$

At a distance of 4 kilometers:

L = 380 meters

H_e = 330 meters

σ_z = 31 meters

σ_z = 120 meters

p = 380 - 330/31 = 50/31 = 1.61

$$\int_{-\infty}^{p} I dp = 0.9463$$

σ_{yf} = 120 + 41 = 161

$$\therefore X_{4KM} = \frac{7.98X10^7 \ X \ 0.9463}{161 \ X \ 380} = 1234.13 \ \mu grams \ per \ meter^3$$

For 5 kilometers the entire plume is engulfed. Use Turner's equation for limited mixing, but let L vary and now use σ_y for unstable air.

<u>At a distance of 5 kilometers</u>:

L_s = 420 meters

$$X_{5KM} = \frac{Q}{\sqrt{2\pi}\,\sigma_y\,L\,\bar{u}}, \qquad \text{for } Z = 0, \text{ and } Y = 0$$

The σ_y used in this equation must be for the unstable air (B stability). However, since the plume only started dispersing in unstable air in the fumigation zone (and not at the source) a virtual source must be used to calculate downwind distances, X', that will be used to calculate σ_y .

The virtual source may be located as follows:

(1) Find σ_{yf} at X_e , in our example X_e = 4.5 kilometers

σ_{yf} = 41 + 130 = 171 meters, where $\sigma_{yf} = \sigma_{y\ stable} + H_e/8$

(2) On the σ_y graph (Turner) for the unstable (B) find that downwind distance where σ_{yu} = 171 meters

This turns out to be 1.1 kilometers. Thus the virtual point source will be located 1.1 kilometers upwind of the X_e .

$$X'_o = X_e - 1.1 = 3.4 \text{ kilometers}$$

(3) $X' = X - X'_o$

Appendix

A-1. Lyons, Walter and Cole, Henry S. 1973. "Fumigation and Plume Trapping on the Shores of Lake Michigan During Stable Onshore Flow." *Journal of Applied Meteorology*. 12:494-510.

A-2. Peters, L. K. 1975. "On the Criteria for the Occurrence of Fumigation Inland From a Large Lake." *Atmospheric Environment*. 9:809-816.

A-3. Cumulative Standardized Normal Distribution (table).

Fumigation and Plume Trapping on the Shores of Lake Michigan During Stable Onshore Flow[1]

WALTER A. LYONS

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AND HENRY S. COLE

Division of Science, The University of Wisconsin-Parkside, Kenosha 53140

(Manuscript received 1 March 1972, in revised form 16 January 1973)

ABSTRACT

Previous studies have shown that the lake breeze circulation cell which develops along the western shore of Lake Michigan during almost half of the warm season days has detrimental effects upon the air quality of the Gary-Chicago-Milwaukee area. However, stable onshore flow associated with a synoptic-scale pressure gradient occurs for an additional 15% of warm season days. This study examines the dispersion patterns during gradient, onshore flow. Fumigation and plume trapping, in particular, appear to cause serious degradation of air quality. Continuous fumigation of elevated plumes develops on days with strong insolation Plume trapping occurs when a plume is emitted into a shallow layer of unstable air capped by a deep lid of stable air. This condition is frequent on overcast spring days.

Two days characterized by easterly gradient winds were studied: 27 May 1970, overcast; 25 June 1970, predominately sunny. The studies utilized meteorological data obtained from ground observers, ship's records, a wiresonde, and from aircraft photography.

A computer diffusion model incorporating the mesoscale meteorological characteristics for each day predicted ground level concentrations from several sources including a large coal burning power plant. The model for the fumigating power plant plume (25 June) yielded estimates in excess of 1.0 ppm SO_2 7 km downwind of the plant.

Limited air monitoring data appear to confirm the diffusion model estimates and observations of plume behavior.

1. Introduction

There is mounting evidence that residents of highly populated, industrialized areas near Great Lakes shorelines receive higher than expected dosages of pollutants during spring and summer months. Papers by Olsson (1969), Lyons (1972), and Olsson *et al.* (1968), among others, have shown that the lake breeze circulation cell which frequently develops during the warm season has very detrimental effects upon the air quality in nearshore areas. This situation often occurs when the synoptic-scale pattern does not warrant the declaration of an "Air Stagnation Advisory."

This study will show, however, that other common mesoscale regimes markedly degrade local air quality. On many warm season days, either clouds sufficiently reduce insolation and/or gradient winds are too strong to permit the formation of an organized lake breeze circulation cell. Yet, on these days, serious pollution problems frequently develop on the downwind shores. This paper deals primarily with non-lake, breeze, onshore flow regimes.

Lake Michigan (Fig. 1) is roughly 140 km wide and 520 km long. Reaching depths of almost 300 m, its water temperatures lag considerably behind those of the air during spring and summer, not reaching a quasi-steady state with nearly uniform surface temperatures (near 20C) until July, according to Church (1945) and Mortimer (1968). Thus, throughout the "warm season," and especially during April, May and June, the land air is warmer than the lake surface both day and night, with the temperature contrast often as large as 25C.

In the absence of lake breezes, gradient winds advect warm land air from one shore to the other. Bellaire (1965) was among the first to study the low-level modification of the air under these conditions. Using ship-towed wiresondes, he found an extremely intense, but also very shallow (≤ 150 m), inversion layer formed by conductive cooling. Lyons (1970) presented additional observational data and developed a numerical simulation scheme for this phenomena, which he termed a "conduction inversion." The atmosphere above the surface conduction layer also tends to be stably stratified as it flows onshore, not having been heated from below as is the case over land during the day. The deep pool of cooler air produces a lake mesohigh of

[1] Contribution No. 69, Center for Great Lakes Studies, The University of Wisconsin-Milwaukee.

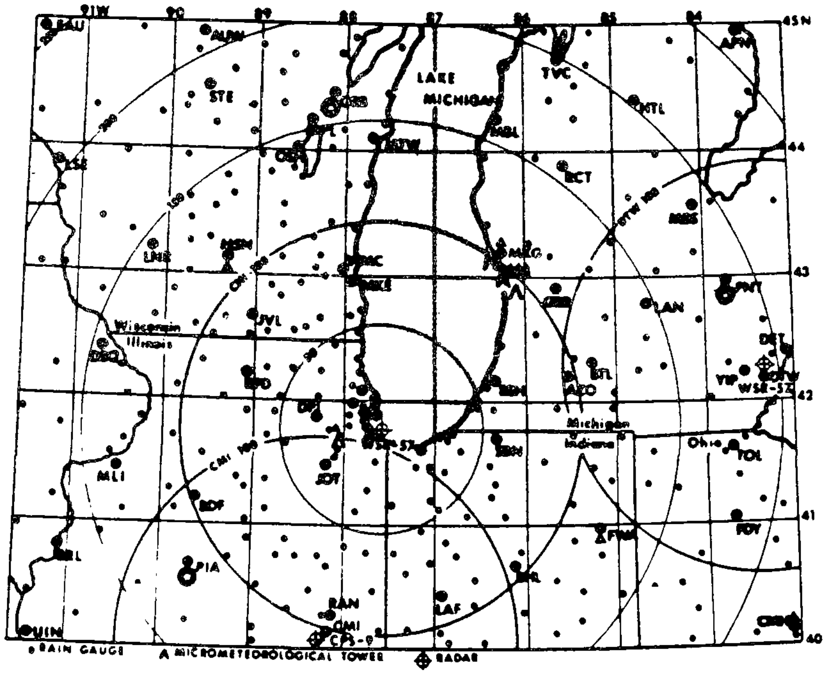

FIG. 1. Area of investigation. Power plant under study is located 15 km south of Milwaukee, Wisc. (MKE). Stars show locations of NOAA radiosonde stations in area. Hourly weather data are available at locations shown by large circle.

some 2 mb excess pressure with a mean subsidence approaching 3–5 cm sec^{-1}, which further stabilizes the lake airmass (Lyons, 1971). As the air flows onshore during the day, the surface temperature deficit rapidly disappears within about 20 km inland fetch (Herkoff, 1969), while in the vertical a thermal internal boundary (TIBL) originates at the shoreline and erodes the overlying stable cap (Bierly, 1968).

From a pollution viewpoint, this situation clearly represents a hazardous regime. If there were an elevated point source of some pollutant near the shoreline, the effluent would initially be emitted into the stratified layers at higher levels and flow inland. As soon as the plume intersected the deepening TIBL, intense downward mixing would cause high concentrations to reach the surface at some point several kilometers inland. Upward dispersion is restricted by a capping layer of stable unmodified lake air. This phenomenon, known as fumigation, has long been recognized in connection with the burn-off of nocturnal radiation inversions, producing unusually high surface concentrations for 30–60 min. During stable onshore flow on sunny days, however, fumigation may be almost continuous through the day, from an hour or so after sunrise and before sunset. Since it is estimated that stable-gradient onshore flow occurs in the Chicago-Milwaukee area on about 15% of the spring and summer days, this phenomenon is not an occasional but rather frequent occurrence.[2]

[2] About three times that number of days are associated with lake breezes. If the lake breeze penetrates far enough inland (say 10 km), and has a sufficiently deep inflow layer (perhaps 300 m or more), the identical fumigation problem defined below occurs under that regime also.

At night or when skies are overcast, elevated plumes advect inland with minimal vertical diffusion. At such times, however, low-level sources become problems. During the spring, the inshore waters are warming rapidly while a vast pool of cold water remains offshore. Fig. 2, a NOAA-1 infrared map of the Great Lakes on the night of 28 May 1971, clearly illustrates the "thermal bar" pattern discussed by Rodgers (1965). This condition results in the formation of a shallow

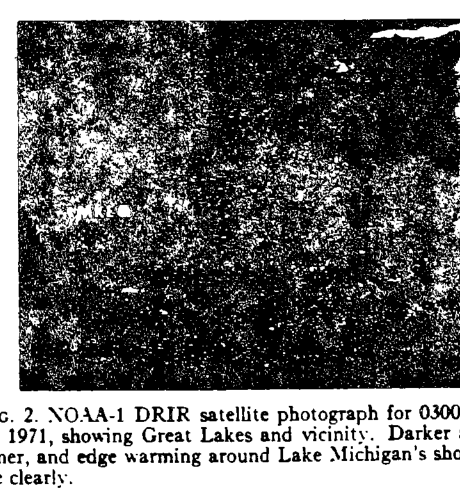

FIG. 2. NOAA-1 DRIR satellite photograph for 0300 CST 28 May 1971, showing Great Lakes and vicinity. Darker areas are warmer, and edge warming around Lake Michigan's shore shows quite clearly.

