EPA-910/9-88-202

USER'S GUIDE FOR THE FUGITIVE DUST MODEL (FDM)

Prepared by:

Kirk D. Winges

Prepared for:

Region 10
U. S. Environmental Protection Agency
1200 Sixth Avenue
Seattle, Washington 98101

Project Administrator:

Robert B. Wilson

June, 1988

TRC

Environmental Consultants

21907 64th Avenue. W.
Suite 230
Mountlake Terrace, WA 98043

(206) 778-5003

A TRC Company

TABLE OF CONTENTS

1.0 INTRODUCTION

The Fugitive Dust Model (FDM) is a computerized air quality model specifically designed for computing concentration and deposition impacts from fugitive dust sources. The sources may be point, line or area sources. The model has not been designed to compute the impacts of buoyant point sources, thus it contains no plume-rise algorithm. The model is generally based on the well-known Gaussian Plume formulation for computing concentrations, but the model has been specifically adapted to incorporate a gradient-transfer deposition algorithm. Emissions for each source are broken into a series of particle size classes and each particle size class has a gravitational setting velocity and a deposition velocity specified for it. Either concentration or deposition can be computed at a series of receptor locations.

The model is designed to work with pre-processed meteorological data or with card-images of meteorological data either hourly or in STability ARray (STAR) format. In addition to a standard printed output, the model allows a "plotter" output file which consists of a series of records containing only the x-coordinate, the y-coordinate and an average concentration. This series of records is printed for each averaging time requested. The model allows printer and plotter output for 1-hour averages, 3-hour averages, 8-hour averages, 24-hour averages and a long-term average which is the average over the entire meteorological data base provided. Additionally, a sequential output tape for post-processing with the POSTZ program can be created. Up to 200 receptors can be processed, and up to 100 sources can be processed.

The sources can be of three types: points, lines or areas. The line source algorithm is based on the CALINE3 line source routine. The area source algorithm is also based on the CALINE3 routine. For area sources, the user supplies the coordinates of the center and the dimension in the x and y directions. Area sources need not be square, but rather can be rectangular, up to an aspect ratio of 1 to 5 (ratio of width to length). Area sources with the length greater than five times the width must be divided in a series of area sources, or modeled as a line source. The model divides the area source into a series of line sources perpendicular to the wind direction. Emissions from all sources may be divided into a maximum of 20 particle size classes.

2.0 TECHNICAL DESCRIPTION

Basic Equations

The Fugitive Dust Model (FDM) is a Gaussian-plume based air quality model specifically designed for the analysis of the dispersion of fugitive dust. The model incorporates a detailed deposition routine based on the equations of Ermak (1977). The basic equations as developed by Ermak are as follows:

$$C = \frac{Q}{2\pi\sigma_y\sigma_z u}\exp\left(\frac{-y^2}{2\sigma_y^2}\right)\exp\left[\frac{-v_g(z-h)}{2K} - \frac{v_g^2\sigma_z^2}{8K^2}\right]\left\{\exp\left(\frac{-(z-h)^2}{2\sigma_z^2}\right) + \exp\left(\frac{-(z+h)^2}{2\sigma_z^2}\right) - (2\pi)^{1/2}\frac{v_1\sigma_z}{K}\exp\left(\frac{v_1(z+h)}{K} + \frac{v_1^2\sigma_z^2}{2K^2}\right)\operatorname{erfc}\left[\frac{v_1\sigma_z}{2^{1/2}K} + \frac{z+h}{2^{1/2}\sigma_z}\right]\right\} \quad (1)$$

where:

C	=	concentration in g/m^3
Q	=	emission rate in g/sec
u	=	wind speed in m/sec
σ_y, σ_z	=	standard deviation of plume width in m
y, z	=	coordinates of horizontal and vertical location in m
v_g	=	gravitational settling velocity in m/sec
h	=	plume centerline height in m
K	=	eddy diffusivity
u_d	=	deposition velocity in m/sec
v_1	=	$u_d - v_g/2$

The above equation is transformed and manipulated in several ways by the model, prior to actually computing the concentrations.

Treatment of Meteorological Conditions

Meteorological data can be provided to the FDM in three formats: a sequentially processed meteorological data using the format produced by the RAMMET pre-processor, card images of hourly meteorological data or a statistically-produced Stability Array. If sequential meteorological data are used (either the RAMMET pre-processed format or card image format), the model requires average values over the shortest averaging period for wind speed, wind direction, atmospheric stability temperature and mixing height. Wind speed is used directly in the above equation to determine the concentration. Wind speed is also used in combination with temperature and atmospheric stability to determine the values for deposition velocity if the user asks the model to compute deposition velocity (the user can alternatively enter deposition velocities with the input stream). Wind direction is used to determine the location of the receptor with respect to the center point of each source in a coordinate system defined with the wind direction parallel to the x-axis.

Atmospheric stability is used to determine the values for the standard deviations of the horizontal and vertical plume dimension above. The atmospheric stability for each unit of meteorological data (usually hourly values) is specified as one of six possible stability classes, using the classification scheme of Turner (1970). The computation of the actual parameters from the Turner classification is made using the equations and coefficients listed in the User's Guide for the Industrial Source Complex (ISC) Model (EPA, 1986). The determination of the values for these parameters is based solely on downwind distance and stability class.

The model is generally very insensitive to values of the mixing height, since fugitive dust emissions are usually released at ground level and reflections off the mixing height are only significant at very far distances from the source or at elevated receptors. However, the model does consider such reflections in the standard fashion. Equation (1) is computed at $z = z+nH_m$ and $z = z-nH_m$ for even values of n starting with 2 and progressing until concentrations are no longer significant. The values computed from these reflections are added to the value computed from the original computation of Equation (1) to arrive at the total concentration at the receptor height. Some users have noted very slow computation times when very low mixing heights are input. Users are urged to consider the computation time when selecting mixing heights for input to the model.

Treatment of Deposition

Equation (1) accounts for deposition through two parameters: the gravitational settling velocity and the deposition velocity. As its name implies, the gravitational settling velocity accounts for removal of particulate matter from the atmosphere due to gravity. Since only the larger particles have sufficient mass to overcome turbulent eddies, this mechanism is significant only for the larger size ranges (e.g. particles greater than 30 micrometers). The deposition velocity accounts for removal of particles by turbulent motion which brings the particulate matter into contact with the surface and allows it to be removed by impaction or adsorption at the surface. It is known that for smaller particles the deposition velocity is most important in determine the removal rates, while for larger particles the gravitational settling process becomes more critical (Nifong and Winchester 1970). In the FDM the emission rate, Q, is divided into a user determined number of particles size classes (maximum of 20). Each of the classes has a unique gravitational settling velocity and deposition velocity. The user may enter these parameters directly, or may enter characteristic diameters of each particle and ask the model to compute the deposition velocity and gravitational settling velocity using the methods detailed in Scire et. al. (1986).

The model computes the gravitational settling velocities for each particle size class using the relationship:

$$v_g \quad \frac{(d_p)^2 \, g \, (P_p - P_g) \, C}{18 \, U_a} \qquad (2)$$

where: v_g = gravitational settling velocity (m/sec)
d_p = particle diameter (m)
g = gravitational acceleration (m/sec^2)
P_p = particle density (g/m^3)
P_g = air density (g/m^3)
U_a = viscosity of air (= .0183 g/m-sec)
C = Cunningham correction for small particles (dimensionless)

The factor C is determined from the following expression:

$$C = 1 + (2L/d_p)[a_1 + a_2 \, \mathrm{Exp}(-a_3 \, d_p/L)] \qquad (3)$$

where: L = mean free path of air molecules, 0.0000000653 m
$a_1 = 1.257$
$a_2 = 0.40$
$a_3 = 0.55$

The deposition velocity is determined from the expression:

$$u_d = \frac{1}{r_a + r_d + r_a r_d v_g} + v_g \qquad (4)$$

where: u_d = Deposition velocity (m/sec)
v_g = Gravitational Settling Velocity (m/sec)

$$r_d = (Sc^{-2/3} + 10^{-3/St})^{-1} \, u_*^{-1} \qquad (5)$$

$$r_a = \frac{1}{k\,u_*} [\ln(z/z_0) - SY_H] \qquad (6)$$

$$SY_H = \begin{cases} -5\ z/l & 0 < z/l < 1 \\ 0 & z/l = 0 \\ \mathrm{Exp}[0.598 + 0.39\ \ln(-z/l) - 0.090\ (\ln(-z/l))^2] & -1 < z/l < 0 \end{cases} \qquad (7)$$

z = height above ground (m)
k = von Karman constant (0.35)
u_* = friction velocity (m/sec)
z_0 = roughness height (m) -- a user entered parameter
l = Monin-Obukhov Length (m)

The final two parameters in the list above are computed with an iterative procedure using the equations presented by Draxler (1979). Table 1 provides some typical values for the roughness height.

Table 1

Typical Values for the Roughness Height

Surface		Roughness Height (m)
Scrub Oak, average 30-ft height		1.0
Long Grass (0.6 - 0.7 m)	1.5 m/sec at 2 m	0.09
	6.2 m/sec at 2 m	0.037
Mown Grass (0.03 m high)		0.007
Natural Snow		0.001
Sunbaked Sandy Alluvium		0.0003
Smooth Mud Flat		0.00001
Ocean Surface,	10-15 m/sec	0.000021
	light wind	0.001

ref. Blackadar, A. K., A Survey of Wind Characteristics Below 1500 ft., Meteorological Monographs, 4:22, p3, 1960.

Each particle size class is treated separately by the model. The results for different particle size classes are summed at the end to develop a total suspended particulate concentrations. Alternatively, the model can compute the deposition rate. In this event, the concentrations for each particle size class are multiplied by the deposition velocity for that particle size classes and the results are summed to determine the total deposition rate.

Emission Rates as a Function of Wind Speed

One of the unique characteristics of fugitive dust is that often emission rates are a function of the wind speed. The FDM has the capability to directly compute the effect of wind speed on emission rate. For each source, the emission rate is calculated by the equation:

$$Q = Q_0 u^s \tag{8}$$

where:
Q = emission rate in g/sec
Q_0 = proportionality constant
u = wind speed (m/sec)
s = wind speed dependance parameter

The emissions for every source are entered as a proportionality constant and a wind speed dependance parameter (Q_0 and s). For sources which do not vary with wind speed, the emission rate is simply entered for Q_0 and s is entered as 0 (the default). However, for sources which do vary with wind speed both parameters must be specified. Examples would include the cubic dependance on wind speed of some wind erosion emission estimates (Woodruff and Siddoway). Also in "Compilation of Air Pollutant Emission Factors" (AP-42), many fugitive dust sources are shown to linearly depend on wind speed, such as batch and continuous loading and unloading operations and losses from open storage stockpiles.

Treatment for Line Sources

Line sources are treated virtually the same as the CALINE3 Model (California Department of Transportation, 1979). The code has actually been lifted from the CALINE3 Model and incorporated in the FDM for the line source treatment. The CALINE3 line source algorithm involves the division of the line source into a series of elements oriented perpendicular to the wind. The number of elements and their orientation depends on the geometery of the line source with respect to the receptor and the wind. Further details on the algorithm for line sources can be found in the User's Guide referenced above. The deposition capability has been modified to be consistent with the treatment above.

Treatment for Area Sources

Area sources are specified by the user with a center point, an x-dimension, a y-dimension and the various emission parameters from Equations (1) and (8). The model computes concentrations from the area sources by first rotating coordinate system so that the origin is at the receptor and the x-axis is aligned with the wind direction. The portion of the area source which is upwind (in the range of positive x values) is considered. The area source is divided into a series of 5 line sources oriented perpendicular to the wind direction. The line sources are then treated just as the other line sources in the model. It is possible for receptors to be located within area sources, but only the portion of the area source upwind of the receptor is considered.

Special Considerations when Using a STAR

If meteorological data is provided to the model in the form of a Stability Array, the model computes concentrations in a fundamentally different manner from the other meteorological options. Instead of using the CALINE3 algorithm as the basis for line and area sources, the model now computes concentrations as 22.5 degree sector averages, and much of the CALINE3 algorithm is moot. The sector averaging differences are true for point sources as well. In fact the model calls entirely different subroutines for computations with a STAR. The option of writing a sequential output file for post-processing is also eliminated when running with a STAR. The same deposition algorithms are used. The main difference is that Equation (1) is integrated in the cross wind (y) direction from minus infinity to plus infinity and the result divided evenly over a the 22.5 degree sector referenced by one of the 16 possible wind direction categories in the STAR. Thus a point, area or line source of small x-extent (when compared with downwind distance) and entirely contained within a 22.5 degree sector will give roughly the same concentrations at a downwind receptor.

3.0 USER'S INSTRUCTIONS

Information is provided to the model in either one or two files. The first is referred to as the FDM input file and contains information on the receptors, sources and various model switches and options. The FDM input file also can contain the meteorological data, expressed as a series of card-images (either as a series of 1-hour episodes, or a statistically produced STability ARray (STAR)). If, however, the user elects to supply meteorological data in the standard pre-processed format, using the RAMMET pre-processor program, a second file must be identified with the meteorological data.

The model was developed on an IBM-PC/XT/AT compatible computer, but is written in standard FORTRAN code, and may be adapted for operation on a mainframe or other computer system. The instructions provided here are those which apply to an IBM-PC compatable computer, running a standard Disk Operating System (DOS). The model requirements for PC operation are a minimum of 256 K of memory and a math-coprocessor. An additional requirement is that the device driver, ANSI.SYS or a compatible be installed on the machine. The ANSI.SYS file is provided with most DOS packages. To install it, the user must make sure that the statement "DEVICE = ANSI.SYS" is present in the CONFIG.SYS file in the user's root directory of the drive used to boot the computer. It should be noted that some operating systems provide their own special version of the ANSI.SYS device driver. For example the commercial software called DOUBLEDOS provides a version called "DBLDANSI.SYS". The FDM package is compatible with any such device driver.

The program prompts the user for the names of the input files and output files. The input files must have been prepared prior to the operation of the run. Directions for preparing the FDM input file are detailed in the next section of this chapter. If the meteorological option is selected to provide the data in pre-processed format, it must be in a standard "UNFORMATTED" file. Compilers differ in the form for "UNFORMATTED" files, thus it may be necessary to run a separate program, also provided in this package, called "UNFORMAT" which will take a formatted file containing the RAMMET pre-processed output and transform it to an unformatted file, suitable for the FDM input. Contained in the diskettes which are provided is a FORTRAN program for transforming the data if required, along with a test data set illustrating the use of this program.

Once the input files are prepared and stored on a disk drive, the FDM program is initiated by typing "FDM". The program prompts for the name of the input files, and prompts for file names where the output files are to go.

> CAUTION -- The FDM program will erase old files with the same name as that specified for output, so that if the user enters a name for the output file which already exists on the disk drive, it will be overwritten.

There are three types of output files which can be created. Output options are discussed in Section 3.2.

3.1 The FDM Input File

The FDM input file provides the model with most, if not all, of the information needed for execution of the program. Information is provided to the model through a series of card images which consist of a maximum of 80 columns of data. Table 1 provides a summary of the information needed and the format for each entry in the file. Sample input files and output files are included on the diskette.

The meaning and possible values for each of the parameters is explained in Table 2.

3.2 The FDM output files

Output can be obtained from FDM in three formats. First, the standard output file, as contained on the diskette, which documents all the inputs and the computed concentrations or depositions for the model. The second form of output is a "plotter" file which contains every concentration printed by the model along with the coordinates for that concentrations. The format is a generic form which simply presents the x coordinate, the y coordinate and the concentration/deposition.

The third format for the output is a sequential tape of concentrations for post processing by the POSTZ program, available on the UNAMAP system. POSTZ is a post-processor designed for the SHORTZ air quality model. The SHORTZ air quality model has the capability of writing an output tape of sequential concentrations for every combination of meteorological condition, source and receptor. These tapes, on the IBM PC system take the form of a disk file. FDM has been equipped with the option of writing a tape of a format suitable for input to the POSTZ program. Much of the information on the tape is not used by the POSTZ model, thus in many cases the FDM has been instructed to write "dummy" variables to the tape to keep the format correct, but which do not enter in the calculation of any of the POSTZ results.

The advantage to the POSTZ post-processor option is that many alternate averaging times can be examined, specific periods of a longer meteorological data base can be examined, the results for certain sources can be scaled up or down, and a number of other manipulations can be performed with the data. The POSTZ program also prepares high-five and top 50 tables which are useful for many regulatory applications of the model.

The major disadvantages to using the POSTZ program are that the sequential tape file written by FDM for POSTZ input can be very large, and can exceed the capacity of many typical hard disks. For example, a run containing 15 sources, 200 receptors and 1 year of sequential meteorological data will write a tape file that is over 100,000,000 bytes in length. Discretion must be exercised when selecting this option.

TABLE 2
SUMMARY OF INFORMATION REQUIRED FOR FDM INPUT

Card 1 Title Card

Col	Format	Information
1-80	A80	Title

Card 2 Switches

Col	Format	Information
2	I1	Concentration/Deposition Switch. If =1 then model computes concentration. If = 2 then model computes deposition. Default is 1.
4	I1	Met. Option Switch. If = 1 then met. data is read from cards (format shown below). If = 2 then met is read from pre-processed meteorological file. If = 3 then meteorological data is read as a STAR contained later in this input file. Note that the selection of the STAR option makes many of the later options not applicable. Default is 1.
6	I1	Plotter Output Switch. If = 1 then no plotter file is made. If = 2 then a plotter file name is asked for and the model writes a file with a formatted output of x, y, concen. for every averaging time requested to be analyzed. Default is 1.
8	I1	Print Output Switch. If = 1 then meteorological data are not printed. If = 2 then meteorological data are printed. Default is 1.
10	I1	Post Processor Switch. If = 1 then no post processor file is written. If = 2, then a post processor file is written which can be processed with the POSTZ program to develop High-5 tables, scale sources, or other

		operations. The user should see the POSTZ User's Guide for further information. This option is not available and this switch is ignored when the met. option switch = 3. Default is 1.
12	I1	Deposition Parameters Option Switch. If = 1 then the model will compute deposition velocity and gravitational settling velocity automatically on an hour by hour basis. If = 2 then the User will enter single values of the deposition velocity and gravitational velocity for each particle size class to be used for all hours. Default is 1.
14	I1	1-Hour Switch. If = 1 then 1-hour average concentrations are not printed, If = 2 then 1-hour average concentrations are printed. This option is not available and this switch is ignored when the met. option switch = 3. Default is 1.
16	I1	3-Hour Switch. If = 1 then 3-hour average concentrations are not printed. If = 2 then 3-hour average concentrations are printed. This option is not available and this switch is ignored when the met. option switch = 3. Default is 1.
18	I1	8-Hour Switch. If = 1 then 8-hour average concentrations are not printed. If = 2 then 8-hour average concentrations are printed. This option is not available and this switch is ignored when the met. option switch = 3. Default is 1.
20	I1	24-Hour Switch. If = 1 then 24-hour average concentrations are not printed. If = 2 then 24-hour average concentrations are printed. This option is not available and this switch is

Col	Format	Information
		ignored when the met. option switch = 3. Default is 1.
22	I1	Long-term Switch. If = 1 then average concentrations over the entire meteorological data base provided are not printed. If = 2 then such long term average concentrations are printed. This option is not available and this switch is ignored when the met. option switch = 3. Default is 1.

Card 3 STAR Data (These Cards are <u>only</u> read if Met. Option Switch = 3)

Col	Format	Information
1-60	6F10.0	A total of 96 cards are read here with the information being the frequency of winds for each combination of wind speed class, wind direction class and atmospheric stability class. Each card contains six values corresponding to the six possible wind speed classes. The order of the cards is 16 cards for the 16 possible wind direction classes for the first stability class, followed by the next 16 cards for the second stability class, followed by 16 cards for each subsequent stability class up to the final (sixth) stability class. The wind direction cards are ordered with north being first, north-northeast being second and proceeding clockwise until north-northwest is entered. Stabilities start with Turner Class A, and proceed to Turner Class F. The sum of all 576 values entered here should be 1.0.

Card 4 Mixing Heights for each Stability Class when using a STAR (This Card is <u>only</u> read if Met. Option Switch = 3)

Col	Format	Information
1-60	6F10.0	Six values are read here to indicate the characteristic mixing height to be used with each stability class when using a STAR for input meteorological data.

Mixing heights should be entered in meters above ground.

Card 5 Characteristic Wind speeds for each wind speed class when using a STAR (This Card is only read if Met. Option Switch = 3)

Col	Format	Information
1-60	6F10.0	Six values are read here to indicate the characteristic wind speed to be used by the model for each of the wind speed classes when running with meteorological data entered in the form of a STAR. Wind speed values should be entered in meters per second.

Card 6 Integer Parameters

Col	Format	Information
1-5	I5	Number of Sources
6-10	I5	Number of Receptors
11-15	I5	Number of Particle Size Classes, with a maximum of 20 allowed. Note that in order to compute any deposition values or to compute any concentrations which have deposition accounted for, this parameter must be set to some value other than 0.
16-20	I5	Number of Hours of Meteorological data to be processed in this run.

Card 7 Real Parameters

Col	Format	Information
1-10	F10.0	ATIM - the length of time in one unit of meteorological data entry in minutes. Generally, this is entered as 60.
11-20	F10.0	Surface Roughness Height in cm.
21-30	F10.0	SCAL - a scaling factor for all entries involving distance. The model assumes all entries for coordinates or dimensions are in meters. If the user desires to enter some other units, he may enter a conversion factor here such that when the units he has entered are multiplied by SCAL the result will be in meters.

31-40	F10.0	PD - the density of the particulate matter in grams per cubic meter. Typical values range from 1.0 to 3.0 depending on the type of material which comprises the particulate matter.

Card 8 Meteorological Data Selection Switches. These cards are entered only if a sequentially pre-processed meteorological data set is being used (Met. Option Switch = 2). The switches allow the user to select a certain portion of the sequential data set for processing and skip the rest.

Col	Format	Information
1-80	80I1	A series of 1's or zero's is used to determine if a particular day from the sequentially pre-processed meteorological data set is to be processed in this run. The first number entered corresponds to day 1, etc. A total of 366 values (4 and 1/2 cards) is needed to enter all 366 values. If a 1 is entered the day is to be processed, if a zero is entered the day is to be skipped.

Card 9 Characteristic Particle Diameters (not entered if the Number of Particle Size Classes is 0)

Col	Format	Information
1-10	8F10.0	The average or typical diameter for each particle size class is entered here in micrometers (um or meters X 10^{-6}). A total of 20 particle size classes can be specified and a characteristic diameter must be specified for each particle size class used. 8 values can be placed on each card here. Use as many cards as necessary to provide the number of particle size classes specified, but do not include any blank cards.

Card 10 General Particle Size Distribution (not entered if the Number of Particle Size Classes is 0)

Col	Format	Information
1-10	8F10.0	The fraction of the emissions which are contained in each particle size class are entered

here. A total of 20 particle size classes can be specified and a fraction must be specified for each particle size class used. 8 values can be placed on each card here. Use as many cards as necessary to provide the number of particle size classes specified, but do not include any blank cards. This card refers to a general particle size distribution which is used for all sources here unless over-ridden by a specific switch entered on each source card. When over-ridden on the source cards which follow, the user may specify a specific size distribution to use for a specific source, or may have the model assume no deposition for a specific source.

Card 11 Gravitational Settling Velocities. This card is only entered if the number of particle size classes is greater then zero and the deposition parameters options switch is set to 2. Otherwise, the model computes gravitational settling velocities automatically. This option is only used if the user has some reason to use specialized gravitational settling velocities.

Col	Format	Information
1-10	8F10.0	The gravitational settling velocities in m/sec are entered here. A total of 20 particle size classes can be specified and a gravitational settling velocity must be specified for each particle size class used. 8 values can be placed on each card here. Use as many cards as necessary to provide the number of particle size classes specified, but do not include any blank cards.

Card 12 Deposition Velocities. This card is only entered if the number of particle size classes is greater then zero and the deposition parameters options switch is set to 2. Otherwise, the model computes deposition velocities automatically. This option is only used if the user has some reason to use specialized deposition velocities.

Col	Format	Information
1-10	8F10.0	The deposition velocities in m/sec are entered here. A total of 20 particle size classes can be specified and a deposition velocity must be specified for each particle size class used. 8 values can be placed on each card here. Use as many cards as necessary to provide the number of particle size classes specified, but do not include any blank cards.

Card 13 Receptors

Col	Format	Information
1-10	F10.0	X-Coordinate of receptors in meters, or in units which will be converted to meters when multiplied by SCAL entered above.
11-20	F10.0	Y-Coordinate (units as above)
21-30	F10.0	Z-Coordinate

Each receptor is entered on a single card. A total of 200 receptors may be specified.

Card 14 Source Information

Col	Format	Information
2	I1	Type of source. 1 = point source, 2 = line source, and 3 = area source.
3	I1	Particle size override switch. If this switch is left blank or set to 0, the model uses the particle size distribution specified in card 10 to apply to this source. If, however, this value is set to 1, the model reads a second card (or as many cards as necessary), after card 14 to specify the particle size distribution for this source. If this value is set to 2, the model assumes no deposition for this source.
3-15	F12.0	Emission rate. For point sources, the units are grams per second (g/sec). For line sources the units are grams per meter per second (g/m-sec). For area sources the units are grams per square meter per second (g/m^2-

sec). Note if this source is a wind-speed dependant source, the emission rate entered here is the proporitonality constant of the wind speed dependant espression of the form: $E = Q_0u^w$ where E is the emission rate, Q_0 is the proportionality constant, u is the wind speed in m/sec and w is the wind speed dependance factor.

16-20	F5.0	Wind speed dependance factor. See the note under emissions above. If the source is not a function of wind speed, leave this column blank and enter the emission rate in colums 3-15 as above.
21-30	F10.0	X-coordinate. For point sources, this is the x-coordinate of the source. For line sources, this is the x-coordinate of one end of the line source. For area sources, this is the x-coordinate of the center of the area source. In all cases the values are in meters, or in units which will be converted to meters when the computer multiplies by the value entered for SCAL above.
31-40	F10.0	Y-coordinate. For point sources, this is the y-coordinate of the source. For line sources this is the y-coordinate for one end of the line source (the same end as the above x-coordinate). For area sources, this is the y-coordinate of the center of the area source. In all cases the values are in meters, or in units which will be converted to meters when the computer multiplies by the value entered for SCAL above.
41-50	F10.0	2nd X-coordinate. For point sources, this column is not used. For line sources, this is the x-coordinate for the other end of the line source. For area sources, this is the x-dimension of the area source. In all cases the values are in meters, or in units which will be converted to meters when the computer multiplies by the value entered

Col	Format	Information
		for SCAL above.
51-60	F10.0	2nd Y-coordinate. For point sources, this column is not used. For line sources, this is the y-coordinate for the other end of the line source. For area sources, this is the y-dimension of the area source. In all cases the values are in meters, or in units which will be converted to meters when the computer multiplies by the value entered for SCAL above.
61-70	F10.0	Height of emission. The release height for the emissions from this source in meters, or in units which will be converted to meters when the computer multiplies by the value entered for SCAL above. There is no plume rise in FDM, thus for a source with plume rise, the plume rise must be computed manually and added to the stack height and entered here.
71-80	F10.0	Source width. This parameter applies only to line sources, and refers to the width of the line source in meters, or in units which will be converted to meters when the computer multiplies by the value entered for SCAL above.

Card 14A Optional Particle Size data for Source

If the particle size switch in column 3 of the source card is set to 1, then this card (or group of cards) is read, otherwise, this card (or cards) is not read and should not be included. This card (or cards) specifies the particle size distribution for <u>this source only</u> and follows the exact same format as Card 10.

<u>Col</u>	<u>Format</u>	<u>Information</u>
1-10	8F10.0	The fraction of the emissions which are contained in each particle size class are entered here. A total of 20 particle size classes can be specified and a fraction must be specified for each particle size class used. 8 values can be placed on each card

here. Use as many cards as necessary to provide the number of particle size classes specified, but do not include any blank cards.

Card 15 Meteorological data

Meteorological data are entered only if the met option switch is set to 1. If meteorological data are to be entered here, each hour of data is entered on a separate card. Note that none of the meteorological values are affected by the specification of SCAL above.

Col	Format	Information
1-10	F10.0	Wind speed in m/sec.
11-20	F10.0	Wind direction -- the direction in degrees from north from which the wind is <u>coming</u>.
25	I1	Stability class, where 6 values are possible and reflect Turner classes A-F, and 1=A, 2=B, 3=C, 4=D, 5=E and 6=F.
31-40	F10.0	Mixing Height in meters.
41-50	F10.0	Ambient Temperature in degrees Kelvin.

4.0 VALIDATION/SAMPLE RUNS

A validation study was performed using measured air quality and meteorological data from a major western surface mining operation. Appendix A details the validation study and results. As the appendix indicates, the FDM model offers improved performance over the currently-recommended model for fugitive dust impact assessment, the Industrial Source Complex Model.

Appendix B provides samples of input and output streams for the FDM Model. These are actually sample input streams from the validation study.

Appendix C contains a complete listing of the FORTRAN code for the FDM Model. The version of the code contained in the appendix is that used for IBM-PC computers. Some minor changes would be necessary to generate a mainframe computer code from the code contained in the appendix.

REFERENCES

California Department of Transportation, 1979. "CALINE3 - A versatile Dispersion Model for Predicting Air Pollutant Levels Near Highways and Arterial Streets", Office of Transportation Laboratory, Department of Transportation, State of California, Sacramento, California 95807, No. FHWA/CA/TL-79/23.

Draxler, R. R., 1979. "Estimating Vertical Diffusion from Routine Meteorological Tower Measurements," Atmospheric Environment, Vol13, pp.1559-1564.

Ermak, D. L., 1977. "An Analytical Model for Air Pollutant Transport and Deposition from a Point Source," Atmospheric Environment, Vol.11, pp. 231-237.

EPA, 1986. "Industrial Source Complex (ISC) Dispersion Model User's Guide - Second Edition, Volume I., EPA_450/4-86-005a, June.

Nifong, G. D. and Winchester, J. W., 1970. "Particle Size Distributions of Trace Elements in Pollution Aerosols," University of Michigan, Document No. COO-1705-8, August.

Scire, J. S., D. C. DiChristofaro and D. G. Strimaitis, 1986. "Development and Application of a Deposition Modeling Approach for PCDD and PCDF Emissions from the Proposed Brooklyn Navy Yard Resource Recovery Facility," Sigma Research Corporation, Lexington Massachusetts, Report No. A026-100.

Turner, D. B. 1970. "Workbook of Atmospheric Dispersion Estimates," AP-26, EPA Research Triangle Park, N.C.

APPENDIX A

VALIDATION STUDY FOR THE FDM MODEL

1.0 INTRODUCTION

The Fugitive Dust Model (FDM) was developed specifically for computing concentrations and deposition rates of particulate matter from fugitive dust sources. This document details a validation study of the model. Model predictions were computed using daily emission data and on-site meteorology from a major source of fugitive dust (a western surface mining operation), and the results were compared with measured values for the same period. Similar computations were performed with the current model recommended by EPA in the Guideline on Air Quality Models -- the Industrial Source Complex (ISC) Model.

The FDM Model is designed specifically for computation of the impacts of fugitive dust sources. It has been under development for many years in several formats. The primary use of the model is for the computation of concentrations and deposition rates resulting from emission sources such as open pit mining operations or hazardous waste sites where fugitive dust is a concern. The model contains no plume rise algorithm and is thus not capable of handling buoyant sources. It was recognized from the start that ultimate acceptance of the model would hinge on its ability to accurately predict concentrations from fugitive dust sources. To that end, a model validation effort was conceived using actual fugitive dust emissions and measured particulate concentrations. This report documents the findings of the validation exercise.

The current report is organized into three sections, in addition to this introduction. Section 2.0 describes the methodology, and the key modeling input values such as the model layout used in the current study. Section 3.0 discusses the modeling results and compares the values to measured values. Finally, Section 4.0 presents the conclusions of the investigation.

2.0 METHODOLOGY AND MODEL INPUTS

Both FDM and ISC are capable of predicting average concentrations of both Total Suspended Particulate Matter (TSP) and particulate matter less than 10 micrometers in mass mean diameter (PM-10) for a variety of averaging times. The averaging periods of interest are those for which standards or PSD increments are in effect. In most air quality permitting investigations, the period of greatest concern for fugitive dust impacts is the 24-hour average, since both a standard and a PSD increment exist for 24-hour PM-10 and TSP concentrations respectively. Although a similar standard exists for annual-average concentrations, the experience gained from the conduct of air quality permitting investigations indicates that most fugitive dust emitting projects have far more difficulty demonstrating compliance with the 24-hour criteria than the annual criteria. As a result, this investigation focuses on 24-hour average concentrations. For the FDM model one version of the program deals with all averaging times, but for the ISC model separate versions are available for computing short- and long-term averages. The ISCST (for Short Term) version of the ISC Model was used in this investigation.

The current validation exercise was conducted using data obtained from a large western surface coal mining operation. The mining operation was selected for the validation study for the following reasons:

- Mining operations are major sources of fugitive dust, and have been the subject of numerous air quality studies and investigations dating back to the early 1970's. Published emission factors are available for most mining sources, and most western air pollution agencies have had to deal with the complex problems associated with computing mining fugitive dust impacts.

- The mining industry and the particular mining company in question were very cooperative in providing the data and information necessary for the model validation.
- The mine in question is a large operation and has an extensive monitoring network for measurement of both PM-10 and TSP concentrations at a total of 5 stations located in the immediate area of the mine. Many have referred to the mine as the "most monitored mine in the history of the industry".
- In addition to the air quality data, on-site meteorological data were available for the validation investigation.
- Both the air quality and meteorological data are collected in compliance with the full requirements of a PSD monitoring network, including quality assurance provisions. The data are routinely submitted to the local air pollution agency as part of the permit for the mining operation.

Data were obtained from the mining company for a period of one entire dry season, April through September of 1986. Since sampling was conducted on a six-day cycle for TSP and PM-10, a total of 32 case days were available for the validation study.

The emission inventory for the current investigation was computed for each of the 32 case days studied. Published emission factors taken from the literature were used in the analysis. Generally, reliance was made on the EPA's emission factor reference, Document AP-42. The mining company provided the input information needed to compute the emissions from the factors for each of the 32 case days. Information provided by the mining company included tonnage mined, transported and processed (crushed) on each day, and the tonnage and locations for disposal of the waste material removed on each day. Other general information on the equipment in use at the mine and the schedule for each item were also provided.

The emissions from the mining operation were divided into a total of 56 separate sources for FDM input, based on the actual layout of the mine. For the haul roads, a total of 27 separate sections of road were identified, and the actual truck traffic identified for each section. Emissions were computed for each section of road based on the activity on that section of road for each case day. Figure 2-1 illustrates the location of the sources as defined by the FDM Model.

For the ISC model runs, it was not possible to use the same emission source layout as the FDM runs, since ISC does not have the capability to treat line sources directly. As a result, each of the FDM line sources were broken into a series of volume sources for ISC input. Also, ISC does not have the capability to treat rectangular area sources, so the area source layout was revised for square area sources only. For the ISC runs a total of 170 individual sources were used in the modeling. The total emissions for each case day were identical in the FDM and ISC model inputs.

Particle size distributions assumed in the modeling consisted of five separate particle size classes: 0-2.5, 2.5-5, 5-10, 10-15 and >15 micrometers. The modeling results were interpreted in terms of both the total suspended particulate (TSP) concentrations (the sum of all particle size classes) and the concentration of particles smaller than 10 micrometers in mass mean diameter (PM-10). The PM-10 concentrations were computed as the sum of the first three particle size classes from the modeling. Particle size distributions of emitted sources were obtained from literature measurements of particle size distributions in the vicinity of mining operations.

A total of five air quality monitoring stations are located in the project area. The stations are identified by number. The locations of the stations are shown in Figure 2-1. Following are descriptions of each of the stations:

- AQ-1 Located in the center of the mining operation by the haul road to the waste dump. The station consists of two co-located

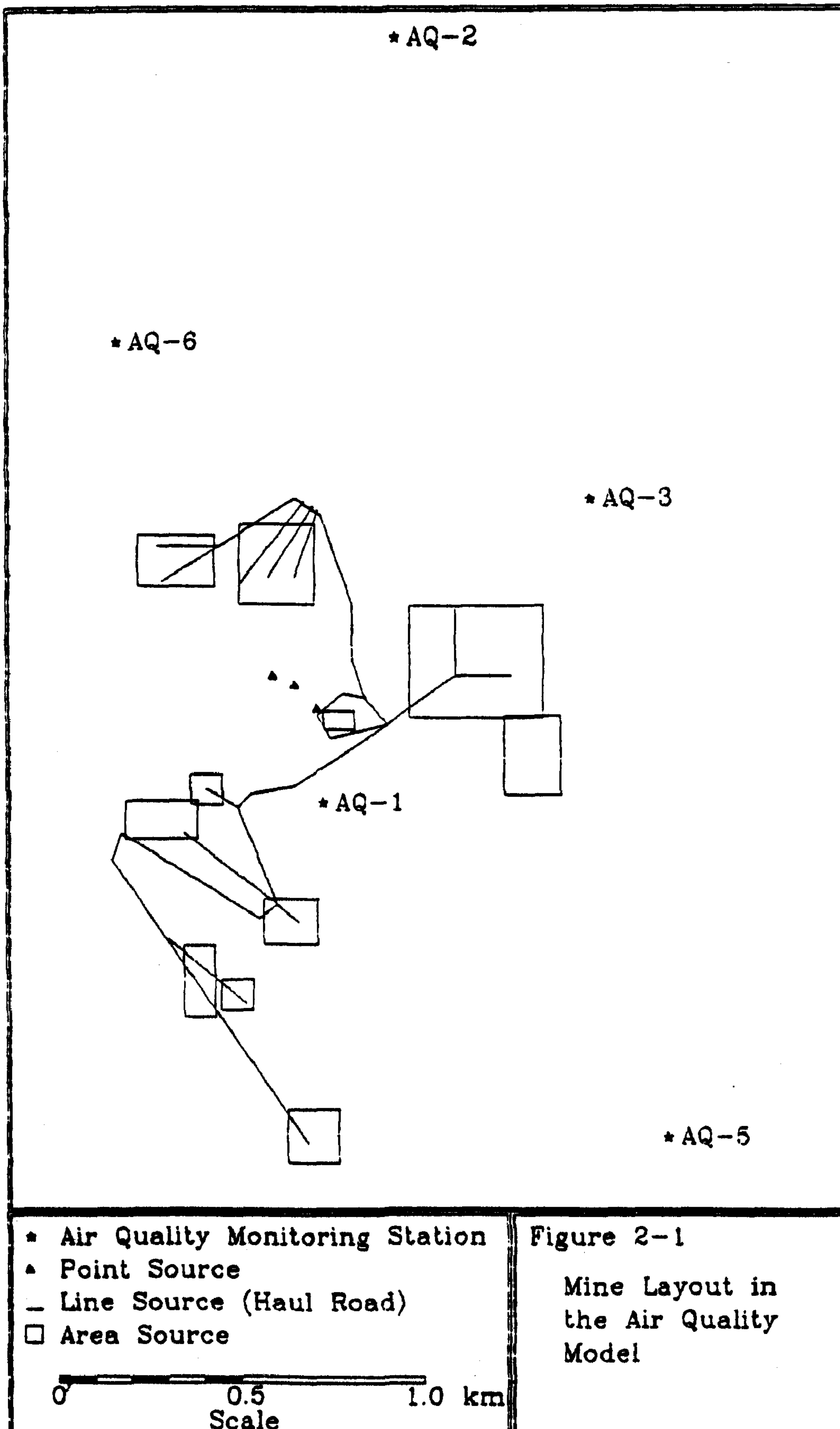


Figure 2-1

Mine Layout in the Air Quality Model

PM-10 monitors and a meteorological station.

- AQ-2 Located atop the ridge to the north of the mine. It is often a background station, with little impact from the mine. Equipment consists of a PM-10 monitor and a TSP monitor.
- AQ-3 Located to the east of the major mining operations. Equipment includes a PM-10 monitor and two co-located TSP monitors.
- AQ-5 Located to the south of the mine. It consists of a PM-10 monitor and a TSP monitor.
- AQ-6 Located to the north west of the mining operation on a hill. Equipment consists of a PM-10 monitor and a TSP monitor.

Measured PM-10 and TSP data at the five monitoring stations were compiled by the mining company and transmitted to TRC in hard copy and floppy disk format. TRC extracted the case days from the overall particulate data and input the values to a "spread-sheet" program for comparison with the model predictions.

The ultimate goal of this investigation was to compare the model predictions to these measured data. The modeled concentrations, however, contain only the contribution of the mining operation to the ambient particulate levels, while the monitored values contain all particulates, whether from the mine or not. The "background" contribution to the particulate loading is highly variable and difficult to quantify. The approach taken here to estimation of background concentrations was to scan all five measured values for each case day and select the lowest value as the background. The modeled concentrations, discussed in the next chapter, are added to the background for each day to determine the total impact for comparison to the measured values.

Meteorology is measured at several locations in the vicinity of the mine. Two candidate locations were considered for the air quality modeling study: a monitor location near AQ-1 and a monitor location near AQ-6 (see Figure 2-1). Ultimately the AQ-1 meteorology data were selected based on the quality of the data and the representative nature of the wind speed and wind direction data to the mine emission sources. Examination of Figure 2-1 shows the location of the monitor to be central to the emitting sources at the mine.

Both the FDM and ISC models require information on the hourly values for wind speed, wind direction temperature, atmospheric stability and mixing height. Wind speed, wind direction and temperature are measured directly by the sensors at AQ-1. Atmospheric stability is a measure of the turbulent mixing capacity of the atmosphere and was estimated for the current investigation from the standard deviation of the wind direction, also recorded at AQ-1. Stability is expressed as one of 6 classes labeled A through F, where A is the least stable (greatest turbulent mixing) and F is the most stable (least turbulent mixing). The conversion from standard deviation of the wind direction to stability is accomplished as follows (based on Gifford, 1976):

Standard Deviation	Stability Class
> 22.5	A
17.5 - 22.5	B
12.5 - 17.5	C
7.5 - 12.5	D
3.75 - 7.5	E
< 3.75	F

For fugitive dust impacts, results are generally very insensitive to values used for mixing height because the emissions are released at or near the ground, and the impacts are generally very close to the source. As a result the emissions have little opportunity to mix vertically to the height of the mixing layer. To provide the models with values for these required values, mixing heights were assigned by stability class using the following general values:

Stability Class	Mixing Height (m)
A	1,600.
B	1,200.
C	800.
D	400.
E	10,000.
F	10,000.

3.0 AIR QUALITY MODELING RESULTS

The FDM and ISC models were run for the 32 case days identified earlier and the predicted concentrations, both PM-10 and TSP, computed as the sum of the modeled concentration and the background as discussed earlier. The results are presented in two formats here. First, the measured versus predicted values are shown in Tables 3-1 through 3-4 for FDM TSP, ISC TSP, FDM PM-10 and ISC PM-10 respectively. Second, a "scatter plot" of the measured and predicted values for these same four cases are shown in Figures 3-1 through 3-4.

The performance of each model is generally good for most of the days given the usual accuracy of air quality models. However, the figures clearly show a tendency on the part of ISC for large over-predictions on a few case days. It is these case days which are of greatest concern to regulators, since the 24-hour TSP standards and PSD increments refer only to the highest one or two days per year.

A number of different techniques, including cumulative frequency plots, and various statistical functions have been used in the past to evaluate air quality model performance. Air quality models are frequently quoted to predict within a factor of two, thus one means of comparison is to determine what number of the data points are within a factor of two. For FDM, the TSP predicted results are within a factor of two of the measured results for 94 percent of the values. For the FDM PM-10 results, the measured and predicted values are within a factor of two for 96 percent of the values. For the ISC results, the same comparison shows 87 percent for TSP and 86 percent for PM-10.

Table 3-1. Comparison of Measured and FDM Predicted TSP Concentrations (ug/m3)

		AQ-2		AQ-3		AQ-5		AQ-6	
Day	Date	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.
1	3/21/86			22.7	30.1	35.8	11.2	11.1	13.2
2	3/27/86	40.9	39.6					39.3	54.7
3	4/8/86	9.6	9.9			22.6	10.4	7.6	11.0
4	4/14/86	14.8	10.6	40.0	33.7	10.5	9.8	9.8	14.5
5	4/20/86	23.2	15.9	21.2	15.4	17.9	15.3	15.3	15.4
6	4/26/86	13.5	10.9	14.3	10.9	16.2	11.4	10.9	10.9
7	5/2/86	7.9	7.2	14.9	66.1	5.8	4.7	4.7	4.7
8	5/8/86	10.2	9.4	10.1	9.4	17.3	10.1	9.4	9.4
9	5/14/86	19.9	18.2	18.3	18.3	33.1	19.9	18.2	18.2
10	5/20/86	11.9	6.1	44.0	17.9	16.1	8.6	6.1	6.1
11	5/26/86	11.7	8.4			11.5	8.9	8.4	8.4
12	6/1/86	36.6	27.6			27.5	27.6	37.7	27.7
13	6/7/86	20.2	18.3	26.7	18.6	33.0	18.8	18.3	18.3
14	6/13/86	34.8	29.7	48.8	58.7	27.3	27.6	58.0	38.2
15	6/19/86	13.8	16.2	23.9	45.2	29.2	14.1	15.5	24.7
16	6/25/86	37.2	38.3	76.2	67.8			34.5	39.8
17	7/2/86	27.6	25.7	43.0	37.1	30.7	27.0	25.1	25.8
18	7/7/86	25.4	19.3	64.8	49.5	17.3	17.4	21.8	29.4
19	7/13/86	36.7	31.1	46.9	31.1	31.1	31.1	32.0	32.5
20	7/19/86	32.2	28.5	35.5	31.0	31.7	29.0	28.3	28.3
21	7/25/86	22.6	16.1	33.5	35.4	15.4	15.4	25.7	50.5
22	7/31/86	34.3	29.2	58.7	39.0	34.5	31.4	28.9	30.3
23	8/6/86	41.6	30.3	57.8	49.7	29.5	28.1	28.0	38.5
24	8/12/86	36.8	30.6	52.1	44.1	53.8	32.1	30.1	31.8
25	8/18/86	27.6	19.5	57.2	41.4	26.6	19.2	18.9	25.1
26	8/24/86	36.9	28.2	45.4	28.2	35.5	28.3	28.2	28.2
27	8/30/86	28.9	27.2	32.5	27.5	45.7	27.2	27.1	27.1
28	9/5/86					64.4	27.4	25.7	26.2
29	9/11/86					52.7	33.6	32.3	38.6
30	9/17/86					9.5	5.4	4.7	4.9
31	9/23/86					37.7	29.3	26.9	37.6
32	9/29/86					30.5	13.2	12.9	13.3

Table 3-2. Comparison of Measured and FDM Predicted PM-10 Concentrations (ug/m3)

		AQ-1		AQ-2		AQ-3		AQ-5		AQ-6	
Day	Date	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.
1	3/21/86	17.0	14.0	6.0	5.4	15.4	9.9	12.4	4.4	4.4	5.0
2	3/27/86	36.9	29.3	22.5	19.4					19.3	31.4
3	4/8/86	8.6	13.4	4.2	4.4	14.6	13.1	13.5	4.4	3.6	4.7
4	4/14/86	21.4	16.5	4.7	4.9	10.2	11.6	5.5	4.7	5.8	6.4
5	4/20/86	17.3	13.1	11.8	10.5	12.1	10.1	10.6	10.1	10.1	10.1
6	4/26/86	14.7	8.7	7.2	5.4	5.4	5.4	6.7	5.5	5.9	5.4
7	5/2/86	4.5	6.4	4.5	3.4	6.1	20.3	3.7	2.7	2.7	2.7
8	5/8/86	16.2	13.6	4.1	4.1	5.0	4.1	6.1	4.3	4.2	4.1
9	5/14/86	16.0	15.4	9.5	8.5	8.9	8.5	12.5	9.0	8.5	8.5
10	5/20/86	7.4	8.3	3.5	2.7	10.2	6.0	3.5	3.4	2.7	2.7
11	5/26/86	6.4	4.2			5.1	4.0	4.5	4.2	4.0	4.0
12	6/1/86	19.5	14.9	20.7	14.3	18.7	14.4	14.3	14.3	19.9	14.4
13	6/7/86	15.5	12.6	8.4	8.4	11.2	8.5	13.3	8.6	9.8	8.4
14	6/13/86	20.0	21.1			23.2	28.8	16.3	16.4	23.6	19.7
15	6/19/86	15.7	19.6	10.0	7.6	10.1	16.6	11.3	8.0	7.6	7.6
16	6/25/86	29.5	26.2	24.4	20.4	31.8	29.1	19.2	19.4	21.4	21.0
17	7/2/86	28.2	22.1	19.0	13.8	20.7	17.0	14.9	14.2	13.6	13.8
18	7/7/86	24.1	14.7	14.1	11.2	25.8	20.0	10.6	10.6	12.6	15.2
19	7/13/86	23.1	20.4	22.6	19.7	22.7	19.7	19.7	19.7		
20	7/19/86	24.9	23.1	19.9	17.2	18.8	18.0	18.7	17.4	17.2	17.2
21	7/25/86	12.0	11.7	13.8	10.7	15.5	16.2	10.5	10.5		
22	7/31/86	25.8	27.7	21.9	17.3	29.6	20.1	21.9	18.0	17.2	17.6
23	8/6/86	26.3	23.0	24.7	19.7	26.6	24.9	19.7	18.7	18.7	23.7
24	8/12/86	43.2	30.5	22.8	18.8	25.6	22.7	30.1	19.3	18.7	19.2
25	8/18/86	38.7	37.9	15.7	12.2	33.7	18.5	16.5	12.1	12.0	15.8
26	8/24/86	24.1	21.3	22.1	18.9	21.0	18.9			18.9	18.9
27	8/30/86	19.9	15.8	16.9	14.4	14.6	14.5	21.1	14.4	14.4	14.4
28	9/5/86	65.9	29.2					34.1	16.5	16.0	16.1
29	9/11/86	35.0	25.2					24.9	19.0	18.6	20.5
30	9/17/86	6.7	21.3					4.4	3.2	3.0	3.0
31	9/23/86	27.0	26.9							19.7	23.3
32	9/29/86	20.1	25.2					13.5	8.6	8.5	8.6