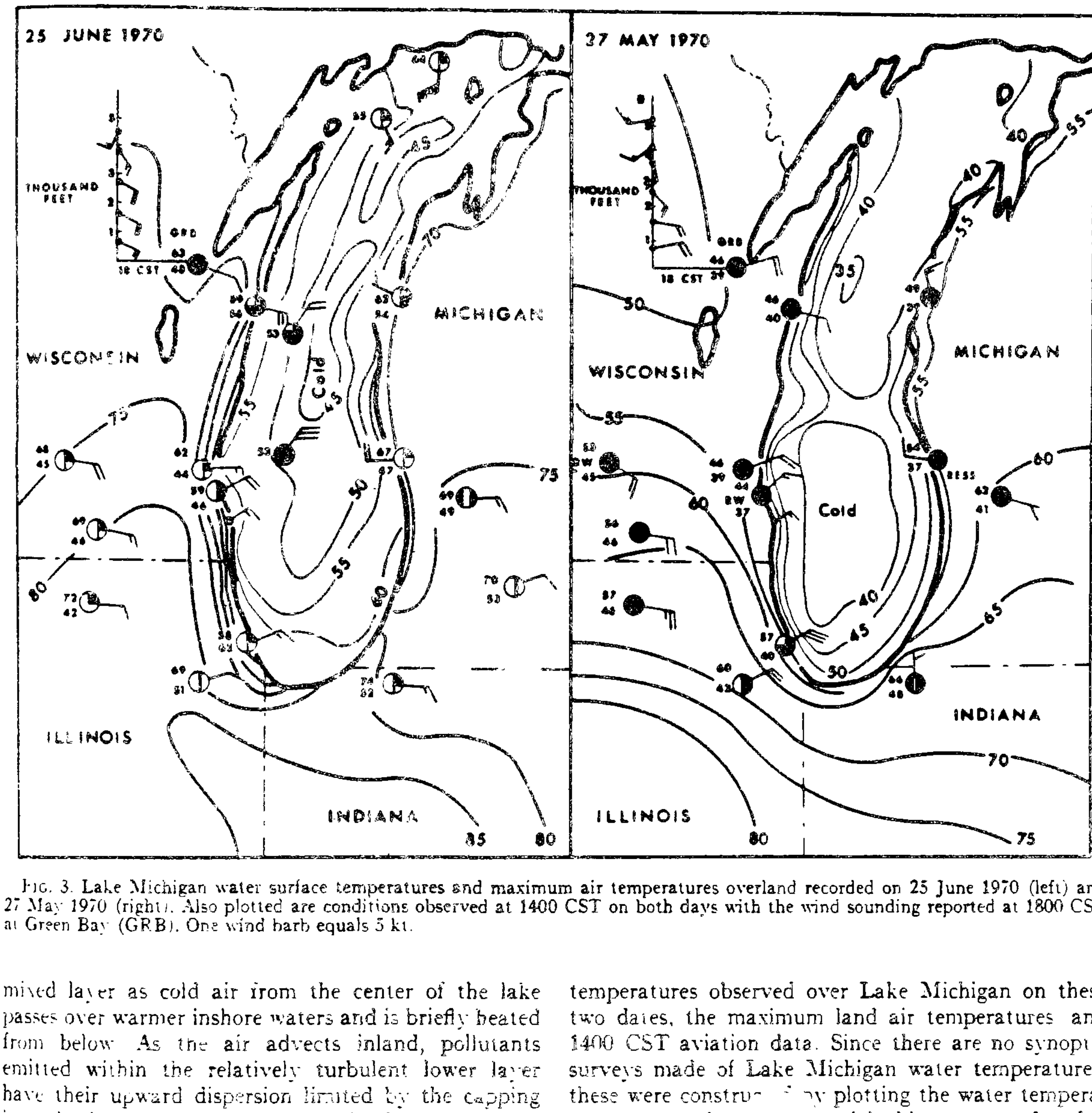

FIG. 3. Lake Michigan water surface temperatures and maximum air temperatures overland recorded on 25 June 1970 (left) and 27 May 1970 (right). Also plotted are conditions observed at 1400 CST on both days with the wind sounding reported at 1800 CST at Green Bay (GRB). One wind barb equals 5 kt.

mixed layer as cold air from the center of the lake passes over warmer inshore waters and is briefly heated from below. As the air advects inland, pollutants emitted within the relatively turbulent lower layer have their upward dispersion limited by the capping inversion layer above. The matter is further complicated by increased turbulence due to the shoreline discontinuity in roughness lengths. The thermal and frictional effects, working in tandem, produce plume trapping, which often results in high ground level pollutant concentrations.

In this paper, field work that assessed the seriousness of these problems will be described. Following this, a simple numerical model is used which suggests the direction of future research in terms of mathematical simulation and pollution monitoring.

2. Observations of plume behavior

Field studies were conducted two days, 27 May 1970 and 25 June 1970. Fig. 3 shows the mean water surface temperatures observed over Lake Michigan on these two dates, the maximum land air temperatures and 1400 CST aviation data. Since there are no synoptic surveys made of Lake Michigan water temperatures, these were constructed by plotting the water temperature reports from commercial ships over a five-day period. A cold central core of water existed with temperatures below 40F in late May and still less than 50F in late June, but with water temperatures in the mid-50's near shore for both periods. The synoptic situation for both of the days was similar (Figs. 4 and 7), that is, easterly gradient flow of relatively warm air across Lake Michigan.

a. 27 May 1970

On this date a large high pressure cell was present north of the Great Lakes (Fig. 4). Overcast conditions prevailed in the vicinity of the lake, and while temperatures exceeded 80F in Illinois (where skies were only partly cloudy), they remained in the 50's in south-

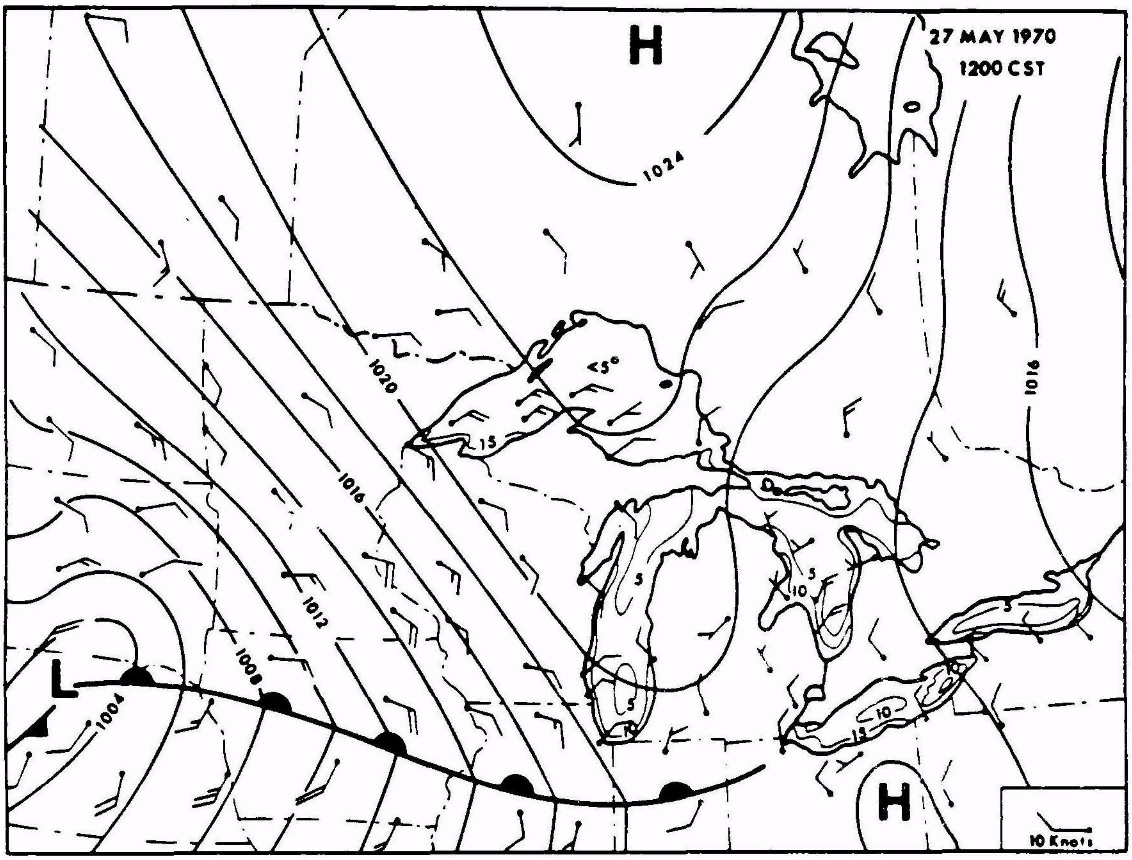

Fig. 4. Synoptic chart for 1200 CST 27 May 1970 with isobars every 2 mb, and 5C water surface temperature isotherms for Great Lakes. One wind barb equals 10 kt.

ern Wisconsin (Fig. 3). Thus, there was relatively little warming of the air as it flowed inland. An aerial view toward the southwest from a location due east of downtown Milwaukee showed two distinct smoke plumes from shoreline point sources (Fig. 5). The southernmost, a very large power plant, had a plume which rose to an effective stack height of ~350 m above lake level as it flowed inland. Another source, a fertilizer plant, located north of the power plant, was emitting very dense white smoke from a stack estimated to be

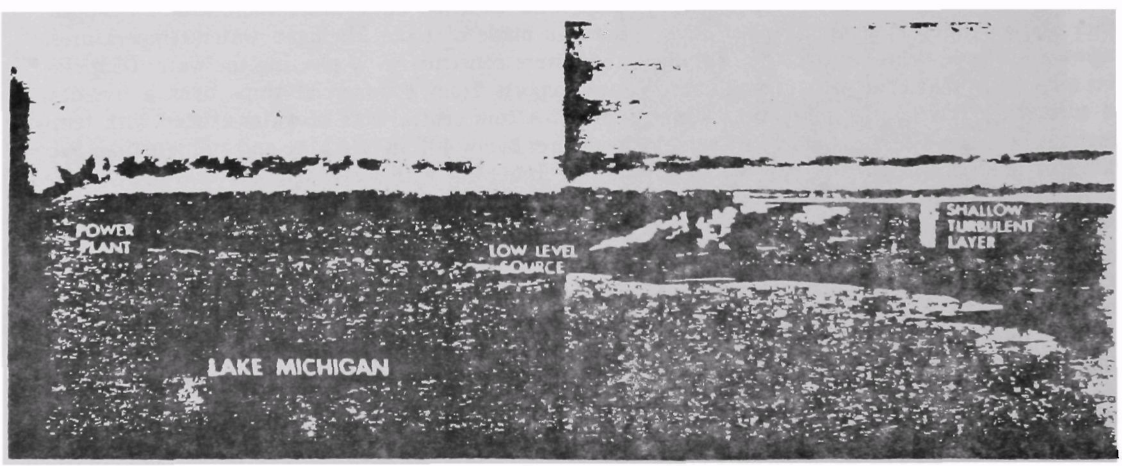

Fig. 5. Composite aerial photograph from 500 m above the lake, looking southwest from Milwaukee harbor, at 1415 CST 27 May 1970. Evident is the power plant plume streaming inland in the stable layer aloft, with a low-level plume exhibiting strong mixing in the shallow turbulent layer near the ground.