Table 3-3. Comparison of Measured and ISC Predicted TSP Concentrations (ug/m3)

		AQ-2		AQ-3		AQ-5		AQ-6	
Day	Date	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.
1	3/21/86			22.7	37.8	35.8	11.4	11.1	17.2
2	3/27/86	40.9	39.5					39.3	136.5
3	4/8/86	9.6	13.0			22.6	11.4	7.6	16.6
4	4/14/86	14.8	10.5	40.0	63.9	10.5	9.8	9.8	29.7
5	4/20/86	23.2	18.7	21.2	17.2	17.9	15.3	15.3	17.2
6	4/26/86	13.5	10.9	14.3	10.9	16.2	11.7	10.9	10.9
7	5/2/86	7.9	9.9	14.9	138.1	5.8	4.7	4.7	4.8
8	5/8/86	10.2	9.4	10.1	9.4	17.3	9.5	9.4	9.4
9	5/14/86	19.9	18.2	18.3	18.4	33.1	22.8	18.2	18.2
10	5/20/86	11.9	6.1	44.0	28.9	16.1	10.6	6.1	6.1
11	5/26/86	11.7	8.5			11.5	12.6	8.4	8.6
12	6/1/86	36.6	28.2			27.5	27.7	37.7	29.7
13	6/7/86	20.2	18.3	26.7	18.8	33.0	19.5	18.3	18.3
14	6/13/86	34.8	30.2	48.8	176.0	27.3	27.7	58.0	59.7
15	6/19/86	13.8	13.8	23.9	249.0	29.2	15.7	15.5	13.8
16	6/25/86	37.2	42.3	76.2	95.0			34.5	47.8
17	7/2/86	27.6	25.4	43.0	45.6	30.7	31.9	25.1	25.8
18	7/7/86	25.4	19.1	64.8	61.9	17.3	17.3	21.8	77.8
19	7/13/86	36.7	32.7	46.9	31.1	31.1	31.1	32.0	49.5
20	7/19/86	32.2	28.4	35.5	32.3	31.7	30.1	28.3	28.3
21	7/25/86	22.6	16.0	33.5	44.1	15.4	15.4	25.7	154.7
22	7/31/86	34.3	29.4	58.7	45.7	34.5	33.5	28.9	30.8
23	8/6/86	41.6	30.7	57.8	62.7	29.5	28.0	28.0	102.7
24	8/12/86	36.8	30.4	52.1	54.5	53.8	31.4	30.1	33.5
25	8/18/86	27.6	19.3	57.2	58.8	26.6	19.1	18.9	59.1
26	8/24/86	36.9	28.2	45.4	28.2	35.5	28.7	28.2	28.3
27	8/30/86	28.9	27.3	32.5	31.0	45.7	27.3	27.1	27.2
28	9/5/86					64.4	26.9	25.7	25.9
29	9/11/86					52.7	33.3	32.3	48.1
30	9/17/86					9.5	5.1	4.7	4.7
31	9/23/86					37.7	30.5	26.9	65.9
32	9/29/86					30.5	12.9	12.9	13.1

Table 3-4. Comparison of Measured and ISC Predicted PM-10 Concentrations (ug/m3)

		AQ-1		AQ-2		AQ-3		AQ-5		AQ-6	
Day	Date	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.	Meas.	Pred.
1	3/21/86	17.0	37.3	6.0	6.2	15.4	12.1	12.4	4.5	4.4	6.2
2	3/27/86	36.9	43.5	22.5	19.4					19.3	107.3
3	4/8/86	8.6	29.7	4.2	5.2	14.6	21.5	13.5	4.7	3.6	6.2
4	4/14/86	21.4	46.8	4.7	4.9	10.2	20.3	5.5	4.7	5.8	11.4
5	4/20/86	17.3	26.6	11.8	13.0	12.1	11.3	10.6	10.1	10.1	10.7
6	4/26/86	14.7	12.3	7.2	5.4	5.4	5.4	6.7	5.6	5.9	5.4
7	5/2/86	4.5	17.8	4.5	4.2	6.1	41.2	3.7	2.7	2.7	2.7
8	5/8/86	16.2	17.9	4.1	4.1	5.0	4.1	6.1	4.1	4.2	4.1
9	5/14/86	16.0	25.4	9.5	8.5	8.9	8.5	12.5	9.8	8.5	8.5
10	5/20/86	7.4	16.1	3.5	2.7	10.2	9.3	3.5	4.0	2.7	2.7
11	5/26/86	6.4	5.3			5.1	4.2	4.5	5.2	4.0	4.1
12	6/1/86	19.5	16.6	20.7	14.5	18.7	15.7	14.3	14.4	19.9	14.9
13	6/7/86	15.5	14.8	8.4	8.4	11.2	8.5	13.3	8.7	9.8	8.4
14	6/13/86	20.0	44.1			23.2	82.8	16.3	16.4	23.6	25.8
15	6/19/86	15.7	80.4	10.0	7.6	10.1	240.0	11.3	8.1	7.6	7.6
16	6/25/86	29.5	44.7	24.4	21.6	31.8	36.7	19.2	19.4	21.4	23.6
17	7/2/86	28.2	33.9	19.0	13.7	20.7	19.5	14.9	15.7	13.6	13.8
18	7/7/86	24.1	20.7	14.1	11.1	25.8	23.4	10.6	10.6	12.6	31.7
19	7/13/86	23.1	22.9	22.6	20.2	22.7	19.7	19.7	19.7		
20	7/19/86	24.9	30.5	19.9	17.2	18.8	18.4	18.7	17.7	17.2	17.2
21	7/25/86	12.0	13.9	13.8	10.7	15.5	18.8	10.5	10.5		
22	7/31/86	25.8	43.5	21.9	17.3	29.6	22.0	21.9	18.5	17.2	17.8
23	8/6/86	26.3	27.7	24.7	19.9	26.6	28.7	19.7	18.7	18.7	62.2
24	8/12/86	43.2	43.4	22.8	18.8	25.6	25.7	30.1	19.1	18.7	19.7
25	8/18/86	38.7	92.5	15.7	12.1	33.7	23.5	16.5	12.1	12.0	40.4
26	8/24/86	24.1	24.0	22.1	18.9	21.0	18.9			18.9	18.9
27	8/30/86	19.9	19.1	16.9	14.5	14.6	15.5	21.1	14.5	14.4	14.4
28	9/5/86	65.9	44.4					34.1	16.3	16.0	16.1
29	9/11/86	35.0	36.5					24.9	18.9	18.6	23.3
30	9/17/86	6.7	57.3					4.4	3.1	3.0	3.0
31	9/23/86	27.0	39.8							19.7	31.6
32	9/29/86	20.1	43.2					13.5	8.5	8.5	8.6

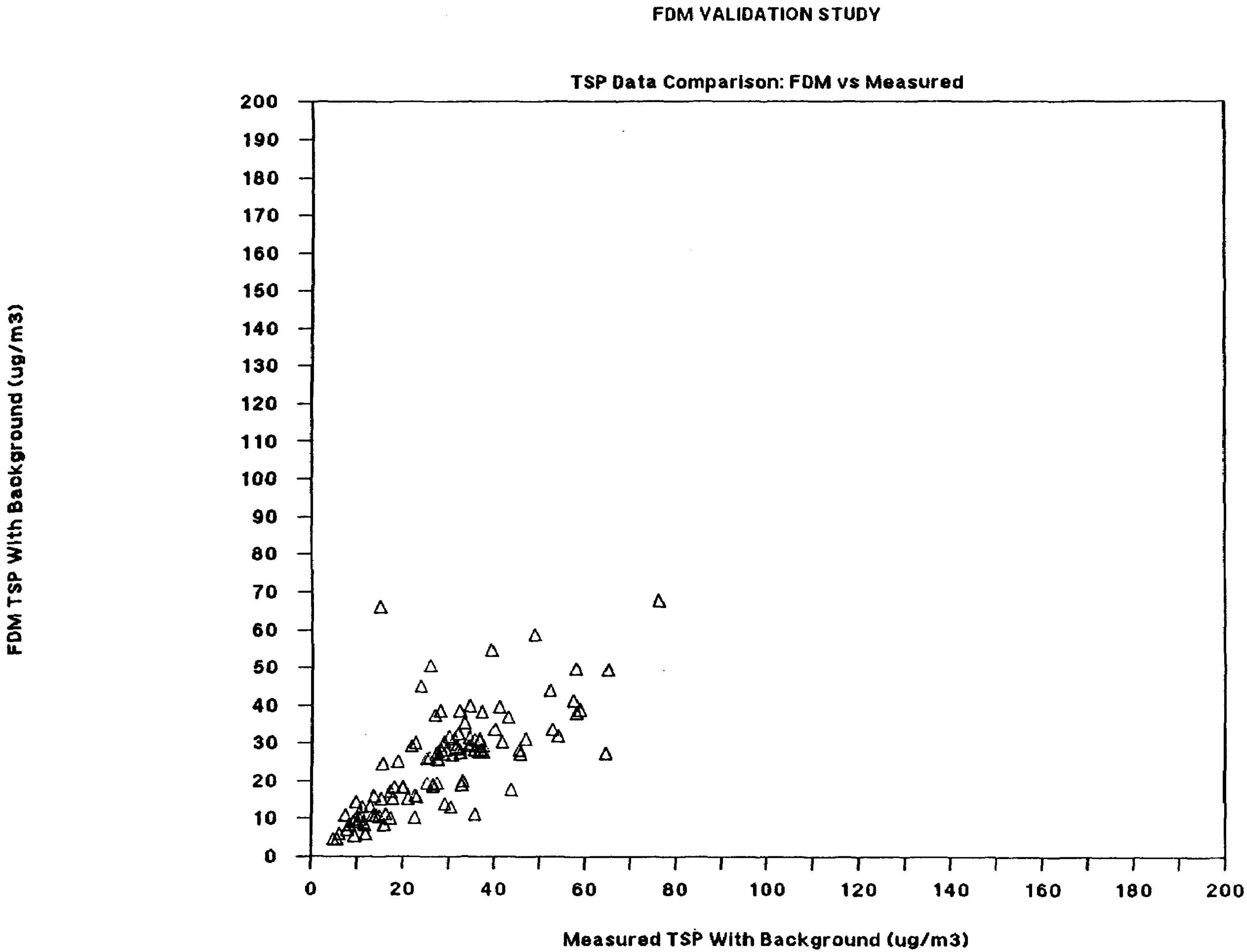


Figure 3-1 FDM Evaluation for TSP

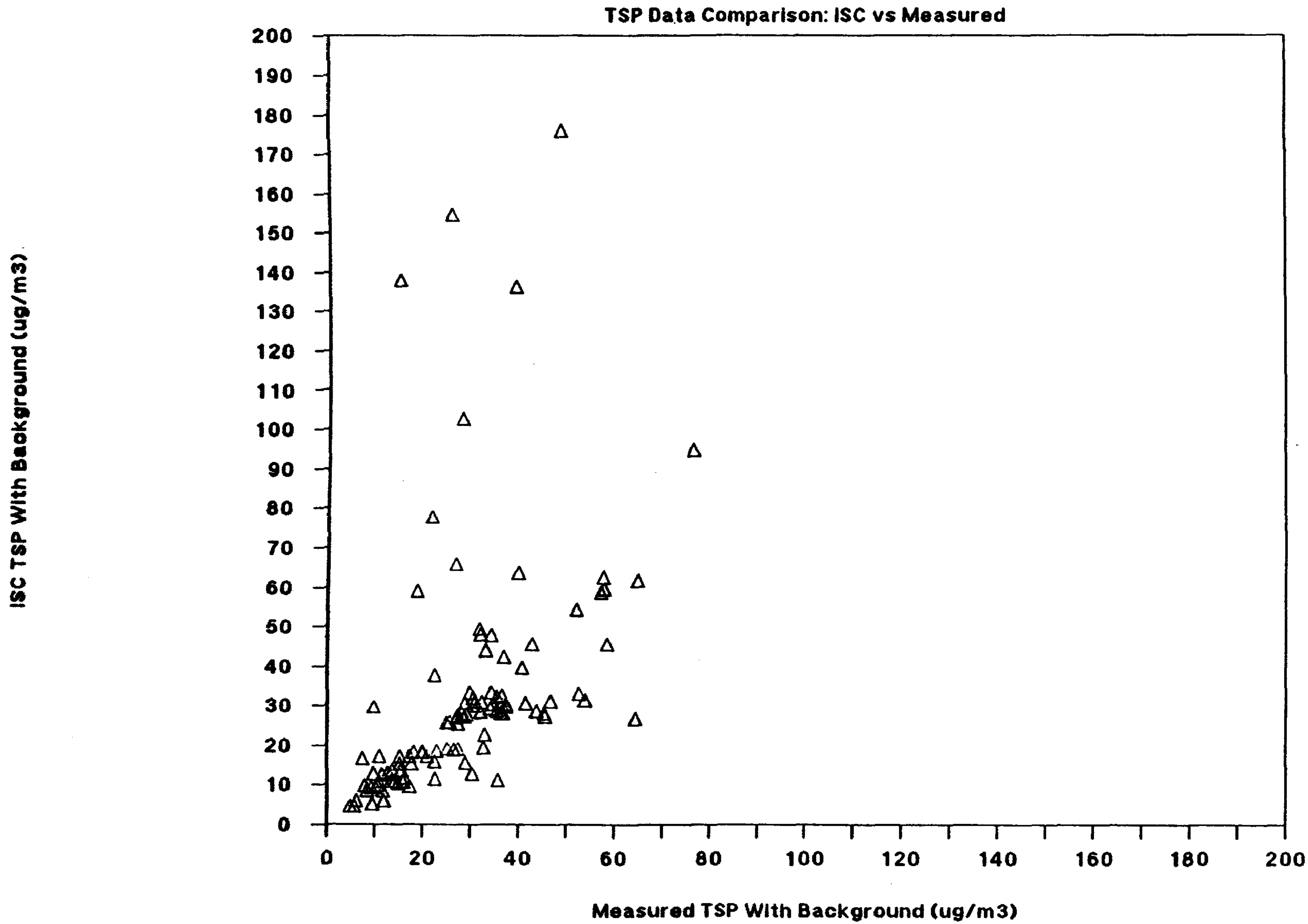


Figure 3-2 ISC Evaluation for TSP

FDM VALIDATION STUDY

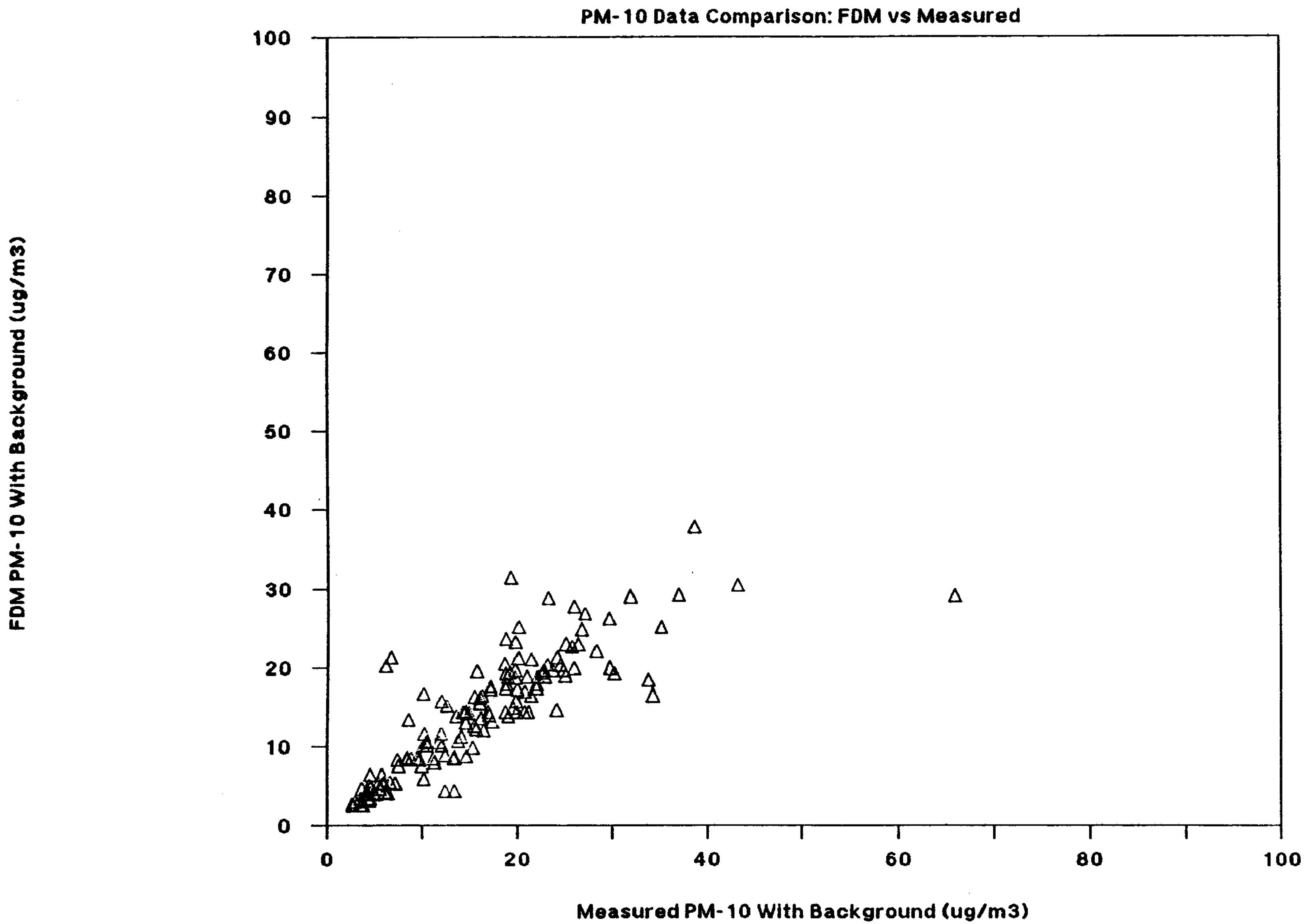


Figure 3-3 FDM Evaluation for PM-10

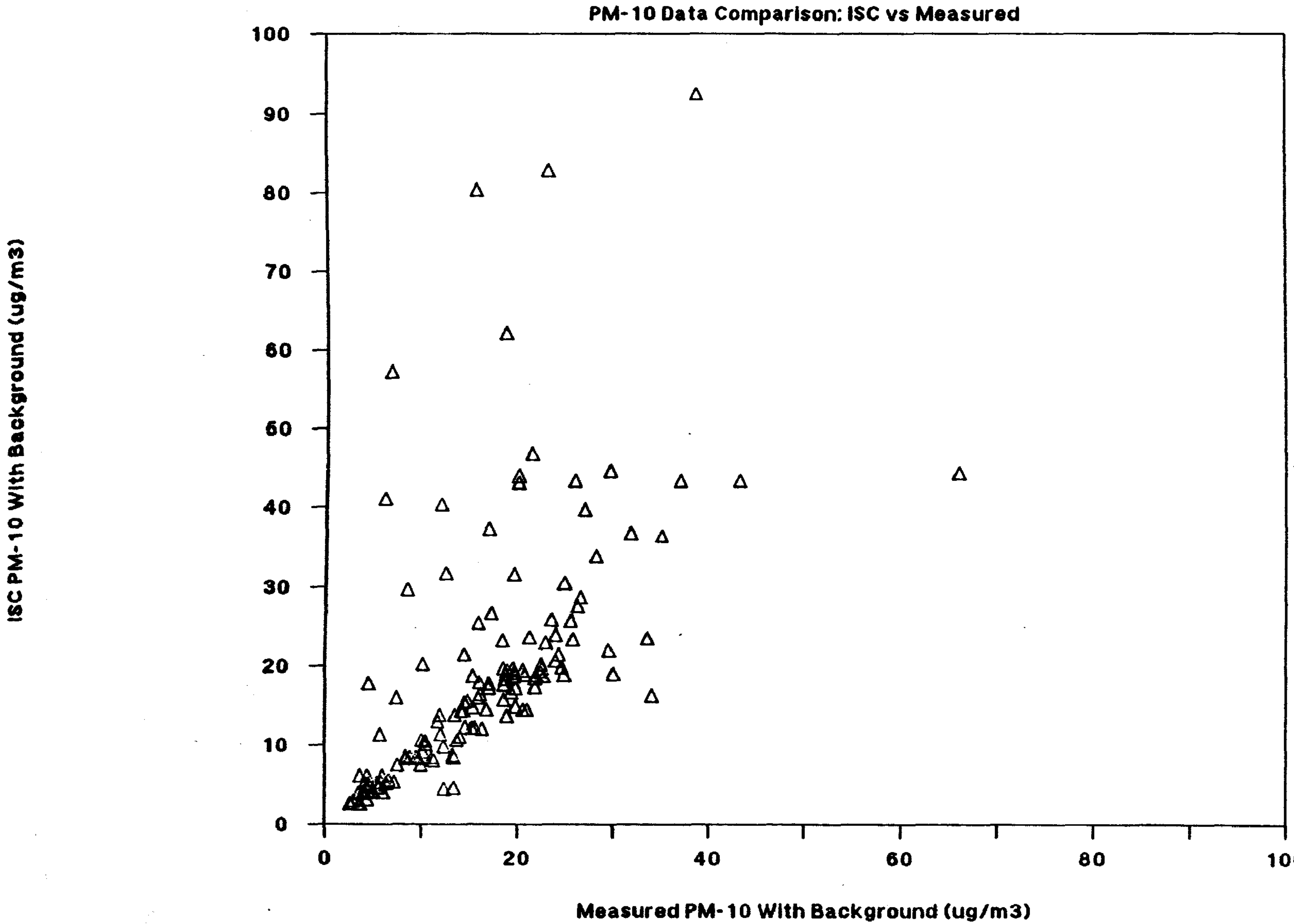


Figure 3-4 ISC Evaluation for PM-10

EPA has recently been recommending a new method for evaluation of model performance (Cox et. al., 1987). It also centers on the concept of accuracy within a factor of two, but utilizes a more complicated comparison. There are two steps in the evaluation procedure. First, a screening computation is completed using two quantities, the fractional bias for the average values and a fractional bias for the standard deviation. They are defined as follows:

$$FB = \frac{OB - PR}{(OB + PR)/2}$$

where: FB = fractional bias of the average
OB = average of highest 25 observed values
PR = average of highest 25 predicted values

$$FO = \frac{S_o - S_p}{(S_o + S_p)/2}$$

where: FO = fractional bias of the standard deviation
S_o = standard deviation of the highest 25 observed values
S_p = standard deviation of the highest 25 predicted values

The screening evaluation is performed by computing both of the above parameters, and plotting on a special graph. The second level of analysis is more complex. The second level is called the statistical test and involves using the same fractional bias computation as above, but rather than using the average and standard deviations of the observed and predicted values, the technique uses a parameter called the robust estimate of the highest concentration (RHC). In addition, the computation of the fractional bias is done for several averaging period and differing meteorological techniques and the results used to compute a composite performance measure. Finally, a statistical technique called "bootstrapping" is used where values are extracted at random from the overall data set to create a "sampled" data set, which is used in the computation of these same performance measures. By conducting this random sampling many times, the statistician can determine if differences in model performance are statistically significant. More details on the technique can be found in Cox's paper.

Using the screening technique, for the TSP concentrations in the current model evaluation, the computed values for the FB for FDM was 0.126 and the FO was 0.041. For the PM-10 concentrations the FB for FDM was 0.184 and the FO was 0.713. For ISC, the TSP values were -0.494 for the FB and -1.323 for the FO, while for PM-10 the values were -0.610 for the FB and -1.307 for the FO. The values are plotted in Figures 3-5 and 3-6 for TSP and PM-10 respectively. The box at the center of the figure is an indication of the "factor of two" performance of the model. If the data plots within the box, then the model is said to have performed within a factor of two. Since the current model evaluation results for FDM show the TSP plot within the box, the model performance for FDM is judged to be within the customary factor of two that EPA and others use as a guide. For PM-10, the FDM model predictions fall slightly outside the box, due primarily to a large difference in the standard deviation, not the average values. Further investigation of the results indicates the large FO was caused by a single high measured concentration in the PM-10 data base of 142 values. Removal of this single data point causes the FO to drop to 0.5 and the performance is within the box. As later discussions will show, the FDM model's overall performance for PM-10 was generally good, since the second level of analysis is far less sensitive to a single high value. Conversely, the results for ISC plot well outside the box as a result of many data points

FDM Model Validation Project

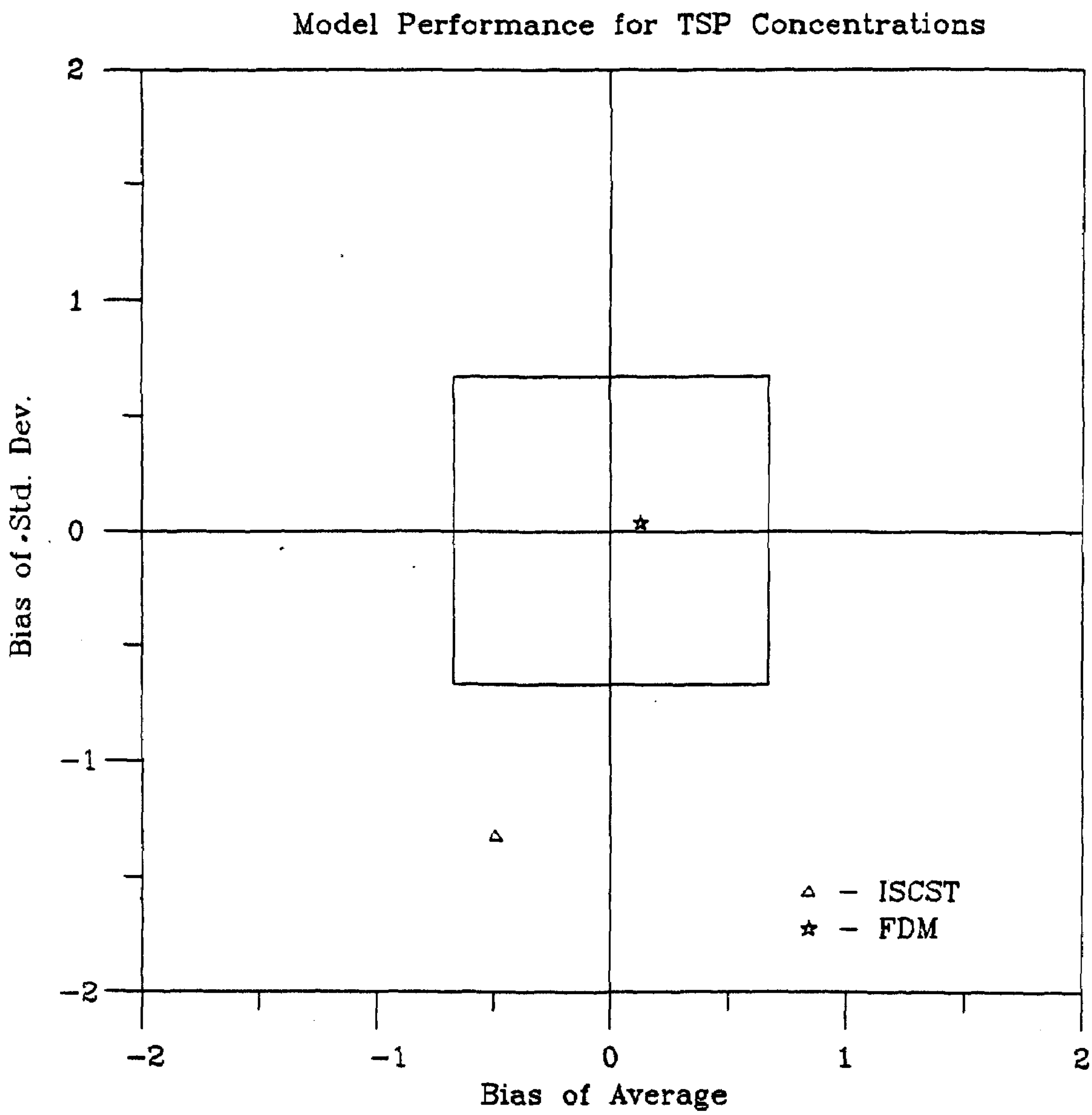


Figure 3–5. Model Comparison for TSP

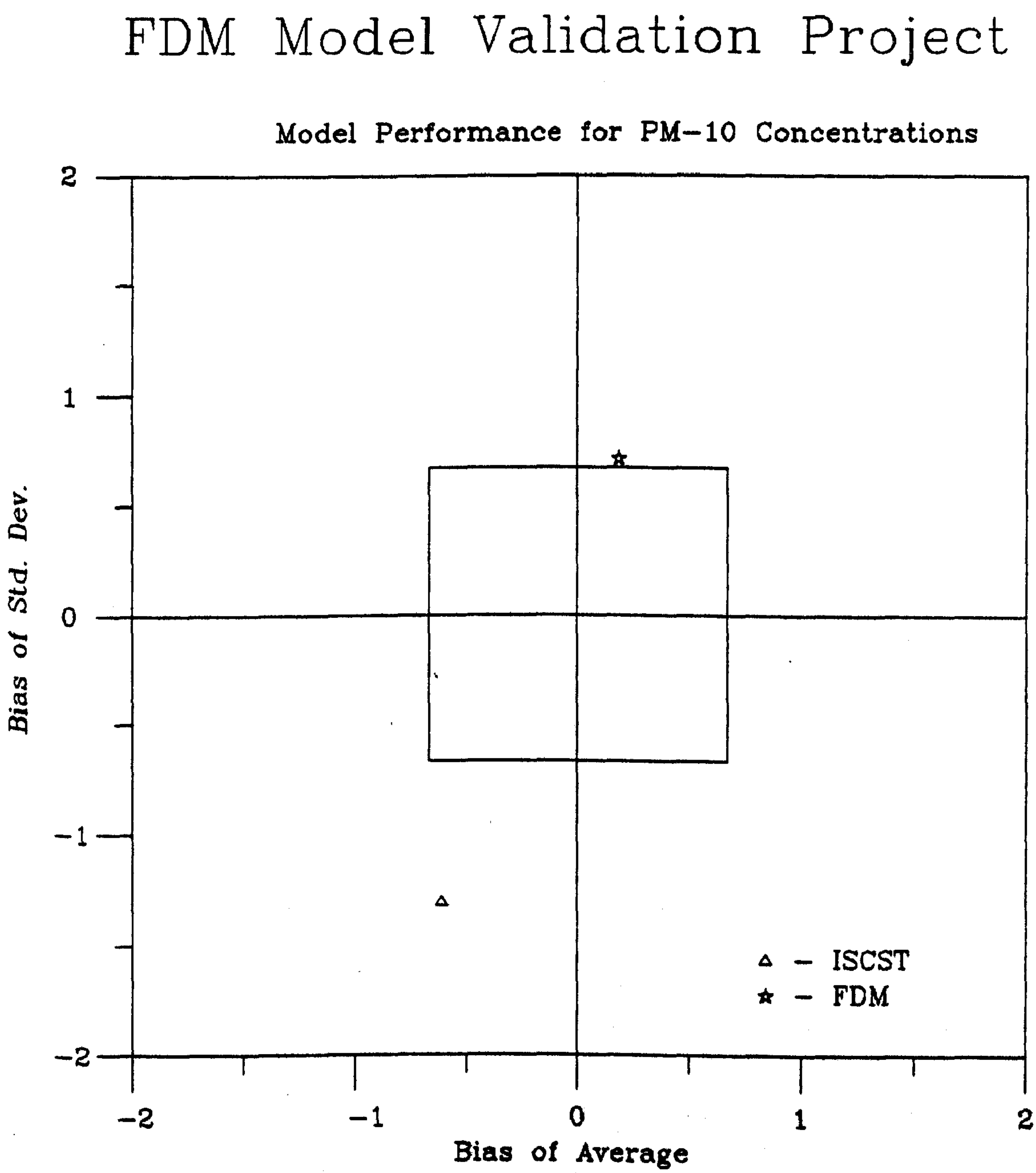


Figure 3-6. Model Comparison for PM-10

which are significantly over-predicted.

The second level of screening was a more complex undertaking. The technique has been developed primarily for predicting concentrations of sulfur dioxide or other gaseous compounds for which the data available generally include hourly observations of SO_2 concentration and meteorology on a continuous basis for a year or more. The measurement of particulate usually is done in 24-hour samples which are not continuous. As a result, modifications had to be made to the statistical evaluation methods to apply them to the current application. The modifications to the technique of Cox are summarized as follows:

- o Only 24-hour values were available, thus only the only averaging time in the evaluation was 24-hour. Cox refers to a calculation of a "scientific" evaluation which uses 1-hour average concentrations. This computation was dispensed with. Given the single averaging time used here. the composite performance measure used here was equal to the Absolute Fractional Bias of the RHC values for the 24-hour samples.

- o Since only 32 case days were examined, and since data were not available at all stations for all of the days, it was determined to combine all of the data into a single sampling set for the purposes of computing the RHC, rather than conducting the computation on a site-by-site basis as the guidance suggests. The data sets would have been too small if the separation of the values by site had been performed.

- o The bootstrapping technique calls for the construction of a number of trial "years" by sampling the data set. Since sampling a six month, intermittent data set to create a full year of data, would extend the data beyond its measurement bounds, the sampling was performed only to create a trial set equivalent in size to the original data set. Thus for TSP, 111 values are in the original data set and each bootstrap sample was composed of 111 randomly-sampled values. Note that no persistance of 3 days was used since the data are sampled on a six-day cycle, and persistence is not relevant.

The bootstrapping analysis was completed for both TSP and PM-10 values for both models. Although not customarily presented in this fashion, the frequency distribution of the Fraction Bias of the RHC's calculated in the bootstrapping analysis for TSP are shown in Figure 3-7. Note that the figure presents the fractional bias, not the absolute fractional bias. As the figure shows, there is a clear separation between the FDM values and the ISC values, indicating a significantly different performance. Note that the values for ISC are all negative, while the values for FDM are closer to zero, but predominantly positive. The implication of the figure is that FDM slightly under-predicts while ISC drastically over-predicts.

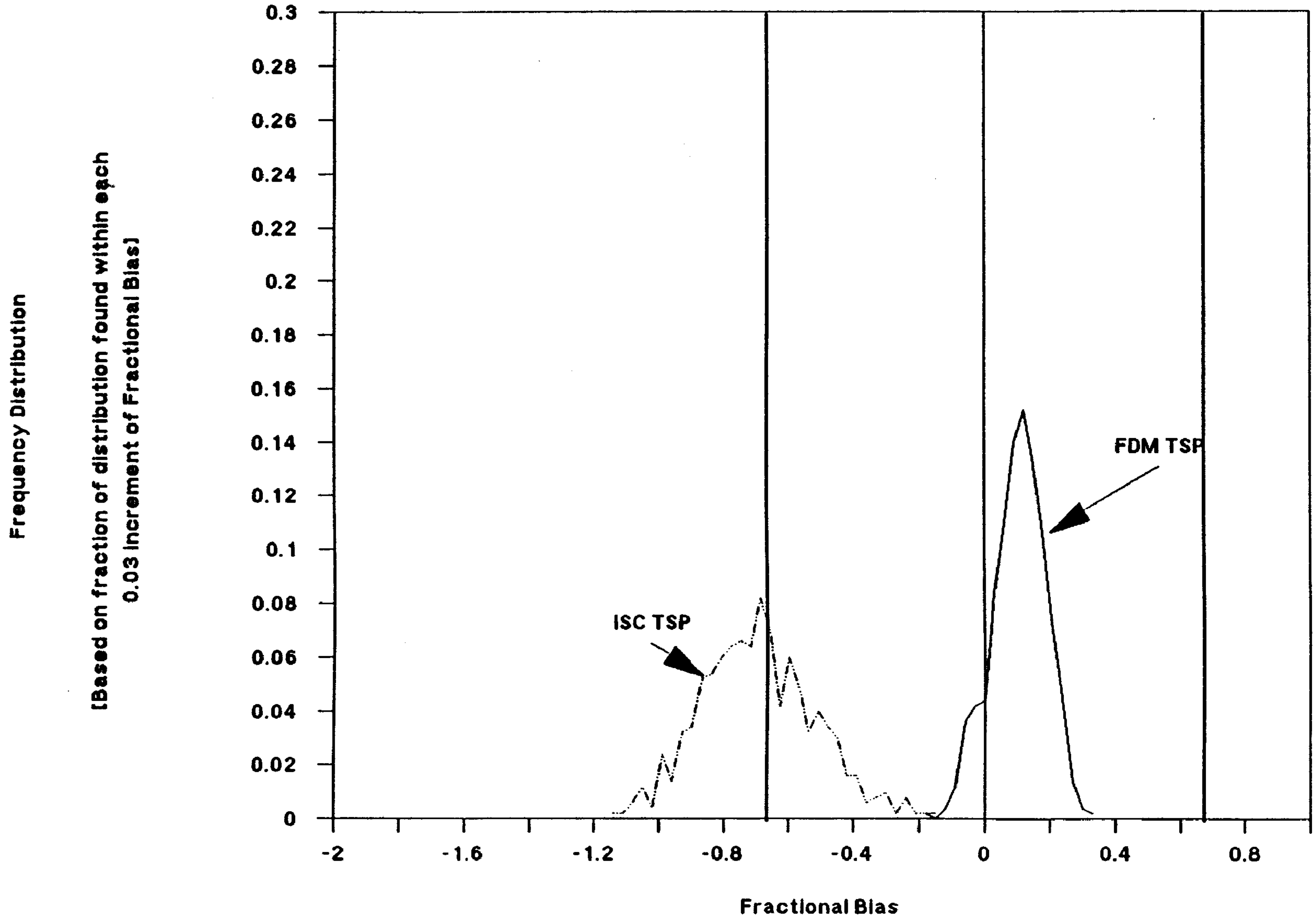
When the results for TSP and PM-10 are presented in the more customary fashion for 95% confidence limits, as shown in Figure 3-8, it is clear that the FDM Model is closer to reality than the ISC Model. In fact a significant portion of the statistical distribution of ISC Values are outside the factor of 2 performance criteria indicated by the dark line in Figure 3-8.

The previous discussion would lead to the conclusion that generally, the FDM model performs acceptably with the data, while the ISC model does not. In actuality, as earlier figures show, both models do reasonably well for the majority of data points. However, ISC has the tendency for large over-prediction on few days. Unfortunately, it is these days which are the focus of the permitting regulations. Most regulations concern the <u>maximum</u> or <u>second highest</u> concentration, so the ISC over-prediction on these days causes very misleading results in air quality permitting studies. The problem tends to occur when the source to receptor distance is short (e.g. the distance to the haul road from AQ-1) and it tends to occur under stable, low wind speed conditions.

One of the major advantages of the FDM approach is the avoidance of these large over-predictions. The improved prediction occurs due to the superior deposition algorithm in the FDM Model. During low wind speed stable

FDM MODEL VALIDATION STUDY

Figure 3-7
Fractional Bias Distributions Calculated from RHC Values



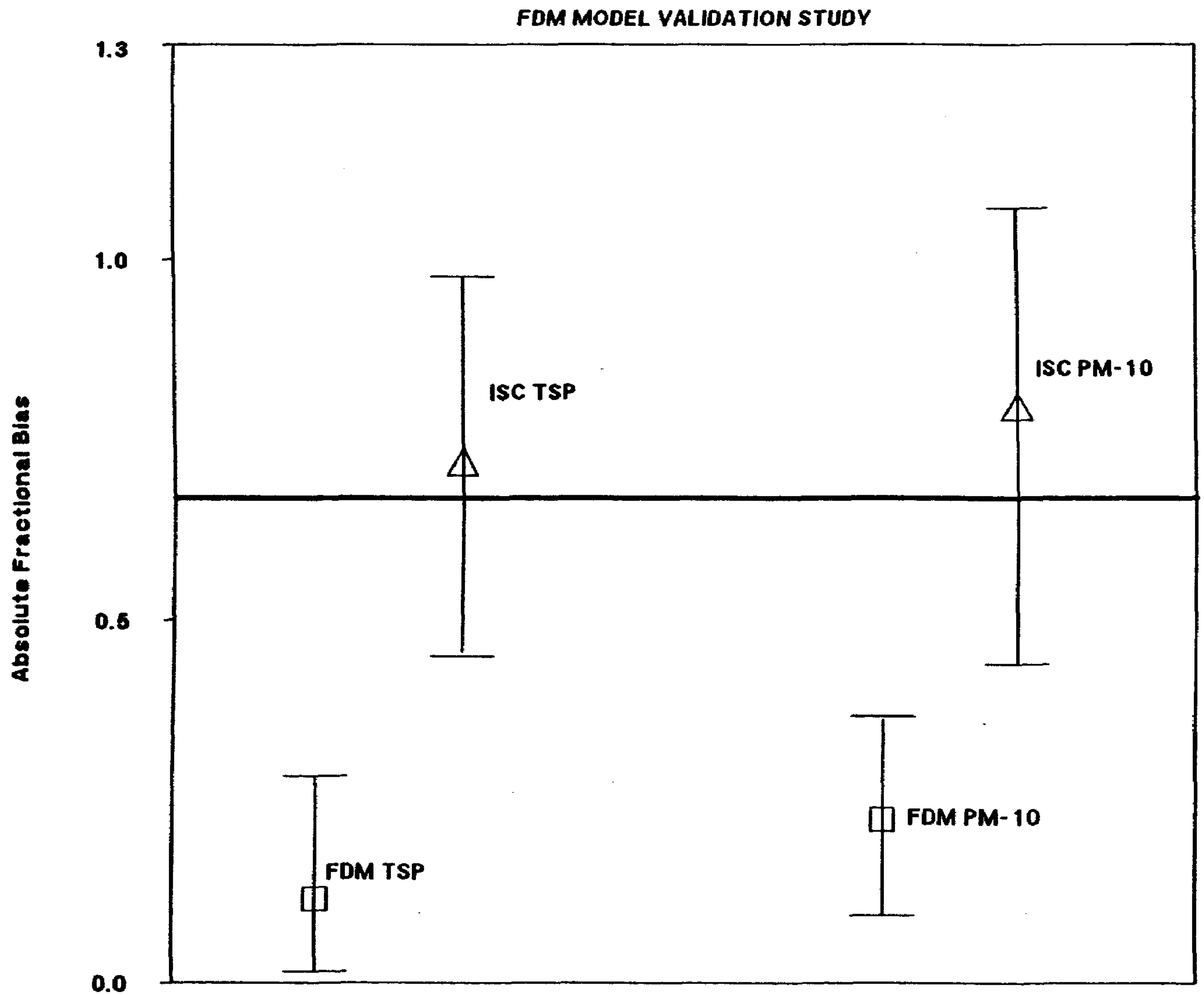


Figure 3-8. Absolute Fractional Bias at 95% Bootstrap Confidence Bounds

conditions, the ISC model allows very high concentrations to be predicted, not reflecting the deposition which would occur during the long travel times to the receptor. FDM more accurately represents the behavior of particles in the atmosphere.

4.0 CONCLUSIONS

The previous analysis has determined that the FDM Model performs generally well in characterizing particulate concentrations in the vicinity of the fugitive dust source. The ISC model also performed well for the bulk of the samples analyzed, but failed poorly on the high end of the statistical distribution, leading to large over-predictions of the highest and second highest concentrations, which are the focus of many air quality regulations for short-term particulate concentrations. The FDM Model is judged to be superior in predicting the impacts from fugitive dust sources for the data evaluated in this study.

REFERENCES

Cox, W. M. 1987. "Protocol for Determining the Best Performing Model", U. S. Environmental Protection Agency Report, September.

Gifford, F. A, Jr., 1976. "Turbulent Diffusion Typing Schemes - A Review, Nuclear Saf., 17: 68:86.

Winges, K. D., 1982. "Development of an Air Quality Model for Mining Fugitive Dust", Presented at the Annual Meeting of the Air Pollution Control Association, New Orleans, June.