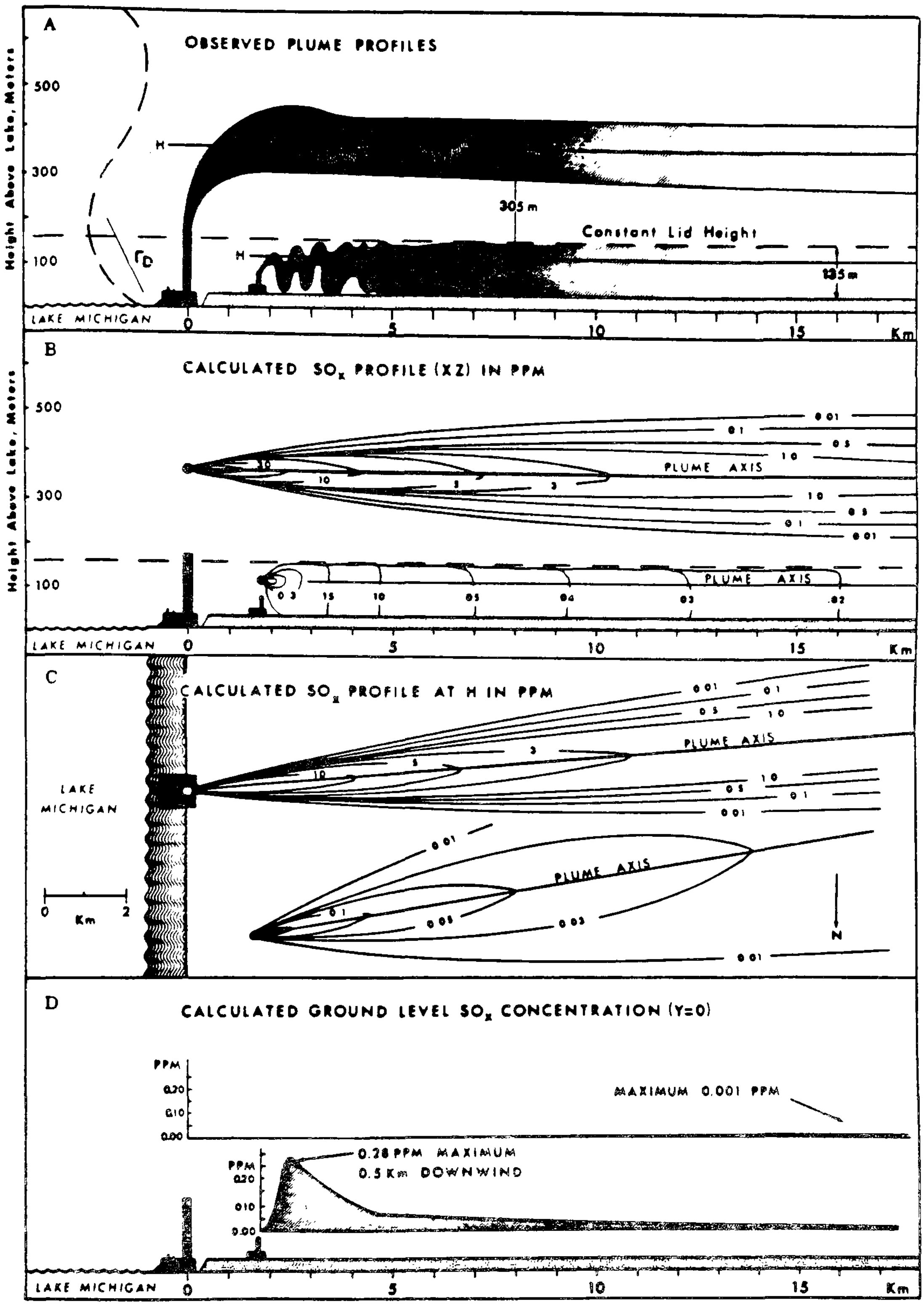

FIG. 6a. Schematic of conditions observed looking south along shoreline at 1400 CST, 27 May 1970. Dashed line is approximate temperature profile measured by aircraft. 6b. Computed SO_x concentrations (in parts per million) from high- and low-level sources, in x, z plane along centerline of plume. 6c. Computed SO_x concentrations in x, y plane, from

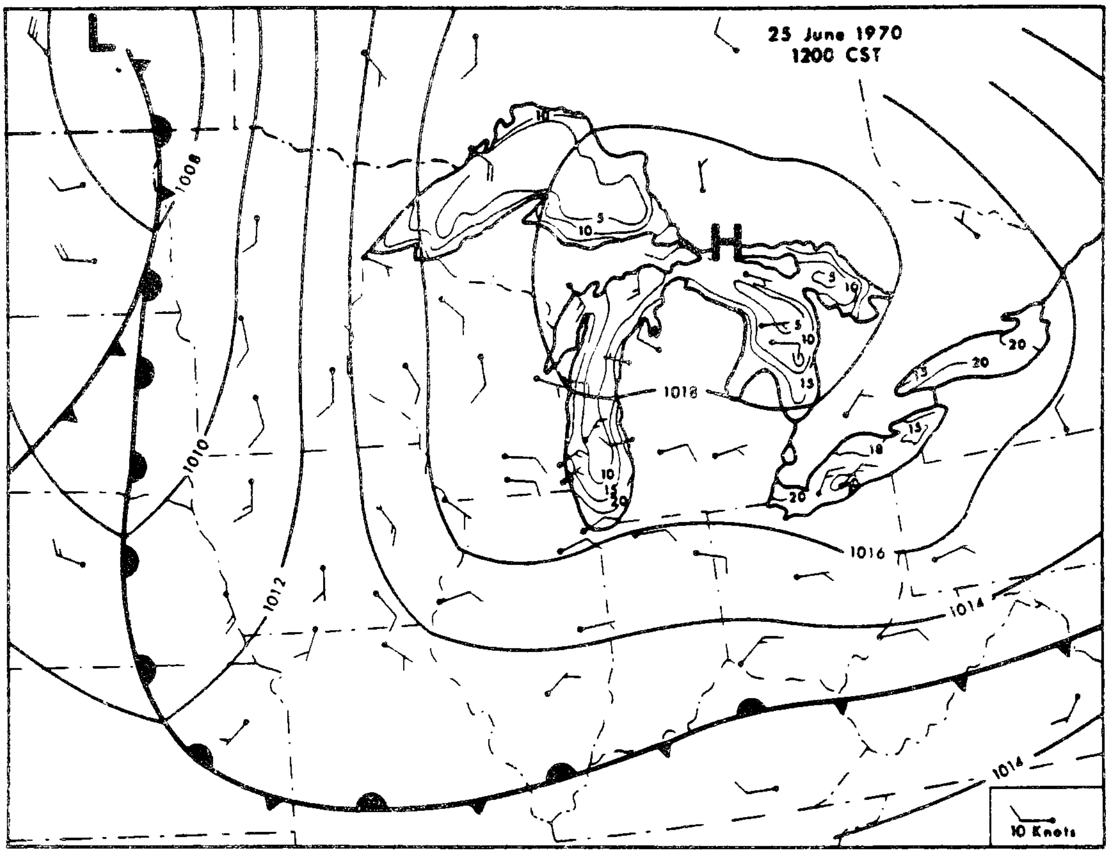

FIG. 7. Synoptic chart for 1200 CST 25 June 1970 with isobars every 2 mb, and 5C water surface temperature isotherms

only 20 m in height above the ground, but instead of fanning as the power plant plume did, it exhibited marked looping

On this cloudy day the air temperature at the beaches was 7C, and an automobile traverse normal to the shoreline showed less than a 1C increase in 10 km as the air flowed inland. In other words, there was virtually no remodification of the lake air on the western shoreline. In an attempt to measure the gross thermal structure of the atmosphere at the lake shore, the aircraft's cockpit air temperature was monitored during a stepwise assent over the shoreline from the surface to ~700 m. It was found that the lapse rate was very close to dry adiabatic in the bottom 150 m but there was a strong capping inversion to approximately 600 m height above the lake, topped by a layer of more nearly neutral lapse rate. It appears that the stable layer between 150 and 600 m was, in fact, the nocturnal inversion that existed when this air mass had left the eastern shoreline early that morning. The nearly neutral surface layer most likely developed during the last few kilometers of fetch over the water where the surface water temperatures had rapidly increased from about 5 to 15C in a matter of 10 km. This warm inshore water destroyed the intense conduction inversion which had probably been present close to the surface in the middle of the lake.

Fig. 6a is a schematic diagram showing the conditions on 27 May. Shown are the elevated power plant plume and the low-level plume from the fertilizer plant The power plant plume is being emitted into the stable air aloft and moves inland with relatively little vertical diffusion. A radically different situation (plume trapping) occurs close to the surface. There, the air is relatively turbulent and pollutants released within this shallow layer experience a rather large degree of mixing, especially in the horizontal. Furthermore, there is virtually no warming of this air mass as it travels inland, with this condition maintaining itself for many tens of kilometers. Since the effective mixing height is extremely limited, very high pollution concentrations would be expected at the ground. By contrast, the

both high- and low-level sources, each at their respective effective plume height H. 6d. Calculated ground level ($z=0$) SO_2 values below the plume centerline for both sources.