APPENDIX -B

SAMPLE INPUT AND OUTPUT STREAMS

SAMPLE INPUT STREAM FOR FDM

```
VALIDATION STUDY OF FDM MODEL PM10 CASE NO. 20
 1 1 2 1 1 1 1 1 1 2 1
   56    5    3   24
 60.       1.        1.        2.5
1.25       3.75      7.5       12.5      20.
0.0262     0.0678    0.1704    0.1536    0.5820
622.       1103.
824.       3191.
1344.      1939.
1554.      183.
61.        2365.
 10.166950E-02  0.00     610.0     1363.0        0.0        0.0
 10.212000E-01  1.00     610.0     1363.0        0.0        0.0
 10.371000E-01  1.00     549.0     1426.0        0.0        0.0
 10.318000E-02  1.00     488.0     1451.0        0.0        0.0
 30.112861E-04  0.00    1055.0     1512.0      354.0      305.0
 30.337000E-08  3.00    1055.0     1512.0      354.0      305.0
 30.112861E-04  0.00    1203.0     1256.0      149.0      217.0
 30.337000E-08  3.00    1203.0     1256.0      149.0      217.0
 30.100962E-06  0.00     237.0     1789.0      208.0      140.0
 30.337000E-08  3.00     237.0     1789.0      208.0      140.0
 30.194560E-06  0.00     513.0     1780.0      207.0      219.0
 30.337000E-08  3.00     513.0     1780.0      207.0      219.0
 30.121500E-03  0.00     683.0     1353.0       84.0       50.0
 30.337000E-08  3.00     683.0     1353.0       84.0       50.0
 30.379174E-05  0.00     318.0     1158.0       87.0       82.0
 30.337000E-08  3.00     318.0     1158.0       87.0       82.0
 30.379174E-05  0.00     549.0      795.0      149.0      122.0
 30.337000E-08  3.00     549.0      795.0      149.0      122.0
 30.379174E-05  0.00     195.0     1075.0      195.0      104.0
 30.337000E-08  3.00     195.0     1075.0      195.0      104.0
 30.379174E-05  0.00     402.0      597.0       85.0       85.0
 30.337000E-08  3.00     402.0      597.0       85.0       85.0
 30.379174E-05  0.00     299.0      634.0       85.0      195.0
 30.337000E-08  3.00     299.0      634.0       85.0      195.0
 30.379174E-05  0.00     610.0      207.0      140.0      146.0
 30.337000E-08  3.00     610.0      207.0      140.0      146.0
 20.198317E-03  0.00     999.7     1658.1      999.7     1475.2          30.0
 20.198317E-03  0.00    1146.0     1475.2      999.7     1475.2          30.0
 20.396634E-03  0.00     999.7     1475.2      816.9     1341.1          30.0
 20.104667E-03  0.00     816.9     1341.1      755.9     1414.3          30.0
 20.275440E-04  0.00     755.9     1414.3      694.9     1426.5          30.0
 20.275440E-04  0.00     694.9     1426.5      621.8     1365.5          30.0
 20.502678E-04  0.00     621.8     1365.5      658.4     1304.5          30.0
 20.413160E-04  0.00     658.4     1304.5      816.9     1341.1          30.0
 20.771232E-04  0.00     755.9     1414.3      719.3     1511.8          30.0
 20.771232E-04  0.00     719.3     1511.8      719.3     1670.3          30.0
 20.771232E-04  0.00     719.3     1670.3      634.0     1914.1          30.0
 20.771232E-04  0.00     634.0     1914.1      560.8     1962.9          30.0
 20.192808E-04  0.00     560.8     1962.9      353.6     1828.8          30.0
 20.964040E-05  0.00     353.6     1828.8      182.9     1828.8          30.0
```

20.964040E-05	0.00	353.6	1828.8	195.1	1731.3	30.0
20.192808E-04	0.00	585.2	1950.7	414.5	1731.3	30.0
20.192808E-04	0.00	609.6	1938.5	487.7	1743.5	30.0
20.192808E-04	0.00	621.8	1926.3	560.8	1743.5	30.0
20.250650E-03	0.00	816.9	1341.1	560.8	1170.4	30.0
20.250650E-03	0.00	560.8	1170.4	438.9	1146.0	30.0
20.250650E-03	0.00	438.9	1146.0	402.3	1109.5	30.0
20.250650E-03	0.00	402.3	1109.5	317.0	1158.2	30.0
20.000000E+00	0.00	402.3	1109.5	512.1	841.2	30.0
20.000000E+00	0.00	512.1	841.2	573.0	792.5	30.0
20.000000E+00	0.00	512.1	841.2	256.0	1036.3	30.0
20.000000E+00	0.00	512.1	841.2	463.3	804.7	30.0
20.000000E+00	0.00	463.3	804.7	85.3	1036.3	30.0
20.000000E+00	0.00	85.3	1036.3	61.0	963.2	30.0
20.000000E+00	0.00	61.0	963.2	597.4	182.9	30.0
20.000000E+00	0.00	207.3	755.9	426.7	573.0	30.0
1.50	7.3	2	1200.0	291.2		
1.19	354.4	1	1400.0	290.9		
0.61	340.9	1	1400.0	290.4		
3.14	13.5	5	10000.0	290.0		
4.66	16.0	5	10000.0	289.9		
5.54	12.6	5	10000.0	290.1		
6.08	13.3	5	10000.0	290.3		
7.04	11.4	4	400.0	291.6		
7.57	12.6	4	400.0	293.5		
6.34	18.7	4	400.0	295.3		
4.41	29.6	3	800.0	297.1		
2.19	52.9	1	1400.0	298.9		
1.84	56.2	1	1400.0	300.9		
2.28	32.8	1	1400.0	302.4		
2.57	198.4	1	1400.0	303.2		
3.15	186.4	1	1400.0	303.2		
2.12	218.4	1	1400.0	304.1		
3.34	193.5	1	1400.0	303.9		
4.35	228.5	2	1200.0	302.8		
4.55	240.5	4	400.0	301.1		
3.28	270.5	1	1400.0	298.9		
2.20	277.8	1	1400.0	297.4		
2.23	297.0	4	400.0	296.2		
1.56	339.9	1	1400.0	295.3		

FUGITIVE DUST MODEL (FDM)
VERSION 1.0
JANUARY, 1988

RUN TITLE:
VALIDATION STUDY OF FDM MODEL PM10 CASE NO. 20

INPUT FILE NAME: PM10F20.IN
OUTPUT FILE NAME: PM10F20.OUT
PLOT OUTPUT WRITTEN TO FILE NAME: PM10F20.DAT

CON/DEP SWITCH 1=CONCEN, 2=DEPO	1
MET OPTION SWITCH, 1=CARDS, 2=PREPROCESSED	1
PLOT FILE OUTPUT, 1=NO, 2=YES	2
MET DATA PRINT SWITCH, 1=NO, 2=YES	1
POST-PROCESSOR OUTPUT, 1=NO, 2=YES	1
DEP. VEL./GRAV. SETL. VEL., 1=DEFAULT, 2=USER	1
PRINT 1-HOUR AVERAGE CONCEN, 1=NO, 2=YES	1
PRINT 3-HOUR AVERAGE CONCEN, 1=NO, 2=YES	1
PRINT 8-HOUR AVERAGE CONCEN, 1=NO, 2=YES	1
PRINT 24-HOUR AVERAGE CONCEN, 1=NO, 2=YES	2
PRINT LONG-TERM AVERAGE CONCEN, 1=NO, 2=YES	1
NUMBER OF SOURCES PROCESSED	56
NUMBER OF RECEPTORS PROCESSED	5
NUMBER OF PARTICLE SIZE CLASSES	3
NUMBER OF HOURS OF MET DATA PROCESSED	24
LENGTH IN MINUTES OF 1-HOUR OF MET DATA	60.
ROUGHNESS LENGTH IN CM	1.00
SCALING FACTOR FOR SOURCE AND RECPTORS	1.0000
PARTICLE DENSITY IN G/CM**3	2.50

GENERAL PARTICLE SIZE CLASS INFORMATION

PARTICLE SIZE CLASS	CHAR. DIA. (CM)	GRAV. SETTLING VELOCITY (M/SEC)	DEPOSITION VELOCITY (M/SEC)	FRACTION IN EACH SIZE CLASS
1	0.0001250	0.00013	**	0.0262
2	0.0003750	0.00110	**	0.0678
3	0.0007500	0.00432	**	0.1704

** COMPUTED HOURLY BY FDM

RECEPTOR COORDINATES (X,Y,Z)

```
(   622.,  1103.,   0.) (   824.,  3191.,   0.) (  1344.,  1939.,   0.)
(  1554.,   183.,   0.) (    61.,  2365.,   0.) (
```

SOURCE INFORMATION

TYPE	ENTERED EMIS. RATE (G/SEC, G/SEC/M OR G/SEC/M**2)	TOTAL EMISSION RATE (G/SEC)	WIND SPEED FAC.	X1 (M)	Y1 (M)	X2 (M)	Y2 (M)	HEIGHT (M)	WIDTH (M)
1	0.001669500	0.00167	0.000	610.	1363.	0.	0.	0.00	0.00
1	0.021200000	0.02120	1.000	610.	1363.	0.	0.	0.00	0.00
1	0.037100000	0.03710	1.000	549.	1426.	0.	0.	0.00	0.00
1	0.003180000	0.00318	1.000	488.	1451.	0.	0.	0.00	0.00
3	0.000011286	1.21856	0.000	1055.	1512.	354.	305.	0.00	0.00
3	0.000000003	0.00036	3.000	1055.	1512.	354.	305.	0.00	0.00
3	0.000011286	0.36491	0.000	1203.	1256.	149.	217.	0.00	0.00
3	0.000000003	0.00011	3.000	1203.	1256.	149.	217.	0.00	0.00
3	0.000000101	0.00294	0.000	237.	1789.	208.	140.	0.00	0.00
3	0.000000003	0.00010	3.000	237.	1789.	208.	140.	0.00	0.00
3	0.000000195	0.00882	0.000	513.	1780.	207.	219.	0.00	0.00
3	0.000000003	0.00015	3.000	513.	1780.	207.	219.	0.00	0.00
3	0.000121500	0.51030	0.000	683.	1353.	84.	50.	0.00	0.00
3	0.000000003	0.00001	3.000	683.	1353.	84.	50.	0.00	0.00
3	0.000003792	0.02705	0.000	318.	1158.	87.	82.	0.00	0.00
3	0.000000003	0.00002	3.000	318.	1158.	87.	82.	0.00	0.00
3	0.000003792	0.06893	0.000	549.	795.	149.	122.	0.00	0.00
3	0.000000003	0.00006	3.000	549.	795.	149.	122.	0.00	0.00
3	0.000003792	0.07690	0.000	195.	1075.	195.	104.	0.00	0.00
3	0.000000003	0.00007	3.000	195.	1075.	195.	104.	0.00	0.00
3	0.000003792	0.02740	0.000	402.	597.	85.	85.	0.00	0.00
3	0.000000003	0.00002	3.000	402.	597.	85.	85.	0.00	0.00
3	0.000003792	0.06285	0.000	299.	634.	85.	195.	0.00	0.00
3	0.000000003	0.00006	3.000	299.	634.	85.	195.	0.00	0.00
3	0.000003792	0.07750	0.000	610.	207.	140.	146.	0.00	0.00
3	0.000000003	0.00007	3.000	610.	207.	140.	146.	0.00	0.00
2	0.000198317	0.03627	0.000	1000.	1658.	1000.	1475.	0.00	30.00
2	0.000198317	0.02901	0.000	1146.	1475.	1000.	1475.	0.00	30.00
2	0.000396634	0.08992	0.000	1000.	1475.	817.	1341.	0.00	30.00
2	0.000104667	0.00997	0.000	817.	1341.	756.	1414.	0.00	30.00
2	0.000027544	0.00171	0.000	756.	1414.	695.	1427.	0.00	30.00
2	0.000027544	0.00262	0.000	695.	1427.	622.	1366.	0.00	30.00
2	0.000050268	0.00358	0.000	622.	1366.	658.	1305.	0.00	30.00
2	0.000041316	0.00672	0.000	658.	1305.	817.	1341.	0.00	30.00
2	0.000077123	0.00803	0.000	756.	1414.	719.	1512.	0.00	30.00
2	0.000077123	0.01222	0.000	719.	1512.	719.	1670.	0.00	30.00
2	0.000077123	0.01992	0.000	719.	1670.	634.	1914.	0.00	30.00
2	0.000077123	0.00678	0.000	634.	1914.	561.	1963.	0.00	30.00
2	0.000019281	0.00476	0.000	561.	1963.	354.	1829.	0.00	30.00
2	0.000009640	0.00165	0.000	354.	1829.	183.	1829.	0.00	30.00
2	0.000009640	0.00179	0.000	354.	1829.	195.	1731.	0.00	30.00
2	0.000019281	0.00536	0.000	585.	1951.	415.	1731.	0.00	30.00
2	0.000019281	0.00443	0.000	610.	1939.	488.	1744.	0.00	30.00
2	0.000019281	0.00372	0.000	622.	1926.	561.	1744.	0.00	30.00
2	0.000250650	0.07714	0.000	817.	1341.	561.	1170.	0.00	30.00

2	0.000250650	0.03116	0.000	561.	1170.	439.	1146.	0.00	30.00
2	0.000250650	0.01296	0.000	439.	1146.	402.	1110.	0.00	30.00
2	0.000250650	0.02462	0.000	402.	1110.	317.	1158.	0.00	30.00
2	0.000000000	0.00000	0.000	402.	1110.	512.	841.	0.00	30.00
2	0.000000000	0.00000	0.000	512.	841.	573.	793.	0.00	30.00
2	0.000000000	0.00000	0.000	512.	841.	256.	1036.	0.00	30.00
2	0.000000000	0.00000	0.000	512.	841.	463.	805.	0.00	30.00
2	0.000000000	0.00000	0.000	463.	805.	85.	1036.	0.00	30.00
2	0.000000000	0.00000	0.000	85.	1036.	61.	963.	0.00	30.00
2	0.000000000	0.00000	0.000	61.	963.	597.	183.	0.00	30.00
2	0.000000000	0.00000	0.000	207.	756.	427.	573.	0.00	30.00

24 HOUR AVERAGE FOR HOUR ENDING 24
CONCENTRATIONS IN MICROGRAMS/M**3

(622., 1103., 5.883) (824., 3191., 0.043) (1344., 1939., 0.768)
(1554., 183., 0.216) (61., 2365., 0.008) (

APPENDIX C

FORTRAN COMPUTER CODE

```
      PROGRAM FDM
CC
CC FDM - Fugitive Dust Model
CC User's Instructions:
CC
CC Card 1    Title Card
CC      Col        Format          Information
CC      1-80       A80             Title
CC
CC Card 2    Switches
CC      Col        Format          Information
CC      2          I1              Concentration/Deposition Switch.  If =1 then
CC                                 model computes concentration.  If = 2 then
CC                                 model computes deposition.  Default is 1.
CC
CC      4          I1              Met. Option Switch.  If = 1 then met. data is
CC                                 read from cards (format shown below).  If = 2
CC                                 then met is read from pre-processed
CC                                 meteorological file.  If = 3 then
CC                                 meteorological data is read as a STAR
CC                                 contained later in this input file.  Note that
CC                                 the selection of the STAR option makes many of
CC                                 the later options not applicable.  Default is
CC                                 1.
CC
CC      6          I1              Plotter Output Switch.  If = 1 then no plotter
CC                                 file is made.  If = 2 then a plotter file name
CC                                 is asked for and the model writes a file with
CC                                 a formatted output of x, y, concen. for every
CC                                 averaging time requested to be analyzed.
CC                                 Default is 1.
CC
CC      8          I1              Print Output Switch.  If = 1 then
CC                                 meteorological data are not printed.  If = 2
CC                                 then meteorological data are printed.  Default
CC                                 is 1.
CC
CC      10         I1              Post Processor Switch.  If = 1 then no post
CC                                 processor file is written.  If = 2, then a
CC                                 post processor file is written which can be
CC                                 processed with the POSTZ program to develop
CC                                 High-5 tables, scale sources, or other
CC                                 operations.  The user should see the POSTZ
CC                                 User's Guide for further information.  This
CC                                 option is not available and this switch is
CC                                 ignored when the met. option switch = 3.
CC                                 Default is 1.
CC
CC      12         I1              Deposition Parameters Option Switch.  If = 1
CC                                 then the model will compute deposition
CC                                 velocity and gravitational settling velocity
CC                                 automatically on an hour by hour basis.  If =
```

```
CC                                  2 then the User will enter single values of
CC                                  the deposition velocity and gravitational
CC                                  velocity for each particle size class to be
CC                                  used for all hours.  Default is 1.
CC
CC      14         I1               1-Hour Switch.  If = 1 then 1-hour average
CC                                  concentrations are not printed,  If = 2 then
CC                                  1-hour average concentrations are printed.
CC                                  This option is not available and this switch
CC                                  is ignored when the met. option switch = 3.
CC                                  Default is 1.
CC
CC      16         I1               3-Hour Switch.  If = 1 then 3-hour average
CC                                  concentrations are not printed.  If = 2 then
CC                                  3-hour average concentrations are printed.
CC                                  This option is not available and this switch
CC                                  is ignored when the met. option switch = 3.
CC                                  Default is 1.
CC
CC      18         I1               8-Hour Switch.  If = 1 then 8-hour average
CC                                  concentrations are not printed.  If = 2 then
CC                                  8-hour average concentrations are printed.
CC                                  This option is not available and this switch
CC                                  is ignored when the met. option switch = 3.
CC                                  Default is 1.
CC
CC      20         I1               24-Hour Switch.  If = 1 then 24-hour average
CC                                  concentrations are not printed.  If = 2 then
CC                                  24-hour average concentrations are printed.
CC                                  This option is not available and this switch
CC                                  is ignored when the met. option switch = 3.
CC                                  Default is 1.
CC
CC      22         I1               Long-term Switch.  If = 1 then average
CC                                  concentrations over the entire meteorological
CC                                  data base provided are not printed.  If = 2
CC                                  then such long term average concentrations are
CC                                  printed.  This option is not available and
CC                                  this switch is ignored when the met. option
CC                                  switch = 3.  Default is 1.
CC
CC Card 3    STAR Data (These Cards are only read if Met. Option Switch = 3)
CC      Col        Format           Information
CC      1-60       6F10.0           A total of 96 cards are read here with the
CC                                  information being the frequency of winds for
CC                                  each combination of wind speed class, wind
CC                                  direction class and atmospheric stability
CC                                  class.  Each card contains six values
CC                                  corresponding to the six possible wind speed
CC                                  classes.  The order of the cards is 16 cards
CC                                  for the 16 possible wind direction classes for
CC                                  the first stability class, followed by the
```

```
CC                                  next 16 cards for the second stability class,
CC                                  followed by 16 cards for each subsequent
CC                                  stability class up to the final (sixth)
CC                                  stability class.  The wind direction cards are
CC                                  ordered with north being first, north-
CC                                  northeast being second and proceeding
CC                                  clockwise until north-northwest is entered.
CC                                  Stabilities start with Turner Class A, and
CC                                  proceed to Turner Class F.  The sum of all 576
CC                                  values entered here should be 1.0.
CC
CC Card 4    Mixing Heights for each Stability Class when using a STAR (This
CC           Card is only read if Met. Option Switch = 3)
CC      Col         Format          Information
CC      1-60        6F10.0          Six values are read here to indicate the
CC                                  characteristic mixing height to be used with
CC                                  each stability class when using a STAR for
CC                                  input meteorological data.  Mixing heights
CC                                  should be entered in meters above ground.
CC
CC Card 5    Characteristic Wind speeds for each wind speed class when using a
CC           STAR (This Card is only read if Met. Option Switch = 3)
CC      Col         Format          Information
CC      1-60        6F10.0          Six values are read here to indicate the
CC                                  characteristic wind speed to be used by the
CC                                  model for each of the wind speed classes when
CC                                  running with meteorological data entered in
CC                                  the form of a STAR.  Wind speed values should
CC                                  be entered in meters per second.
CC Card 6    Integer Parameters
CC      Col         Format          Information
CC      1-5         I5              Number of Sources
CC
CC      6-10        I5              Number of Receptors
CC
CC      11-15       I5              Number of Particle Size Classes, with a
CC                                  maximum of 20 allowed.  Note that in order to
CC                                  compute any deposition values or to compute
CC                                  any concentrations which have deposition
CC                                  accounted for, this parameter must be set to
CC                                  some value other than 0.
CC
CC      16-20       I5              Number of Hours of Meteorological data to be
CC                                  processed in this run.
CC
CC Card 7    Real Parameters
CC      Col         Format          Information
CC      1-10        F10.0           ATIM - the length of time in one unit of
CC                                  meteorological data entry in minutes.
CC                                  Generally, this is entered as 60.
CC
CC      11-20       F10.0           Surface Roughness Height in cm.
```

```
CC
CC      21-30     F10.0           SCAL - a scaling factor for all entries
CC                                involving distance.  The model assumes all
CC                                entries for coordinates or dimensions are in
CC                                meters.  If the user desires to enter some
CC                                other units, he may enter a conversion factor
CC                                here such that when the units he has entered
CC                                are multiplied by SCAL the result will be in
CC                                meters.
CC
CC      31-40     F10.0           PD - the density of the particulate matter in
CC                                grams per cubic meter.  Typical values range
CC                                from 1.0 to 3.0 depending on the type of
CC                                material which comprises the particulate
CC                                matter.
CC
CC Card 8   Meteorological Data Selection Switches.  These cards are entered
CC          only if a sequentially pre-processed meteorological data set is
CC          being used (Met. Option Switch = 2).  The switches allow the user
CC          to select a certain portion of the sequential data set for
CC          processing and skip the rest.
CC      Col       Format          Information
CC      1-80       80I1           A series of 1's or zero's is used to determine
CC                                if a particular day from the sequentially pre-
CC                                processed meteorological data set is to be
CC                                processed in this run.  The first number
CC                                entered corresponds to day 1, etc.  A total of
CC                                366 values (4 and 1/2 cards) is needed to
CC                                enter all 366 values.  If a 1 is entered the
CC                                day is to be processed, if a zero is entered
CC                                the day is to be skipped.
CC
CC Card 9   Characteristic Particle Diameters (not entered if the Number of
CC          Particle Size Classes is 0)
CC      Col       Format          Information
CC      1-10      8F10.0          The average or typical diameter for each
CC                                particle size class is entered here in
CC                                micrometers (um or meters X 10-6).  A total of
CC                                20 particle size classes can be specified and
CC                                a characteristic diameter must be specified
CC                                for each particle size class used.  8 values
CC                                can be placed on each card here.  Use as many
CC                                cards as necessary to provide the number of
CC                                particle size classes specified, but do not
CC                                include any blank cards.
CC
CC Card 10  General Particle Size Distribution (not entered if the Number of
CC          Particle Size Classes is 0)
CC      Col       Format          Information
CC      1-10      8F10.0          The fraction of the emissions which are
CC                                contained in each particle size class are
CC                                entered here.  A total of 20 particle size
```

```
CC                                  classes can be specified and a fraction must
CC                                  be specified for each particle size class
CC                                  used.  8 values can be placed on each card
CC                                  here.  Use as many cards as necessary to
CC                                  provide the number of particle size classes
CC                                  specified, but do not include any blank cards.
CC                                  This card refers to a general particle size
CC                                  distribution which is used for all sources
CC                                  here unless over-ridden by a specific switch
CC                                  entered on each source card.  When over-ridden
CC                                  on the source cards which follow, the user may
CC                                  specify a specific size distribution to use
CC                                  for a specific source, or may have the model
CC                                  assume no deposition for a specific source.
CC
CC Card 11   Gravitational Settling Velocities.  This card is only entered if
CC           the number of particle size classes is greater then zero and the
CC           deposition parameters options switch is set to 2.  Otherwise, the
CC           model computes gravitational settling velocities automatically.
CC           This option is only used if the user has some reason to use
CC           specialized gravitational settling velocities.
CC      Col        Format           Information
CC      1-10       8F10.0           The gravitational settling velocities in m/sec
CC                                  are entered here.  A total of 20 particle size
CC                                  classes can be specified and a gravitational
CC                                  settling velocity must be specified for each
CC                                  particle size class used.  8 values can be
CC                                  placed on each card here.  Use as many cards
CC                                  as necessary to provide the number of particle
CC                                  size classes specified, but do not include any
CC                                  blank cards.
CC
CC Card 12   Deposition Velocities.  This card is only entered if the number of
CC           particle size classes is greater then zero and the deposition
CC           parameters options switch is set to 2.  Otherwise, the model
CC           computes deposition velocities automatically.  This option is only
CC           used if the user has some reason to use specialized deposition
CC           velocities.
CC      Col        Format           Information
CC      1-10       8F10.0           The deposition velocities in m/sec are entered
CC                                  here.  A total of 20 particle size classes can
CC                                  be specified and a deposition velocity must be
CC                                  specified for each particle size class used.
CC                                  8 values can be placed on each card here.  Use
CC                                  as many cards as necessary to provide the
CC                                  number of particle size classes specified, but
CC                                  do not include any blank cards.
CC
CC Card 13   Receptors
CC      Col        Format           Information
CC      1-10       F10.0            X-Coordinate of receptors in meters, or in
CC                                  units which will be converted to meters when
```

```
CC                                        multiplied by SCAL entered above.
CC      11-20       F10.0                 Y-Coordinate (units as above)
CC      21-30       F10.0                 Z-Coordinate
CC
CC                                        Each receptor is entered on a single card.  A
CC                                        total of 200 receptors may be specified.
CC
CC Card 14    Source Information
CC      Col         Format                Information
CC       2          I1                    Type of source. 1 = point source, 2 = line
CC                                        source, and 3 = area source.
CC       3          I1                    Particle size override switch.  If this switch
CC                                        is left blank or set to 0, the model uses the
CC                                        particle size distribution specified in card
CC                                        10 to apply to this source.  If, however, this
CC                                        value is set to 1, the model reads a second
CC                                        card (or as many cards as necessary), after
CC                                        card 14 to specify the particle size
CC                                        distribution for this source.  If this value
CC                                        is set to 2, the model assumes no deposition
CC                                        for this source.
CC       3-15       F12.0                 Emission rate.  For point sources, the units
CC                                        are grams per second (g/sec).  For line
CC                                        sources the units are grams per meter per
CC                                        second (g/m-sec).  For area sources the units
CC                                        are grams per square meter per second (g/m^2
CC                                        -sec). Note if this source is a wind-speed
CC                                        dependant source, the emission rate entered
CC                                        here is the proporitonality constant of the
CC                                        wind speed dependant espression of the form:
CC                                        E = Q0u^w where E is the emission rate, Q0 is
CC                                        the proportionality constant, u is the wind
CC                                        speed in m/sec and w is the wind speed
CC                                        dependance factor.
CC      16-20       F5.0                  Wind speed dependance factor.  See the note
CC                                        under emissions above.  If the source is not a
CC                                        function of wind speed, leave this column
CC                                        blank and enter the emission rate in columns
CC                                        3-15 as above.
CC      21-30       F10.0                 X-coordinate.  For point sources, this is the
CC                                        x-coordinate of the source.  For line sources,
CC                                        this is the x-coordinate of one end of the
CC                                        line source.  For area sources, this is the x-
CC                                        coordinate of the center of the area source.
CC                                        In all cases the values are in meters, or in
CC                                        units which will be converted to meters when
CC                                        the computer multiplies by the value entered
CC                                        for SCAL above.
CC      31-40       F10.0                 Y-coordinate.  For point sources, this is the
CC                                        y-coordinate of the source.  For line sources
CC                                        this is the y-coordinate for one end of the
CC                                        line source (the same end as the above x-
```

```
CC                                         coordinate).  For area sources, this is the y-
CC                                         coordinate of the center of the area source.
CC                                         In all cases the values are in meters, or in
CC                                         units which will be converted to meters when
CC                                         the computer multiplies by the value entered
CC                                         for SCAL above.
CC      41-50      F10.0                   2nd X-coordinate.  For point sources, this
CC                                         column is not used.  For line sources, this is
CC                                         the x-coordinate for the other end of the line
CC                                         source.  For area sources, this is the x-
CC                                         dimension of the area source.  In all cases
CC                                         the values are in meters, or in units which
CC                                         will be converted to meters when the computer
CC                                         multiplies by the value entered for SCAL
CC                                         above.
CC      51-60      F10.0                   2nd Y-coordinate.  For point sources, this
CC                                         column is not used.  For line sources, this is
CC                                         the y-coordinate for the other end of the line
CC                                         source.  For area sources, this is the y-
CC                                         dimension of the area source.  In all cases
CC                                         the values are in meters, or in units which
CC                                         will be converted to meters when the computer
CC                                         multiplies by the value entered for SCAL
CC                                         above.
CC      61-70      F10.0                   Height of emission.  The release height for
CC                                         the emissions from this source in meters, or
CC                                         in units which will be converted to meters
CC                                         when the computer multiplies by the value
CC                                         entered for SCAL above.  There is no plume
CC                                         rise in FDM, thus for a source with plume
CC                                         rise, the plume rise must be computed manually
CC                                         and added to the stack height and entered
CC                                         here.
CC      71-80      F10.0                   Source width.  This parameter applies only to
CC                                         line sources, and refers to the width of the
CC                                         line source in meters, or in units which will
CC                                         be converted to meters when the computer
CC                                         multiplies by the value entered for SCAL
CC                                         above.
CC
CC Card 14A  Optional Particle Size data for Source
CC                                         If the particle size switch in column 3 of the
CC                                         source card is set to 1, then this card (or
CC                                         group of cards) is read, otherwise, this card
CC                                         (or cards) is not read and should not be
CC                                         included.  This card (or cards) specifies the
CC                                         particle size distribution for this source
CC                                         only and follows the exact same format as Card
CC                                         10.
CC      Col        Format                  Information
CC      1-10       8F10.0                  The fraction of the emissions which are
CC                                         contained in each particle size class are
```

```
CC                                          entered here.  A total of 20 particle size
CC                                          classes can be specified and a fraction must
CC                                          be specified for each particle size class
CC                                          used.  8 values can be placed on each card
CC                                          here.  Use as many cards as necessary to
CC                                          provide the number of particle size classes
CC                                          specified, but do not include any blank cards.
CC
CC Card 15   Meteorological data
CC                                          Meteorological data are entered only if the
CC                                          met option switch is set to 1.  If
CC                                          meteorological data are to be entered here,
CC                                          each hour of data is entered on a separate
CC                                          card.  Note that none of the meteorological
CC                                          values are affected by the specification of
CC                                          SCAL above.
CC      Col        Format                   Information
CC      1-10       F10.0                    Wind speed in m/sec.
CC      11-20      F10.0                    Wind direction -- the direction in degrees
CC                                          from north from which the wind is coming.
CC      25         I1                       Stability class, where 6 values are possible
CC                                          and reflect Turner classes A-F, and 1-A, 2-B,
CC                                          3-C, 4-D, 5-E and 6-F.
CC      31-40      F10.0                    Mixing Height in meters.
CC      41-50      F10.0                    Ambient Temperature in degrees Kelvin.
CC
CC
      CHARACTER*40 FINAME,FINAM1
      CHARACTER*80 TITLE
      CHARACTER*4 TITTAP(20),DUMCHR
      REAL MIXH
      INTEGER CLAS
      LOGICAL IFLAGW
      COMMON/CONAV/C(200)
      COMMON/CONCEN/ XR(200),YR(200),ZR(200)
      COMMON/MET/ BRG,U,MIXH
      COMMON/ANNUAL/AMIX(6),ROSE(6,16,6),UCLAS(6),CDSWA(2,20,100),
     1 V1A(20,6,6),VSA(20,6,6),IOFF(100),WSD(100)
      COMMON/PARAM/DEG,RAD,ATIM,SZ10,DREF,XVEC,YVEC,V1(20),VS(20),NPS,
     1 NR,PY1,PY2,CDSW(2,20,100),ICDSW,IPLTOP,IL
      DIMENSION KST(24),SPEED(24),TEMP(24),AFV(24),AFVR(24),HLH(2,24)
      DIMENSION XL1(100),XL2(100),Q(100),ITYP(100),DIA(20),CUNN(20),
     *    YL1(100),VD(20),C3(200),C8(200),FRAC(20),
     *    YL2(100),HL(100),WL(100),AZ(6),AY1(6),VG(20),
     *    AY2(6),C24(200),CANN(200),WD(24),ISCAN(366),C1(200),
     *    CS(200),VG1(20),VD1(20),SNDF(16),CSDF(16)
      DATA AZ/1112.,556.,353.,219.,124.,56./
      DATA AY1/0.46,0.29,0.18,0.11,0.087,0.057/
      DATA AY2/1831.,1155.,717.,438.,346.,227./
      DATA C3/200*0./,C8/200*0./,C24/200*0./,CANN/200*0./,DAY/1./
      DATA I3CT/0/,I8CT/0/,I24CT/0/,NU/0/,DUMMY/0./,ISCAN/366*1/
      DATA DUMCHR/'    '/,ZREF/10./,C1/200*0./
```

```
      DATA SNDF/0.,0.38268,0.70711,0.92388,1.0,0.92388,0.70711,
     X 0.38268,0.,-0.38268,-0.70711,-0.92388,-1.0,-0.92388,
     X -0.70711,-0.38268/,
     X CSDF/1.0,0.92388,0.70711,0.38268,0.,-0.38268,-0.70711,
     X -0.92388,-1.0,-0.92388,-0.70711,-0.38268,0.,0.38268,
     X 0.70711,0.92388/
      DO 1 I=1,100
 1    IOFF(I)=0.
      IFLAGW = .TRUE.
C**** CALL UNDERO(IFLAGW)
       CALL DISP
      WRITE(*,2012)
 2012 FORMAT(1X,'^[[37m')
      WRITE(*,2000)
 2000 FORMAT(1X,'^[[22;58HInput/Output Files')
      WRITE(*,2001)
 2001 FORMAT(1X,'^[[17;9HName of Input File?..')
      READ(*,2002) FINAM1
      OPEN(5,FILE=FINAM1)
 2002 FORMAT(A20)
      WRITE(*,2003)
 2003 FORMAT(1X,'^[[17;9H                                  ')
      WRITE(*,2010) FINAM1
 2010 FORMAT(1X,'^[[17;58H',A20)
      WRITE(*,2004)
 2004 FORMAT(1X,'^[[17;9HName of Output File?..')
      READ(*,2002) FINAME
      OPEN(6,FILE=FINAME)
      WRITE(*,2003)
      WRITE(*,2011) FINAME
 2011 FORMAT(1X,'^[[19;58H',A20)
      WRITE(*,2005)
 2005 FORMAT(1X,'^[[22;58H                  ')
      WRITE(*,2006)
 2006 FORMAT(1X,'^[[22;58HReading Inputs')
 575  PI=3.1415926
      RAD=PI/180.
      DEG=180./PI
      DREF=ALOG(10000.)
      WRITE(6,250)
 250  FORMAT(1H1,//,20X,'FUGITIVE DUST MODEL (FDM)',/20X,'VERSION 1.0',
     */20X,'JANUARY, 1988')
   10 READ (5,100,END=9999) TITLE
 100  FORMAT(A80)
      WRITE(6,251) TITLE
 251  FORMAT(//,5X,'RUN TITLE:',/,10X,A80/)
      WRITE (6,260) FINAM1
 260  FORMAT(10X,'INPUT FILE NAME: ',A20)
      WRITE(6,261) FINAME
 261  FORMAT(10X,'OUTPUT FILE NAME: ',A20)
      READ (5,120,END=9999) ICDSW,IMETOP,IPLTOP,IPRTOP,IPOST,IDEPOP,I1HR
     *,I3HR,I8HR,I24HR,IANN
```

```
120  FORMAT(11I2)
     IF(ICDSW.LT.1) ICDSW=1
     IF(ICDSW.GT.2) ICDSW=2
     IF(IMETOP.LT.2) GOTO 21
     IF(IMETOP.GT.2) THEN
     IPOST=1
     GOTO 29
     ENDIF
     WRITE(*,2026)
2026 FORMAT(1X,'^[[17;9HName of Met. File?..')
     READ(*,2002) FINAME
     OPEN(2,FILE=FINAME,FORM='UNFORMATTED')
     WRITE(*,2003)
     WRITE(6,262) FINAME
262  FORMAT(10X,'MET DATA READ FROM FILE NAME: ',A20)
     GOTO 21
29   DO 70 I=1,6
     DO 70 J=1,16
     READ(5,1020) (ROSE(K,J,I),K=1,6)
1020 FORMAT(6F10.0)
70   CONTINUE
     READ(5,1020) (AMIX(I),I=1,6)
     READ(5,1020) (UCLAS(I),I=1,6)
21   IF(IPLTOP.LT.2) GOTO 20
     WRITE(*,2025)
2025 FORMAT(1X,'^[[17;9HName of Plot File?..')
     READ(*,2002) FINAME
     OPEN(1,FILE=FINAME)
     WRITE(6,263) FINAME
263  FORMAT(10X,'PLOT OUTPUT WRITTEN TO FILE NAME: ',A20)
     WRITE(*,2003)
20   IF(IPOST.LT.2) GOTO 60
     WRITE(*,2027)
2027 FORMAT(1X,'^[[17;9HName of Output Tape?..')
     READ(*,2002) FINAME
     OPEN(3,FILE=FINAME,FORM='UNFORMATTED')
     WRITE(6,264) FINAME
264  FORMAT(10X,'POST-PROCESSOR OUTPUT WRITTEN TO FILE NAME: ',A20)
     WRITE(*,2003)
60   READ (5,110) NS,NR,NPS1,NM
110  FORMAT(4I5)
     IF(IMETOP.GT.2) NM=576
     READ (5,111) ATIM,ZO,SCAL,PD
111  FORMAT(4F10.0)
     IF(ATIM.EQ.0.) ATIM=60.
     IF(ZO.EQ.0.) ZO=1.0
     IF(SCAL.EQ.0.) SCAL=1.0
     IF (IMETOP.NE.2) GOTO 34
     READ(5,124) (ISCAN(I),I=1,366)
124  FORMAT(80I1)
     ITMET=0
     DO 41 I=1,366
```

```
      ITMET=ITMET+ISCAN(I)
41    CONTINUE
      NM=ITMET*24
34    WRITE(6,252) ICDSW,IMETOP,IPLTOP,IPRTOP,IPOST,IDEPOP,I1HR,I3HR,
     *I8HR,I24HR,IANN,NS,NR,NPS1,NM,ATIM,Z0,SCAL,PD
252   FORMAT(//,10X,'CON/DEP SWITCH 1=CONCEN, 2=DEPO',19X,I1,/,
     *             10X,'MET OPTION SWITCH, 1=CARDS, 2=PREPROCESSED',8X,I1,
     *        /,10X,'PLOT FILE OUTPUT, 1=NO, 2=YES',21X,I1,/,
     *             10X,'MET DATA PRINT SWITCH, 1=NO, 2=YES',16X,I1,/,
     *             10X,'POST-PROCESSOR OUTPUT, 1=NO, 2=YES',16X,I1,/,
     *             10X,'DEP. VEL./GRAV. SETL. VEL., 1=DEFAULT, 2=USER',5X,
     *I1,/,
     *             10X,'PRINT 1-HOUR AVERAGE CONCEN, 1=NO, 2=YES',10X,I1,/,
     *             10X,'PRINT 3-HOUR AVERAGE CONCEN, 1=NO, 2=YES',10X,I1,/,
     *             10X,'PRINT 8-HOUR AVERAGE CONCEN, 1=NO, 2=YES',10X,I1,/,
     *             10X,'PRINT 24-HOUR AVERAGE CONCEN, 1=NO, 2=YES',9X,I1,/,
     *             10X,'PRINT LONG-TERM AVERAGE CONCEN, 1=NO, 2=YES',7X,I1,
     *        /,10X,'NUMBER OF SOURCES PROCESSED',20X,I4,/,
     *             10X,'NUMBER OF RECEPTORS PROCESSED',18X,I4,/,
     *             10X,'NUMBER OF PARTICLE SIZE CLASSES',16X,I4,/,
     *             10X,'NUMBER OF HOURS OF MET DATA PROCESSED',10X,I4,/,
     *             10X,'LENGTH IN MINUTES OF 1-HOUR OF MET DATA',6X,F6.0,/,
     *             10X,'ROUGHNESS LENGTH IN CM',20X,F9.2,/,
     *             10X,'SCALING FACTOR FOR SOURCE AND RECPTORS',3X,F10.4,/,
     *             10X,'PARTICLE DENSITY IN G/CM**3',15X,F9.2)
      WRITE(*,2015)
2015  FORMAT(1X,'^[[17;9HWill Process:')
      WRITE(*,2016) NM
2016  FORMAT(1X,'^[[18;11HNumber of Met Cond...',I4)
      WRITE(*,2017) NS
2017  FORMAT(1X,'^[[19;11HNumber of Sources....',I4)
      WRITE(*,2018) NR
2018  FORMAT(1X,'^[[20;11HNumber of Receptors..',I4)
      IF(IMETOP.NE.2) GOTO 42
      WRITE(6,125) (ISCAN(I),I=1,366)
125   FORMAT(/10X,'PREPROCESSED METEOROLOGICAL DATA SELECTION SWITCHES',
     */10X,80I1,/,10X,80I1,/,10X,80I1,/,10X,80I1,/,10X,46I1)