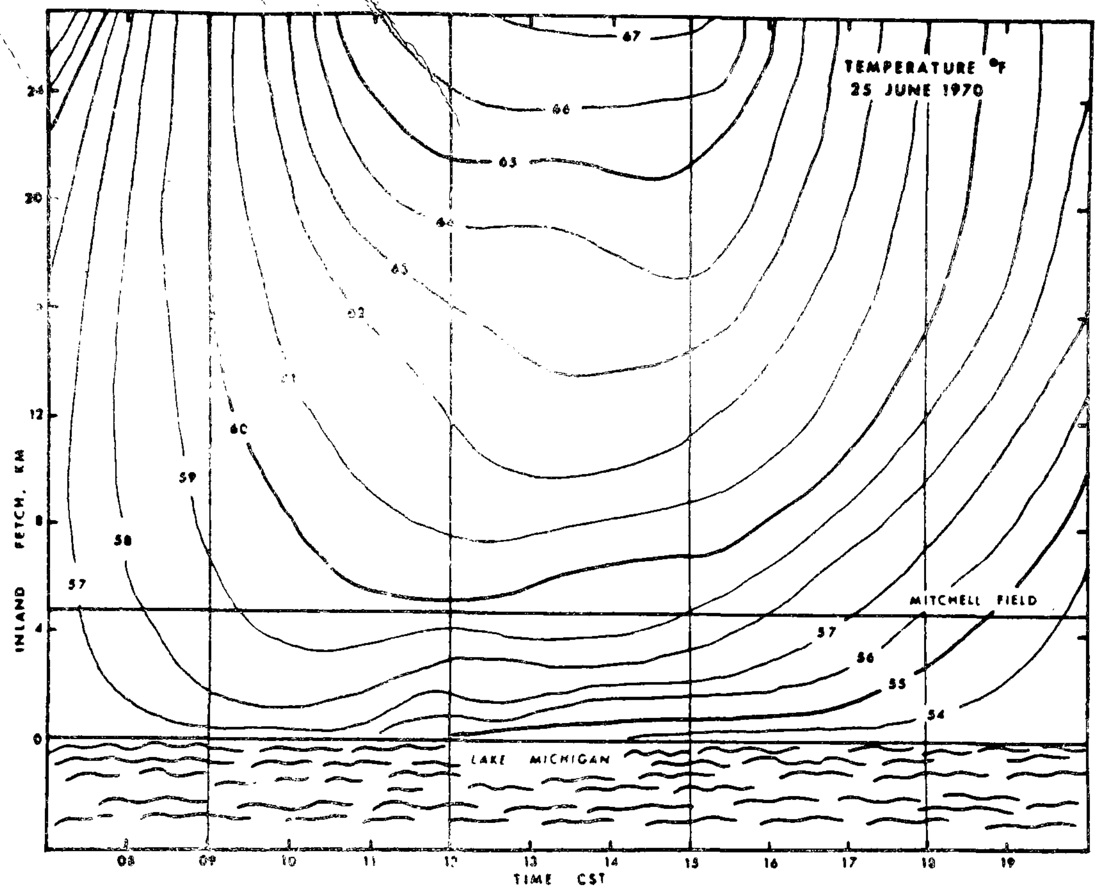

FIG. 8. Smoothed isotherms of all air temperatures collected on 25 June 1970 and plotted as a function of time and wind fetch inland from the shore. The nearshore water temperatures varied from 52 to 55F.

power plant plume in the stable layer aloft was observed to travel westward as far as the eye could see. It is unlikely that any of the power plant plume material ever reached the surface during this period.

b. 25 June 1970: Fumigation

On this date, synoptic conditions were quite similar to those described above with a notable exception that the area was largely free of heavy cloud cover save for some fairly dense cirrus moving down from the northwest later in the day. From the maximum temperature isotherms (Fig. 3), it is evident that considerable warming of the lake air occurred within the first few kilometers of overland fetch. Fig. 7, at 1200 CST, shows a large high centered over northern Lake Huron promoting easterly flow at the surface over Lake Michigan. Maximum daytime air temperatures in Michigan and Wisconsin away from the lake ranged upward to 25C, compared to lake water temperatures as low as 5C near the center (Fig. 3). It is likely that easterly flow from the Michigan shoreline during the day produced a rather strong conduction inversion over mid-lake. However, again due to the warmer water in the final stages of the air's passage over the lake, a shallow neutral layer was found close to the surface. Likewise, a strong capping inversion was found at higher levels, as on 27 May. The surface air temperatures warmed rapidly as the air advected inland on the western shoreline. Fig. 8 shows the analysis of surface air temperatures as a function of time of day and distance inland from the shore. These data were obtained from the NWS station at Mitchell Field, some 5 km inland, and from numerous hygrothermographs at colleges and industrial facilities throughout the area. Furthermore, 10 students from the University of Wisconsin-Milwaukee, armed with sling psychometers, traveled predetermined routes measuring air temperature. The representation used in Fig. 8 is very useful; it shows at a glance the temperatures experienced at any inland point as a function of time and also the temperature gradient on a line parallel to the wind direction as it flowed inland. The surface winds were generally from 060°, becoming somewhat more easterly later in the afternoon. Fig. 8 shows that the temperature remained nearly constant at the shoreline,

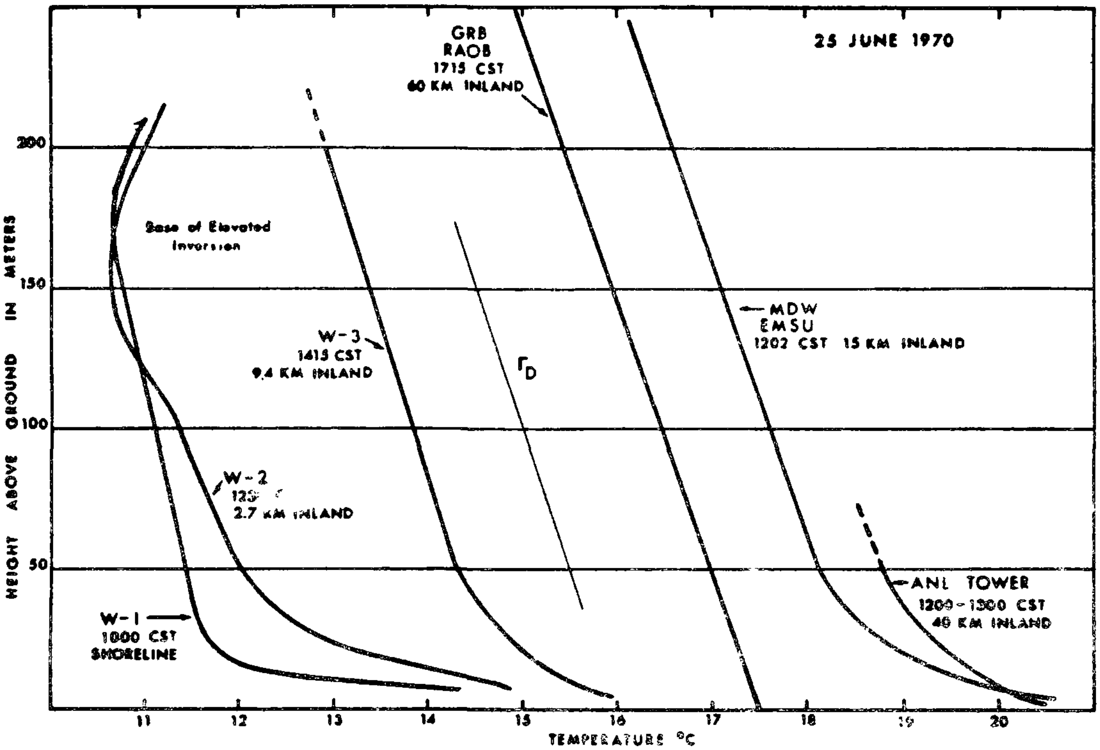

FIG. 9. Low-level soundings obtained at various locations on 25 June 1970. W-1, W-2 and W-3 refer to three wiresonde runs made at the shore, 2.7 km inland, and 9.4 km inland. Included for comparison are the 1715 CST raob ascent from Green Bay (GRB) and the 1202 CST EMSU run from Chicago's Midway Airport (MDW), and the micrometeorological tower data from Argonne National Laboratory, 40 km west of Chicago.

and that the temperature gradient reversed itself after sunrise, from initially cooler temperatures inland to considerably warmer by early afternoon. The air warmed by about 6C after traveling ~25 km over the heated land. Heating of up to 20C in the same distance is often found on those days with very strong insolation.

Of greater interest to our study, however, are the vertical temperature profiles as a function of distance from the lake. A wire sounding system transported by truck was used to determine low-level temperature profiles. Soundings were taken at several fixed locations along a road normal to the shoreline. The first sounding made at the shoreline (W-1 in Fig. 9) revealed a nearly neutral layer almost 160 m deep coming onshore during early morning, with a superadiabatic lapse in the lowest 25 m. Above this turbulent surface layer was a strong inversion extending upward to approximately 800 m above the lake (indicated by aircraft temperature cockpit readings; see Fig. 10a). As the air moved inland over the warm ground the unstable layer, or thermal boundary layer (TIBL), deepened rapidly. This is shown by soundings W-2 and W-3 taken at 2.7 and 9.4 km inland. A late afternoon sounding at the shoreline showed relatively little change in the thermal characteristics of the air flowing onshore during the course of the day. In Fig. 9, a plot of the wire soundings, a sounding obtained by the Chicago Midway EMSU low-level radiosonde, and the Argonne National Laboratory micrometeorological tower data showed a superadiabatic layer in the lowest 50 m overlain by a deep neutral layer. Both sites are located 15 km inland. The Green Bay (GRB) radiosonde, sufficiently far inland to be undisturbed by lake effects, showed the adiabatic layer (the mixing layer) to extend to about 1500 m late in the afternoon. The top of the TIBL is generally considered to increase in depth in a quasi-parabolic manner as the air flows inland (Bierly, 1968). Observers in our single engine spotter aircraft kept notations of the locations where turbulence was encountered (Fig. 10a).

On 25 June, the center line of the power plant plume reached an effective stack height of ~320 m as it flowed westward in a stable layer aloft. The top of the TIBL intercepted the plume about 7 km inland (Fig. 10a) where observers on the ground and in the air clearly saw particulate matter from the plume rapidly mixing downward. Those directly beneath the point of plume fumigation noted the extremely strong taste and smell of sulfur dioxide. On this day the fumigation continued from 0930 to 1430, after which the cirrus overcast quickly reduced ground heating and the TIBL turbulence no longer penetrated to plume

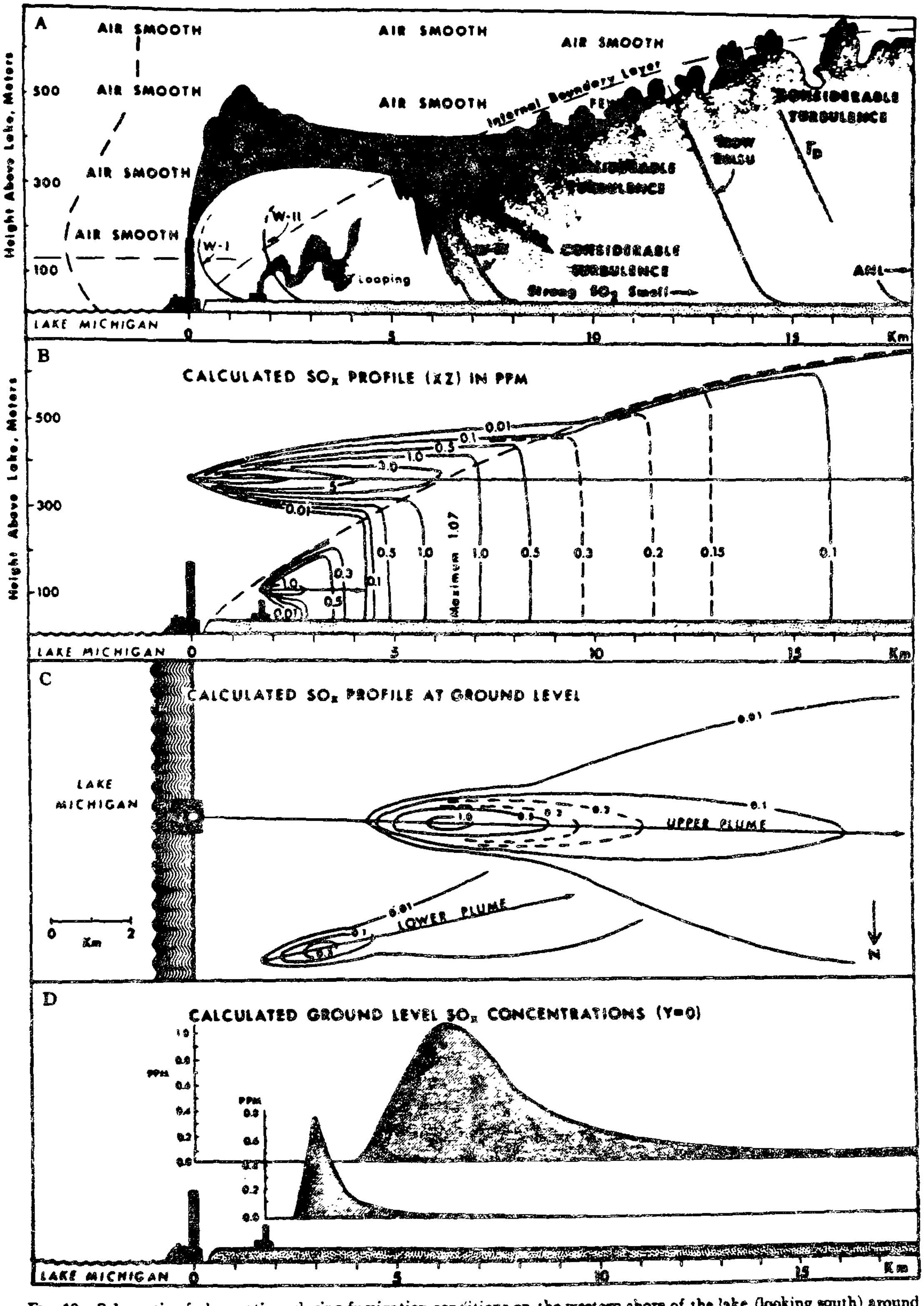

FIG. 10a. Schematic of observations during fumigation conditions on the western shore of the lake (looking south) around 1400 CST 25 June 1970. Plotted are the reports of turbulence encountered by the spotter aircraft, plus the approximate temperature profile over the water. 10b. Computed profiles of SO_x concentrations from both high- and low-level sources in

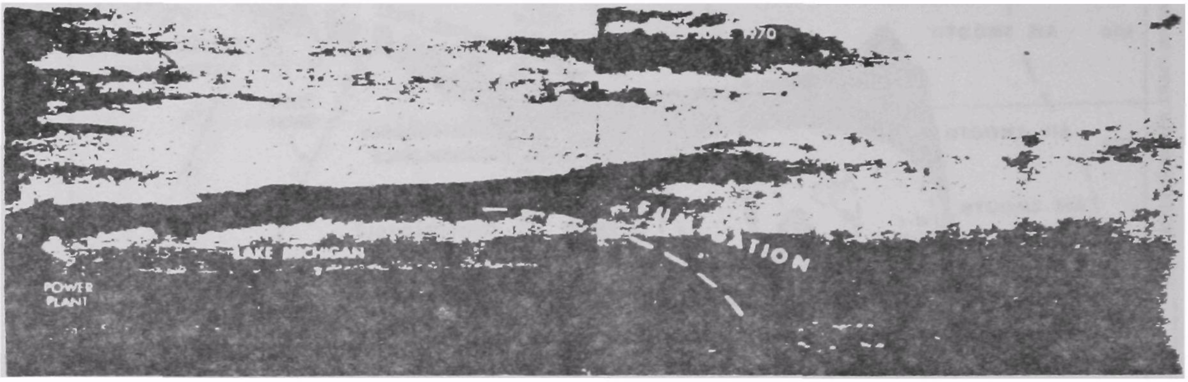

FIG. 11. Panoramic view of fumigating power plant plume at 1430 CST 25 June 1970, looking east through south toward shoreline from a point about 10 km inland, 700 m above ground.

altitude. During the late afternoon the plume remained aloft and advected many tens of kilometers inland with little lateral or horizontal dispersion, much like on 27 May.

During the first portion of the day while the power plant fumigation was occurring, the effective stack height of the low-level fertilizer plant was below the top of the TIBL at all times. It exhibited marked looping and diffused rapidly within the deepening turbulent boundary layer.

Fig. 11 is a panoramic aircraft photograph of fumigation from the power plant plume. On this particular day the fumigation began 7 km inland, although on days with stronger insolation, it has been seen within 2-3 km of the shoreline. Fig. 12 is an end-on view of the low-level plume resembling that of 27 May except that it mixed within a greater depth as it flowed inland due to the increasing depth of the TIBL.

3. Calculations of pollutant concentrations

Unfortunately, very little ambient air monitoring has been done near the power plant in question. It is, however, possible to estimate pollutant concentrations by using the relatively simple diffusion equations summarized by Turner (1969). While having their imperfections, they have been widely used for ball-park estimates. The following is meant to be more illustrative than conclusive (in terms of absolute values of pollutants), but it clearly points the finger at areas needing immediate attention.

a. Dispersion in a homogeneous, infinite atmosphere

In an atmosphere where the stability (turbulence) classes are more or less uniform in the space occupied by a plume, it is commonly assumed that plume matter spreads horizontally and vertically from the center line in a Gaussian profile. The basic equation can be written

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

where χ is pollutant concentration, Q is the source strength (mass per unit time), σ_y and σ_z the lateral and vertical standard deviations of concentrations within a Gaussian plume (implicit functions of x), u the mean wind speed, x, y, z the axial, transverse and vertical directions, H the effective stack height (plume centerline), $a=0.693$, and ξ the half-life of the pollutant (assumed 3 hr for SO_2). For particulates, no fallout or reaction is assumed and the half-life exponential term drops from the equation.

The values of σ_y and σ_z, empirically derived by Pasquill (1961) and Gifford (1961) from actual observa-

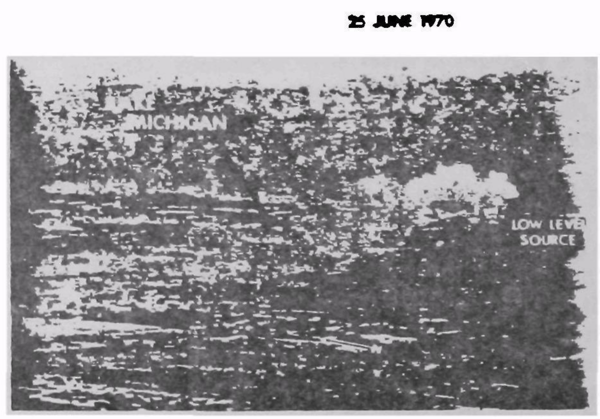

FIG. 12. View toward the east-northeast of low-level plume at 1420 CST 25 June 1970, from about 7 km inland and 700 m above ground.

the x, z plane along plume centerline. 10c. Computed SO_2 concentrations in x, y plane at ground level ($z=0$). 10d. Computed ground level SO_2 concentrations below plume centerline ($z=y=0$).

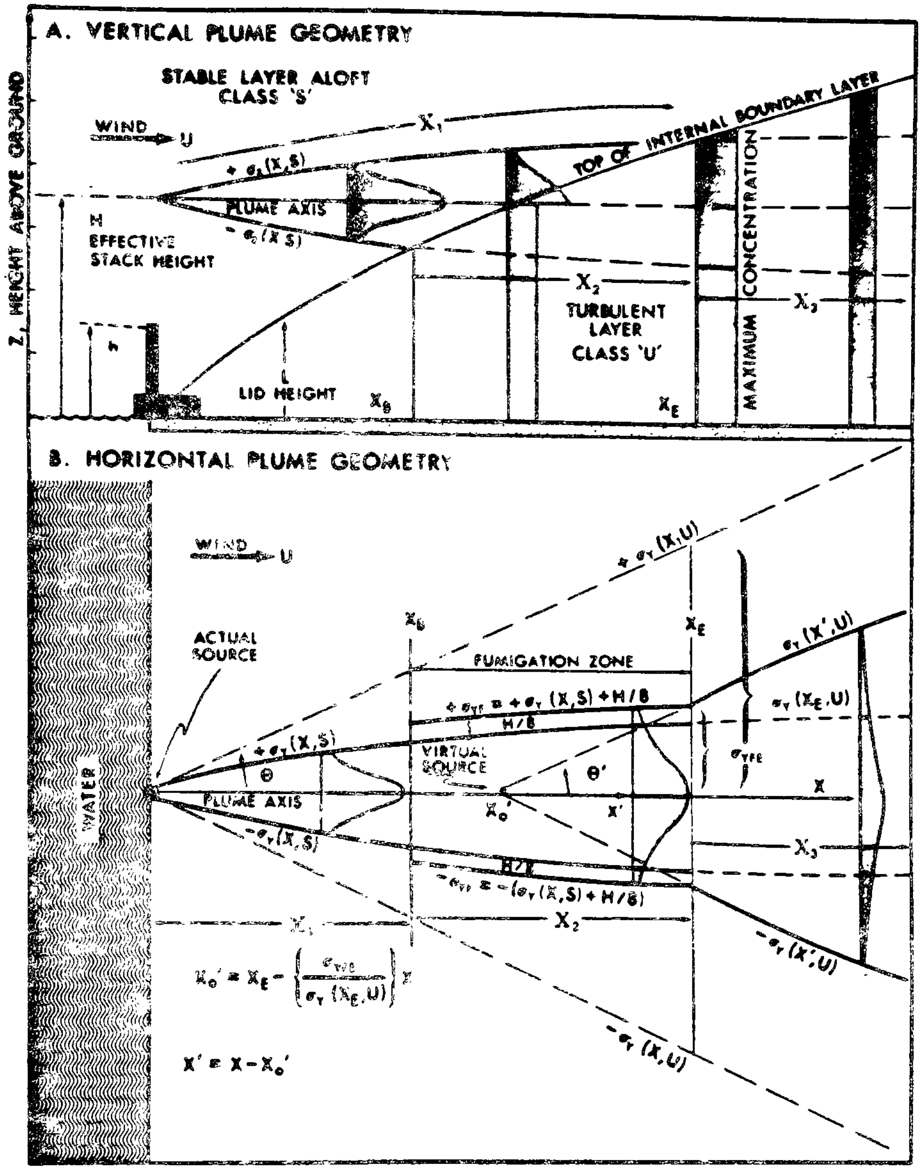

FIG. 13. Geometry used in the calculation of pollutant concentrations during periods of continuous fumigation. See text for explanation.