42    IF(NPS1.LE.0) GOTO 30
      NPS=NPS1
      READ(5,121) (DIA(I),I=1,NPS)
121   FORMAT(8F10.0)
      READ(5,121) (FRAC(I),I=1,NPS)
      IF(IDEPOP.LT.2) GOTO 35
      READ(5,121) (VG(I),I=1,NPS)
      READ(5,121) (VD(I),I=1,NPS)
      GOTO 36
35    DO 37 I=1,NPS
      DIA(I)=DIA(I)*.0001
      CUNN(I)= 1.0+.00001306/DIA(I)*(1.257+.4*EXP(-84227*DIA(I)))
      VG(I)=DIA(I)*DIA(I)*3011.*(PD-.00129)*CUNN(I)
37    CONTINUE
36    ITEST=0
```

```
      DO 270 I=1,NPS
      IF(FRAC(I).NE.0.) ITEST=1
270   CONTINUE
      IF(ITEST.EQ.0) THEN
      WRITE(6,271)
271   FORMAT(10X,'*****ERROR*****',/,
     *'***** PARTICLE SIZE DISTRIBUTION SET TO 0*****')
      STOP
      ENDIF
      WRITE(6,254)
254   FORMAT(//,10X,'GENERAL PARTICLE SIZE CLASS INFORMATION',//,
     *10X,'                             GRAV.                FRACTION',/,
     *10X,'  PARTICLE         CHAR.  SETTLING  DEPOSITION   IN EACH',/,
     *10X,'      SIZE          DIA.  VELOCITY    VELOCITY      SIZE',/,
     *10X,'     CLASS          (CM)   (M/SEC)     (M/SEC)     CLASS',/,
     *10X,'     -----   ---------  --------  ----------   --------')
      IF(IDEPOP.GE.2) WRITE(6,255)(I,DIA(I),VG(I),VD(I),FRAC(I),I=1,NPS)
255   FORMAT(10X,I9,2X,F10.7,2X,F8.5,2X,F10.4,2X,F8.4)
      IF(IDEPOP.LT.2) THEN
      WRITE(6,272) (I,DIA(I),VG(I),FRAC(I),I=1,NPS)
272   FORMAT(10X,I9,2X,F10.7,2X,F8.5,2X,'         **',2X,F8.4)
      WRITE(6,273)
273   FORMAT(10X,'----------',/,10X,'** COMPUTED HOURLY BY FDM')
      ENDIF
      DO 576 J=1,NS
      DO 576 I=1,NPS
      CDSWA(1,I,J)=FRAC(I)
      CDSWA(2,I,J)=FRAC(I)
576   CONTINUE
      GOTO 40
30    NPS=1
      IDEPOP=2
      DO 577 J=1,NS
      CDSWA(1,1,J)=1.0
      CDSWA(2,1,J)=0.
      FRAC(1)=1.
      VG(1)=0.
      VD(1)=0.
577   CONTINUE
40    DO 1000 I=1,NR
      READ (5,130) XR(I),YR(I),ZR(I)
130   FORMAT(3F10.0)
      XR(I)=SCAL*XR(I)
      YR(I)=SCAL*YR(I)
      ZR(I)=SCAL*ZR(I)
1000  CONTINUE
      WRITE(6,256)
256   FORMAT(1H1,//,10X,'RECEPTOR COORDINATES (X,Y,Z)'/)
      WRITE(6,257) (XR(I),YR(I),ZR(I),I=1,NR)
257   FORMAT(3('(',F7.0,',',F7.0,',',F4.0,')',2X))
      IF(IPOST.LT.2) GOTO 61
      NHOURS=24
```

```
      IF(NM.LT.24) NHOURS=24
      NDAYS=NM/24+.99
      WRITE(3) NS,NU,NU,NU,NR,NHOURS,NDAYS,NU
      READ(TITLE,1010) (TITTAP(I),I=1,20)
1010  FORMAT(20A4)
      WRITE(3) (NU,I=1,20),(TITTAP(J),J=1,20),(DUMCHR,K=1,9)
      WRITE(3) (XR(I),I=1,NR),(YR(J),J=1,NR)
      WRITE(3) (DUMMY,I=1,NR)
      WRITE(3) (DUMMY,I=1,11)
      WRITE(3) (I,I=1,NS),(NU,I=1,NS),((DUMMY,J=1,9),I=1,NS),(NU,I=1,NS)
     *,((DUMMY,J=1,20),I=1,NS),(NU,I=1,NS)
61    WRITE(6,258)
258   FORMAT(1H1,//,10X,'SOURCE INFORMATION',//,
     *10X,'        ENTERED EMIS.      TOTAL
     *                             ',/,
     *10X,'         RATE (G/SEC,  EMISSION    WIND
     *                             ',/,
     *10X,'          G/SEC/M OR       RATE   SPEED     X1       Y1       X2
     *      Y2  HEIGHT   WIDTH',/,
     *10X,'TYPE     G/SEC/M**2)   (G/SEC)    FAC.    (M)      (M)      (M)
     *     (M)      (M)      (M)',/,
     *10X,'---- --------------- ---------- ------ ------- ------- ------
     *- ------- ------- -------')
      DO 1050 I=1,NS
      READ (5,122) ITYP(I),K,Q(I),WSD(I),XL1(I),YL1(I),XL2(I),YL2(I),
     *HL(I),WL(I)
122   FORMAT(I2,I1,F12.0,F5.0,6F10.0)
      IF(K.NE.0.AND.NPS1.EQ.0) THEN
      WRITE(6,1500)
1500  FORMAT('**********ERROR**  CANNOT RESIZE A SOURCE WHEN NPS=0')
      STOP
      ENDIF
      XL1(I)=SCAL*XL1(I)
      XL2(I)=SCAL*XL2(I)
      YL1(I)=SCAL*YL1(I)
      YL2(I)=SCAL*YL2(I)
      HL(I)=SCAL*HL(I)
      WL(I)=SCAL*WL(I)
      IF(ITYP(I).EQ.1) TEMIS=Q(I)
      IF(ITYP(I).EQ.3) TEMIS=Q(I)*XL2(I)*YL2(I)
      IF(ITYP(I).EQ.2) THEN
      ALENTH=((XL1(I)-XL2(I))**2+(YL1(I)-YL2(I))**2)**.5
      TEMIS=Q(I)*ALENTH
      ENDIF
      WRITE(6,259) ITYP(I),Q(I),TEMIS,WSD(I),XL1(I),YL1(I),XL2(I),YL2(I)
     *,HL(I),WL(I)
259   FORMAT(10X,I4,1X,F15.9,1X,F10.5,1X,F6.3,4(1X,F7.0),1X,F7.2,1X,F7.2
     *)
      Q(I)=Q(I)*1000000.
      IF(K.EQ.2) THEN
      IOFF(I)=1
      WRITE(6,123)
```

```
123   FORMAT(10X,'****THIS SOURCE HAS NO DEPOSITION')
      ENDIF
      IF(K.EQ.1) THEN
      READ(5,121) (FRAC(K),K=1,NPS)
      WRITE(6,265)
265   FORMAT(10X,'****SOURCE RE-SIZED, SIZE DISTRIBUTION BY CLASS IS:')
      WRITE(6,126) (FRAC(K),K=1,NPS)
126   FORMAT(10X,6F7.4)
      DO 31 J=1,NPS
      CDSWA(1,J,I)=FRAC(I)
      CDSWA(2,J,I)=FRAC(I)
31    CONTINUE
      ENDIF
1050  CONTINUE
      IF(IMETOP.GT.2) GOTO 300
      METCNT=0
      IF (IMETOP.LT.2) GOTO 24
      READ(2) ID,IYEAR,IDM,IYEAR
24    DO 9000 IM=1,NM
      IF(IMETOP.LT.2) GOTO 22
      METCNT=METCNT+1
      IF (IM.NE.1.AND.METCNT.LE.24) GOTO 23
      METCNT=1
33    READ(2) IYEAR,IMO,DAY,KST,SPEED,TEMP,AFV,AFVR,HLH
      IDAY=DAY
      IF(ISCAN(IDAY).NE.1) GOTO 33
23    CLAS=KST(METCNT)
      U=SPEED(METCNT)
      MIXH=HLH(1,METCNT)
      TA=TEMP(METCNT)
      BRG=AFVR(METCNT)+180.
      IF(BRG.GT.360.) BRG=BRG-360.
      WD(METCNT)=BRG
      GOTO 25
22    READ (5,190) U,BRG,CLAS,MIXH,TA
190   FORMAT(2F10.0,I5,5X,2F10.0)
      METCNT=METCNT+1
      IF (METCNT.GT.24) DAY=DAY+1.
      IF (METCNT.GT.24) METCNT=1
      SPEED(METCNT)=U
      TEMP(METCNT)=TA
      KST(METCNT)=CLAS
      HLH(1,METCNT)=MIXH
      AFVR(METCNT)=BRG+180.
      WD(METCNT)=BRG
      IF(AFVR(METCNT).GT.360.) AFVR(METCNT)=AFVR(METCNT)-360.
25    BRG=BRG+180.
      IF (BRG.GE.360.) BRG=BRG-360.
      IF(IDEPOP.LT.2) CALL VCAL(ZREF,ZO,TA,CLAS,NPS,U,VG,VD,CUNN,DIA)
      DO 39 I=1,NPS
      DO 39 J=1,NS
      CDSW(2,I,J)=CDSWA(2,I,J)*VD(I)
```

```
      CDSW(1,I,J)=CDSWA(1,I,J)
      IF(IOFF(J).EQ.1) CDSW(2,I,J)=0.
39    CONTINUE
      XVEC=COS(RAD*(450.-BRG))
      YVEC=SIN(RAD*(450.-BRG))
      AFAC=(ATIM/3.0)**.2
      SY1=ALOG(AY1(CLAS)*((Z0/3.)**.2)*AFAC)
      SY10=ALOG(AY2(CLAS)*((Z0/3.)**.07)*AFAC)
      PY1=EXP(SY1)
      PY2=(SY10-SY1)/DREF
      SZ10=ALOG(AZ(CLAS)*((Z0/10.)**.07)*AFAC)
      IF(IPOST.LT.2) GOTO 62
      HOUR=METCNT*100.
      IPOST1=4*NS
      WRITE(3) DUMMY,U,(DUMMY,I=1,10),HOUR,(DUMMY,I=1,IPOST1)
62    DO 720 J=1,NR
      C(J)=0.
 720  CONTINUE
      DO 8000 IL=1,NS
       WRITE (*,2014) IM,IL
2014  FORMAT(1X,'^[[22;55HMET =',I4,' SOURCE =',I3)
      WSD1=U**WSD(IL)
      DO 4000 I=1,20
      V1(I)=VD(I)-VG(I)/2.
      VS(I)=VG(I)
      IF(IOFF(IL).EQ.1) THEN
      VS(I)=0.
      V1(I)=0.
      ENDIF
4000  CONTINUE
      GO TO(4100,4200,4300),ITYP(IL)
4100  CALL POINT(CS,XL1(IL),YL1(IL),CLAS,HL(IL),Q(IL))
      CONTINUE
      GOTO 8002
4200  CALL LINE(CS,XL1(IL),YL1(IL),XL2(IL),YL2(IL),WL(IL),HL(IL),Q(IL))
      GOTO 8002
4300  CALL AREA(CS,XL1(IL),YL1(IL),XL2(IL),YL2(IL),Q(IL),HL(IL))
8002  DO 8003 I=1,NR
      CS(I)=CS(I)*WSD1
8003  CONTINUE
      IF(IPOST.GE.2)  WRITE(3) (CS(I),I=1,NR)
      DO 8001 I=1,NR
      C(I)=C(I)+CS(I)
      CS(I)=0.
8001  CONTINUE
8000  CONTINUE
      IF(I1HR.LT.2) GOTO 50
      CALL CONAV(C1,1,IM,1)
50    IF(I3HR.LT.2) GOTO 51
      I3CT=I3CT+1
      CALL CONAV(C3,3,IM,I3CT)
51    IF(I8HR.LT.2) GOTO 52
```

```
      I8CT=I8CT+1
      CALL CONAV(C8,8,IM,I8CT)
 52   IF(I24HR.LT.2) GOTO 53
      I24CT=I24CT+1
      CALL CONAV(C24,24,IM,I24CT)
 53   IF(IANN.LT.2) GOTO 54
      IDUM=IM
      CALL CONAV(CANN,NM,IM,IDUM)
 54   IF(IPRTOP.NE.2) GOTO 9000
      IF(METCNT.EQ.24.OR.IM.EQ.NM) THEN
      WRITE(6,27) DAY,IM-23,IM
 27   FORMAT(1H1,//,'          METEOROLOGICAL DATA FOR DAY',F5.0,' (HOUR
     *S ',I4,' TO ',I4,')',//,
     *'       WIND         WIND   STABILITY    MIXING     AMBIENT',/,
     *'      SPEED   DIRECTION       CLASS    HEIGHT        TEMP.',/,
     *'    (M/SEC)   (DEGREES)    (TURNER)       (M)    (DEG. K)',/,
     *' ---------   ---------   ---------   -------   ---------')
      WRITE(6,28) (SPEED(I),WD(I),KST(I),HLH(1,I),TEMP(I),I=1,METCNT)
 28   FORMAT(F10.2,3X,F9.0,3X,I9,3X,F7.0,3X,F9.1)
      DO 26 I=1,24
      SPEED(I)=999.
      AFVR(I)=999.
      KST(I)=9
      HLH(1,I)=999.
      TEMP(I)=999.9
26    CONTINUE
      ENDIF
 9000 CONTINUE
      GOTO 9999
 300  TA=293.
      DO 310 IS=1,6
      DO 310 IU=1,6
      IF(IDEPOP.LT.2) THEN
      CALL VCAL(ZREF,Z0,TA,IS,NPS,UCLAS(IU),VG1,VD1,CUNN,DIA)
      ENDIF
      DO 320 I=1,NPS
      IF(IDEPOP.LT.2) THEN
      VSA(I,IU,IS)=VG1(I)
      V1A(I,IU,IS)=VD1(I)-VG1(I)/2.
      ENDIF
      IF(IDEPOP.GE.2) THEN
      VSA(I,IU,IS)=VG(I)
      V1A(I,IU,IS)=VD(I)-VG(I)/2
      ENDIF
 320  CONTINUE
 310  CONTINUE
      DO 330 IL=1,NS
      DO 340 IR=1,NR
       WRITE (*,2019) IL,IR
 2019 FORMAT(1X,'^[[23;55HSOURCE =',I3,' RECP =',I3)
      GOTO(400,401,402) ITYP(IL)
 400  X1=XL1(IL)-XR(IR)
```

```
      Y1-YL1(IL)-YR(IR)
      IF(X1.EQ.0..AND.Y1.EQ.0.) GOTO 340
      R1-(X1*X1+Y1*Y1)**0.5
      ARG-Y1/R1
      THETA-ACOS(ARG)
      IF(X1.LT.0.) THETA-6.2831853-THETA
      IW-THETA/0.392699+1.5
      XVIRT-0.
      CALL PTCAL(C,R1,XVIRT,ZR(IR),IR,IW,HL(IL),Q(IL))
      GOTO 340
401   CALL LINEA(C,XL1(IL),YL1(IL),XL2(IL),YL2(IL),IR,XR(IR),YR(IR),
     *ZR(IR),HL(IL),Q(IL),SNDF,CSDF)
      GOTO 340
402   CALL AREAA(C,XL1(IL),YL1(IL),XL2(IL),YL2(IL),IR,XR(IR),YR(IR),
     *ZR(IR),HL(IL),Q(IL),SNDF,CSDF)
340   CONTINUE
330   CONTINUE
      IF(ICDSW.EQ.1) THEN
      WRITE(6,1100)
1100  FORMAT(1H1,/,10X,'AVERAGE CONCENTRATIONS IN MICROGRAMS/M**3',/,
     *10X,'FOR STATISTICAL WIND ROSE',/)
      ENDIF
      IF(ICDSW.EQ.2) THEN
      WRITE(6,1101)
1101  FORMAT(1H1,/,10X,'AVERAGE DEPOSITION IN MICROGRAMS/M**2/SEC',/,
     *10X,'FOR STATISTICAL WIND ROSE',/)
      ENDIF
      WRITE(6,1102) (XR(I),YR(I),C(I),I-1,NR)
1102  FORMAT(3(' (',F7.0,',',F7.0,',',F10.3,') '))
      IF(IPLTOP.LT.2) GOTO 9999
      DO 360 I-1,NR
      WRITE(1,1103) XR(I),YR(I),C(I)
1103  FORMAT(3F15.5)
360   CONTINUE
9999  WRITE(*,2013)
2013  FORMAT(1X,'^[[2J')
      STOP
      END
```

```
      SUBROUTINE VCAL(ZREF,Z0,TA,IS,NPS,U,VG,VD,CUNN,DIA)
      DIMENSION VG(20),VD(20),DIA(20),CUNN(20)
      CALL KCAL(ZREF,Z0,TA,IS,U,USTAR,ZOL)
      IF(ZOL.GT.0.) SSH=-5.*ZOL
      IF(ZOL.EQ.0.) SSH=0.
      IF(ZOL.LT.0.) THEN
      SSH=EXP(.598+.39*ALOG(-ZOL)-0.09*(ALOG(-ZOL))**2)
      ENDIF
      RA=2.857/USTAR*(ALOG(ZREF/Z0)-SSH)
      DO 1 I=1;NPS
      SC=1.73E12*DIA(I)/CUNN(I)/TA
      ST=VG(I)*USTAR*USTAR/.1776
      IF(ST.LT..1) ST=.1
      Q1=-3/ST
      IF(Q1.LT.-10.) Q1=-10.
      RD=1./(SC**(-.6667)+10**(Q1))/USTAR
      VD(I)=1./(RA+RD+RA*RD*VG(I))+VG(I)
1     CONTINUE
      RETURN
      END
     SUBROUTINE KCAL(ZREF,Z0,TA,IS,U,USTAR,ZOL)
      DIMENSION DTDZ(6)
      DATA DTDZ/4*0.,0.02,0.035/
     B=9.81*ZREF*ZREF*DTDZ(IS)/TA/U/U
     A1=ALOG(ZREF/Z0)
     IF(B.LT.0.) GOTO 1
     XH=0.05
     X=0.15
     FH=XH/((A1+.33333)/1.33333)**2-B
10   IF(X.EQ.0.2) X=0.19999999
     IF(X.LT.0.2) GOTO 12
     XTEST=-A1/5/(1-A1)
     IF(X.GE.XTEST)X=XTEST-.0001
12   F=X/(A1*(1.-5*X)+5*X)**2-B
     PH=1./(1.-5*X)
     PS=-5*X*PH
     IF(ABS(F).LT.0.0001) GOTO 100
     IF(X.EQ.XH) GOTO 100
     SL=(F-FH)/(X-XH)
     BINT=F-SL*X
     XNEW=-BINT/SL
     IF(ABS((XNEW-X)/XNEW).LT.0.0001) GOTO 100
     XH=X
     FH=F
     X=XNEW
     GOTO 10
1    XH=0.
     FH=-B
     X=-.05
20   IF(X.GE..06667) X=.06666
     IF(X.EQ.0.) X=0.0001
     PH=1.0/(1.0-15*X)**.25
```

```
      ZETA=(1.0-15*X)**.25
      ZETA0=(1.0-15*X*Z0/ZREF)**.25
      ARG1=ALOG((ZETA-1.0)*(ZETA0+1.0)/((ZETA+1.0)*(ZETA0-1.0)))
      ARG2=2.0*(ATAN(ZETA)-ATAN(ZETA0))
       PS=A1-ARG1-ARG2
      F=X/((A1-PS)/PH)**2-B
      IF(ABS(F).LT..0001) GOTO 100
      SL=(F-FH)/(X-XH)
      BINT=F-SL*X
      XNEW=-BINT/SL
      IF(ABS((XNEW-X)/XNEW).LT.0.0001) GOTO 100
      XH=X
      FH=F
      X=XNEW
      GOTO 20
  100 IF(X.LT.0.) ZOL=X
      IF(X.GE.0.) ZOL=X/(1.0-5*X)
      USTAR=0.35*U/(A1-PS)
      IF(ZOL.LT.0.) PHH=0.74/(1.-9*ZOL)**.5
      IF(ZOL.GE.0.) PHH=.74+5*ZOL
      EDDY=.35*USTAR*ZREF/PHH
      RETURN
      END
```

```
      SUBROUTINE LINE(C,XL1,YL1,XL2,YL2,W,H,Q1)
      REAL NE,LIM,KZ,LB,INC,MIXH
      REAL*8            HYP,SIDE,FAC2,PD,A,B,L,D,
     *    XPRI,YPRI,APRI,BPRI,LPRI,DPRI,XD,YD,
     *    LL,INTG(6)
      COMMON/CONCEN/ XR(200),YR(200),ZR(200)
      COMMON/MET/ BRG,U,MIXH
      COMMON/PARAM/DEG,RAD,ATIM,SZ10,DREF,XVEC,YVEC,V1(20),VS(20),NPS,
     1 NR,PY1,PY2,CDSW(2,20,100),ICDSW,IPLTOP,IL
      DIMENSION Y(6),WT(5),C(200)
      DATA WT/0.25,0.75,1.,0.75,0.25/
  880 W2=W/2.
      LL=SQRT((XL1-XL2)**2+(YL1-YL2)**2)
      XD=XL2-XL1
      YD=YL2-YL1
      LB=DEG*(  ACOS( ABS(XD)/LL))
      IF (XD.GT.0.  .AND.
     *    YD.GE.0.) LB=90.-LB
      IF (XD.GE.0.  .AND.
     *    YD.LT.0.) LB=90.+LB
      IF (XD.LT.0.  .AND.
     *    YD.LE.0.) LB=270.-LB
      IF (XD.LE.0.  .AND.
     *    YD.GT.0.) LB=270.+LB
      PHI=ABS(BRG-LB)
      IF (PHI.LE.90.) GO TO 7600
      IF (PHI.GE.270.) GO TO 5000
      PHI=ABS(PHI-180.)
      GO TO 7600
 5000 PHI=ABS(PHI-360.)
 7600 IF (PHI.LT.20.) GO TO 7630
      IF (PHI.LT.50.) GO TO 7620
      IF (PHI.LT.70.) GO TO 7610
      BASE=4.
      GO TO 7650
 7610 BASE=2.
      GO TO 7650
 7620 BASE=1.5
      GO TO 7650
 7630 BASE=1.1
 7650 PHI=RAD*(PHI)
      IF (PHI.GT.1.5706) PHI=1.5706
      IF (PHI.LT.0.00017) PHI=0.00017
      DSTR=1.
 7800 TR=DSTR*W2/U
      SGZ1=ALOG((1.8+0.11*TR)*(ATIM/30.)**0.2)
      PZ2=(SZ10-SGZ1)/(DREF-ALOG(W2))
      PZ1=EXP((SZ10+SGZ1-PZ2*(DREF+ALOG(W2)))/2.)
      DO 6000 IR=1,NR
      A=(XR(IR)-XL1)**2+(YR(IR)-YL1)**2
      B=(XR(IR)-XL2)**2+(YR(IR)-YL2)**2
      L=(B-A-LL**2)/(2.*LL)
```

```
      IF (A.GT.L**2) D= SQRT(A-L**2)
      IF (A.LE.L**2) D=0.
      UWL=LL+L
      DWL=L
      XPRI=XR(IR)+D*XVEC
      YPRI=YR(IR)+D*YVEC
      APRI=(XPRI-XL1)**2+(YPRI-YL1)**2
      BPRI=(XPRI-XL2)**2+(YPRI-YL2)**2
      LPRI=(BPRI-APRI-LL**2)/(2.*LL)
      IF ((APRI-LPRI**2).GT..001) DPRI=SQRT(APRI-LPRI**2)
      IF ((APRI-LPRI**2).LT..001) DPRI=0.
      IF (DPRI.LT.D) D=-D
      IF (LPRI-L) 5725,5735,5735
 5725 TEMP=UWL
      UWL=-DWL
      DWL=-TEMP
 5735 CONTINUE
 5750 Z=ZR(IR)
 3050 SGN=1.
 3060 NE=0.
      STP=1.
      FINI=1.
      IF (SGN.EQ.1. .AND.
     *    UWL.LE.0. .AND.
     *    DWL.LT.0.) SGN=-1.
 3080 IF (SGN.EQ.-1. .AND.
     *    UWL.GT.0. .AND.
     *    DWL.GE.0.) GO TO 6000
      ED1=0.
      ED2=SGN*W
 3110 IF (SGN.EQ.-1.) GO TO 3160
      IF (ED1.LE.DWL .AND. ED2.LE.DWL) GO TO 3770
      IF (ED1.GT.DWL .AND. ED2.LT.UWL) GO TO 3250
      IF (ED1.LE.DWL) ED1=DWL
      IF (ED2.LT.UWL) GO TO 3250
      ED2=UWL
      SGN=-1.
      NE=-1.
      GO TO 3250
 3160 IF (ED1.GE.UWL .AND. ED2.GE.UWL) GO TO 3770
      IF (ED1.LT.UWL .AND. ED2.GT.DWL) GO TO 3250
      IF (ED1.GE.UWL) ED1=UWL
      IF (ED2.GT.DWL) GO TO 3250
      ED2=DWL
      FINI=0.
 3250 EL2=ABS(ED2-ED1)/2.
      ECLD=(ED1+ED2)/2.
      ELL2=W2/COS(PHI)+(EL2-W2*TAN(PHI))*SIN(PHI)
      IF (PHI.GE.ATAN(W2/EL2)) CSL2=W2/SIN(PHI)
      IF (PHI.LT.ATAN(W2/EL2)) CSL2=EL2/COS(PHI)
      EM2=ABS((EL2-W2/TAN(PHI))*SIN(PHI))
      EN2=(ELL2-EM2)/2.
```

```
      QE=Q1*CSL2/W2
      FET=(ECLD+D*TAN(PHI))*COS(PHI)
      HYP=ECLD**2+D**2
      SIDE=FET**2
      IF (SIDE.GT.HYP) YE=0.
      IF (SIDE.LE.HYP) YE= SQRT(HYP-SIDE)
      IF (FET.LE.-CSL2) GO TO 3830
      IF (FET.GE.CSL2) GO TO 3320
      QE=QE*(FET+CSL2)/(2.*CSL2)
      FET=(CSL2+FET)/2.
 3320 SGZ=PZ1*FET**PZ2
      KZ=SGZ**2*U/(2.*FET)
      SGY=PY1*FET**PY2
      FAC1=0.399/(SGZ*U)
      Y(1)=YE+ELL2
      Y(2)=Y(1)-EN2
      Y(3)=Y(2)-EN2
      Y(4)=Y(3)-2*EM2
      Y(5)=Y(4)-EN2
      Y(6)=Y(5)-EN2
      DO 3480 I=1,6
      LIM=ABS(Y(I)/SGY)
      T=1./(1.+0.23164*LIM)
      ARG=LIM**2/(-2.)
      IF (LIM.GT.5.) INTG(I)=0.
      IF (LIM.LE.5.) INTG(I)=0.3989*EXP(ARG)*(0.3194*T-0.3566*T**2+
     *    1.7815*T**3-1.8213*T**4+1.3303*T**5)
 3480 CONTINUE
      FAC2=0.
      DO 3530 I=1,5
      IF ((SIGN(1.,Y(I))).EQ.(SIGN(1.,Y(I+1))))
     *    PD= ABS(INTG(I+1)-INTG(I))
      IF ((SIGN(1.,Y(I))).NE.(SIGN(1.,Y(I+1))))
     *    PD=1.-INTG(I)-INTG(I+1)
      FAC2=FAC2+PD*QE*WT(I)
 3530 CONTINUE
      FACT=FAC1*FAC2
 3580 FAC3=0.
      DO 3560 ID=1,NPS
      IF (V1(ID).EQ.0.) GO TO 3670
      ARG=V1(ID)*SGZ/(KZ*SQRT(2.))+(Z+H)/(SGZ*SQRT(2.))
      CALL DEPO(ARG,EFRC)
      FAC3=(1.414214)*V1(ID)*SGZ/KZ*EXP(-.5*(Z+H/SGZ)**2)*EFRC
 3670 CONTINUE
      IF (VS(ID).EQ.0.) GO TO 3710
      FAC4=EXP(-VS(ID)*(Z-H)/(2.*KZ)-(VS(ID)*SGZ/KZ)**2/8.)
      FACT=FACT*FAC4
 3710 FAC5=0.
      CNT=0.
 3720 EXLS=0.
 3730 ARG1=-0.5*((Z+H+2.*CNT*MIXH)/SGZ)**2
      IF (ARG1.LT.-44.) EXP1=0.
```

```
      IF (ARG1.GE.-44.) EXP1=EXP(ARG1)
      ARG2=-0.5*((Z-H+2.*CNT*MIXH)/SGZ)**2
      IF (ARG2.LT.-44.) EXP2=0.
      IF (ARG2.GE.-44.) EXP2=EXP(ARG2)
      FAC5=FAC5+EXP1+EXP2
      IF (MIXH.GE.1000.) GO TO 3760
      IF ((EXP1+EXP2+EXLS).EQ.0. .AND. CNT.LE.0.) GO TO 3760
 3740 IF (CNT.GT.0.) GO TO 3750
      CNT=ABS(CNT)+1.
      GO TO 3720
 3750 CNT=-1.*CNT
      EXLS=EXP1+EXP2
      GO TO 3730
 3760 INC=FACT*(FAC5-FAC3)*CDSW(ICDSW,ID,IL)
      C(IR)=C(IR)+INC
 3560 CONTINUE
 3770 IF (FINI.EQ.0.) GO TO 6000
      NE=NE+1.
      STP=BASE**NE
      IF (NE.EQ.0.) GO TO 3080
      ED1=ED2
      ED2=ED2+SGN*STP*W
      GO TO 3110
 3830 IF (SGN.EQ.1.) GO TO 3770
 6000 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DEPO(ARG,CERF)
       DATA P/.47047/,A1/.34802/,A2/.09588/,A3/.74786/
       X=ARG
       IF(ARG.GE.1.0) GO TO 1
       T=1.0/(1.0+P*X)
       FCN=A1*T-A2*T**2+A3*T**3
       CERF=FCN*1.77245
       RETURN
1      I=10
       VAL=2.0*X
3      ITEST=I/2.0+0.5
       ITEST=ITEST*2
       IF(ITEST.EQ.I) GO TO 2
       VAL=X*2.0+I*1.0/VAL
       I=I-1
       IF(I.EQ.0) GO TO 4
       GO TO 3
2      VAL=X+I*1.0/VAL
       I=I-1
       GO TO 3
4      VAL=2.0/VAL
       CERF=VAL
       RETURN
       END
```

```
      SUBROUTINE AREA(C,XS,YS,XDIM,YDIM,Q,H)
      COMMON/PARAM/DEG,RAD,ATIM,SZ10,DREF,XVEC,YVEC,V1(20),VS(20),NPS,
     1 NR,PY1,PY2,CDSW(2,20,100),ICDSW,IPLTOP,IL
      DIMENSION X(4),Y(4),XX(4),YY(4),XA(5),YA(5),XB(5),YB(5),C(200)
      X(1)=XS-XDIM/2
      X(2)=X(1)
      X(3)=XS+XDIM/2
      X(4)=X(3)
      Y(1)=YS-YDIM/2
      Y(2)=YS+YDIM/2
      Y(3)=Y(2)
      Y(4)=Y(1)
      DO 1 I=1,4
      XX(I)=X(I)*XVEC+Y(I)*YVEC
      YY(I)=Y(I)*XVEC-X(I)*YVEC
1     CONTINUE
      DO 2 I=1,4
      X(I)=XX(I)
      Y(I)=YY(I)
2     CONTINUE
      DO 3 I=1,4
      K=I+1
      DO 3 J=K,4
      IF(X(I).LT.X(J)) GOTO 3
      HOLD=X(J)
      X(J)=X(I)
      X(I)=HOLD
      HOLD=Y(J)
      Y(J)=Y(I)
      Y(I)=HOLD
3     CONTINUE
      XLEN=X(4)-X(1)
      DX=XLEN/5
      DX2=DX/2
      X1=X(1)+DX2
      IF(X(1).EQ.X(2)) GOTO 10
      SL12=(Y(2)-Y(1))/(X(2)-X(1))
      SL13=(Y(3)-Y(1))/(X(3)-X(1))
      SL42=(Y(4)-Y(2))/(X(4)-X(2))
      SL43=(Y(4)-Y(3))/(X(4)-X(3))
      TL=0.
      DO 4 I=1,5
      IF(X1.GT.X(2)) GOTO 5
      Y2=Y(1)+(X1-X(1))*SL12
      Y3=Y(1)+(X1-X(1))*SL13
      GOTO 6
5     Y2=Y(4)-(X(4)-X1)*SL42
      IF(X1.GT.X(3)) GOTO 7
      Y3=Y(1)+(X1-X(1))*SL13
      GOTO 6
7     Y3=Y(4)-(X(4)-X1)*SL43
6     TL=TL+ABS(Y3-Y2)
```

```
      XA(I)-X1*XVEC-Y2*YVEC
      YA(I)-Y2*XVEC+X1*YVEC
      XB(I)-X1*XVEC-Y3*YVEC
      YB(I)-Y3*XVEC+X1*YVEC
      X1-X1+DX
4     CONTINUE
      GOTO 20
10    DY1-Y(1)-Y(2)
      DY-ABS(DY1)
      TL-5*DY
      DO 11 I-1,5
      Y2-Y(1)
      Y3-Y(2)
      XA(I)-X1*XVEC-Y2*YVEC
      YA(I)-Y2*XVEC+X1*YVEC
      XB(I)-X1*XVEC-Y3*YVEC
      YB(I)-Y3*XVEC+X1*YVEC
      X1-X1+DX
11    CONTINUE
20    Q1-Q*XDIM*YDIM/TL
      DO 30 I-1,5
      CALL LINE(C,XA(I),YA(I),XB(I),YB(I),DX,H,Q1)
30    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE POINT(C,XS,YS,IST,H,Q)
      REAL MIXH
      COMMON/CONCEN/ XR(200),YR(200),ZR(200)
      COMMON/MET/ BRG,U,MIXH
      COMMON/PARAM/DEG,RAD,ATIM,SZ10,DREF,XVEC,YVEC,V1(20),VS(20),NPS,
     1 NR,PY1,PY2,CDSW(2,20,100),ICDSW,IPLTOP,IL
      DIMENSION SASIGZ(38),SBSIGZ(38),SC(6),SD(6),XDIS(10,6),INDSGZ(6),
     *C(200)
            DATA SASIGZ / 122.8,
     X               158.08,170.22,179.52,217.41,258.89,346.75,2*453.85,
     1 90.673,98.483,109.3,61.141,34.459,32.093,32.093,33.504,36.65,
     X  44.053,24.26,
     2        23.331,21.628,21.628,22.534,24.703,26.97,35.42,47.618,
     3 15.209,14.457,13.953,13.953,14.823,16.187,17.836,22.651,27.074,
     4 34.219 /
      DATA SBSIGZ /.9447,
     X               1.0542,1.0932,1.1262,1.2644,1.4094,1.7283,2*2.1166,
     1 .93198,.98332,1.0971,.91465,.86974,.81066,.64403,.60486,.56589,
     X  .51179,.8366,
     2        .81956,.75660,.63077,.57154,.50527,.46713,.37615,.29592,
     3 .81558,.78407,.68465,.63227,.54503,.46490,.41507,.32681,.27436,
     4 .21716 /
      DATA SC,SD / 24.1667,18.333,12.5,8.333,6.25,4.1667,2.5334,1.8096,
     1 1.0857,.72382,.54287,.36191 /
      DATA XDIS/.1,.15,.2,.25,.3,.4,.5,3.11,1.E20,0.,  .2,.4,1.E20,7*0.,
     1 1.E20,9*0.,  .3,1.,3.,10.,30.,1.E20,4*0.,  .1,.3,1.,2.,4.,10.,
     2 20.,40.,1.E20,0.,  .2,.7,1.,2.,3.,7.,15.,30.,60.,1.E20/
      DATA INDSGZ /0,9,12,13,19,28/,TWOPI/6.283185/
      CSANG=-XVEC
      SNANG=-YVEC
      DO 1 IR=1,NR
      X1=XS-XR(IR)
      Y1=YS-YR(IR)
      X=X1*CSANG+Y1*SNANG
      Y=Y1*CSANG-X1*SNANG
      IF (X.LE.0) GOTO 1
   10 IF(IST .NE. 3) GOTO 20
      IXDIST = 13
      GOTO 80
   20 I = 1
   30 IF(X/1000.-XDIS(I,IST) .LE. 0.0) GOTO 40
      I = I + 1
      GOTO 30
40    IXDIST = INDSGZ(IST) + I
80    SZ = SASIGZ(IXDIST)*(X/1000.)**SBSIGZ(IXDIST)
      IF(SZ.GT.5000.) SZ=5000.
      TH=0.017453293*(SC(IST) - SD(IST)*ALOG(X/1000.))
      SY=.46511628*X*TAN(TH)
       HT=H
       IF(H.GT.MIXH) HT=MIXH
       IF(ZR(IR).GT.MIXH) GO TO 1
       I=1
```

```
      CALL DIST(ZR(IR),X,HT,SZ,U,ZFACT,KR)
100   K=I*2
      ZH=K*MIXH-ZR(IR)
      CALL DIST(ZH,X,HT,SZ,U,SUM,KR)
      IF(KR.EQ.1) GOTO 900
      ZFACT=ZFACT+SUM
      ZH=K*MIXH+ZR(IR)
      CALL DIST(ZH,X,HT,SZ,U,SUM,KR)
      IF(KR.EQ.1) GOTO 900
      ZFACT=ZFACT+SUM
      I=I+1
      IF(I.GT.10) GOTO 900
      GO TO 100
900   YARG=-0.5*Y*Y/SY/SY
      IF (YARG.LT.-25.) GOTO 901
      YFACT=EXP(YARG)
      C(IR)=Q/TWOPI/SY/SZ/U*YFACT*ZFACT
      GOTO 1
901   C(IR)=0.
1     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DIST(Z,X,H,SIGZ,U,SUM,KR)
      COMMON/PARAM/DEG,RAD,ATIM,SZ10,DREF,XVEC,YVEC,V1(20),VS(20),NPS,
     1 NR,PY1,PY2,CDSW(2,20,100),ICDSW,IPLTOP,IL
      DATA S2/1.414214/
      KR=0
      SUM=0.
      DO 10 IPS=1,NPS
      GAM=V1(IPS)*S2*X/SIGZ/U + (Z+H)/S2/SIGZ
      IF(GAM.GT.1000.) GO TO 10
      BET=X/S2/SIGZ/U
      A1=-VS(IPS)*(Z-H)*S2*BET/SIGZ-VS(IPS)*VS(IPS)*BET*BET
      A2=-(Z-H)*(Z-H)/2/SIGZ/SIGZ
      A3=-(Z+H)*(Z+H)/2/SIGZ/SIGZ
      CALL DEPO(GAM,CERF)
      IF (A2.LT.-20.) GO TO 1
      IF(A3.LT.-20.) GO TO 2
      T1=EXP(A2)+EXP(A3)-4*V1(IPS)*BET*EXP(A3)*CERF
      GO TO 4
1     IF(A3.LT.-20.) GO TO 11
      T1=EXP(A3)-4*V1(IPS)*BET*EXP(A3)*CERF
      GO TO 4
2     T1=EXP(A2)
4     IF(A1.LT.-20.) GO TO 10
      T2=EXP(A1)
      IF(T1.LT..0001) KR=1
      SUM=SUM+T1*T2*CDSW(ICDSW,IPS,IL)
10    CONTINUE
      IF(SUM.EQ.0.) GOTO 11
      RETURN
11    KR=1
      SUM=0.
      RETURN
      END
```

```
      SUBROUTINE DISP
      CHARACTER*1 SIDE,TOP,ULCOR,LLCOR,URCOR,LRCOR,SOLID
      SIDE=CHAR(186)
      TOP=CHAR(205)
      ULCOR=CHAR(201)
      LLCOR=CHAR(200)
      URCOR=CHAR(187)
      LRCOR=CHAR(188)
      SOLID=CHAR(219)
      WRITE(*,199)
199   FORMAT(1X,'^[[2J')
      WRITE(*,120)
120   FORMAT(' ^[[32m')
      WRITE(*,100) ULCOR,(TOP,I=1,40),URCOR,ULCOR,(TOP,J=1,28),URCOR
100   FORMAT(2X,42A1,6X,30A1)
      WRITE(*,101) (SIDE,I=1,4)
101   FORMAT(2X,A1,40X,A1,6X,A1,28X,A1)
      WRITE(*,102) SIDE,(SOLID,I=1,23),(SIDE,J=1,3)
102   FORMAT(2X,A1,3X,9A1,3X,8A1,4X,3A1,3X,3A1,4X,A1,6X,A1,28X,A1)
      WRITE(*,103) SIDE,(SOLID,I=1,17),(SIDE,J=1,3)
103   FORMAT(2X,A1,3X,3A1,9X,3A1,3X,3A1,3X,4A1,1X,4A1,4X,A1,6X,A1,2X,
     1 'IBM PC/XT/AT Version 1.0',2X,A1)
      WRITE(*,104) SIDE,(SOLID,I=1,18),(SIDE,J=1,3)
104   FORMAT(2X,A1,3X,3A1,9X,3A1,3X,3A1,3X,9A1,4X,A1,6X,A1,28X,
     1 A1)
      WRITE(*,105) SIDE,(SOLID,I=1,19),(SIDE,J=1,3)
105   FORMAT(2X,A1,3X,6A1,6X,3A1,3X,3A1,3X,3A1,1X,A1,1X,3A1,
     14X,A1,6X,A1,6X,'^[[31m',
     1'TRC Environmental','^[[32m',5X,A1)
      WRITE(*,106) SIDE,(SOLID,I=1,15),(SIDE,J=1,3)
106   FORMAT(2X,A1,3X,3A1,9X,3A1,3X,3A1,3X,3A1,3X,3A1,4X,
     1A1,6X,A1,6X,
     1'^[[31m','Consultants, Inc.','^[[32m',5X,A1)
      WRITE(*,107) SIDE,(SOLID,I=1,15),(SIDE,J=1,3)
107   FORMAT(2X,A1,3X,3A1,9X,3A1,3X,3A1,3X,3A1,3X,3A1,4X,
     1A1,6X,A1,28X,A1)
      WRITE(*,108) SIDE,(SOLID,I=1,17),(SIDE,J=1,3)
108   FORMAT(2X,A1,3X,3A1,9X,8A1,4X,3A1,3X,3A1,4X,A1,6X,A1,28X,A1)
      WRITE(*,101) (SIDE,I=1,4)
      WRITE(*,100) LLCOR,(TOP,I=1,40),LRCOR,LLCOR,(TOP,J=1,28),LRCOR
      WRITE(*,109)
109   FORMAT('   ')
      WRITE(*,100) ULCOR,(TOP,I=1,40),URCOR,ULCOR,(TOP,J=1,28),URCOR
      WRITE(*,110) (SIDE,I=1,4)
110   FORMAT(2X,A1,'Input Board:',28X,A1,6X,A1,'Status Board:',15X,A1)
      WRITE(*,101) (SIDE,I=1,4)
      WRITE(*,111) (SIDE,I=1,4)
111   FORMAT(2X,A1,40X,A1,6X,A1,4X,'Input File:',13X,A1)
      WRITE(*,101) (SIDE,I=1,4)
      WRITE(*,112) (SIDE,I=1,4)
112   FORMAT(2X,A1,40X,A1,6X,A1,4X,'Output File:',12X,A1)
      WRITE(*,101) (SIDE,I=1,4)
```

```
      WRITE(*,101) (SIDE,I=1,4)
      WRITE(*,113) (SIDE,I=1,4)
113   FORMAT(2X,A1,40X,A1,6X,A1,4X,'Currently Processing:',3X,A1)
      WRITE(*,101) (SIDE,I=1,4)
      WRITE(*,100) LLCOR,(TOP,I=1,40),LRCOR,LLCOR,(TOP,J=1,28),LRCOR
      RETURN
      END
```

```
      SUBROUTINE CONAV(CAV,N,IM,ICT)
      COMMON/CONAV/C(200)
      COMMON/CONCEN/ XR(200),YR(200),ZR(200)
      COMMON/PARAM/DEG,RAD,ATIM,SZ10,DREF,XVEC,YVEC,V1(20),VS(20),NPS,
     1 NR,PY1,PY2,CDSW(2,20,100),ICDSW,IPLTOP,IL
      DIMENSION CAV(200)
      DO 1 I=1,NR
      CAV(I)=CAV(I)+C(I)/N
 1    CONTINUE
      IF(ICT.LT.N) GOTO 999
      IF(ICDSW.EQ.1) THEN
      WRITE(6,1000) N,IM
 1000 FORMAT(1H1,/,10X,I5,' HOUR AVERAGE FOR HOUR ENDING ',I5,/,
     *20X,'CONCENTRATIONS IN MICROGRAMS/M**3',/)
      ENDIF
      IF(ICDSW.EQ.2) THEN
      WRITE(6,1003) N,IM
 1003 FORMAT(1H1,/,10X,I5,' HOUR AVERAGE FOR HOUR ENDING ',I5,/,
     *20X,'DEPOSITION IN MICROGRAMS/M**2/SEC',/)
      ENDIF
      WRITE(6,1001) (XR(I),YR(I),CAV(I),I=1,NR)
 1001 FORMAT(3(' (',F7.0,',',F7.0,',',F10.3,') '))
      IF(IPLTOP.LT.2) GOTO 3
      DO 4 I=1,NR
      WRITE(1,1002) XR(I),YR(I),CAV(I)
1002  FORMAT(3F15.5)
 4    CONTINUE
      ICT=0
 3    DO 2 I=1,NR
      CAV(I)=0.
 2    CONTINUE
 999  RETURN
      END
```

```
      SUBROUTINE PTCAL(C,X,SY0,Z,IR,IW,H,Q)
      REAL MIXH
      COMMON/ANNUAL/ AMIX(6),ROSE(6,16,6),UCLAS(6),CDSWA(2,20,100),
     1 V1A(20,6,6),VSA(20,6,6),IOFF(100),WSD(100)
      COMMON/PARAM/DEG,RAD,ATIM,SZ10,DREF,XVEC,YVEC,V1(20),VS(20),NPS,
     1 NR,PY1,PY2,CDSW(2,20,100),ICDSW,IPLTOP,IL
      DIMENSION SASIGZ(38),SBSIGZ(38),XDIS(10,6),INDSGZ(6),
     *C(200),PS(6),QS(6)
            DATA SASIGZ / 122.8,
     X              158.08,170.22,179.52,217.41,258.89,346.75,2*453.85,
     1 90.673,98.483,109.3,61.141,34.459,32.093,32.093,33.504,36.65,
     X  44.053,24.26,
     2        23.331,21.628,21.628,22.534,24.703,26.97,35.42,47.618,
     3 15.209,14.457,13.953,13.953,14.823,16.187,17.836,22.651,27.074,
     4 34.219 /
      DATA SBSIGZ /.9447,
     X              1.0542,1.0932,1.1262,1.2644,1.4094,1.7283,2*2.1166,
     1 .93198,.98332,1.0971,.91465,.86974,.81066,.64403,.60486,.56589,
     X  .51179,.8366,
     2        .81956,.75660,.63077,.57154,.50527,.46713,.37615,.29592,
     3 .81558,.78407,.68465,.63227,.54503,.46490,.41507,.32681,.27436,
     4 .21716 /
      DATA XDIS/.1,.15,.2,.25,.3,.4,.5,3.11,1.E20,0.,  .2,.4,1.E20,7*0.,
     1 1.E20,9*0.,  .3,1.,3.,10.,30.,1.E20,4*0.,  .1,.3,1.,2.,4.,10.,
     2 20.,40.,1.E20,0.,  .2,.7,1.,2.,3.,7.,15.,30.,60.,1.E20/
      DATA INDSGZ /0,9,12,13,19,28/,PS/209.14,154.46,103.26,68.26,51.06,
     1 33.92/,QS/1.124,1.109,1.091,1.088,1.086,1.088/
      XY=0.
      DO 2 IST=1,6
      MIXH=AMIX(IST)
      IF(SY0.EQ.0.) GOTO 10
      XY=(SY0/PS(IST))**QS(IST)*1000.
      XV=XY+X
   10 IF(IST .NE. 3) GOTO 20
      IXDIST = 13
      GOTO 80
   20 I = 1
   30 IF(X/1000.-XDIS(I,IST) .LE. 0.0) GOTO 40
      I = I + 1
      GOTO 30
40    IXDIST = INDSGZ(IST) + I
80    SZ = SASIGZ(IXDIST)*(X/1000.)**SBSIGZ(IXDIST)
      IF(SZ.GT.5000.) SZ=5000.
       HT=H
       IF(H.GT.MIXH) HT=MIXH
       IF(Z.GT.MIXH) GO TO 2
       DO 3 IU=1,6
       U=UCLAS(IU)
       IF(ROSE(IU,IW,IST).EQ.0.) GOTO 3
       DO 90 I=1,NPS
       VS(I)=VSA(I,IU,IST)
       V1(I)=V1A(I,IU,IST)
```

```
      CDSW(1,I,IL)=CDSWA(1,I,IL)
      CDSW(2,I,IL)=CDSWA(2,I,IL)*(V1(I)+VS(I)/2)
      IF(IOFF(IL).EQ.1) THEN
      CDSW(2,I,IL)=0.
      VS(I)=0.
      V1(I)=0.
      ENDIF
90    CONTINUE
      I=1
      CALL DIST(Z,X,HT,SZ,U,ZFACT,KR)
100   K=I*2
      ZH=K*MIXH-Z
      CALL DIST(ZH,X,HT,SZ,U,SUM,KR)
      IF(KR.EQ.1) GOTO 900
      ZFACT=ZFACT+SUM
      ZH=K*MIXH+Z
      CALL DIST(ZH,X,HT,SZ,U,SUM,KR)
      IF(KR.EQ.1) GOTO 900
      ZFACT=ZFACT+SUM
      I=I+1
      IF(I.GT.10) GOTO 900
      GO TO 100
900   C(IR)=C(IR)+1.0028*Q*U**WSD(IL)*ZFACT/XV/U/SZ*ROSE(IU,IW,IST)
3     CONTINUE
2     CONTINUE
      RETURN
      END
```

```
      SUBROUTINE AREAA(C,XS,YS,XDIM,YDIM,IR,XR,YR,ZR,H,Q,SNDF,CSDF)
      COMMON/PARAM/DEG,RAD,ATIM,SZ10,DREF,XVEC,YVEC,V1(20),VS(20),NPS,
     1 NR,PY1,PY2,CDSW(2,20,100),ICDSW,IPLTOP,IL
      COMMON/ANNUAL/ AMIX(6),ROSE(6,16,6),UCLAS(6),CDSWA(2,20,100),
     1 V1A(20,6,6),VSA(20,6,6),IOFF(100),WSD(100)
      DIMENSION X(4),Y(4),XX(4),YY(4),XA(5),YA(5),XB(5),YB(5),C(200),
     *SNDF(16),CSDF(16),XXX(4),YYY(4)
      XXX(1)=XS-XDIM/2-XR
      XXX(2)=XXX(1)
      XXX(3)=XS+XDIM/2-XR
      XXX(4)=XXX(3)
      YYY(1)=YS-YDIM/2-YR
      YYY(2)=YS+YDIM/2-YR
      YYY(3)=YYY(2)
      YYY(4)=YYY(1)
      DO 100 IW=1,16
      SND=SNDF(IW)
      CSD=CSDF(IW)
      DO 1 I=1,4
      XX(I)=YYY(I)*CSD+XXX(I)*SND
      YY(I)=YYY(I)*SND-XXX(I)*CSD
1     CONTINUE
      IF(XX(1).LE.0..AND.XX(2).LE.0..AND.XX(3).LE.0..AND.XX(4).LE.0.)
     * GOTO 100
      DO 2 I=1,4
      X(I)=XX(I)
      Y(I)=YY(I)
2     CONTINUE
      DO 3 I=1,4
      K=I+1
      DO 3 J=K,4
      IF(X(I).LT.X(J)) GOTO 3
      HOLD=X(J)
      X(J)=X(I)
      X(I)=HOLD
      HOLD=Y(J)
      Y(J)=Y(I)
      Y(I)=HOLD
3     CONTINUE
      XLEN=X(4)-X(1)
      DX=XLEN/5
      DX2=DX/2
      X1=X(1)+DX2
      IF(X(1).EQ.X(2)) GOTO 10
      SL12=(Y(2)-Y(1))/(X(2)-X(1))
      SL13=(Y(3)-Y(1))/(X(3)-X(1))
      SL42=(Y(4)-Y(2))/(X(4)-X(2))
      SL43=(Y(4)-Y(3))/(X(4)-X(3))
      TL=0.
      DO 4 I=1,5
      IF(X1.GT.X(2)) GOTO 5
      Y2=Y(1)+(X1-X(1))*SL12
```

```
      Y3=Y(1)+(X1-X(1))*SL13
      GOTO 6
5     Y2=Y(4)-(X(4)-X1)*SL42
      IF(X1.GT.X(3)) GOTO 7
      Y3=Y(1)+(X1-X(1))*SL13
      GOTO 6
7     Y3=Y(4)-(X(4)-X1)*SL43
6     TL=TL+ABS(Y3-Y2)
      XA(I)=X1
      YA(I)=Y2
      XB(I)=X1
      YB(I)=Y3
      X1=X1+DX
4     CONTINUE
      GOTO 20
10    DY1=Y(1)-Y(2)
      DY=ABS(DY1)
      TL=5*DY
      DO 11 I=1,5
      Y2=Y(1)
      Y3=Y(2)
      XA(I)=X1
      YA(I)=Y2
      XB(I)=X1
      YB(I)=Y3
      X1=X1+DX
11    CONTINUE
20    Q1=Q*XDIM*YDIM/TL
      DO 30 I=1,5
      IF(XA(I).LE.0.) GOTO 30
      IF(YA(I).GE.YB(I)) GOTO 13
      YHOLD=YA(I)
      YA(I)=YB(I)
      YB(I)=YHOLD
13    TEST=.19891237*XA(I)
      TESTN=-TEST
      IF(YA(I).LT.TESTN) GOTO 30
      IF(YB(I).GT.TEST) GOTO 30
      IF(YA(I).GT.TEST) YA(I)=TEST
      IF(YB(I).LT.TESTN) YB(I)=TESTN
      DY=YA(I)-YB(I)
      Q2=Q1*DY
      DAREA=DY*DX
      SY0=SQRT(DAREA)/4.3
      CALL PTCAL(C,XA(I),SY0,ZR,IR,IW,H,Q2)
30    CONTINUE
100   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LINEA(C,XL1,YL1,XL2,YL2,IR,XR,YR,ZR,H,Q,SNDF,CSDF)
      COMMON/ANNUAL/ AMIX(6),ROSE(6,16,6),UCLAS(6),CDSWA(2,20,100),
     1 VIA(20,6,6),VSA(20,6,6),IOFF(100),WSD(100)
      DIMENSION SNDF(16),CSDF(16),C(200)
      XMIN=1.0
      BETA=0.1989124
      N=5
      XX1=XL1-XR
      YY1=YL1-YR
      XX2=XL2-XR
      YY2=YL2-YR
      DO 9 IW=1,16
      SND=SNDF(IW)
      CSD=CSDF(IW)
      X1=YY1*CSD+XX1*SND
      Y1=YY1*SND-XX1*CSD
      X2=YY2*CSD+XX2*SND
      Y2=YY2*SND-XX2*CSD
      DX=X2-X1
      IF(DX.GE.0.)GO TO 1
      DX=-DX
      X0=X2
      X2=X1
      X1=X0
      Y0=Y2
      Y2=Y1
      Y1=Y0
1     DY=Y2-Y1
      IF(DY) 2,3,4
2     DY=-DY
      Y1=-Y1
       Y2=-Y2
4     XI=(X1*Y2-Y1*X2)/DY
      IF(ABS(DX).LT.1.) GO TO 5
      SL=DY/DX
      XA=SL*XI
      XB=1.E+20
      IF(SL.NE.BETA) XB=XA/(SL-BETA)
      XA=XA/(SL+BETA)
6     YA=-BETA*XA
      YB=BETA*XB
      GO TO 7
5     XA=X1
      XB=X1
      GO TO 6
3     XB=Y1/BETA
      XA=-XB
      YA=Y1
      YB=Y1
7     IF(XB.GT.0.)GO TO 8
       IF(XA.LE.0.) GO TO 9
       IF(X2.LE.XA) GO TO 9
```

```
      IF(X1.GT.XA) GO TO 10
      X1=XA
      Y1=YA
      GO TO 10
8     IF(XA.GT.0.) GO TO 11
      IF(X2.LE.XB) GO TO 9
      IF(X1.GE.XB) GO TO 10
      X1=XB
      Y1=YB
      GO TO 10
11    IF(Y2.LE.YA.OR.Y1.GE.YB) GO TO 9
      IF(DX.NE.0.) GO TO 12
      IF(Y1.LT.YA) Y1=YA
      IF(Y2.GT.YB) Y2=YB
      GO TO 10
12    IF(X1.GE.XA) GO TO 13
      X1=XA
      Y1=YA
13    IF(X2.LE.XB) GO TO 10
      X2=XB
      Y2=YB
10    DX=(X2-X1)/N
      DY=(Y2-Y1)/N
      DL=SQRT(DX*DX+DY*DY)
      Q1=Q*DL
      X=X1+0.5*DX
      Y=Y1+0.5*DY
      DO 14 I=1,N
      XP=X
      IF(XP.LT.XMIN) XP=XMIN
      SYO=DL/4.3
      CALL PTCAL(C,XP,SYO,ZR,IR,IW,H,Q1)
      X=X+DX
      Y=Y+DY
14    CONTINUE
9     CONTINUE
      RETURN
      END
```