tions, are grouped into six subjectively determined stability classes ranging from Class A (extremely unstable) to Class F (moderately stable). The application of (1) here assumes the ground is flat. While the western shore of Lake Michigan around Milwaukee does have steep bluffs about 30 m high, the ground has virtually no relief and a negligible slope for many miles inland.

b. Modeling plume trapping

If the mixing layer into which a plume was being emitted were not of infinite (or at least very great) depth, then vertical plume dispersion would be restricted by the overlying lid (usually the base of stable inversion layer aloft) at some distance downstream. Turner (1969) presents a scheme for calculating $\chi\ (x,y,z:H)$ for a plume trapped within a layer bounded by the surface and a discrete upper lid limiting the diffusion. After a given distance downwind from the source, the vertical concentration profile begins a transition from Gaussian to uniform. Horizontal dispersion is assumed to behave in a Gaussian manner throughout this process for all values of x. With Eq. (1) as is, and modified for a lid, it is possible to simulate the dispersion regime found on the western shore of the lake on 27 May 1970.

c. Modeling continuous plume fumigation

Turner describes a mathematical technique for predicting surface concentrations for the case of nocturnal inversion breakup fumigation, which causes unusually high pollutant concentrations for a short period of time. The shoreline fumigation is by contrast almost a steady-state process, and the procedure outlined below was used to modify Turner's technique for this specific application.

The dispersion regime downwind of an elevated source at the shoreline was divided into three zones. Separate equations (see Fig. 13) are used to compute $\chi_1\ (x,y,z:H)$; $\chi_2\ (x,y,z:H)$; $\chi_3\ (x,y,z:H)$. The first zone [in which $\chi_1\ (x,y,z:H)$ applies] is essentially the same as described in Section 3a, where an elevated plume is emitted into a homogeneous, relatively stable layer. For any part of the plume above the TIBL, (1) is rewritten, using $\sigma_z(s,x)$ and $\sigma_y(s,x)$ for the standard deviations for plume spreading in stable air (s), here explicitly written as functions of downwind travel (x) from the source ($x=0$).

The second zone [where $\chi_2\ (x,y,z:H)$ applies] is that portion of the area where $x_b \leqslant x \leqslant x_e$ and $z \leqslant L(x)$, $L(x)$ being defined as the (variable) height of the TIBL upper boundary. Point x_b occurs where $L(x)=H-2.15\sigma_z(s,x)$, that is, where the turbulence is just beginning to disturb the lower portion of the plume. At point x_e, $L(x)=H+2.15\sigma_z(s,x)$, and the bulk of the plume has been mixed into the deepening TIBL. In the area $x_b \leqslant x \leqslant x_e$, the profile of concentrations below $L(x)$, that is, within the turbulent mixed layer, is considered to be uniform in the vertical (though still Gaussian in the horizontal). Thus, for $z \leqslant L(x)$, concentrations are found by

$$\chi_2(x,y,z:H) = \frac{Q\exp(-ax/\xi u)}{(2\pi)^{\frac{1}{2}}\sigma_{yf}(s,x)uL(x)}\left[\int_{-\infty}^{p}(2\pi)^{-\frac{1}{2}}\exp\left(-\frac{p^2}{2}\right)dp\right] \times\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_{yf}(x,s)}\right)^2\right], \quad (2)$$

where

$$p=(L(x)-H)/[\sigma_z(s,x)], \quad (3)$$

$$\sigma_{yf}(s,x)=\sigma_y(s,x)+(H/8), \quad (4)$$

and $\sigma_{yf}(s,x)$ is the standard deviation in the y direction that applies in the fumigation zone $x_b \leqslant x \leqslant x_e$. It is used in place of $\sigma_y(s,x)$ in order to correct for the additional horizontal spreading that results from the intense mixing that is occurring at this time (Bierly and Hewson, 1962). Maximum ground level concentrations are predicted at distance x_e from the source. At this distance, the entire plume is assumed to have been mixed into the unstable boundary layer.

Zone three is essentially the same as plume trapping except that the lid height is variable. Concentrations are assumed to be uniform in the vertical below the lid. However, complications arise in the choice of appropriate σ_y values in this zone. Since the entire plume is now within the unstable layer, $\sigma_y(u,x)$ values based on x, the distance from the plume source, are unreasonably large since the unstable condition only begins affecting the plume between x_b and x_e. The use of $\sigma_y(u,x)$ based on actual distance from the source would grossly overestimate the lateral dispersion. More realistic plume widths and concentrations are estimated from $\sigma_y(u,x')$, a standard deviation based on x', the distance downwind from a virtual point source that lies between x_b and x_e. A schematic of the geometry used to define the virtual plume source is shown in Fig. 13b, where in the x, y plane, two plume boundary lines for the unstable case are shown. These lines represent $\sigma_y(u,x)$ and $\sigma_y(u,x')$, the former originating at the actual source, the latter at the virtual point source, x_0'.

As drawn here, both lines are assumed to be straight and parallel (for $x \leqslant x_e$), an assumption which can be accepted, and which allows a simple trigonometric determination of x_0'. The distance downwind of the virtual source is found by noting that

$$x'=x-[x_e-(x_e-x_0')]; \quad (5)$$

x_0' can be derived from the trigonometric identity

$$\tan\theta'=\sigma_y(u,x_e)/x_e=\sigma_{yf}(s,x_e)/(x_e-x_0'), \quad (6)$$

where θ' is the angle made by the intersection of the $\sigma_y(u,x')$ line and the plume centerline.

Thus, for zone three, concentrations are estimated by

$$\chi_3(x',y,z:H)=\frac{Q\exp(-ax/\xi u)}{(2\pi)^{\frac{1}{2}}\sigma_y(u,x')L(x)u} \times\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y(u,x')}\right)^2\right]. \quad (7)$$

In this equation, $\sigma_y(u,x')$ is based on x', the distance downwind of the virtual point source x_0'.

4. Results of numerical simulation

The calculations were made on a UNIVAC 1108, using a 33 m vertical grid spacing (about the effective plume centerline, $z=H$), and 100 m horizontal grid spacing. The program was run to simulate behavior of plumes from the two sources discussed above. The power plant, rated at 1350 MW, has four stacks, two at 45 m above the lake, a third at 137 m, and the fourth at 167 m. At the time of this research only one of the stacks, the tallest, did not have an electrostatic precipitator operating. The smoke in the various photographs came only from the tallest stack, and usually had a density of between number 2 and number 4 on the Ringlemann scale. Using data published in the 1969 Emission Inventory of Milwaukee County, this power plant was rated to have an approximate source strength

(Q) of 10,000 tons year^{-1} for particulates, and 130,000 tons year^{-1} for sulfur oxide.[3] The low fertilizer plant stack has a height of approximately 20 m above ground. No source strength data whatsoever were available for this plant, but for the purpose of comparison it was arbitrarily assumed to have outputs equal to 5% and 20% of the power plant's, for sulfur dioxide and particulates, respectively.

a. 27 May 1970

The plume behavior for 27 May 1970 from these two sources was modeled. The lower level point source had an effective plume height estimated at 100 m above ground level and was trapped within the shallow turbulent layer only 135 m deep. A mean wind speed of 6 m sec^{-1} was taken from the Madison pibal sounding at 1800 CST. The stability class in the stable inversion layer aloft was taken to be the most stable available, Class F, and within the plume trapping layer close to the surface, Class B was applied.

Fig 6b shows vertical cross sections, i.e., x, z profiles of SO_x concentrations, along the $y=0$ axes of both plumes. As can be seen, the predicted plume from the power plant at no time extends anywhere near the surface, corresponding to visual observations. The SO_2 from the low-level source decreases to almost background levels after some 15 km of fetch inland, but not before having rather high peak values at the surface just downwind of the source.

Fig. 6c shows the calculated x, y profiles of SO_x at the respective plume levels (H) for both plumes. Fig. 6d are the calculated ground concentrations ($z=0$) beneath the respective plume axes ($y=0$). Virtually no sulfur oxide from the power plant plume is predicted to reach the surface at any point. However, at a distance of 0.5 km downwind of the low level source, a peak of 0.28 ppm SO_x was predicted.

The models clearly illustrate that under the type of conditions that existed on 27 May 1970 a high stack would be of considerable benefit. Any pollutant emitted into the stable layer would continue to reside there as it advected many tens of kilometers inland. On the other hand, sources emitted into the shallow turbulent layer above the surface would become trapped within this layer resulting in inordinately high concentrations even from relatively small sources. These conditions appear to be quite typical for any period of stable onshore flow along the shores of the Great Lakes on a cloudy day or during nighttime.

b. 25 June 1970

Conditions for 25 June 1970 included a mean wind speed U of 6 m sec^{-1}, and an observed effective stack height H for the power plant of 320 m above the ground.

[3] Since the field observations were made, electrostatic precipitators have been installed, greatly reducing the power plant's particulate emissions.

In this case, the top of the TIBL, $L(x)$, was read into the program as a look-up table It is shown as a dotted line in Fig. 10a and was determined from the wire soundings and by a plot of turbulence encountered by the spotter aircraft. The turbulence first encountered the plume (x_b) at 5 km inland and reached the plume's upper portion (x_e) at 6.8 km inland—the point of expected maximum fumigation. In the computations, Class F stability was assumed above the TIBL and Class A (considerable turbulence) was chosen for the region below the TIBL. The same source strengths (Q) were used as in the previous section.

Fig. 10b illustrates the calculated SO_x profiles in the x, z plane along the plume centerlines ($y=0$). Fig. 10c shows the calculated ground level SO_x concentrations in the x, y plane for the two plumes studies For the high-level power plant plume there are essentially no surface effects until a point at least 5 km inland under these conditions. The model calculates maximum concentrations of 1.07 ppm at 6.8 km inland and estimates that an area of several square kilometers will exceed 0.5 ppm SO_x. This fumigation spot, as one might call it, will tend to move around with variations in wind direction during the day. It will also tend to move in and out along the plume axis as the intensity of insolation increases and wains during the course of the day. Note also that the model for the low-level source, even though rated at 5% of the power plant emissions, does calculate a rather high peak value of 0.77 ppm. Fig. 10b shows the ground-level calculated SO_x profiles beneath the centerline of both plumes. While it is obvious that a high stack does indeed help to ameliorate the extreme surface concentrations under these fumigation regimes, unless the plume can rise entirely above the maximum TIBL level reached during the day, a high stack only moves the fumigation spot inland and somewhat reduces its intensity, but it does not eliminate it.

It is unfortunate that at the time the above observations were made there were no adequate surface monitoring devices for sulfur oxides in the areas of interest. State officials, at one time, in attempting to monitor the effects of this power plant, had a continuous monitoring SO_2 device located approximately 1.5 km southwest of the stack—obviously of little help for detecting fumigation episodes. During 1971, however, some limited monitoring of surface SO_2 concentrations was undertaken during fumigation of the power plant plume. On 28 May 1971, a day almost identical to 25 June 1970, at a point some 8 km southwest of the plant, concentrations as high as 9 ppm were measured using a modified West-Gaeke method. These were samples taken for about 10 min duration directly beneath the fumigating plume centerline. Additional readings taken in August 1971 yielded similarly high ground level concentrations. While the monitoring is of a preliminary nature, it appears possible that the calculated SO_2 concentration estimates are on the conservative side. The observers who had the misfortune of taking the SO_2 observations reported a strong odor, taste, and definite irritation of the nose and mouth.

Calculations of suspended particulates were also made using the same equations. Fig. 14a shows a vertical (x,z) profile of suspended particulates ($\mu g\ m^{-3}$) for both sources. As with the SO_x the high-level power plant plume stays entirely aloft. The lower plume remains trapped at low levels producing significant particulate values within several kilometers of the source at the surface. Fig. 14b shows the calculated particulate x, y profiles at $z=H$ for both plumes on 27 May 1970. Fig. 14c shows the x, z profiles for particulates during the 25 June 1970 fumigation case. Fig. 14d gives the calculated ground level ($z=0$) concentrations of particulates from both plumes. Due to the fairly high degree of control present on the power plant stack as far as particulates were concerned, the predicted peak ground level concentrations are not excessive, only 215 $\mu g\ m^{-3}$. The low-level source yields quite high particulate concentrations at the surface, almost 400 $\mu g\ m^{-3}$, 1.6 km downwind.

An estimate of the overall patterns that result from these regimes can be made from the analysis of the 24-hr high-volume sampler data taken in Milwaukee County on both days. Fig. 15a shows the average suspended particulate readings measured at ten sites through Milwaukee County on 27 May 1970. It can be seen that the air coming in off the lake had values of 20 $\mu g\ m^{-3}$, close to the typical background level found in this area. High-level plumes from major point sources located in the industrial valley that runs through the center of Milwaukee were kept aloft in the stable capping inversion. Numerous low-level sources became trapped close to the surface and produced average values in excess of 90 $\mu g\ m^{-3}$. No sulfur dioxide was recorded in any of the three monitoring sites within the county.

On 25 June 1970 (Fig. 15b) the surface pattern of suspended particulates looks very much the same. The air coming in off the lake had values close to 30 $\mu g\ m^{-3}$, but as it passed through the industrial area, it rapidly accumulated suspended particulates to produce a 24-hr average of close to 90 $\mu g\ m^{-3}$ downwind of the major industrial valley. In this case both the high- and low-level sources were mixed together through the TIBL which was progressively deepening as the air flowed inland. Two stations reported significant sulfur dioxide concentrations during the day, presumably from high-level sources fumigating to the surface.

5. Conclusions

Fumigation and plume trapping are not new phenomena to the air pollution meteorologist. However, their frequency and intensity near the shores of the Great Lakes pose special problems to air quality regions in these areas. The Air Quality Display Models (AQDM) which are used to model air quality and implementation strategies for various areas across the country generally use mean mixing depths supplied from a climatology based upon standard radiosonde network data. By interpolating values between Green Bay, Wisc., and Peoria, Ill., the mean summer mixing depth should be approximately 1500 m in the Milwaukee area. However, since neither of these radiosonde stations are affected by the presence of the Great Lakes, it is obvious that inappropriate data is being put into the AQDM. In fact, during the summer on many days a value for the mean mixing depth of $\frac{1}{10}$ the above would probably be more appropriate near the shoreline. Furthermore, if local air pollution forecasting in the vicinity of the Great Lakes is to be successful, the low-level EMSU radiosonde stations should be put in very close proximity to the shoreline. Currently-operating stations are too far inland to regularly observe the intense lake inversions. The Chicago EMSU radiosonde is usually launched some 15 km inland at Midway Airport.

It is important to emphasize that the type of extreme episode that can result from plume fumigations of the types described here would very frequently be associated with synoptic-scale patterns that appear to promote good dispersion. Fumigation could occur on a day when an Air Stagnation Advisory is least likely to be issued. In fact, the sunniest days with generally good dispersion over land are precisely the days with strongest plume fumigation on the lee shore of a Great Lake. As it is now written, the emergency episode plans for the southeast Wisconsin Air Quality Control Region do not take into account the intense short-burst problems associated with large point source plume fumigations. Even though episodic levels affect areas of only several square kilometers, they can very frequently occur in areas with very high population density.

This study, though admittedly preliminary, suggests some obvious problems for those concerned with locating permanent pollution monitoring stations in areas adjacent to the Great Lakes. It also raises the much larger question of what zoning restrictions should be placed on the future development of shoreline areas.

The conditions associated with plume trapping during spring must also be considered in terms of some future proposed developments on the western shore of Lake Michigan. As a result of the ongoing dispute about thermal pollution of the lake by fossil fuel and nuclear power plants, a move is underway to require the installation of cooling towers. One wonders what might happen if a large wet cooling tower were placed along the shoreline on a day such as 27 May 1970. Wet cooling towers frequently emit several tens of thousands of gallons of water into the atmosphere every minute. The fog formed may drift inland for many miles diffusing only very slowly, presenting a hazard to road travel, aircraft operations from nearby airports, and

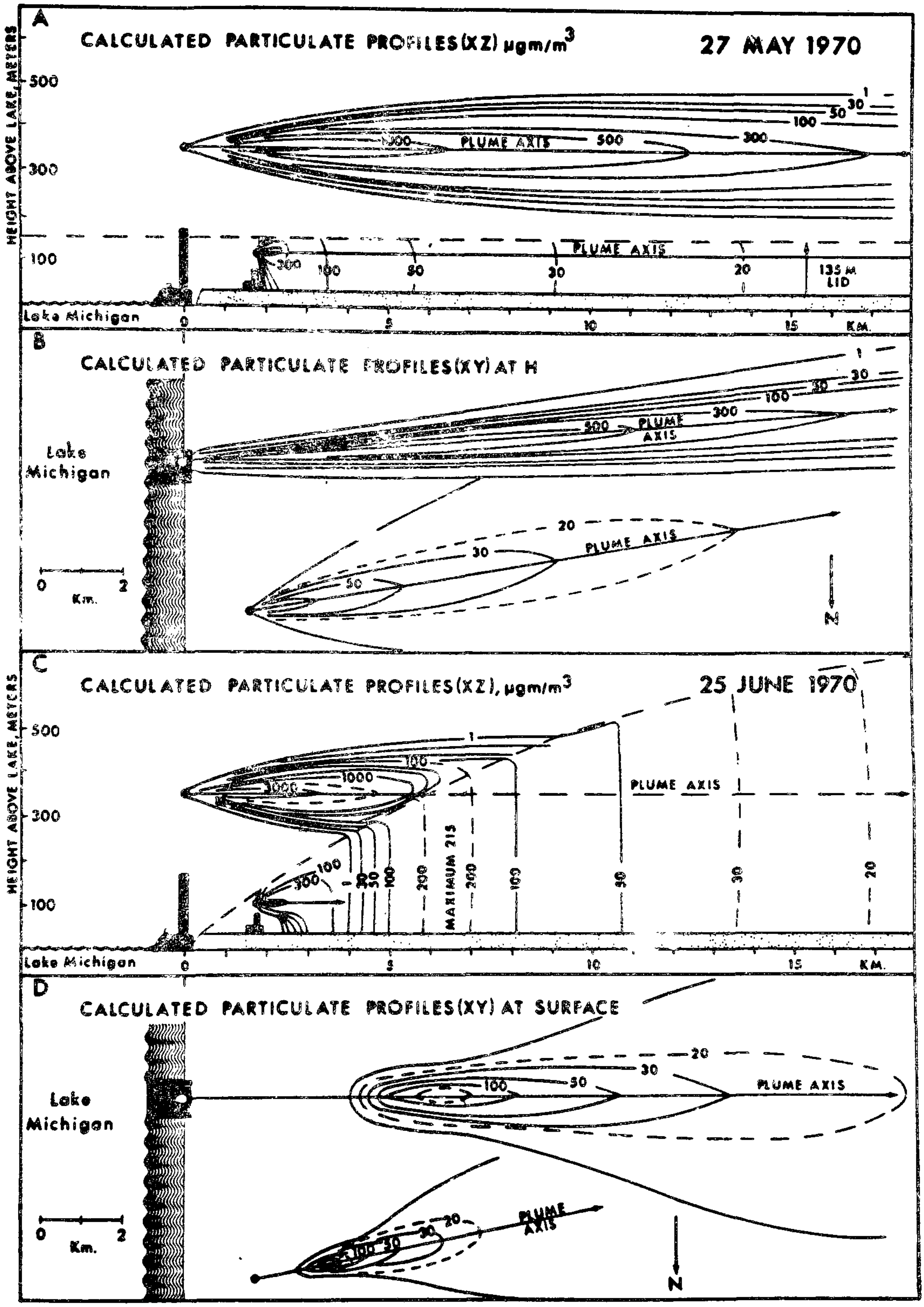

FIG. 14a. Computed suspended particulate concentrations (μg m^{-3}) in x, z plane along plume centerline from both sources representing conditions on 27 May 1970. 14b. Patterns in x, y plane of both plumes at their respective equivalent

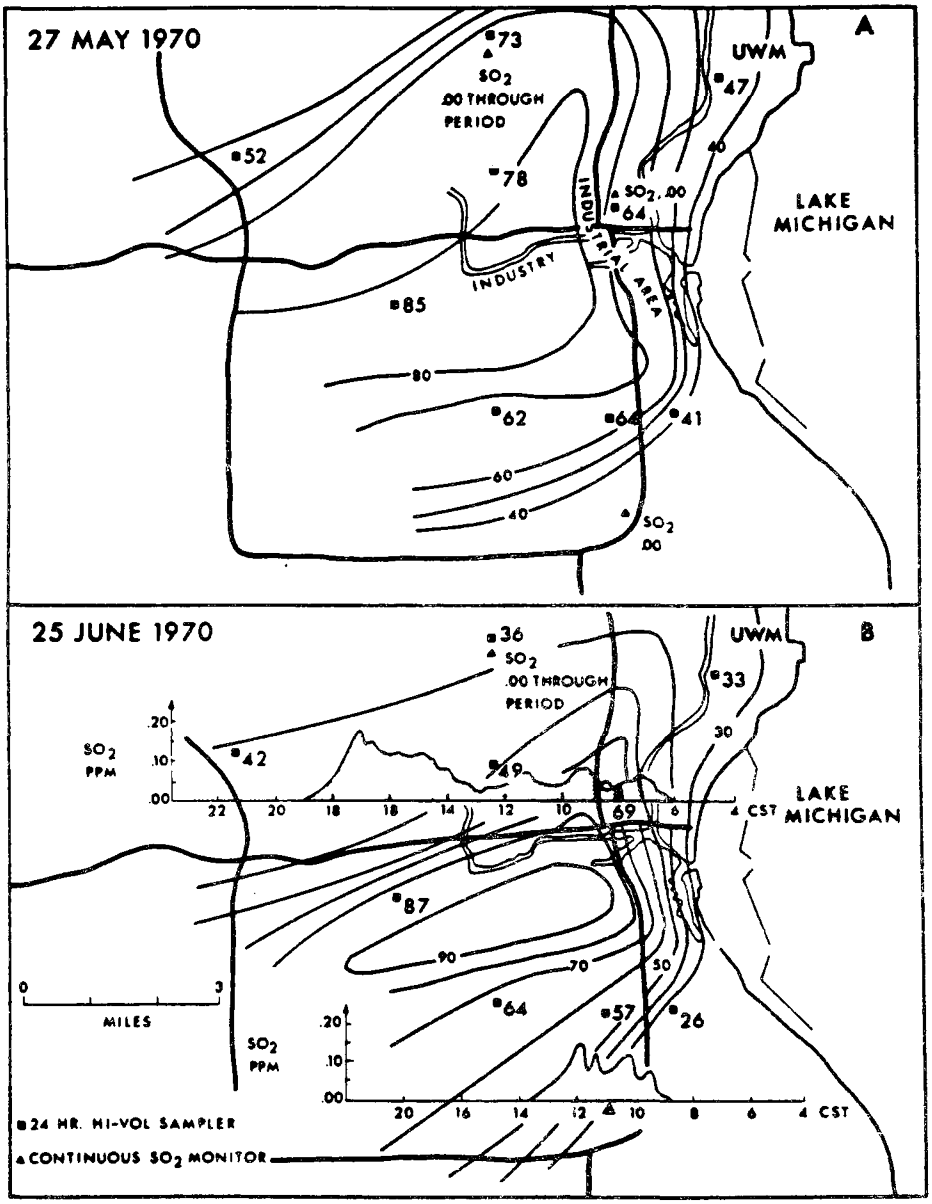

FIG. 15. Analysis of 24 hr high-volume particulate sampler readings ($\mu g\ m^{-3}$) in the vicinity of downtown Milwaukee (heavy lines are major expressways), for 27 May and 25 June, 1970, as well as traces of continuous SO_2 monitoring stations for 25 June.

during winter, perhaps, result in icing conditions. Dry cooling towers may represent a wiser choice.

In the Chicago area, Lake Michigan itself has been considered the probable site for a major jetport, to be built on a landfill approximately 5 mi offshore southeast of downtown Chicago. With winds from the east to southeast, which occur on more than half of all spring and summer afternoons at the Chicago shore, the highly odoriferous fumes from the jet aircraft fueling, taxiing, and taking-off would be trapped close to the surface and drift inland directly onto a highly populated shoreline. Unless significant advances in eliminating the more offensive components of jet exhausts are made, Chicago could have built itself a stench problem to rival the Chicago stockyards of days gone by. Furthermore, the large increase in shoreline automobile traffic

stack heights H. 14c. Same as 14a except for continuous fumigations conditions observed on 25 June 1970. 14d. Same as 14b except for continuous fumigation conditions of 25 June 1970.

that would accompany the operation of a jetport would have further aggravated any photochemical smog problem, thus adding injury to insult.

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A-2. On the Criteria for the Occurrence of Fumigation Inland from a Large Lake*

There is no doubt that the occurrence of the Thermal Internal Boundary Layer on the shores of large lakes presents adverse dispersion conditions which must be taken into account in evaluating the dispersive capabilities of such an area. However, the location and strength of the fumigation depend in a complex way on the form of the boundary, the height of the emission, the location of the source with respect to the boundary, the stability in the turbulent and the overlying layers, and the initial plume conditions, so that full scale modelling is necessary to derive meaningful results. This, it seems to me, makes reliance on oversimplified criteria inadvisable, especially when these are derived from theoretical models based on unverified or unrealistic premises.

Thus, in the Boundary Layer model of Peters the assumption is made that the land surface temperature remains unmodified by the advected air. In fact, due to the low conductive capacity of the land surface, as well as the solar heat input, such an assumption is unjustified (Priestley, 1959). The imposition of this boundary condition then leads to the prediction that the temperatures inland tend to stable stratification, contrary to observations such as those of Hirt *et al.* (1970).

In the derivation of the Flux Model, an oversimplification in the derivation of the energy balance equation leads to the result that the height of the Boundary [equation (8)] varies linearly with inland distance.

By considering the energy flux needed to modify the initial stably stratified layer to adiabatic conditions (which is certainly a more reasonable assumption) and assuming constant heat flux, it is found that

$$z^2 = \frac{2 q_h x}{\alpha c_p \rho u}.$$

where α is the potential temperature gradient in the stable air mass (Plate, 1971). By this method, one avoids prescribing the surface temperature. It is seen that the boundary height now increases as the square root of inland distance for given α. For the data of Hirt *et al.* the above relation with a value of $q_h = 100$ cal $m^{-2}s^{-1}$ predicts a height of boundary of 250 m at 10 km, in agreement with the observations.

The same value of q_h gives reasonable agreement with the data of Weisman and Hirt (1975) as outlined in Table 1.

* Peters L. K. (1975) *Atmospheric Environment* **9**, 809–816.

Table 1.

	α	ΔT(°C)	u(m s^{-1})	p(calc)	p(obs)
4 June	0·052	15	3·0	2·0	1·7
5 June	0·050	16	2·9	2·0	1·9
6 June	0·030	14	3·5	2·5	3·3
7 July	0·085	15	3·2	1·5	2·7
8 July	0·100	15	3·2	1·4	1·2
22 August	0·015	8	2·9	3·8	5·5

Here

$$p = \left(\frac{2q_h}{ac_p\rho u}\right)^{1/2}$$

and the observations are averages for the day indicated on the north shore of Lake Erie, where a parabolic boundary was observed to form quite regularly. (The power of x in $z = px^n$ varied from 0·37 to 0·67 with an average value of 0·50).

In using a model of the boundary to delineate criteria for the occurrence of fumigation, the location of the sources with respect to the boundary is crucial. This factor also influences the intensity of the fumigation, as does the level of turbulence in the boundary layer. In view of such considerations, the only reliable method available is to model the situation as was done by Lyons (1973) for example. Such modeling of the d[illegible] of Hirt *et al.* leads to good agreement with observations of SO_2 dispersion (Weisman and Hirt, 1975).

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AUTHORS' REPLY

We thank Dr. Weisman for his comments on our paper. However, there are several points that we feel should be clarified.

Weisman states that the constant land surface temperature boundary condition is unjustified. While there can be some argument for a constant flux boundary condition, the results of Moroz (1967) show that the temperature variations near the surface after the onset of lake breeze is only a few degrees centigrade. This leads one to conclude that the constant land surface temperature condition is probably the better compromise if one wants to maintain model simplicity until much more field data is available.

The second point made is that the imposition of the constant land surface temperature boundary condition leads to the prediction that the temperatures inland lead to stable stratification. This statement is inaccurate. The third boundary condition (i.e. for $z \to \infty$, $T = T_s + az$) leads to the stable stratification inland. This boundary condition could have been made more general by presuming $T = T_s + f(z)$ leading to other inland temperature profiles. The importance of this third boundary condition, however, is that the model development is limited to inland distances such that the thermal boundary layer is still contained within the initial stable stratification. We would not propose that this model would be valid for extremely large inland distances where the initial stable stratification is already dissipated.

After criticizing the simplicity of our model, Weisman then proceeds to show the thermal boundary layer depth for another model which is certainly no more complex. However, to obtain even rough agreement with the field studies of Weisman and Hirt (1975), an unacceptably high heat flux (100 cal $m^{-2}s^{-1}$) must be used.

Our boundary layer model predicts that the thermal well mixed layer, H^*, varies as

$$H^* = \left\{-\frac{4\epsilon_H x}{U}\ln\left[\frac{a-l}{T_s - T_w}\left(\frac{\pi\epsilon_H x}{U}\right)^{1/2}\right]\right\}^{1/2}$$

which is approximately a square root dependence for realistic system parameters. Values of p in agreement with Weisman and Hirt (1975) would correspond to using typical values of ϵ_H in our model in the range of 1–10 m^2s^{-1}. These are not unreasonable values for the eddy diffusivity (cf. Prophet, 1961; Smith and Niemann, 1969; Cowling and White, 1941).

We will show in a future paper that this general approach can also be extended to predict quite well the early morning inversion breakup.

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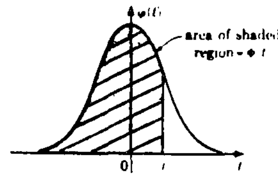
A-3. Cumulative Standardized Normal Distribution Φ(t)

CUMULATIVE STANDARDIZED NORMAL DISTRIBUTION Φ(t)

This table gives Φ(t) for various values of t.



t	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998

The entries from 3.49 to 3.61 all equal .9998.
The entries from 3.62 to 3.89 all equal .9999.
All entries from 3.90 and up equal 1.0000.

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16. ABSTRACT

The Student Workbook is to be used with course 423, "Dispersion of Air Pollution - Theory and Modeling Application", as designed and presented by the EPA Air Pollution Training Institute (APTI). The Student Workbook contains introductory material, lesson outlines, problem sets, and class exercises.

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