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. EPA-910/9-88-202	2.	3. Recipient's Accession No.

4. Title and Subtitle	5. Report Date
USER'S GUIDE FOR THE FUGITIVE DUST MODEL (FDM)	June 1988
	6.
7. Author(s) Kirk D. Winges	8. Performing Organization Rept. No.
9. Performing Organization Name and Address TRC Environmental Consultants, Inc. 21907 64th Ave. W, Suite 230 Mountlake Terrace, WA 98043	10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) (G)
12. Sponsoring Organization Name and Address U.S. Environmental Protection Agency, Region 10 1200 Sixth Ave., Seattle, WA 98101	13. Type of Report & Period Covered Final Report 14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

The Document provides a technical description and User's Instructions for the Fugitive Dust Model. The FDM is a Gaussian-plume base dispersion model specifically designed for computation of fugitive dust concentrations and deposition rates. It's chief advantage over other models is an advance deposition algorithm. A validation study has been performed and is included as an appendix. The document also includes sample input and output printouts and a complete listing of the FORTRAN computer code.

17. Document Analysis a. Descriptors

Air Pollution
Mathematical Models
Computer Dispersion Models
Fugitive Dust

b. Identifiers/Open-Ended Terms

Dispersion

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
	Unclassified	106
	20. Security Class (This Page)	22. Price
	Unclassified	

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce