Review of Nine Rural Air Quality Models for AMS Steering Committee

by

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ABSTRACT

Nine air quality models have been evaluated for technical performance characteristics including model physics, assumptions, range of application, state-of-the-art techniques, inherent limitations, and clarity of documentation. Model performance statistics have been examined to confirm or revise initial impressions found during the preliminary evaluation. This work has been performed for the American Meteorological Steering Committee responsible to the U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards under their mission to evaluate rural air quality simulation models.

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LIST OF SYMBOLS

Symbol	Definition	Numerical Value
B2	Much Better	1
B1	A Little Better	2
C	Comparable	3
W1	A Little Worse	4
W2	Much Worse	5

1.0 INTRODUCTION

The Prevention of Significant Deterioration and nonattainment provisions of the 1977 Amendments to the Clean Air Act explicitly require the use of air quality models. To decide in an objective manner which models should be included in EPA's "Guideline on Air Quality Models", EPA has undertaken a systematic evaluation of rural models. AMS through a steering committee is coordinating a peer review of ten air quality models (COMPTER, CRSTER, MPSDM, MPTER, MULTIMAX, PLUME5, SCSTER, TEM-8, 3141 and 4141).[1-8] This report represents an evaluation of the above models by a peer review panel member.

The review has been accomplished in three parts - a qualitative comparison of modeling approaches on technical grounds,[18] an evaluation of statistical results from model/field concentration values,[10] and a consideration of a set of questions posed by the Woods Hole Conference.[11] Chapter 2.0 discusses in some detail the foundation for such evaluation.

2.0 PROCEDURES

This chapter discusses the historical framework for model evaluation (Section 2.1), the modified workbook comparison techniques (Section 2.2), and the details and limitations of the field comparison data (Section 2.3).

2.1 General Considerations

A great deal of confusion continues to exist as to what evidence or process is adequate to establish evaluation, verification, validation, or calibration of an air quality model. Turner (1979) attempts to clarify any semantic differences between these terms.[15] Specifically he defines Performance Evaluation as:

> Determining the performance of a model for different conditions through a particioning of the data.

Egan et. al. (1981), Hilst (1978), and Fox (1981) summarize various workshops prepared to consider the problems of air quality model validation.[11-13] Most participants identified problems in the areas of intent of use, reliability of data sets used to evaluate models, and the statistical nature of the actual comparison between models and field data.

The Woods Hole Conference recommended basing performance evaluation on the magnitude of differences between observed and predicted concentrations. The recommended performance measures were the bias (average), the variance (noise), and the gross variability (gross error) of the differences. Correlation measures in space and time were also considered helpful. Nappo (1980) and Venkatram (1981) emphasize that dispersion models predict averages of ensembles of observations made over those atmospheric conditions which have been assumed and parameterized, rather than single observations made by a particular monitor.[20,21]

Model validations based on comparison of predicted with observed concentrations without taking into account such natural variability of the observations may not be very meaningful. Rao and Visalli (1981) among others emphasize the importance of extreme value theory to qualitatively and quantitatively evaluate the performance of models.[19] Such estimates are important as long as regulatory needs specify limitations on first or second highest expected values.

Indeed Woods Hole participants felt "strongly" that scientific judgement (ie. scientific performance -- or recognition of cause-and-effect relationships) might prove to be the only efective method to distiguish between models (Fox (1981)). This leads to the "qualitative" type of evaluation provided by the use of a modified "Workbook" approach found in Chapter 3.0 and the response to Woods Hole Questions (Appendix 1) found in Chapter 5.0.

Despite the variety of emphasis within the recent liberature it is clear that the engineering and scientific concensus recommends a balanced approach which includes both "scientific" as well as "operational" criteria. Indeed recent articles by Wilson, Cox, and Mackay (1982) and Trout (1982) both recommend that air quality models be examined with respect to their regulatory characteristics, ability to reproduce monitor data, and physically correct foundations.[16,17] Wilson, et. al. (1982) provide a decision flow diagram for evaluating a proposed air quality model. It is the intent of the next report sections to speak to such procedures.

2.2 Qualitative Evaluation by a Workbook Approach

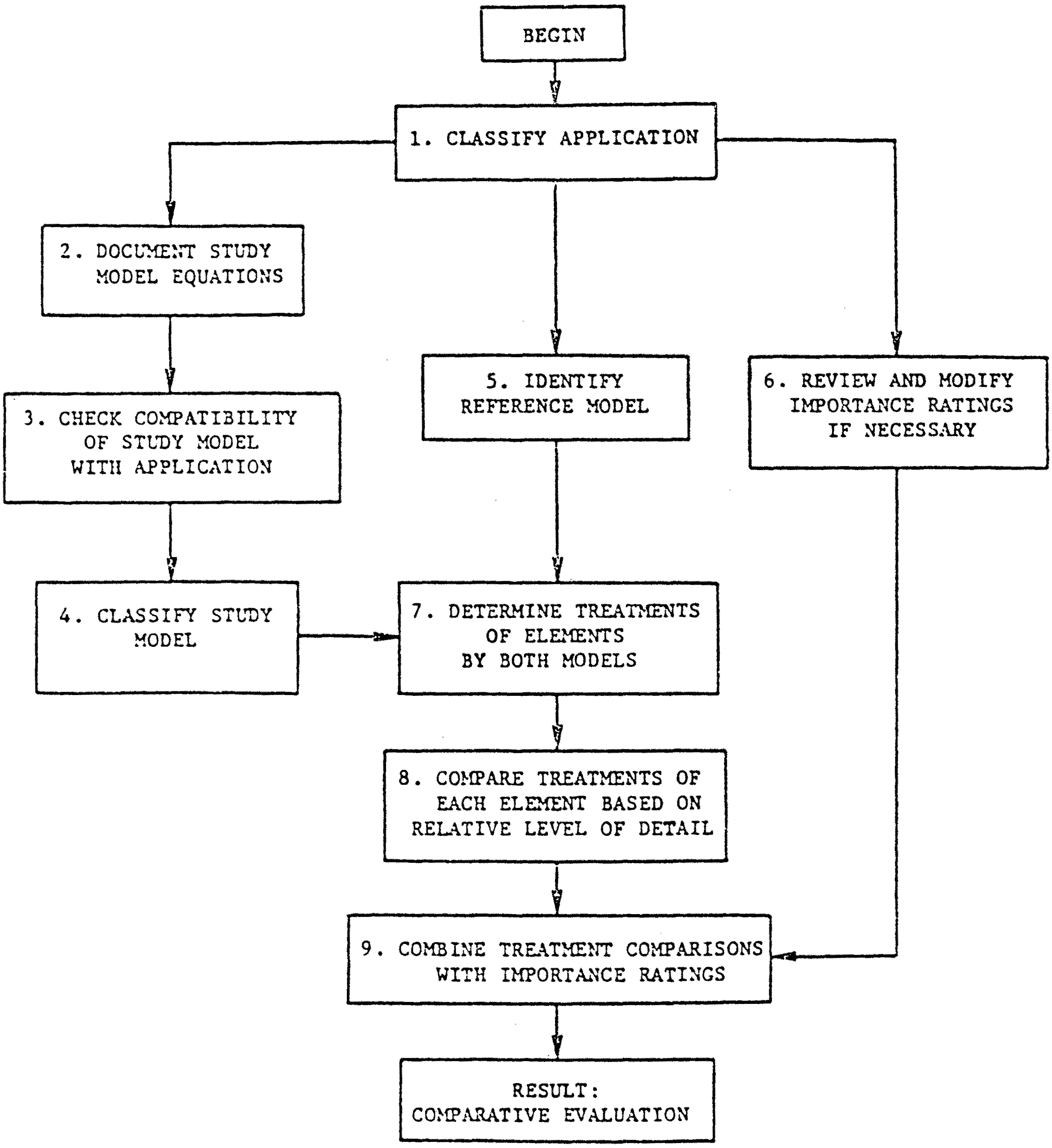
It is not necessarily possible or prudent to judge one model "better" or "worse" than another in an overall sense. Each air quality model represents the synthesis of many submodules each potentially different. These submodules deal with such details as source/receptor relationships, input sources and meteorological conditions, advection or dispersion processes, plume trajectories, and removal processes, terrain corrections, etc. For a given application the combination of submodules in one air quality model may produce more or less reliable results then another air quality model in a different application environment. Nonetheless it shall be assumed that if a given model contains a set of modules each which appear more "scientifically sophisticated," more "up to date", and speak to a wider range of atmospheric and terrain situations then it should be judged "better" in that the user is more likely to receive reliable guidance through its use.

The EPA (1978) has recommended the use of a "Workbook for Comparison of Air Quality Models" to guide the approval of alternate models to those included in the official "Guideline on Air Quality Models."[18] This workbook describes a technique for the qualitative comparison of modeling approaches on technical grounds. The procedure is application-specific; that is, the results depend upon the specific situation to be modeled. Normally the user identifies both the application of interest and an associated EPA "reference model." This reference model serves as a standard of comparison against which the user gages the "study model" being evaluated. The models are compared by the way in which each model treats twelve submodules of atmospheric dispersion called "application elements." These "elements" represent physical and chemical phenomena that govern atmospheric pollutant concentrations. The importance of each element to the application is defined in terms of an importance rating. The individual comparisons, together with their associated importance ratings, form the basis upon which the final comparative evaluation of the two models is made. Figure 1 reproduced from the workbook displays a block diagram for the procedure for the comparison of air quality simulation models. Figure 2 indicates how the individual application elements interact to predict concentrations. The workbook contains tables of importance ratings for different application situations, tables to guide the user when examining each application element, and forms upon which to register comments and conclusions.

The workbook approach is applied herein to the intercomparison of the ten rural air-quality models with certain revisions. First, each air quality model (COMPTER, CRSTER, MPSDM, MPTER, MULTIMAX, PLUME5, SCESTER, TEM-8, 3141, and 4141) is chosen in sequence as the reference model and intercompared with all other models. Second, the range of possible applications for all the models was examined in terms of the workbook classification scheme (see Figure 3), and a set of possible common applications identified. Third, since all comparisons were generic rather than specific no application element category was deemed "critical." Fourth, even application elements deemed "irrelevant" to a given application were evaluated for qualitative submodule standing. Finally, although the workbook only stipulates a study model is BETTER than, COMPARABLE to, or WORSE than a reference model. I chose to categorize model behavior as

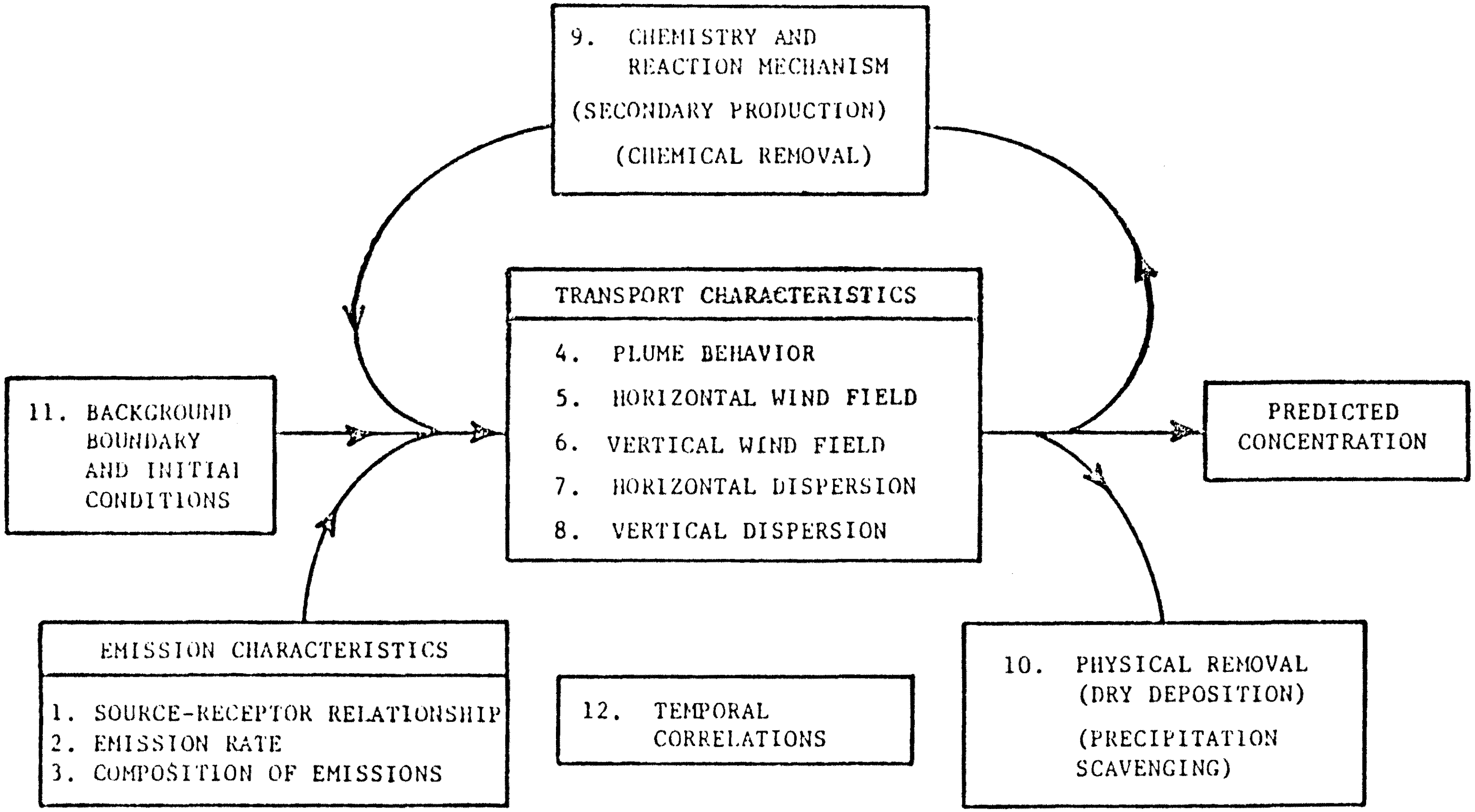
1) a LOT BETTER than (B2),
2) a LITTLE BETTER than (B1),
   COMPARABLE to (C),
3) a LITTLE WORSE than (W1), or
4) a LOT WORSE than (W2)

some reference model. This division was used because differences between models were often slight or subtle. A complete set of evaluation forms are included here for reference (see Figures 4 to 8). An



Note: Numbers in the boxes refer to the steps in the comparison procedure as given in Table 2.1.

Figure 1. Procedure for the Comparison of Air Quality Simulation Models



Note: Temporal correlations relate the time variations of all other application elements.

Figure 2. Application Elements as Major Factors Affecting Pollutant Concentrations

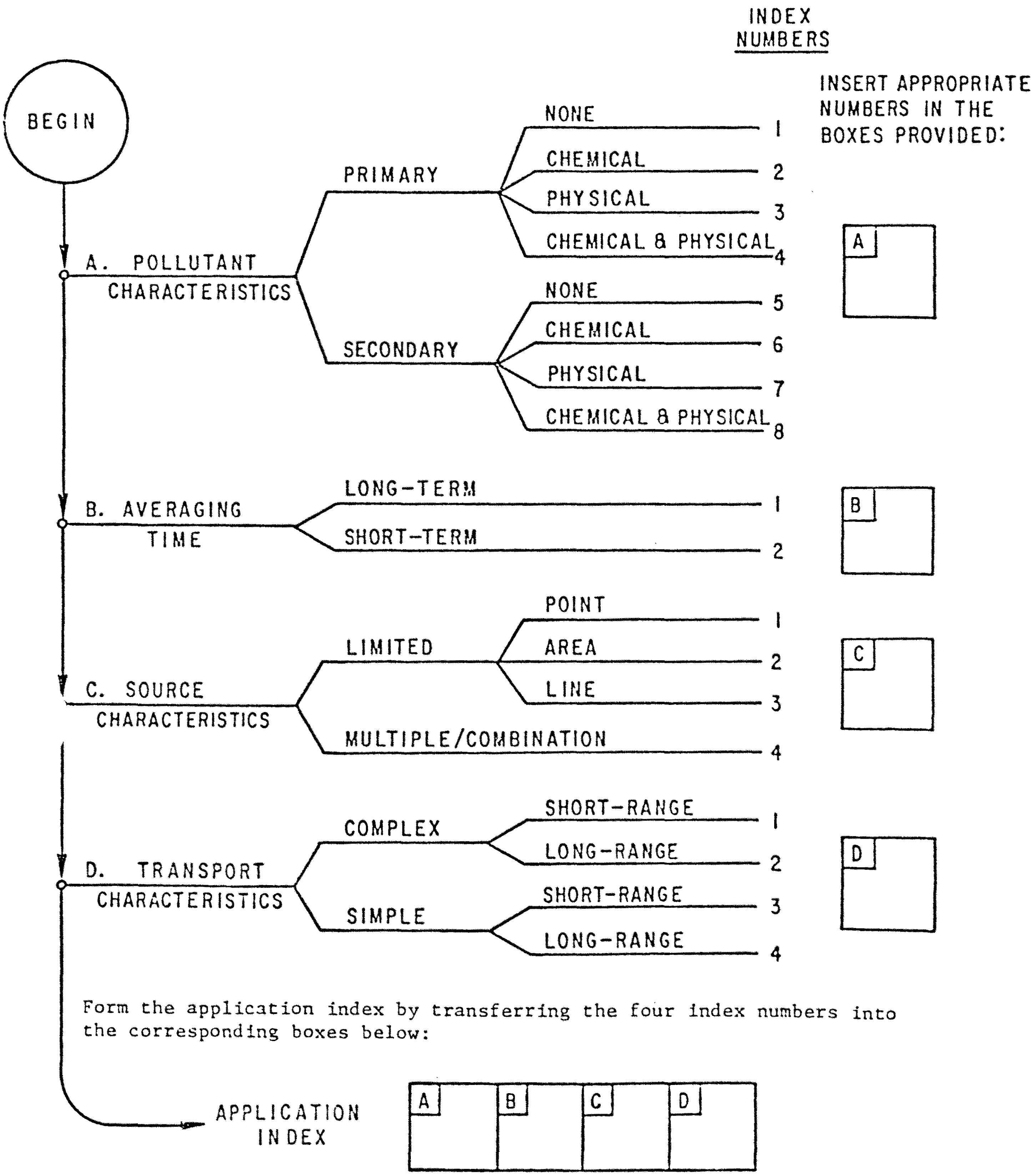


Figure 3. Application Classification Form

Study Model:

References:

Abstract:

Classification:

Application Index: Reference Model:

Application Description:

Model Applicability: Applicable ☐ Not Applicable ☐

Figure 4. Evaluation Form: Part A: Abstract and References

<u>Study Model</u>:

<u>Equations</u>:

Figure 5. Evaluation Form: Part A (reverse): Equations

Application Index:

Application Element	Importance Rating: Initial	Importance Rating: Modified[a]
Source-Receptor Relationship		
Emission Rate		
Composition of Emissions		
Plume Behavior		
Horizontal Wind Field		
Vertical Wind Field		
Horizontal Dispersion		
Vertical Dispersion		
Chemistry and Reaction Mechanism		
Physical Removal Processes		
Background, Boundary, Initial Conditions		
Temporal Correlations		

[a]With the exception of the designation of IRRELEVANT elements, it is expected that at most one CRITICAL designation and possibly one other modification may be made.

Figure 6. Evaluation Form: Part B: Importance Ratings

Application Index:__________

Application Element:	Application Element:
Reference Model:	Reference Model:
Treatment:	Treatment:
Study Model:	Study Model:
Importance Rating:	Importance Rating:
Comparative Evaluation:	Comparative Evaluation:
Treatment:	Treatment:

Figure 7. Evaluation Form: Part C: Treatment of Elements

Application Index:__________ Reference Model:__________ Study Model:__________

Importance Rating of Application Elements	Number of Treatments: Total	BETTER	COMPARABLE	WORSE	Comparative Rating of Study Model
CRITICAL					__________
HIGH					__________
MEDIUM					__________
LOW					
IRRELEVANT	_____	XXX	XXX	XXX	
Total	(Should equal 12)				
			TECHNICAL EVALUATION		__________

Figure 8. Evaluation Form: Part D: Technical Comparison

additional form (Figure 9) is introduced to permit overall intercomparison of the various models.

Chapter 3.0 contains the results of the workbook comparison, Appendix 2 reproduces the work copies of the forms produced during the evaluation of each model.

2.3 Statistical Evaluation by Field Data Comparison

TRC Environmental Consultants, Inc. working under contract to EPA, has assembled an air quality data base, setup and run the dispersion models, and produced statistical comparisons of observed and predicted air quality.[10] This is the first time statistical tests of this sort have been applied to a group of models by EPA.

Other studies such as Londergan et. al. (1980) have examined model reliability by statistical means. In this case seven models recommended by EPA for evaluating air quality impacts of stationary sources were considered: RAM, RAMR, CRSTER, PAL, PTMTP, TEM5 and VALLEY.[14] Model performance statistics were developed for six separate sets of field data (Hanford 67, Green Glow, NRTS, TMI, and Ocean Breeze) for near grond releases for flat rural terrain, for six separate sets of statistics (Dry Gulch, Shoreline, Woodlot, St. Lous, Rancho Seco, and Paramount) for near ground releases with surface roughness, for four separate sets of statistics (Hanford 67, Rancho Seco, Karlsruhe, and Fort Wayne) for elevated releases from a fixed height, and for three separate sets of statistics (Goodyear, Benecia, and Garfield) for elevated buoyant releases. The authors compared mean predicted values to mean observed values (and maximum ten values predicted to maximum ten values observed) rather than examine difference statistics.

The Londergan et. al. (1980) report results, taken together, demonstrate that the standard EPA dispersion models are not reliable within a

APPLICATION ELEMENT: ____________________

	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUMES	SCESTER	TEM 8	3141/4141
COMPTER	-								
CRSTER		-							
MPSDM			-						
MPTER				-					
MULTIMAX					-				
PLUMES						-			
SCESTER							-		
TEM 8								-	
3141/4141									-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Figure 9. Application Element

factor of 2 for predicting concentrations for characteristic dispersion conditions at most locations.[14] Model performance was highly uneven, and included systematic departures from observed dispersion behavior even for flat rural conditions.

The more recent results, Londergan et. al. (1982), produced for the current intercomparison are more limited in application scope.[10] Only one site was examined in detail. The data for the Clifty Creek plant in the Ohio River Valley for the years 1975 and 1976 were selected as the most suitable part of the American Electric Power Corporation (AEP) data set for evaluating rural models.

The Clifty Creek plant, operated by the Indiana-Kentucky Electric Corporation, is a coal-fired, base-load facility located along the Ohio River in southern Indiana. Three 208-meter stacks were used throughout the study period to vent plant emissions. Terrain surrounding the plant includes low ridges and rolling hills. Hill and ridge tap elevations do not exceed stack height

Hourly air quality data were measured by continuous SO_2 monitors at six stations ranging from 3 to 15 kilometers from the Clifty Creek plant. Hourly meteorological data compiled in the standard format from the Meteorological Preprocessor Program (CSRTER) were utilized as input information. All data were interpolated to 7 meters for input to the models, which subsequently used their respective, interval wind-profile algorithms to extrapolate to stack-height values. All programs were modified to accept hourly SO_2 emissions data.

Table I lists the statistical comparisons recommended by the AMS Woods Hole workshop. The methods used to accomplish these comparisons are detailed in Londergan et. al. (1982). I will assume that all values produced are mathematically correct, the methodology appropriate and the results significant. It is obvious that the statistics contain a mass of information. Due to time and resource constraints I have limited my examination of the data to the summary tables.

TRC and EPA agreed because of the particular application selected (Clifty Creek) that MPTER, CRSTER, and PLUME5 would predict equivalent concentration values. Therefore, evaluation statistics were prepared for only eight models including MPTER. In addition modifications were made to several of the computer codes to permit use of the CRSTER preprocessor program and obtain model predictions appropriate for comparison with observed concentrations.

Although the modification of the subject programs may have been practically necessary; I find the adjustments unfortunate, since one disengages the original submodules whose "scientific" evaluation suggested one model was preferable to another. It is also significant that many of the more sophisticated adjustments for terrain height and inversion height become effective only as terrain height exceeds stack height - an option not examined by the Clifty Creek data set.

Finally, although the purported intent of the exercise is to critique model skeletons and submodules the data only reflect the total operation of the program. It is certainly possible a given submodule element is superior in one program to another, yet the total model performance may not reflect this fact.

Chapter 4.0 summarizes the results of statistical model comparisons. The comparisons are created using the form displayed in Figure 9.

Table 1. Summary of Data Sets for Rural Model Evaluation with Clifty Creek Data Base (Suggested by Woods Hole Report.)

Comparison	Data Set
A. Peak Concentration Comparisons	(A-1) Compare highest observed value for each event with highest prediction for same event (paired in time, not location)
	(A-2) Compare highest observed value for the year at each monitoring station with the highest prediction for the year at the same station (paired in location, not time)
	(A-3a) Compare maximum observed value for the year with highest predicted values representing different time or space pairing (fully unpaired; paired in location; paired in time; paired in space and time)
	(A-3b) Compare maximum predicted value for the year with highest observed values for various pairings, as in (A-3a)
	(A-4a) Compare highest N (=25) observed and highest N predicted values, regardless of time or location
	(A-4b) Compare highest N (=25) observed and highest N predicted values, regardless of time, for a given monitoring location. (A total of six data sets.)
	(A-5) Same as (A-4a), but for subsets of events by meteorological conditions (stability and wind speed).
B. All-Concentrations Comparisons	(B-1) Compare observed and predicted values at a given station, paired in time (a total of six data sets).
	(B-3) Compare observed and predicted values at all stations, paired in time and location (one data set).
	(B-4) Same as (B-3), but for subsets of events by meteorological conditions (stability and wind speed).

A rating scale similar to the workbook scale was used, ie., B2, B1, C, W1, and W2. Appendix 2 reproduces the summary data tables form Londergan (1982) - Tables 4a-1 to Table 9c.

3.0 RESULTS OF WORKBOOK COMPARISONS

The procedures followed during this "scientific" evaluation which emphasizes model structure rather than results is described in the EPA (1978) Workbook. Modifications to the normal approach followed for this evaluation are discussed in Section 2.2.

In addition two summary tables are provided which permit rapid intercomparison of the subject air quality models. Table 2 compares the models in the same format suggested by Londergan et. al. (1980), (see Table 3-1, pp 21). This table emphasizes source-receptor features of each model, regions for applications, dispersion coefficients, and wind shear treatment. Differences in source-receptor relationships were not tested during the statistical study since all models were modified to calculate at the six specific monitor locations required by a Clifty Creek simulation. Table 3 summarizes program options. Program documentation is reviewed in Table 4.

Table 2. Features of Air Quality Models

Model	Allowed Number Sources Point	Area	Line	Receptors	Region(s) for Application	Dispersion Coefficients	Reference Height (m)	Wind Profile Exponents A	B	C	D	E	F	G
COMPUTER	50	x	x	200 polar, rectangular US	urban or rural, flat or uneven terrain	Pasquil-Gifford & Pasquil accel	7	0.10	0.15	0.20	0.25	0.30	0.30	0.30
CRSTER	19	x	x	180 polar coord grid 5 radius US	urban or rural flat or uneven	Pasquil-Gifford	7	0.10	0.15	0.20	0.25	0.30	0.30	-
MPSDM	35	x	x	128 US (35 monitors)	urban or rural flat or uneven	ASME or US Δ Pasquil Accel	10 or US	0.09 or US	0.11	0.12	0.14	-	0.20	-
MPTER	250	x	x	180 receptor polar coord or	rural uneven terrain	Pasquil-Gifford Pasquil Accel◇ Exp Depletion	US	0.07 or US ($Z_o \simeq 0.03$ m)	0.07	0.10	0.15	0.35	0.35	-
MULTIMAX	100	x	x	300 polar or rect grid or US	urban or rural flat or uneven	Pasquil-Gifford	7 or US	0.10	0.15	0.20	0.25	0.30	0.30	-
PLUMES	10 locations with 15 stocks colected at each location	x	x	∞ polar or square arrays	urban or rural	Pasquil-Gifford Pasquil Accel◇	10 *	0.10	0.15	0.20	0.25	0.30	0.30	0.30
SCESTER	60	x	x	600 polar, rect or US (15 rings)	urban or rural flat or uneven	Pasquil-Gifford	7 or US	0.10 or US	0.15	0.20	0.25	0.30	0.30	0.30
TEM-8	300	50	x	2500 max 50 x 50	flat level rural terrain	Pasquil-Gifford Exp. Depletion	10	0.10	0.15	0.20	0.25	0.30	0.30	-
3141/ 4141	19 calculated	x	x	180 polar coord 5 radius US	urban or rural flat or uneven	Pasquil-Gifford Briggs Accel◇	7	0.10	0.15	0.20	0.25	0.30	0.30	0.30

◇ Modification of both σ_y & σ_z, weighted as square

Δ Modification to both σ_g & σ_z, vertical distance adjustment

* Modification of σ_z only, weighted as square

US ~ Arbitrary or User Specified

* Extrapolates to other heights HS under different situations of stable layer penetration

Table 3. Model Options

MODEL	Source Conditions: Point	Area	Line	Variable Source Strength	Plume Rise and Dispersion: Variable Height	Stack Downwash	Momentum Rise	Variable Plume Rise	Plume Rise Accelerated σ	Flares	Wind Shear Adjustment	Includes Preprocessor Program	Terrain and Mixing Layer Height Adjustments: Mixing Layer Height	Terrain Following	Terrain Impact	Stable Layer Penetration	Fumigation	Penetration of Mixed Layer
COMPTER	√			√	√			√	√			√*	√	SIGD				
CRSTER	√			√	√		√	√				√*	√	FGD				
MPSDM	√			√	√	√		√	√			√	IGD	IGD			√	√
MPTER	√			√	√	√	√	√	√				√	SIGD				
MULTIMAX	√			√	√					√		√*	√	RHA				
PLUMES	√			√	√			√	√		√	√	√	∇	√	√		√
SCSTER	√			√	√			√			√	√	√	FGD IGD SIGD	√			
TEM-8	√	√			√	√	√	√		√			√					√
3141/4141	√			√	√				√			√	√	SIGD	?			

MODEL	Depletion Mechanisms: Chemical	Deposition	Scavenging	Depletion	Background Concentration Adjustment	Receptor Characteristics: Autogrid	10 min	30 min	1 hr	3 hr	24 hr	Variable	Run Average	Annual	Max Conc.	2nd Max Conc.
COMPTER									√	√	√	√	√	√	√	√
CRSTER									√	√	√	√	√	√	√	√
MPSDM					√	√			√	√	√	√	√	√	√	√
MPTER				√		√			√	√	√	√	√	√	√	√
MULTIMAX					√				√	√	√			√	√	√
PLUMES	√			√	√				√	√	√	√		√	√	√
SCSTER				√					√	√	√	√		√	√	√
TEM-8				√		√	√	√	√	√	√				√	
3141/4141									√	√	√	√		√	√	√

Notes:
- * Uses CRSTER Preprocessor Program
- IGD Intermediate ground displacement ($H - c\Delta Z$)
- SIGD Stratification adjusted intermediate ground displacement ($H - \Delta Z + F_T \Delta Z$) where $F_T = f(\text{stability})$
- RHA Receptor-height adjustement $Z' = Z_{recept}/2,\ Z \leq H-10$
- FGD Full ground displacement ($H - \Delta Z$)
- ∇ Terrain adjustment depending on location wrt H and top or base of stable layer

Table 4. Documentation

Rating of Documentation								
MODEL	Limitations Clearly Stated	Assumptions Stated	Accuracy Stated	Verification Study Included	Sensitivity Study	Easy to Use	Stands Alone	Clear Writing Style
COMPTER						√	√	
CRSTER	√	√	√	V	C	√	√	√
MPSDM	√	√				√	√	√
MPTER	√	√				√	√	√
MULTIMAX	S	S	√	C		√	√	
PLUME5				V/C				
SCSTER		R	R			√	√	√
TEM-8	√	√				√	√	√
3141/4141		√	R	R		√	√	√

Notes:
- S Spread through report
- V Comparison to field Data
- C Comparison to other semi-empirical model results
- R Referenced in other articles or reports

3.1 Performance by Application Element

There are twelve application elements identified by the workbook. They are:

- Source-Receptor Relationships,
- Emission Rate,
- Composition of Emissions,
- Plume Behavior,
- Horizontal Wind Field,
- Vertical Wind Field,
- Horizontal Dispersion,
- Vertical Dispersion,
- Chemistry and Reaction Mechanisms,
- Physical Removal Processes,
- Background, Boundary, Initial Conditions, and
- Temporal Correlations.

One might note here that the Clifty Creek data treatment essentially eliminates any possiblity of comparison of the models features related to five of these categories, ie. source-receptor relationships, emission rate, composition of emissions, chemistry and reaction mechanisms, and physical removal processes.

The EPA (1978) workbook provides numerous tables to subclassify model physics, assumptions and capabilities. A table subcategory has been noted for every model for each factor identified under each application element heading. These codes are summarized in Table 5 of this report, and reflect notations found in Tables 5.1 to 5.15 of the workbook. A quick examination of Table 5 suggests that the foundation physics in most of the air-quality models studied depend on nearly identical algorithms. This suggests any magnitude differences which exist

Table 5. Application Element Comparison Chapter 5 EPA Workbook for Comparison of Air Quality Models

APPLICATION ELEMENTS	Table	Subtable	COMDTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCSTER	TEM-8	3141/4141
Source Receptor Relationship											
Horiz. Source Location	5.1	a	p1	p3	p1	p1	p1	p1	p3	p1	p3
Release Height		b	p1	p1	p1	p1	p1	p1	p1	p2	p1
Downwind Crosswing		c	p1	p1	p1	p1	p1	p1	p1	p1	p1
Source Orientation		d	-	-	-		-	-	-	-	-
Receptor Location		e	1 or 3	3	1 or 3	1 or 3	1 or 3	1 or 3	1 or 3	2	3
Receptor Height (Ten)		f	2	2-7	2	2	2	2	2	7	2-7
Emmission Rate	5.2										
Spatial		s	p1	p1	p1	p1	p1	p1	p1	p-1 A-2	p1
Temporal		t	1	3	1	1	5?	1	1	5	3
Composition of Emissions	5.1										
Chemical		cc	-	-	-	-	-	-	1	-	-
Size Distribution		s	7	7	7	7	7	7	7	7	7
Plume Behavior	5.4		4a	4a	4a	4a	4a	4a	4a	4a	4a
Horizontal Wind Field	5.5										
Horiz. Location			4	4	4	4	4	4	4	4	4
Height			6	6	6	6	6	6	6	6	6
Time			2b	2b	2b	2b	2b	2b	2b	4 or 2b	2b
Vertical Wind Field	5.6		4a	4a	4a	4a	4a	4a	4a	4b	4a
Horizontal Dispersion	5.7		4a	4a	4a	4a	4a	4a	4a	4a	4a
Stability	5.8		2b	2b	2b	2b	2b	2b	2b	2b	2b
Surface Z_o	5.9		3	3	3	3	3	3	3	3	3
Basis for σ	5.10		3	3	3	3	3	3	3	3	3
Vertical Dispersion	5.7		4a	4a	4a	4a	4a	4a	4a	4a	4a
Stability	5.8		2b	2b	2b	2b	2b	2b	2b	2b	2b
Surface Z_o	5.9		3	3	3	3	3	3	3	3	3
Basis for σ	5.10		3	3	3	3	3	3	3	3	3
Chemistry & Reaction Mechanism	5.12		7	7	7	7	7	7	6	7	7
Physical Removal Processes	5.13										
Dry Deposition			4	4	4	2b	4	2b	2b	2b	4
Precip. Scaveng.			5	5	5	5	5	5	5	5	5
Background; BC, IC	5.14	a	3	3	2	4	2	3	2	3	3
Upper BC.		b	1	1	1	1	1	1	1	2	1
Lower BC.		c	2	2	2	2	2	2	2	3	2
Temporal Correlations	5.15		1a	1c	1a	1c	1c	1a	1a	3	1c

Table 6. APPLICATION ELEMENT: Source Receptor Relationship

Application: 1143/1243 Importance: M/M

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	B2	C	C	C	C	C	B1	B2
CRSTER	W2	-	W2	W2	W2	W1	W2	W2	C
MPSDM	C	B2	-	C	C	C	C	B1	B2
MPTER	C	B2	C	-	C	C	C	B1	B2
MULTIMAX	C	B2	C	C	-	C	C	B1	B2
PLUME5	C	B1	C	C	C	-	C	B1	B1
SCESTER	C	B2	C	C	C	C	-	B1	B2
TEM 8	W1	B2	W1	W1	W1	W1	W1	-	B2
3141/4141	W2	C	W2	W2	W2	W1	W2	W2	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

between program predictions are the result of matters of detail rather than overall model approach. Indeed it is somewhat discouraging to find results scatter so widely considering the class family resemblances.

Source Receptor Relationships:

There are six factors considered:

- Horizontal location of sources,
- Release heights,
- Downwind and crosswind distances,
- Orientation of area and line sources,
- Horizontal location of receptors, and
- Height of receptors.

Model intercomparison as shown on Table 6 suggests that COMPTER, MPSDM, MPTER, MULTIMAX, PLUME5 , and SCSTER are nearly equivalent. CRSTER, 3191, and 4141 models are limited by the requirement for co-location of sources. TEM-8 is limited to flat terrain.

Emission Rate:

Spatial and temporal resolution is considered in evaluating emission rate. COMPTER, MPSDM, MPTER, PLUME5, and SCSTER are comparable as noted in Figure 7. MULTIMAX and TEM-8 are somewhat less desirable because they are limited to constant (temporal) emission rates. CRSTER, 3141, and 4141 specify monthly variations in emission rate rather than hourly.

Composition of Emissions:

None of the models are very ambitious with respect to treatment of chemically reacting gases or particles which may be depleted by scavenging or fallout Nonetheless PLUME5 stands out as a model which includes special features to handle NO_2 and decaying compounds (see Table 8).

Table 7. APPLICATION ELEMENT: Emission Rate

Application: 1143/1243 Importance: M/M

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	B1	C	C	B1	C	C	B1	B1
CRSTER	W1	-	W1	W1	C	W1	W1	B1	C
MPSDM	C	B1	-	C	B1	C	C	B1	B1
MPTER	C	B1	C	-	B1	C	C	B1	B1
MULTIMAX	W1	C	W1	W1	-	W1	W1	B1	C
PLUME5	C	B1	C	C	B1	-	C	B1	B1
SCESTER	C	B1	C	C	B1	C	-	B1	B2
TEM 8	W1	W1	W1	W1	W1	W1	W1	-	W1
3141/4141	W1	C	W1	W1	C	W1	W2	B1	-

Ratings:
- B2: A lot better
- B1: A little better
- C : Comparable
- W1: A little worse
- W2: A lot worse

Table 8. APPLICATION ELEMENT: Composition of Emissions

Applications: 1143/1243 Importance: L or I

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	C	C	C	C	W1	C	C	C
CRSTER	C	-	C	C	C	W1	C	C	C
MPSDM	C	C	-	C	C	W1	C	C	C
MPTER	C	C	C	-	C	W1	C	C	C
MULTIMAX	C	C	C	C	-	W1	C	C	C
PLUME5	B1	B1	B1	B1	B1	-	B1	B1	B1
SCESTER	C	C	C	C	C	W1	-	C	C
TEM 8	C	C	C	C	C	W1	C	-	C
3141/4141	C	C	C	C	C	W1	C	C	-

Ratings:
- B2: A lot better
- B1: A little better
- C : Comparable
- W1: A little worse
- W2: A lot worse

Treatment of Plume Behavior:

This element considers whether a validated plume model is used and whether it accounts for downwash, momentum effects, fumigation, or variable plume rise. All of the models calculate an effective stack height for emissions based on the Briggs buoyant plume rise formulations. MULTIMAX, TEM-8, and MPSDM use distance dependent plume rise formulations. The other models use final plume rise for calculating effective stack height at all distances from the source. It appears that an option exists to use variable plume rise in COMPTER, CRSTER, PLUME5, SCSTER, and MPTER. Some models permit adjustments for momentum rise and other adjust for tip downwash. Table 9 suggests PLUME5 and MPSDM are superior.

Treatment of Horizontal Wind Field:

Treatment of Vertical Wind Field:

All models treat these elements similarly (Tables 10 and 11).

Table 9. APPLICATION ELEMENT: Plume Behavior

Application: 1143/1243 Importance: M/H

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	C	W2	C-	C-	W2	C	W1	C
CRSTER	C	-	W2	C-	C	W2	C	W1	W1
MPSDM	B2	B2	-	B1	B2	W1	B2	C	B2
MPTER	C+	C+	W1	-	C+	W2	C+	W1	C+
MULTIMAX	C+	C	W2	C-	-	W2	C	W1	C+
PLUME 5	B2	B2	B1	B2	B2	-	B2	B1	B2
SCESTER	C	C	W2	C-	C	W2	-	W1	C
TEM 8	B1	B1	C	B1	B1	W1	B1	-	B1
3141/4141	C	C-	C-	W2	B1	W2	C	W1	-

Ratings:
- B2: A lot better
- B1: A little better
- C : Comparable
- W1: A little worse
- W2: A lot worse

Table 10. APPLICATION ELEMENT: Horizontal Windfield

Application: 1143/1243 Importance: M/M

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	C	C	C	C	C	C	C	C
CRSTER	C	-	C	C	C	C	C	C	C
MPSDM	C	C	-	C	C	C	C	C	C
MPTER	C	C	C	-	C	C	C	C	C
MULTIMAX	C	C	C	C	-	C	C	C	C
PLUME 5	C	C	C	C	C	-	C	C	C
SCESTER	C	C	C	C	C	C	-	C	C
TEM 8	C	C	C	C	C	C	C	-	C
3141/4141	C	C	C	C	C	C	C	C	-

Ratings: B2: A lot better

B1: A little better

C : Comparable

W1: A little worse

W2: A lot worse

Table 11. APPLICATION ELEMENT: Vertical Wind Field

Application: 1143/1243 Importance: L or I

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	C	C	C	C	C	C	C	C
CRSTER	C	-	C	C	C	C	C	C	C
MPSDM	C	C	-	C	C	C	C	C	C
MPTER	C	C	C	-	C	C	C	C	C
MULTIMAX	C	C	C	C	-	C	C	C	C
PLUME5	C	C	C	C	C	-	C	C	C
SCESTER	C	C	C	C	C	C	-	C	C
TEM 8	C	C	C	C	C	C	C	-	C
3141/4141	C	C	C	C	C	C	C	C	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Treatment of Horizontal and Vertical Dispersion:

The Pasquill-Gifford dispersion coefficients are used by each model except MPSDM. In MPSDM, the ASME dispersion coefficients are used in the Gaussian equation. TEM-8, 3141, and 4141 enhance the dispersion coefficients to correct concentrations to effective averaging times of one hour. Tabulated Pasquill-Gifford and ASME coefficients are based on data most of which are averaged over ten minutes.

Several models enhance dispersion coefficients for entrainment during vertical plume rise. COMPTER, MPSDM, PLUME5, 3141, and 4141 enhance σ_z. MPSDM, PLUME5, 3141, and 4141 enhance σ_y.

PLUME5 and SCSTER correct dispersion for wind shear effects.

Overall PLUME5 appears to be most flexible. MPSDM, MPTER, 3141/4141, and COMPTER are somewhat less desirable as noted in Tables 12 and 13.

Table 12. APPLICATION ELEMENT: Horizontal Dispersion

Application: 1143/1243 Importance: M/H

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	C	W1	W1	C	W2	C	C	W1
CRSTER	C	-	W1	W1	C	W2	C	C	W1
MPSDM	B1	B1	-	C	B1	W1	B1	B1	C
MPTER	B1	B1	C	-	B1	W1	B1	B1	C
MULTIMAX	C	C	W1	W1	-	W2	C	C	W1
PLUME5	B2	B2	B1	B1	B2	-	B2	B2	B1
SCESTER	C	C	W1	W1	C	W2	-	C	W1
TEM 8	C	C	W1	W1	C	W2	C	-	W1
3141/4141	B1	B1	C	C	B1	W1	B1	B1	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Table 13. APPLICATION ELEMENT: Vertical Dispersion

Application: 1143/1243 Importance: H/H

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	B1	W1	C	B1	W1	B1	B1	C
CRSTER	W1	-	W2	W1	C	W2	C	C	W1
MPSDM	B1	B2	-	B1	B2	W1	B2	B2	B1
MPTER	C	B1	W1	-	B1	W1	B1	B1	C
MULTIMAX	W1	C	W2	W1	-	W2	C	C	W1
PLUME5	B1	B2	B1	B1	B2	-	B2	B2	B1
SCESTER	W1	C	W2	W1	C	W2	-	C	W1
TEM 8	W1	C	W2	W1	C	W2	C	-	W1
3141/4141	C	B1	W1	C	B1	W1	B1	B1	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Chemistry and Reaction Rate Mechanisms:

Physical Removed Processes:

Most models are only suitable for long or short term transport of inert gases such as SO_2 or CO_2 or particulates of size less than 20 . The exception (Table 14) is PLUME5 which includes an option to consider exponential decay mechanisms and/or ozone limiting procedures.

MPTER, PLUME5, SCSTER, and TEM-8 include an exponential decay option with a prespecified half-life. This option is suitable to adjust for dry deposition

Tables 14 and 15 reflect these model improvements.

Background, Boundary, and Initial Conditions:

This element accounts for mechanisms to adjust for variations in mixing layer and terrain height. Some models account for mixed layer penetration, all but TEM-8 make some adjustment for receptor location and terrain variation. PLUME5 and SCSTER permit terrain impact under certain conditions. MPSDM and PLUME5 contain the most desirable combination of conditions (see Table 16).

Table 14. APPLICATION ELEMENT: Chemistry and Reaction Mechanisms

Application: 1143/1243 Importance: L or I

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	C	C	C	C	W1	C	C	C
CRSTER	C	-	C	C	C	W1	C	C	C
MPSDM	C	C	-	C	C	W1	C	C	C
MPTER	C	C	C	-	C	W1	C	C	C
MULTIMAX	C	C	C	C	-	W1	C	C	C
PLUME5	B1	B1	B1	B1	B1	-	C	C	C
SCESTER	C	C	C	C	C	W1	-	C	C
TEM 8	C	C	C	C	C	W1	C	-	C
3141/4141	C	C	C	C	C	W1	C	C	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Table 15. APPLICATION ELEMENT: Physical Removal Processes

Application: 1143/1243 Importance: L/L

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	C	C	W1	C	W1	W1	W1	C
CRSTER	C	-	C	W1	C	W1	W1	W1	C
MPSDM	C	C	-	W1	C	W1	W1	W1	C
MPTER	B1	B1	B1	-	B1	C	C	C	B1
MULTIMAX	C	C	C	W1	-	W1	W1	W1	C
PLUME5	B1	B1	B1	C	B1	-	C	C	B1
SCESTER	B1	B1	B1	C	B1	C	-	C	B1
TEM 8	B1	B1	B1	C	B1	C	C	-	B1
3141/4141	C	C	C	W1	C	W1	W1	W1	-

Ratings:
- B2: A lot better
- B1: A little better
- C : Comparable
- W1: A little worse
- W2: A lot worse

Table 16. APPLICATION ELEMENT: Background, Boundary, Initial Conditions

Application: 1143/1243 Importance M/M

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	B1	W1	C	C	W1	C	B1	C
CRSTER	W1	-	W2	C	W1	W1	W2	C	W1
MPSDM	B1	B2	-	B1	B1	C	B1	B2	B1
MPTER	C	C	W1	-	W1	W1	C	C	C
MULTIMAX	C	B1	W1	B1	-	W1	C	B1	C
PLUME5	B1	B1	C	B1	B1	-	B1	B1	B1
SCESTER	C	B2	W1	C	C	W1	-	B2	C
TEM 8	W1	C	W2	C	W1	W1	W2	-	W1
3141/4141	C	B1	W1	C	C	W1	C	B1	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Consideration of Temporal Correlation:

The highest degree of correlation exists when time varying input conditions are used (source strength, and fields, temperature profiles, etc.).

COMPTER, CRSTER, MPSDM, and MPTER permit running averages of hourly model results to calculate 3 hour and 24 hour averages. Table 17 reflects the value of these features in COMPTER, MPSDM, MPTER, and PLUME5.

Table 17. APPLICATION ELEMENT: Temporal Correlations

Application: 1143/1243 Importance: L/M

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	B1	C	C	B1	C	C	B1	B1
CRSTER	W1	-	W1	W1	C	W1	W1	B2	C
MPSDM	C	B1	-	C	B1	C	C	B1	B1
MPTER	C	B1	C	-	B1	C	C	B1	B1
MULTIMAX	W1	C	W1	W1	-	W1	W1	C	C
PLUME5	C	B1	C	C	B1	-	C	B1	B1
SCESTER	C	B1	C	C	B1	C	-	B1	B1
TEM 8	W1	W2	W1	W1	C	W1	W1	-	W2
3141/4141	W1	C	W1	W1	C	W1	W1	B2	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

3.2 Overall Evaluation

All of the elements can be considered together when a specific application is specified. There are two situations for which all models may be reasonably applied. These include application index cases:

1143: Inert primary pollutants released over long periods from multiple source locations. Pollutants will be transported over simple (flat or rolling rural) terrain to short range (<60 km) receptors.

1243: Inert primary pollutants released over short term periods from multiple source locations. Pollutants will be transported over simple (flat or rolling) terrain to short range (<60 km) receptors.

In such situations 3 elements are irrelevent. For Case 1143 one finds one element is of high importance, six are of medium importance, and two are of low importance. For Case 1243 three elements are of high importance, five elements are of medium importance, and one is of low importance. Specific weighting is indicated on each Table 6 to 17. By assigning values of 1 to 5 to ratings B2 through W2 and considering element importance Tables 18 and 19 have been prepared for Cases 1143 and 1243 respectively. The air quality models are listed below in preferred order, ie.:

	RATE
- PLUME5	1
- MPSDM	2
- MPTER	3
- COMPTER	4
- SCSTER	5
- 3141/4141	6 or 7
- MULTIMAX or TEM-8	8 or 9
- CRSTER	10

This represents the conclusion of a subjective "scientific" evaluation.

Table 18. APPLICATION ELEMENT: Total Comparison

Application: 1143

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	B2	W1	C	B1	W2	C+	B1	C+
CRSTER	W2	-	W2	W2	W1	W2	W2	-	W1
MPSDM	B1	B2	-	B1	B2	W1	B2	B2	B1
MPTER	C	B2	W1	-	B1	W1	B1	B2	B2
MULTIMAX	W1	B1	W2	W1	-	W2	C	C	C-
PLUME5	B2	B2	B1	B1	B2	-	B2	B2	B2
SCESTER	C-	B2	W2	W1	C	W2	-	B1	B1
TEM 8	W1	-	W2	W2	C	W2	W1	-	C
3141/4141	C-	B1	W1	W2	C+	W2	W1	C	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Table 19. APPLICATION ELEMENT: Total Comparison

Application: 1243

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	B2	W2	C-	B1	W2	C+	B1	C+
CRSTER	W2	-	W2	W2	W1	W2	W2	C-	W1
MPSDM	B2	B2	-	B1	B2	W2	B2	B2	B2
MPTER	C+	B2	W1	-	B2	W2	B1	B2	B2
MULTIMAX	W1	B1	W2	W2	-	W2	W1	C	W1
PLUME5	B2	B2	B2	B2	B2	-	B2	B2	B2
SCESTER	C-	B2	W2	W1	B1	W2	-	B1	C
TEM 8	W1	C+	W2	W2	C	W2	W1	-	C
3141/4141	C-	B1	W2	W2	B1	W2	C	C	-

Ratings:
B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

4.0 RESULTS OF STATISTICAL COMPARISONS

Section 2.3 discussed the background for the statistical evaluation. That evaluation resulted in the summary of results found in Appendix 2. These summary tables review results of comparisons requested in Table 1.

Data from the years 1975 and 1976 have been examined and a comparative assessment of the behavior of each air quality model is incorporated into Tables 20 through 28. The models perform according to the following ranking:

	$\overline{C_o} - \overline{C_p}$ (25)			$\overline{C_o - C_p}$			$\overline{C_{o_{max}}} - \overline{C_{p_{max}}}$			Overall
	1 hr	3 hr	24 hr	1 hr	3 hr	24 hr	1 hr	3 hr	24 hr	
COMPTER	3	2	2	1	1	1	2	3	1	1
CRSTER	2	1	1	2	2	2	2	1	1	1
MPSDM	2	2	2	2	2	2	3	3	1	2
MPTER	2	1	1	2	2	2	2	1	1	1
MULTIMAX	1	2	3	3	3	3	1	2	2	3
PLUME5	2	1	1	2	2	2	2	1	1	1
SCSTER	1	2	3	3	3	3	1	2	2	3
TEM-8	1	2	3	3	3	3	1	2	2	3
3141/4141	2	3	4	3	3	3	4	4	2	4

Table 4 & 5-1 (Reference 10)

Table 20. APPLICATION ELEMENT: $\overline{C_o} - \overline{C_p}$ (High 25)

1 hr. averaging time
1975 (1976)
All Stations

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	W1 (C)	B1 (W1)	W1 (C)	W2 (W1)	W1 (C)	W2 (W1)	W1 (W2)	C
CRSTER	B1 (C)	-	B1 (C)	C	W2 (W1)	C	W2 (W1)	W1 (W2)	C
MPSDM	W1 (B1)	W1 (C)	-	W1 (C)	W2 (C)	W1 (C)	W2 (C)	W1 (W2)	W1
MPTER	B1 (C)	C	B1 (C)	-	W2 (W1)	C	W2 (W1)	W1 (W2)	C
MULTIMAX	B2 (B1)	B2 (B1)	B2 (C)	B2 (B1)	-	B2 (B1)	C	B1 (W1)	B2 C
PLUME5	B1 (C)	C	B1 (C)	C	W2 (W1)	-	W2 (C)	W1 (W2)	C
SCESTER	B2 (B1)	B2 (B1)	B2 (C)	B2 (B1)	C	B2 (C)	-	B1 (W1)	B2
TEM 8	B1 (B2)	B1 (B2)	B1 (B2)	B1 (B2)	W1 (B1)	B1 (B2)	W1 (B1)	-	C (B2)
3141/4141	C	C	C	C	W2 (C)	C	W2	C (W2)	-

Ratings:
- B2: A lot better
- B1: A little better
- C : Comparable
- W1: A little worse
- W2: A lot worse

Table 4 & 5 - 1 (Reference 10)

Table 21. APPLICATION ELEMENT: $\overline{C_o} - \overline{C_p}$ (High 25)

3 hr. averaging time
1975 (1976)
All Stations

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	W1	C (W1)	W1	C	W1	C	W1 (C)	B1 (C)
CRSTER	B1	-	B1 (C)	C	B1 (C)	C	C	C (B1)	B2
MPSDM	C (B1)	W1 (C)	-	W1 (C)	C	W1 (C)	C	W1 (B1)	B1
MPTER	B1	C	B1 (C)	-	B1 (C)	C	C	C (B1)	B2
MULTIMAX	C	W1 (C)	C	W1 (C)	-	W1 (C)	C	W1 (C)	B1
PLUME5	B1	C	B1 (C)	C	B1 (C)	-	C	C (B1)	B2
SCESTER	C	C	C	C	C	C	-	C	B1
TEM 8	B1 (C)	C (W1)	B1 (W1)	C (W1)	B1 (C)	C (W1)	C	-	B2 C
3141/4141	W1 (C)	W2	W1	W2	W1	W2	W1	W2 (C)	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Table 4 & 5 - 1 (Reference 10)

Table 22. APPLICATION ELEMENT: $\overline{C_o} - \overline{C_p}$ (High 25)   24 hr. averaging time
1975 (1976)
All Stations

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	W1	C	W1	B1	W1	B1	B1	B2
CRSTER	B1	-	B1	C	B2	C	B2	B2	B2
MPSDM	C	W1	-	W1	B1	W1	B1	B1	B2
MPTER	B1	C	B1	-	B2	C	B2	B2	B2
MULTIMAX	W1	W2	W1	W2	-	W2	C	C	B1 (C)
PLUME5	B1	C	B1	C	B2	-	B2	B2	B2
SCESTER	W1	W2	W1	W2	C	W2	-	C	B1 (C)
TEM 8	W1	W2	W1	W2	C	W2	C	-	B1 (C)
3141/4141	W2	W2	W2	W2	W1 (C)	W2	W1 (C)	W1 (C)	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Table 6 & 7 - 1, 2 (Reference 10)

Table 23. APPLICATION ELEMENT: $\overline{(C_o - C_p)}$ Paired in time

1 hr. averaging time
1975 (1976)

1) Highest Concentrations
2) All Concentrations

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	B1	B1	B1	B2	B1	B2	B2	B2
CRSTER	W1	-	C	C	B1	C	B1	B1	B1
MPSDM	W1	C	-	C	B1	C	B1	B1	B1
MPTER	W1	C	C	-	B1	C	B1	B1	B1
MULTIMAX	W2	W1	W1	W1	-	W1	C	C	C
PLUME5	W1	C	C	C	B1	-	B1	B1	B1
SCESTER	W2	W1	W1	W1	C	W1	-	C	C
TEM 8	W2	W1	W1	W1	C	W1	C	-	C
3141/4141	W2	W1	W1	W1	C	W1	C	C	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Table 6 & 7 - 1,2 (Reference 10)

Table 24. APPLICATION ELEMENT: $\overline{C_o - C_p}$ Paired in Time 3 hr. averaging tir 1975 (1976)
1) Highest Concentrations
2) All Concentrations

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	B1	B1	B1	B2	B1	B2	B2	B2
CRSTER	W1	-	C	C	B1	C	B1	B1	B1
MPSDM	W1	C	-	C	B1	C	B1	B1	B1
MPTER	W1	C	C	-	B1	C	B1	B1	B1
MULTIMAX	W2	W1	W1	W1	-	W1	C	C	C
PLUME5	W1	C	C	C	B1	-	B1	B1	B1
SCESTER	W2	W1	W1	W1	C	W1	-	C	C
TEM 8	W2	W1	W1	W1	C	W1	C	-	C
3141/4141	W2	W1	W1	W1	C	W1	C	C	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Table 6 & 7 - 1,2 (Reference 10)

Table 25. APPLICATION ELEMENT: $\overline{C_o - C_p}$ Paired in Time 24 hr. averaging ti
1975 (1976)
1) Highest Concentrations
2) All Concentrations

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	B1	B1	B1	B2	B1	B2	B2	B2
CRSTER	W1	-	C	C	B1	C	B1	B1	B1
MPSDM	W1	C	-	C	B1	C	B1	B1	B1
MPTER	W1	C	C	-	B1	C	B1	B1	B1
MULTIMAX	W2	W1	W1	W1	-	W1	C	C	C
PLUME5	W1	C	C	C	B1	-	B1	B1	B1
SCESTER	W2	W1	W1	W1	C	W1	-	C	C
TEM 8	W2	W1	W1	W1	C	W1	C	-	C
3141/4141	W2	W1	W1	W1	C	W1	C	C	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Tables 8 & 9 (Reference 10)

Table 26. APPLICATION ELEMENT: $\overline{C_{o_{max}}} - \overline{C_{p_{max}}}$ 1 hr averaging time (1975) 1976

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	C	B1 (C)	C	W1	C	W1	W1	B1
CRSTER	C	-	B1 (C)	C	W1	C	W1	W1	B1
MPSDM	W1 (C)	W1 (C)	-	W1 (C)	W2 (W1)	W1 (C)	W2 (W1)	W2 (W1)	C (B1)
MPTER	C	C	B1 (C)	-	W1	C	W1	W1	B1
MULTIMAX	B1	B1	B2 (B1)	B1	-	B1	C	C	B2
PLUME5	C	C	B1 (C)	C	W1	-	W1	W1	B1
SCESTER	B1	B1	B2 (B1)	B1	C	B1	-	C	B2
TEM 8	B1	B1	B2 (B1)	B1	C	B1	C	-	B2
3141/4141	W1	W1	C (W1)	W1	W2	W1	W2	W2	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Tables 8 & 9 (Reference 10)

Table 27. APPLICATION ELEMENT: $\overline{C_{o_{max}}} - \overline{C_{p_{max}}}$ 3 hr averaging time 1975 (1976)

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	W1	B1 (W1)	W1	C (W1)	W1	C (W1)	C (W1)	B1 (C)
CRSTER	B1	-	B2 (C)	C	B1 (C)	C	B1 (C)	B1 (C)	B2 (B1)
MPSDM	W1 (B1)	W2 (C)	-	W2 (C)	W1 (C)	W2 (C)	W1 (C)	W1 (C)	C (B1)
MPTER	B1	C	B2 (C)	-	B1 (C)	C	B1 (C)	B1 (C)	B2 (C)
MULTIMAX	C (B1)	W1 (C)	B1 (C)	W1 (C)	-	W1 (C)	C	C	B1
PLUME5	B1	C	B2 (C)	C	B1 (C)	-	B1 (C)	B1 (C)	B2 (C)
SCESTER	C (W1)	W1 (C)	B1 (C)	W1 (C)	C	W1 (C)	-	C	B1
TEM 8	C (W1)	W1 (C)	B1 (C)	W1 (C)	C	W1 (C)	C	-	B1
3141/4141	W1 (C)	W2 (W1)	C (B1)	W2 (C)	W1	W2 (C)	W1	W1	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Tables 8 & 9 (Reference 10)

Table 28. APPLICATION ELEMENT: $\overline{C_{o_{max}}} - \overline{C_{p_{max}}}$ 24 hr averaging time 1975 (1976)

Study Model \ Ref. Model	COMPTER	CRSTER	MPSDM	MPTER	MULTIMAX	PLUME5	SCESTER	TEM 8	3141/4141
COMPTER	-	C	C	C	B1	C	B1	B1	B1
CRSTER	C	-	C	C	B1	C	B1	B1	B1
MPSDM	C	C	-	C	B1	C	B1	B1	B1
MPTER	C	C	C	-	B1	C	B1	B1	B1
MULTIMAX	W1	W1	W1	W1	-	W1	C	C	C
PLUME5	C	C	C	C	B1	-	B1	B1	B1
SCESTER	W1	W1	W1	W1	C	W1	-	C	C
TEM 8	W1	W1	W1	W1	C	W1	C	-	C
3141/4141	W1	W1	W1	W1	C	W1	C	C	-

Ratings: B2: A lot better
B1: A little better
C : Comparable
W1: A little worse
W2: A lot worse

Table 29. APPLICATION ELEMENT: Statistical Summary

Study Model \ Ref. Model	$\lvert C_o - C_p \rvert$ 1 hr	$\lvert C_o - C_p \rvert$ 3 hr	$\lvert C_o - C_p \rvert$ 24 hr	$\lvert C_o - C_p \rvert$ 1 hr	$\lvert C_o - C_p \rvert$ 3 hr	$\lvert C_o - C_p \rvert$ 24 hr	$\lvert C_{o_m} - C_{p_m} \rvert$ 1 hr	$\lvert C_{o_m} - C_{p_m} \rvert$ 3 hr	$\lvert C_{o_m} - C_{p_m} \rvert$ 24 hr
COMPTER	29	27.5	22	12	12	12	25.5	28	20
CRSTER	27.5	19.5	14	21	21	21	25.5	19	20
MPSDM	27	24.5	22	21	21	21	30	28	20
MPTER	27.5	19.5	14	21	21	21	25.5	19	20
MULTIMAX	16	25	31.5	30	30	30	16.5	23.5	29
PLUMES	27.5	19.5	14	21	21	21	25.5	19	20
SCESTER	15.5	23	31.5	30	30	30	16.5	24.5	29
TEM 8	15.5	23.5	31.5	30	30	30	16.5	24.5	29
3141/4141	27	34.5	31.5	30	30	30	34.5	30.5	29

Overall - COMPTER, CRSTER, MPTER, and PLUME5 did best (Also MPSDM)

1 hr. - COMPTER, MULTIMAX, SCESTER, and TEM 8 did best

24 hr. - COMPTER, CRSTER, MPTER, AND PLUME5 did best (also MPSDM)

Overall the models appear to operate in the preferred order:

	RATE
- COMPTER, CRSTER, MPTER, and PLUME5	1
- MPSDM	2
- MULTIMAX, SCSTER, and TEM-8	3
- 3141/4141	4

Model performance results noted in Section 5 of Londergan et. al. (1982) appear correct upon review. The following observations are pertinent.

- A consistent tendency toward underprediction (positive average differences) is evident in results for all averaging periods for all models except 3141 and 4141.
- Differences decrease and correlations increase as one increases averaging periods.
- For stability classes A and B differences generally indicate overprediction, whereas for stable classes E and F the differences indicate underprediction.
- Results from 1975 and 1976 are not always consistent.
- The volume of statistics is excessive.
- Many of the statistics are as noted "relatively unimportant, repetitious, and redundant."

Finally I would have liked to also see comparisons in the manner of the earlier Londergan et. al. (1980) report.[14] Differences can sometimes also be deceptive. Both absolute and relative measures are valuable.

5.0 RESPONSE TO AMS QUESTIONS

Peer review panel leaders provided the test of "Questions to be Addressed by Reviewers of Air Quality Models" contained in Appendix 1. Questions on individual models (Numbers 1 to 13) have been considered during the preparation of Summary Tables 2 and 3 and the Workbook exercise discussed in Chapter 3.0. "Questions in All Models Within a Category" are considered during the model ranking procedures imposed in Chapter 3.0 and 4.0. Rather than speak further to individual model characteristics I prefer to mention several improvements which can be easily implemented but are missing for all air-quality models reviewed.

Adjustments for Air Pollution Aerodynamics:

Effluent plumes released near the ground or from short stacks on large buildings may be strongly perturbed by building aerodynamics effects. Concentrations may initially increase because gases are deflected downward. On the other hand surface concentrations in other areas may decrease significantly due to accelerated dispersion associated with higher mixing rates downwind of structures. The current set of models do not consider this feature of atmospheric transport.

Review articles on this subject have been proposed by Hosker (1981) and Meroney (1982).[22,23] Fackrell (1981) has recently reviewed the efficiency of a variety of proposed models. (He notes no one model is particularly outstanding relative to the others.)[26] Nonetheless algorithms are simple and easy to implement. Other recent measurements by Li and Meroney (1982) illuminate the effects of near building turbulence on downwind peak to mean concentration ratios.[24] Wilson, Britter, and Meroney (1982) discuss recent results in plumes impacting buildings, terrain, and algorithms to evaluate stack height to building height effects.[25]

Improvements in the Gaussian Plume Model:

The Gaussian plume model will probably continue to dominate as a major tool in air quality analysis. It seems unfortunate, however, that known improvements in the prediction of standard deviations, σ_y and σ_z, take so long to be incorporated in working models. There is now ample evience that different variations of σ_y and σ_z with distance and stability should be used for:

a) ground level versus elevated releases, and

b) rural versus urban versus complex terrain dispersion.

In addition recent advances suggest boundary layer parameters of U_*, W_*, Z_i, Z_o and L may be used through similarity theory to improve estimates of σ_y and σ_z. (Rather than provide a long list of references I refer the reader to Appendix J and Section 3.3.2 of Egan et. al. (1981).)[12]

6.0 CONCLUSIONS AND RECOMMENDATIONS

This review exercise has been very illuminating. I find that a great deal of effort and ingenuity has been directed toward creating effective air quality models suitable for regulatory and engineering decisions. Nonetheless it is somewhat discouraging to find such a small improvement over the years in confirmable reliability. Sometimes the entire decision exercise seems more like a fantasy game -- an exercise in "Dungeons and Dragons" where the meteorologist has magic powers and the air quality model is some magic spell with a success based on a roll of the dice.

Perhaps it is time to readjust our expectations. Certainly it is time to press for realistic regulatory laws which do not legislate conditions which extreme value statistics and the physics of atmospheric transport suggest are unrealistic. Today's dilemma of meeting air quality standards by creating air quality models of increasing complexity but unconvincing reliability is a monster of our own choosing. In essence I object to the continued emphasis on an "adversary" approach to meeting our regulatory problems.* This approach has resulted in decisions being made and scientific program being guided by lawyers with limited technical qualifications. Dialogue between the effluent producer and regulating scientific staff is disccouraged by the entire process.

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* As a side note it is interesting to observe 35,000 lawyers graduated in the USA last year compared to less than 5,000 in Japan. Per 10,000 people the USA currently has 20 lawyers, 40 accountants, and 70 scientist and engineers, whereas Japan has 1 lawyer, 3 accountants and 400 scientists and engineers. Worse yet their zero-sum activities create a great deal of static that further handicap the relatively few producers.

As a final set of recommendations I would propose the following:

- It is time to include non-Gaussian models in any air quality intercomparison process.
- The total statistics examined in this exercise is monolithic. It is time to eliminate those calculations which are uninformative, redundant, or replicative.
- Any future User's Manual must include a clear statement of assumptions, limitations, and accuracy. Validation data should always include a sensitivity study to the effects of different options and runs against a set of prespecified scenarios to be specified by EPA.

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APPENDIX 1

Questions to be Addressed by

Reviewers of Air Quality Models

Questions on Individual Models:

1. For the applications intended for this category of models, does the model address all the source/receptor relationships that are germane?

2. To what degree are the underlying assumptions valid for a typical application?

3. Are the assumptions correctly formulated in the model?

4. Does the model use techniques that are currently state-of-the-art?

5. Are there technically better or more theoretically sound techniques?

6. Does the model make the best use of typically available data bases?

7. Are there obvious technical improvements required in the model?

8. Is the usefulness of the model consistent with the resources required to operate it?

9. What are the inherent attributes and limitations of the model?

10. Is the statistical performance of the model in terms of bias, noise, variability and correlation generally acceptable or within the state-of-the-art?

11. For typical uses, can an objective statement be made about uncertainty associated with the model estimates?

12. What are the attributes and limitations of the model's performance?

13. Are there specific aspects on the application of these models in which they may produce misleading results, i.e., some models may predict fairly well at close distances but become unreliable at longer distances?

Questions on All Models Within a Category (Based on Theoretical and Performance Characteristics):

1. What are the general attributes and limitations of models in this category?

2. How do models within this category compare to one another?

3. Is a specific model or models clearly superior to the other models?

4. Can these models be ranked individually, or in the groups? If so, how should they be ranked?

APPENDIX 2

(SUMMARY STATISTICAL TABLES FROM LONDERGAN ET. AL. (1982), TABLES 4a-1 THROUGH 9c, pp 42-62)

TABLE 4a-1. DIFFERENCE OF OBSERVED AND PREDICTED AVERAGES OF THE 25 HIGHEST SO_2 CONCENTRATION VALUES (UNPAIRED IN TIME OR LOCATION) CLIFTY CREEK (1975) AVERAGING TIME: 1 HOUR

Data Sets	Average Observed Value $\bar{C}_o$ ($\mu g/m^3$)	Difference of Averages ($\bar{C}_o$ - $\bar{C}_p$) For Each Model ($\mu g/m^3$) MPTER	MPSDM	COMPTER	SCSTER
1. All stations/all events (A - 4a)	790.8	-286.9 (-403.1, -170.7)	-423.6 (-643.5, -203.7)	-339.6 (-454.8, -224.4)	-69.3 (-185.8, 47.2)
2. By station/all events (A - 4b)					
Station 1	508.9	-86.1 (-146.5, -25.7)	-7.1 (-75.7, 61.5)	-172.1 (-228.3, -115.9)	26.8 (-38.4, 92.0)
Station 2	535.0	-310.0 (-397.5, -222.5)	-200.2 (-309.7, -90.7)	-333.6 (-418.0, -249.2)	-141.8 (-214.2, -69.4)
Station 3	580.0	-355.0 (-480.2, -229.8)	-411.0 (-597.5, -224.5)	-428.8 (-554.8, -302.8)	-140.1 (-271.1, -9.1)
Station 4	550.0	-117.8 (-193.4, -42.2)	-38.0 (-128.6, 52.6)	-141.8 (-214.8, -68.8)	22.7 (-40.5, 85.9)
Station 5	225.9	-89.4 (-251.5, 72.7)	-337.7 (-566.1, -109.3)	-266.3 (-414.2, -118.4)	23.0 (-101.0, 147.0)
Station 6	512.6	60.8 (-56.2, 177.8)	44.0 (-67.9, 155.9)	24.6 (-90.7, 139.9)	62.2 (-54.8, 179.2)
3. By meteorological condition (A - 5)					
a. Wind Speed					
< 2.5 m/sec	653.5	-210.2 (-303.4, -117.0)	-517.1 (-737.5, -296.7)	-268.5 (-359.4, -177.6)	-95.8 (-190.7, -0.9)
2.5 to 5 m/sec	652.0	-369.3 (-492.2, -246.4)	-118.0 (-232.6, -3.4)	-420.6 (-543.3, -297.9)	-111.9 (-230.1, 6.3)
> 5 m/sec	489.9	-68.0 (-130.9, -5.1)	167.0 (111.8, 222.2)	-129.5 (-189.2, -69.8)	259.1 (200.6, 317.6)
b. Stability Group					
Class A & B	481.3	-481.7 (-574.7, -388.7)	-552.4 (-767.9, -336.9)	-522.1 (-616.0, -428.2)	-358.0 (-443.9, -272.1)
Class C	678.9	-247.9 (-367.0, -128.8)	-335.8 (-500.0, -171.6)	-311.0 (-428.8, -193.2)	20.4 (-85.8, 126.6)
Class D	586.6	28.1 (-19.0, 75.2)	243.9 (209.1, 278.7)	-32.8 (-75.4, 9.8)	350.5 (312.0, 389.0)
Class E & F	398.0	56.2 (-49.2, 161.6)	361.8 (257.8, 465.8)	-207.9 (-315.9, -99.9)	325.7 (223.2, 428.2)

TABLE 4a-2. DIFFERENCE OF OBSERVED AND PREDICTED AVERAGES OF THE 25 HIGHEST SO_2 CONCENTRATION VALUES (UNPAIRED IN TIME OR LOCATION) CLIFTY CREEK (1975) AVERAGING TIME: 1 HOUR

Data Sets	Average Observed Value $\bar{C}_o$ ($\mu g/m^3$)	Difference of Averages ($\bar{C}_o$ - $\bar{C}_p$) For Each Model ($\mu g/m^3$)			
		3141	4141	TEM-8A	MULTIMAX
1. All stations/all events (A - 4a)	790.8	233.8 (131.2, 336.4)	233.8 (131.2, 336.4)	-160.8 (-309.8, -11.8)	-48.9 (-167.8, 70.0)
2. By station/all events (A - 4b)					
Station 1	508.9	190.3 (145.8, 234.8)	109.3 (145.8, 234.8)	18.2 (-53.1, 89.5)	32.8 (-33.8, 99.4)
Station 2	535.0	107.6 (51.4, 163.8)	107.6 (51.4, 163.8)	1.5 (-89.5, 92.5)	-110.3 (-187.7, -32.9)
Station 3	580.0	112.0 (-2.6, 226.6)	112.0 (-2.6, 226.6)	-140.5 (-344.6, 63.6)	-110.3 (-243.8, 23.2)
Station 4	550.0	161.9 (100.8, 223.0)	161.9 (100.8, 223.0)	-82.9 (-157.4, -8.4)	43.5 (-22.7, 109.7)
Station 5	225.9	-14.1 (-89.8, 61.6)	-14.1 (-89.8, 61.6)	-22.3 (-95.6, 51.0)	30.3 (-86.2, 146.8)
Station 6	512.6	206.6 (107.0, 306.2)	206.6 (107.0, 306.2)	121.0 (3.3, 238.7)	65.0 (-51.4, 181.4)
3. By meteorological condition (A - 5)					
a. Wind Speed					
<2.5 m/sec	653.5	138.5 (54.7, 222.3)	138.5 (54.7, 222.3)	-133.4 (-223.1, -43.7)	-82.5 (-179.9, 14.9)
2.5 to 5 m/sec	652.0	184.7 (82.9, 286.5)	184.7 (82.9, 286.5)	-42.2 (-202.8, 118.4)	-77.1 (-196.8, 42.6)
>5 m/sec	489.9	308.5 (251.4, 365.6)	308.5 (251.4, 365.6)	275.0 (121.2, 428.8)	218.0 (162.1, 273.9)
b. Stability Group					
Class A & B	481.3	-60.6 (-121.0, -0.2)	-60.6 (-121.0, -0.2)	-181.5 (-274.3, -88.7)	-337.8 (-426.1, -249.5)
Class C	678.9	251.2 (147.3, 355.1)	251.2 (147.3, 355.1)	-192.9 (-355.4, -30.4)	54.2 (-52.3, 160.7)
Class D	586.6	415.4 (377.0, 453.8)	415.4 (377.0, 435.8)	375.2 (311.2, 439.2)	313.0 (276.2, 349.8)
Class E & F	398.0	336.9 (234.8, 439.0)	246.6 (144.2, 349.0)	389.3 (287.3, 491.4)	170.3 (66.9, 273.7)

TABLE 4b-1. DIFFERENCE OF OBSERVED AND PREDICTED AVERAGES OF THE 25 HIGHEST SO_2 CONCENTRATION VALUES (UNPAIRED IN TIME OR LOCATION) CLIFTY CREEK (1975) AVERAGING TIME: 3 HOUR

Data Sets	Average Observed Value $\bar{C}_o$ ($\mu g/m^3$)	Difference of Averages ($\bar{C}_o - \bar{C}_p$) For Each Model ($\mu g/m^3$) MPTER	MPSDM	COMPTER	SCSTER
1. All stations/all events (A - 4a)	476.3	-43.7 (-99.5, 12.1)	-83.3 (-191.3, 24.7)	-95.6 (-153.0, -38.2)	62.9 (6.0, 119.8)
2. By station/all events (A - 4b)					
Station 1	322.6	12.2 (-27.4, 51.8)	78.8 (41.8, 115.8)	-27.1 (-69.7, 15.5)	119.0 (79.3, 158.7)
Station 2	286.6	-106.6 (-174.1, -39.1)	-14.3 (-63.3, 34.7)	-141.6 (-203.4, -79.8)	-12.2 (-77.7, 53.3)
Station 3	315.9	-87.5 (-159.3, -15.7)	-156.0 (-244.0, -68.0)	-161.6 (-237.8, -85.4)	20.5 (-50.7, 91.7)
Station 4	313.3	-17.7 (-70.7, 35.3)	51.7 (3.4, 100.0)	-66.0 (-115.8, -16.2)	81.5 (30.3, 132.7)
Station 5	125.6	25.7 (-40.2, 91.6)	-108.7 (-233.4, 16.0)	-49.0 (-111.6, 13.6)	57.8 (6.9, 108.7)
Station 6	257.9	94.7 (33.2, 156.2)	70.9 (13.7, 128.1)	75.2 (14.3, 136.1)	95.3 (33.8, 156.8)
3. By meteorological condition (A - 5)					
a. Wind Speed					
<2.5 m/sec	316.2	-28.5 (-97.4, 40.4)	-181.7 (-300.8, -62.6)	-80.2 (-147.8, -12.6)	33.2 (-34.4, 100.8)
2.5 to 5 m/sec	410.5	-63.6 (-121.3, -5.9)	12.6 (-40.9, 66.1)	-114.2 (-173.6, -54.8)	41.1 (-11.2, 93.4)
>5 m/sec	308.1	-8.8 (-65.0, 47.4)	113.9 (62.8, 165.1)	-65.1 (-121.2, -9.0)	179.3 (126.6, 232.0)
b. Stability Group					
Class A & B	228.3	-183.4 (-255.0, -111.8)	-134.9 (-198.1, -71.7)	-209.4 (-282.1, -136.7)	-132.9 (-203.0, -62.8)
Class C	359.0	-82.1 (-147.3, -16.9)	-152.2 (-271.8, -32.6)	-128.4 (-197.8, -59.0)	37.2 (-20.8, 95.2)
Class D	385.5	37.2 (-3.6, 78.0)	131.8 (89.2, 174.4)	-22.4 (-63.1, 18.3)	197.7 (158.9, 236.5)
Class E & F	196.9	44.7 (-10.6, 100.0)	164.1 (115.6, 212.6)	-66.6 (-128.8, -4.4)	164.6 (116.3, 212.9)

TABLE 4b-2. DIFFERENCE OF OBSERVED AND PREDICTED AVERAGES OF THE 25 HIGHEST SO_2 CONCENTRATION VALUES (UNPAIRED IN TIME OR LOCATION) CLIFTY CREEK (1975) AVERAGING TIME: 3 HOUR

Data Sets	Average Observed Value $\bar{C}_o$ ($\mu g/m^3$)	Difference of Averages ($\bar{C}_o$ - $\bar{C}_p$) For Each Model ($\mu g/m^3$)			
		3141	4141	TEM-8A	MULTIMAX
1. All stations/all events (A - 4a)	476.3	179.4 (133.5, 225.3)	179.4 (133.5, 225.3)	39.6 (-41.4, 120.6)	74.6 (17.6, 131.6)
2. By station/all events (A - 4b)					
Station 1	322.6	162.0 (127.7, 196.3)	159.5 (125.6, 193.4)	91.0 (43.2, 138.8)	113.5 (74.3, 152.7)
Station 2	286.6	60.1 (13.9, 106.3)	60.1 (13.9, 106.3)	26.4 (-20.7, 73.5)	-0.6 (-65.6, 64.4)
Station 3	315.9	91.9 (25.9, 157.9)	91.9 (25.9, 157.9)	-20.4 (-125.3, 84.5)	30.7 (-40.4, 101.8)
Station 4	313.3	119.4 (73.7, 165.1)	118.8 (73.1, 164.5)	20.0 (-25.9, 65.9)	86.9 (36.8, 137.0)
Station 5	125.6	31.7 (-7.7, 71.1)	31.7 (-7.7, 71.1)	27.1 (-10.7, 64.9)	60.3 (11.2, 109.4)
Station 6	257.9	120.3 (65.3, 175.3)	120.3 (65.3, 175.3)	61.6 (6.2, 117.0)	96.0 (34.9, 157.1)
3. By meteorological condition (A - 5)					
a. Wind Speed					
<2.5 m/sec	316.2	92.6 (39.3, 145.9)	92.0 (38.8, 145.2)	9.7 (-41.9, 61.3)	40.8 (-26.3, 107.9)
2.5 to 5 m/sec	410.5	144.7 (99.5, 189.9)	144.7 (99.5, 189.9)	26.0 (-59.2, 111.2)	55.0 (2.4, 107.6)
>5 m/sec	308.1	195.4 (144.8, 246.0)	195.4 (144.8, 246.0)	214.1 (147.2, 281.0)	154.1 (102.0, 206.2)
b. Stability Group					
Class A & B	228.3	-37.4 (-96.7, 21.9)	-37.4 (-96.7, 21.9)	-72.9 (-141.1, -4.7)	-126.1 (-195.7, -56.5)
Class C	359.0	112.6 (61.3, 163.9)	112.6 (61.3, 163.9)	-27.5 (-114.0, 59.0)	52.9 (-4.6, 110.4)
Class D	385.5	251.2 (214.0, 288.4)	250.6 (213.3, 287.9)	214.4 (167.8, 261.0)	193.5 (155.1, 231.9)
Class E & F	196.9	166.1 (118.3, 213.9)	118.8 (70.3, 167.3)	193.5 (145.9, 241.1)	96.9 (46.4, 147.4)

TABLE 4c DIFFERENCE OF OBSERVED AND PREDICTED AVERAGES OF THE 25 HIGHEST SO_2 CONCENTRATION VALUES (UNPAIRED IN TIME OR LOCATION) CLIFTY CREEK (1975) AVERAGING TIME: 24 HOUR

Data Sets	Average Observed Value $\bar{C}_o$ ($\mu g/m^3$)	Difference of Averages ($\bar{C}_o - \bar{C}_p$) For Each Model ($\mu g/m^3$)							
		MPTER	MPSDM	CRSTER	SCSTER	3141	4141	TEM-8A	MULTIMAX
1. All stations/all events (A - 4a)	126.7	8.3 (±16.9)	18.0 (±18.6)	-20.3 (±20.2)	54.1 (±14.7)	63.6 (±14.3)	62.7 (±14.3)	46.5 (±15.2)	52.1 (±14.3)
2. By station/all events (A - 4b)									
Station 1	97.4	35.6 (±17.6)	49.1 (±15.1)	20.5 (±19.4)	62.7 (±14.4)	62.0 (±14.4)	59.0 (±14.3)	52.9 (±15.1)	59.2 (±14.4)
Station 2	65.4	-2.6 (±17.6)	8.9 (±15.0)	-15.8 (±17.7)	19.6 (±14.9)	25.5 (±13.5)	25.4 (±13.5)	19.7 (±12.9)	19.3 (±14.7)
Station 3	78.1	+3.0 (±19.9)	-9.3 (±20.9)	-27.3 (±22.0)	28.4 (±18.1)	34.5 (±17.3)	34.5 (±17.2)	20.9 (±19.3)	29.4 (±17.8)
Station 4	64.5	5.7 (±15.4)	24.9 (±11.4)	-15.9 (±20.2)	39.3 (±8.9)	39.4 (±8.4)	37.9 (±8.5)	27.5 (±10.1)	35.1 (±9.6)
Station 5	34.9	19.1 (±11.2)	1.5 (±17.1)	4.5 (±12.9)	24.6 (±8.4)	20.6 (±7.0)	20.6 (±7.0)	18.5 (±7.5)	24.8 (±8.2)
Station 6	57.5	29.1 (±14.7)	25.3(±13.8)	25.9 (±14.8)	29.3 (±14.7)	31.4 (±13.7)	31.5 (±13.7)	21.0 (±13.1)	29.4 (±14.6)

TABLE 5a-1. DIFFERENCE OF OBSERVED AND PREDICTED AVERAGES OF THE 25 HIGHEST SO_2 CONCENTRATION VALUES (UNPAIRED IN TIME OR LOCATION) CLIFTY CREEK (1976) AVERAGING TIME: 1 HOUR

Data Sets	Average Observed Value $\bar{C}_O$ ($\mu g/m^3$)	Difference of Averages ($\bar{C}_O$ - $\bar{C}_P$) For Each Model ($\mu g/m^3$)			
		MPTER	MPSDM	COMPTER	SCSTER
1. All stations/all events (A - 4a)	771.8	-313.0 (-369.3, -256.7)	-233.2 (-326.2, -140.2)	-374.9 (-427.8, -322.0)	-135.1 (-205.2, -65.0)
2. By station/all events (A - 4b)					
Station 1	581.7	18.7 (-41.6, 79.0)	23.1 (-84.6, 130.8)	-81.7 (-147.8, -15.6)	121.6 (67.1, 176.1)
Station 2	658.9	-123.0 (-201.0, -45.0)	12.4 (-57.9, 82.7)	-169.8 (-248.0, -91.6)	25.5 (-57.4, 108.4)
Station 3	450.2	-578.5 (-643.0, -514.0)	-410.7 (-507.2, -314.2)	-665.8 (-723.0, -608.6)	-341.6 (-414.7, -268.5)
Station 4	546.7	-143.6 (-211.8, -75.4)	-82.2 (-167.0, 2.6)	-161.9 (-227.0, -96.8)	-29.2 (-92.6, 34.2)
Station 5	321.3	28.1 (-124.5, 180.7)	-287.6 (-423.5, -151.7)	-201.9 (-352.4, -51.4)	133.0 (-6.6, 272.6)
Station 6	496.8	-35.7 (-113.9, 42.5)	-7.5 (-70.1, 55.1)	-60.6 (-133.1, 11.9)	-34.0 (-112.4, 44.4)
3. By meteorological condition (A - 5)					
a. Wind Speed					
< 2.5 m/sec	669.0	-284.5 (-365.9, -203.1)	-331.7 (-435.3, -228.1)	-353.4 (-428.2, -278.6)	-157.6 (-246.4, -68.8)
2.5 to 5 m/sec	667.5	-284.8 (-350.3, -219.3)	-24.4 (-79.7, 30.9)	-379.6 (-445.6, -313.6)	-61.9 (-134.3, 10.5)
> 5 m/sec	458.5	-141.9 (-237.5, -46.3)	137.6 (86.3, 188.9)	-182.6 (-273.0, -92.2)	140.4 (55.8, 225.0)
b. Stability Group					
Class A & B	541.4	-462.0 (-548.2, -375.8)	-329.3 (-426.9, -231.7)	-511.6 (-593.0, -430.2)	-352.6 (-439.1, -266.1)
Class C	631.4	-308.0 (-381.7, -234.3)	-261.5 (-360.4, -162.6)	-405.0 (-480.9, -329.1)	-37.0 (-102.9, 28.9)
Class D	672.4	154.9 (113.9, 195.9)	306.9 (251.1, 362.7)	103.2 (63.0, 143.4)	422.2 (382.0, 462.4)
Class E & F	343.5	-28.4 (-80.9, 24.1)	323.6 (281.6, 365.6)	-296.6 (-353.1, -240.1)	259.7 (219.3, 300.1)

TABLE 5a-2. DIFFERENCE OF OBSERVED AND PREDICTED AVERAGES OF THE 25 HIGHEST SO_2 CONCENTRATION VALUES (UNPAIRED IN TIME OR LOCATION) CLIFTY CREEK (1976) AVERAGING TIME: 1 HOUR

Data Sets	Average Observed Value $\bar{C}_O$ ($\mu g/m^3$)	Difference of Averages ($\bar{C}_O$ - $\bar{C}_P$) For Each Model ($\mu g/m^3$)			
		3141	4141	TEM-8A	MULTIMAX
1. All stations/all events (A - 4a)	771.8	206.2 (152.1, 260.3)	206.2 (152.1, 260.3)	38.9 (-46.0, 123.8)	-119.8 (-193.4, -46.2)
2. By station/all events (A - 4b)					
Station 1	581.7	282.1 (237.4, 326.8)	282.1 (237.4, 326.8)	197.7 (123.6, 271.8)	134.2 (79.6, 188.8)
Station 2	658.9	242.0 (178.7, 305.3)	242.0 (178.7, 305.3)	302.6 (224.2, 381.0)	72.9 (-15.1, 160.9)
Station 3	450.2	-75.8 (-133.1, -18.5)	-75.8 (-133.1, -18.5)	6.5 (-95.9, 108.9)	-316.9 (-393.4, -240.4)
Station 4	546.7	142.9 (97.1, 188.7)	142.9 (97.1, 188.7)	36.1 (-39.1, 111.3)	-14.0 (-76.1, 48.1)
Station 5	321.3	125.3 (31.6, 219.0)	125.3 (31.6, 219.0)	76.0 (-14.1, 166.1)	132.4 (-4.4, 269.2)
Station 6	496.8	147.6 (101.5, 193.7)	147.6 (101.5, 193.7)	62.5 (-27.1, 152.1)	-27.2 (-110.1, 55.7)
3. By meteorological condition (A - 5)					
a. Wind Speed					
<2.5 m/sec	669.0	146.1 (74.1, 218.1)	146.1 (74.1, 218.1)	-42.6 (-138.7, 53.5)	-154.0 (-247.3, -60.7)
2.5 to 5 m/sec	667.5	185.8 (136.7, 234.9)	185.8 (136.7, 234.9)	282.1 (227.7, 336.5)	-22.1 (-93.2, 49.0)
>5 m/sec	458.5	259.4 (194.6, 324.2)	259.4 (194.6, 324.2)	306.3 (223.0, 389.6)	136.6 (62.8, 210.4)
b. Stability Group					
Class A & B	541.4	-17.6 (-88.7, 53.5)	-17.6 (-88.7, 53.5)	-18.7 (-115.4, 78.0)	-348.6 (-434.8, -262.4)
Class C	631.4	191.1 (128.8, 253.4)	191.1 (128.8, 253.4)	1.2 (-96.2, 98.6)	16.3 (-47.3, 79.9)
Class D	672.4	522.1 (483.3, 560.9)	522.1 (483.3, 560.9)	454.4 (393.6, 515.2)	399.7 (358.7, 440.7)
Class E & F	343.5	277.4 (238.3, 316.5)	184.6 (144.8, 224.4)	281.1 (223.6, 338.6)	96.3 (52.8, 139.8)

TABLE 5b-1. DIFFERENCE OF OBSERVED AND PREDICTED AVERAGES OF THE 25 HIGHEST SO_2 CONCENTRATION VALUES (UNPAIRED IN TIME OR LOCATION) CLIFTY CREEK (1976) AVERAGING TIME: 3 HOUR

Data Sets	Average Observed Value $\bar{C}_o$ (μg/m³)	Difference of Averages ($\bar{C}_o - \bar{C}_p$) For Each Model (μg/m³)			
		HPTER	MPSDM	COMPTER	SCSTER
1. All stations/all events (A - 4a)	480.9	-54.2 (-105.4, -3.0)	-45.4 (-103.6, 12.8)	-127.0 (-184.2, -69.8)	66.7 (22.3, 111.1)
2. By station/all events (A - 4b)					
Station 1	372.7	49.5 (2.4, 96.6)	113.1 (71.9, 154.3)	-6.6 (-58.4, 45.2)	154.4 (113.1, 195.7)
Station 2	373.6	56.1 (1.5, 110.7)	97.3 (47.0, 147.6)	14.1 (-39.1, 67.3)	123.0 (70.8, 175.2)
Station 3	252.8	-191.5 (-261.9, -121.1)	-209.8 (-283.0, -136.6)	-279.5 (-352.1, -206.9)	-65.9 (-124.1, -7.7)
Station 4	360.2	24.0 (-32.0, 80.0)	49.4 (-15.0, 113.8)	-9.6 (-64.1, 44.9)	109.2 (58.0, 160.4)
Station 5	177.1	62.5 (-10.2, 135.2)	-55.8 (-119.0, 7.4)	-36.3 (-109.2, 36.6)	104.5 (42.1, 166.9)
Station 6	287.8	78.0 (29.1, 126.9)	90.0 (56.2, 123.8)	65.1 (16.8, 113.4)	78.7 (29.9, 127.5)
3. By meteorological condition (A - 5)					
a. Wind Speed					
<2.5 m/sec	338.6	-38.5 (-87.9, 10.9)	-120.3 (-182.8, -57.8)	-87.6 (-136.8, -38.4)	29.2 (-11.5, 69.9)
2.5 to 5 m/sec	445.5	-61.6 (-120.5, -2.7)	25.6 (-29.8, 81.0)	-130.1 (-196.6, -63.6)	46.7 (-1.8, 95.2)
>5 m/sec	316.0	6.0 (-46.0, 58.0)	129.4 (84.4, 174.4)	-42.6 (-97.7, 12.5)	156.0 (109.3, 202.7)
b. Stability Group					
Class A & B	263.8	-163.0 (-225.0, -101.0)	-165.7 (-238.7, -92.7)	-192.5 (-258.4, -126.6)	-103.3 (-155.8, -50.8)
Class C	364.3	-89.4 (-151.1, -27.7)	-73.1 (-128.5, -17.7)	-150.9 (-219.4, -82.4)	22.5 (-26.0, 71.0)
Class D	443.1	107.1 (69.0, 145.2)	187.9 (153.9, 221.9)	42.6 (2.1, 83.1)	236.1 (203.1, 269.1)
Class E & F	217.9	47.1 (-4.8, 99.0)	185.8 (149.0, 222.6)	-71.9 (-131.3, -12.5)	182.8 (146.8, 218.8)

TABLE 5b-2. DIFFERENCE OF OBSERVED AND PREDICTED AVERAGES OF THE 25 HIGHEST SO_2 CONCENTRATION VALUES (UNPAIRED IN TIME OR LOCATION) CLIFTY CREEK (1976) AVERAGING TIME: 3 HOUR

Data Sets	Average Observed Value $\bar{C}_o$ ($\mu g/m^3$)	Difference of Averages ($\bar{C}_o - \bar{C}_p$) For Each Model ($\mu g/m^3$)			
		3141	4141	TEM-8A	MULTIMAX
1. All stations/all events (A - 4a)	400.9	190.3 (154.7, 225.9)	190.3 (154.7, 225.9)	147.4 (93.6, 201.2)	86.2 (42.0, 130.4)
2. By station/all events (A - 4b)					
Station 1	372.7	209.0 (175.1, 242.9)	205.8 (172.0, 239.6)	180.6 (141.7, 219.5)	147.1 (106.2, 188.0)
Station 2	373.6	179.4 (136.1, 222.7)	179.4 (136.1, 222.7)	186.8 (141.0, 232.6)	143.6 (91.6, 195.6)
Station 3	252.8	12.5 (-31.0, 56.0)	12.5 (-31.0, 56.0)	11.8 (-49.9, 73.5)	-53.0 (-109.3, 3.3)
Station 4	360.2	156.6 (110.8, 202.4)	156.6 (110.8, 202.4)	122.6 (69.8, 175.4)	119.8 (72.3, 167.3)
Station 5	177.1	96.9 (47.9, 145.9)	96.9 (47.9, 145.9)	78.4 (35.9, 120.9)	104.8 (43.8, 165.8)
Station 6	287.8	130.1 (96.6, 163.6)	130.1 (96.6, 163.6)	93.5 (58.8, 128.2)	81.6 (31.7, 131.5)
3. By meteorological condition (A - 5)					
a. Wind Speed					
<2.5 m/sec	338.6	111.3 (74.3, 148.3)	111.3 (74.3, 148.3)	36.4 (-19.2, 92.0)	40.0 (-0.3, 80.3)
2.5 to 5 m/sec	445.5	170.8 (132.3, 209.3)	170.8 (132.3, 209.3)	202.2 (160.4, 244.0)	65.2 (17.6, 112.8)
>5 m/sec	316.0	191.8 (146.4, 237.2)	191.8 (146.4, 237.2)	231.6 (185.3, 277.9)	147.0 (100.8, 193.2)
b. Stability Group					
Class A & B	263.8	9.3 (-33.9, 52.5)	9.3 (-33.9, 52.5)	-4.9 (-65.7, 55.9)	-93.5 (-144.3, -42.7)
Class C	364.3	113.1 (71.8, 154.4)	113.1 (71.8, 154.4)	108.5 (60.8, 156.2)	44.9 (-2.5, 92.3)
Class D	443.1	306.3 (274.9, 337.7)	306.3 (274.9, 337.7)	271.3 (228.0, 314.6)	236.4 (203.4, 269.4)
Class E & F	217.9	183.0 (148.0, 218.0)	138.7 (101.6, 175.8)	200.0 (163.1, 236.9)	106.3 (64.6, 148.0)

TABLE 5c. DIFFERENCE OF OBSERVED AND PREDICTED AVERAGES OF THE 25 HIGHEST SO_2 CONCENTRATION VALUES (UNPAIRED IN TIME OR LOCATION)
CLIFTY CREEK (1976) AVERAGING TIME: 24 HOUR

Data Sets	Average Observed Value $\bar{C}_o$ ($\mu g/m^3$)	Difference of Averages ($\bar{C}_o - \bar{C}_p$) For Each Model ($\mu g/m^3$)							
		MPTER	MPSDM	COMPTER	SCSTER	3141	4141	TEM-8A	MULTIMAX
1. All stations/all events (A - 4a)	125.3	-1.4 (±9.1)	23.3 (±13.2)	-26.8 (±16.3)	39.7 (±13.8)	55.4 (±10.3)	53.4 (±10.1)	58.5 (±9.5)	40.3 (±13.4)
2. By station/all events (A - 4b)									
Station 1	96.4	20.8 (±14.2)	40.0 (±11.0)	6.6 (±15.9)	49.2 (±11.3)	52.5 (±9.4)	49.6 (±9.7)	55.0 (±9.5)	45.3 (±11.5)
Station 2	84.8	27.4 (±12.1)	36.6 (±9.7)	13.9 (±12.6)	41.0 (±11.2)	45.4 (±9.2)	45.2 (±9.2)	46.1 (±15.9)	43.2 (±10.9)
Station 3	64.3	-27.8 (±21.3)	-19.7 (±17.8)	-60.5 (±20.1)	.9 (±18.3)	10.9 (±14.2)	10.9 (±14.2)	18.4 (±12.8)	2.5 (±17.7)
Station 4	107.7	15.8 (±15.4)	36.2 (±14.1)	-2.4 (±17.6)	53.0 (±12.8)	53.7 (±12.0)	52.4 (±12.0)	55.2 (±12.4)	48.9 (±12.5)
Station 5	40.1	24.4 (±11.8)	7.2 (±11.6)	6.3 (±13.7)	30.2 (±10.3)	27.5 (±9.0)	27.5 (±9.0)	24.9 (±8.2)	30.3 (±10.1)
Station 6	71.8	43.8 (±10.0)	40.2 (±9.7)	40.3 (±10.1)	44.0 (±10.0)	47.2 (±9.0)	47.2 (±8.9)	36.1 (±8.6)	45.0 (±9.9)

TABLE 6a. AVERAGE DIFFERENCE BETWEEN OBSERVED AND PREDICTED CONCENTRATION VALUES EVENT BY-EVENT (PAIRED IN TIME)
CLIFTY CREEK (1975) AVERAGING TIME: 1 HOUR

Data Sets	Number of Events*	Average Observed Value C_o* ($\mu g/m^3$)	Difference of Averages $(\overline{C_o - C_p})$ For Each Model ($\mu g/m^3$)							
			MPTER	MPSIM	COMPTER	SCSTER	3141	4141	TEM-8A	MULTIMAX
1. Highest concentration, event-by-event (A 1)	3576	115.1	34.9 (±9.7)	31.0 (±10.0)	-3.4 (±10.0)	71.9 (±8.4)	71.3 (±7.6)	67.7 (±7.7)	68.2 (±8.6)	65.3 (±8.3)
2. All concentrations, all stations (paired in time and location) (B 3)	5561	93.2	36.5 (±6.8)	33.2 (±6.9)	9.0 (±7.1)	62.7 (±5.8)	56.2 (±5.4)	53.9 (±5.5)	45.8 (±6.2)	58.1 (±5.8)
3. All concentrations, by station (B 1)										
Station 1	1357	95.3	42.2 (±14.4)	51.9 (±13.0)	24.9 (±15.5)	69.5 (±12.0)	59.8 (±11.5)	55.4 (±11.7)	58.6 (±12.9)	63.4 (±12.3)
Station 2	825	102.9	25.6 (±18.7)	29.7 (±10.6)	-1.2 (±18.1)	57.6 (±17.8)	54.8 (±15.9)	54.3 (±15.7)	43.1 (±15.8)	53.6 (±16.8)
Station 3	1037	92.0	35.3 (±17.3)	10.7 (±14.7)	-11.9 (±17.5)	60.7 (±14.8)	57.9 (±14.2)	57.9 (±14.2)	39.6 (±15.1)	50.8 (±14.4)
Station 4	995	100.1	6.8 (±16.8)	19.8 (±10.5)	-30.0 (±17.8)	59.6 (±13.4)	48.5 (±11.8)	41.8 (±11.7)	35.6 (±17.3)	46.8 (±13.7)
Station 5	694	59.6	46.3 (±8.5)	30.4 (±12.6)	27.8 (±10.6)	51.1 (±6.7)	46.0 (±7.1)	46.0 (±7.1)	43.8 (±7.1)	51.1 (±6.6)
Station 6	653	103.5	75.3 (±18.2)	58.7 (±14.3)	67.5 (±18.0)	75.4 (±18.1)	70.0 (±17.5)	70.0 (±17.5)	50.6 (±18.2)	75.7 (±18.1)
4. By meteorological conditions, all stations (B-4)										
a. Wind Speed										
< 2.5 m/sec	2271	88.3	43.4 (±9.8)	14.9 (±12.3)	18.2 (±10.2)	57.4 (±9.1)	50.0 (±8.6)	47.9 (±8.6)	23.8 (±9.8)	55.9 (±9.0)
2.5 to 5 m/sec	2819	91.2	32.0 (±9.4)	44.2 (±7.9)	2.7 (±10.1)	60.3 (±7.8)	56.2 (±7.0)	53.2 (±7.1)	55.2 (±7.7)	54.8 (±7.8)
> 5 m/sec	471	128.3	29.8 (±31.4)	59.9 (±24.5)	0.7 (±31.6)	103.9 (±23.6)	86.5 (±24.8)	86.5 (±24.7)	111.7 (±24.4)	83.3 (±23.1)
b. Stability Group										
Class A & B	565	101.9	-34.9 (±29.4)	-53.4 (±35.3)	-41.7 (±30.8)	-16.3 (±27.3)	-16.2 (±20.3)	-16.2 (±20.3)	-51.8 (±17.9)	-12.9 (±27.1)
Class C	974	111.4	-5.5 (±22.0)	-23.2 (±21.4)	-27.9 (±24.3)	31.1 (±18.0)	20.9 (±15.2)	20.9 (±15.3)	-21.6 (±16.3)	34.6 (±17.7)
Class D	2659	90.5	63.9 (±7.2)	58.6 (±6.2)	30.5 (±7.7)	90.6 (±5.9)	85.8 (±6.1)	85.8 (±6.1)	96.3 (±5.6)	84.8 (±6.0)
Class E & F	1123	59.2	37.9 (±10.6)	63.7 (±8.4)	6.8 (±13.3)	58.7 (±8.5)	56.4 (±8.5)	44.4 (±8.9)	64.7 (±8.5)	45.4 (±9.6)

*Due to the effects of imposing a threshold cutoff value, the number of events and the average observed value differ slightly from model to model. The values listed are those for MPTER.

TABLE 6b. AVERAGE DIFFERENCE BETWEEN OBSERVED AND PREDICTED CONCENTRATION VALUES EVENT-BY-EVENT (PAIRED IN TIME) CLIFTY CREEK (1975) AVERAGING TIME: 3 HOURS

Data Sets	Number of Events*	Average Observed Value $\bar{C}_o$* ($\mu g/m^3$)	Difference of Averages ($\overline{C_o - C_p}$) For Each Model ($\mu g/m^3$)							
			MPTER	MPSDM	COMPTER	SCSTER	3141	4141	TEM-8A	MULTIMAX
1. Highest concentration, event-by-event (A-1)	1271	94.8	29.5 (± 9.2)	26.1 (±9.1)	-0.1 (±9.4)	60.3 (±8.3)	60.4 (±7.5)	56.4 (±7.4)	55.8 (±8.5)	54.5 (±8.1)
2. All concentrations, all stations (paired in time and location) (B-3)	2139	76.3	28.8 (±6.5)	26.3 (±6.5)	5.9 (±6.8)	51.7 (±5.7)	46.8 (±5.4)	44.2 (±5.3)	36.7 (±6.1)	47.6 (±5.6)
3. All concentrations, by station (B-1)										
Station 1	532	78.5	34.2 (±14.3)	43.3 (±12.2)	19.6 (±15.3)	58.1 (±12.2)	51.0 (±11.6)	45.7 (±11.6)	48.9 (±12.8)	53.6 (±12.3)
Station 2	335	80.0	17.5 (±16.1)	21.6 (±14.8)	-3.5 (±15.1)	43.5 (±15.9)	43.0 (±14.3)	42.9 (±14.3)	33.2 (±15.4)	40.4 (±14.7)
Station 3	396	76.5	28.9 (±16.6)	7.3 (±19.8)	-10.3 (±16.4)	49.9 (±14.4)	47.9 (±13.9)	47.8 (±13.9)	31.4 (±14.5)	48.7 (±13.9)
Station 4	398	78.8	5.1 (±14.5)	15.6 (±12.8)	-23.7 (±15.5)	50.7 (±12.2)	41.4 (±11.2)	34.4 (±10.8)	27.4 (±16.3)	38.1 (±12.6)
Station 5	231	52.2	38.9 (±10.6)	22.6 (±16.2)	21.8 (±11.8)	43.3 (±8.2)	39.1 (±7.8)	39.1 (±7.8)	36.3 (±8.2)	43.6 (±7.9)
Station 6	247	85.1	61.1 (±18.2)	48.4 (±17.9)	54.8 (±18.3)	61.2 (±18.2)	55.8 (±17.1)	55.8 (±17.1)	39.5 (±18.2)	61.5 (±18.1)
4. By meteorological conditions, all stations (B-4)										
a. Wind Speed										
< 2.5 m/sec	595	73.4	40.4 (±11.1)	11.3 (±13.7)	18.3 (±11.7)	52.4 (±10.3)	47.0 (±9.8)	44.1 (±9.7)	20.7 (±11.2)	50.7 (±10.3)
2.5 to 5 m/sec	1269	73.4	24.0 (±8.7)	29.7 (±8.0)	1.4 (±9.1)	45.9 (±7.6)	42.0 (±6.8)	39.1 (±6.8)	35.5 (±5.2)	42.0 (±7.6)
> 5 m/sec	275	95.9	26.1 (±19.9)	44.6 (±15.1)	-1.2 (±19.7)	76.9 (±14.2)	68.7 (±16.2)	68.7 (±16.2)	83.4 (±17.0)	67.2 (±14.0)
b. Stability Group										
Class A & B	203	76.1	-27.6 (±24.8)	-33.6 (±22.9)	-35.8 (±27.0)	-14.5 (±22.7)	-13.3 (±17.0)	-13.4 (±16.9)	-39.1 (±16.2)	-12.3 (±23.0)
Class C	400	90.5	12.0 (±18.6)	-12.0 (±20.5)	-3.6 (±20.0)	36.6 (±16.0)	26.9 (±13.8)	26.9 (±14.0)	-6.1 (±13.4)	39.7 (±15.8)
Class D	1162	78.8	42.7 (±7.6)	42.2 (±6.5)	15.4 (±8.2)	68.2 (±6.1)	64.3 (±6.1)	63.2 (±6.2)	67.2 (±6.6)	62.8 (±6.1)
Class E & F	366	52.9	34.8 (±12.2)	55.5 (±9.7)	6.6 (±13.5)	55.0 (±10.0)	54.7 (±10.0)	41.3 (±10.1)	59.2 (±10.4)	42.5 (±11.1)

* Due to the effects of imposing a threshold cutoff value, the number of events and the average observed value differ slightly from model to model. The values listed are those for MPTER.

TABLE 6c. AVERAGE DIFFERENCE BETWEEN OBSERVED AND PREDICTED CONCENTRATION VALUES EVENT-BY-EVENT (PAIRED IN TIME)
CLIFTY CREEK (1975) AVERAGING TIME: 24 HOURS

Data Sets	Number of Events*	Average Observed Value C_o* ($\mu g/m^3$)	Difference of Averages $(\overline{C_o - C_p})$ For Each Model ($\mu g/m^3$)							
			MPTER	MPSIM	COMPTER	SCSTER	3141	4141	TEM-8A	MULTIMAX
1. Highest concentration, event-by-event (A-1)	335	30.5	13.5 (±4.4)	13.3 (±4.3)	3.4 (±4.6)	24.1 (±4.6)	23.9 (±4.2)	23.1 (±4.3)	22.2 (±4.8)	22.7 (±4.2)
2. All concentrations, all stations (paired in time and location) (B-1)	1115	22.6	10.9 (±2.0)	10.3 (±2.0)	5.2 (±2.2)	16.2 (±1.8)	15.1 (±1.8)	14.5 (±1.8)	13.0 (±1.9)	15.3 (±1.8)
3. All concentrations, by station (B-1)										
Station 1	211	29.0	15.0 (±6.4)	17.5 (±6.0)	10.6 (±6.6)	21.8 (±6.2)	19.8 (±6.2)	18.6 (±4.7)	18.6 (±6.1)	20.2 (±6.0)
Station 2	184	21.5	7.5 (±3.9)	8.3 (±4.1)	2.4 (±3.8)	13.4 (±4.0)	13.1 (±3.8)	13.0 (±4.2)	11.0 (±4.4)	12.7 (±3.7)
Station 3	194	24.4	11.5 (±5.6)	6.5 (±5.8)	0.5 (±6.2)	16.9 (±4.9)	16.6 (±4.8)	16.6 (±4.5)	13.0 (±4.4)	16.5 (±4.8)
Station 4	187	24.7	4.3 (±4.4)	7.1 (±3.7)	-3.9 (±5.3)	15.7 (±4.0)	13.3 (±3.6)	11.5 (±4.2)	10.6 (±5.1)	13.0 (±4.0)
Station 5	206	13.7	11.8 (±1.8)	9.4 (±3.0)	9.2 (±2.1)	12.4 (±1.7)	11.8 (±1.8)	11.8 (±1.6)	11.6 (±1.7)	12.5 (±1.7)
Station 6	133	22.2	16.4 (±5.0)	13.3 (±4.8)	15.0 (±5.0)	16.5 (±5.0)	15.5 (±4.9)	15.5 (±4.8)	12.0 (±5.4)	16.5 (±5.0)

* Due to the effects of imposing a threshold cutoff value, the number of events and the average observed value differ slightly from model to model. The values listed are those for MPTER.

TABLE 7a. AVERAGE DIFFERENCE BETWEEN OBSERVED AND PREDICTED CONCENTRATION VALUES EVENT-BY-EVENT (PAIRED IN TIME) CLIFTY CREEK (1976) AVERAGING TIME: 1 HOUR

Data Sets	Number of Events*	Average Observed Value $\bar{C}_o$* ($\mu g/m^3$)	Difference of Averages $(\overline{C_o - C_p})$ For Each Model ($\mu g/m^3$)							
			MPTER	MPSDM	COMPTER	BCSTER	3141	4141	TEM-8A	MULTIMAX
1. Highest concentration, event-by-event (A-1)	4127	127.7	45.9 (±8.9)	50.0 (±8.5)	7.4 (±9.5)	82.4 (±7.6)	82.8 (±7.1)	79.7 (±7.1)	89.0 (±7.0)	76.2 (±7.4)
2. All concentrations, all stations (paired in time and location) (B-3)	6523	99.1	41.8 (±6.9)	44.4 (±6.3)	14.5 (±7.4)	67.7 (±5.9)	62.1 (±5.5)	59.9 (±5.6)	62.4 (±5.0)	63.3 (±5.9)
3. All concentrations, by station (B-1)										
Station 1	1515	100.0	42.6 (±15.8)	56.6 (±13.9)	28.3 (±16.9)	69.1 (±13.6)	61.9 (±12.8)	58.2 (±13.0)	71.2 (±13.5)	64.2 (±14.0)
Station 2	1202	102.9	58.9 (±14.6)	59.6 (±13.5)	34.6 (±15.6)	78.2 (±13.7)	73.4 (±13.2)	72.6 (±9.7)	70.1 (±12.8)	74.9 (±13.1)
Station 3	1114	85.9	11.8 (±19.2)	9.1 (±17.6)	-38.7 (±18.8)	44.3 (±15.6)	42.9 (±13.8)	42.9 (±13.8)	43.1 (±13.7)	41.8 (±14.7)
Station 4	1331	102.4	11.0 (±17.0)	27.8 (±15.5)	-18.6 (±18.0)	58.8 (±15.0)	49.5 (±13.0)	44.2 (±12.9)	57.0 (±16.0)	47.7 (±14.8)
Station 5	485	78.2	55.0 (±13.4)	34.6 (±15.6)	27.8 (±15.6)	66.4 (±11.9)	61.3 (±11.1)	61.3 (±11.1)	54.9 (±11.6)	66.3 (±11.8)
Station 6	876	115.9	92.1 (±12.1)	79.9 (±11.5)	86.1 (±12.1)	92.2 (±12.0)	89.9 (±11.7)	89.9 (±11.7)	72.8 (±12.7)	92.9 (±12.0)
4. By meteorological conditions, all stations (B-4)										
a. Wind Speed										
< 2.5 m/sec	2184	92.0	38.9 (±11.5)	18.6 (±11.6)	12.6 (±12.2)	53.6 (±10.2)	47.9 (±9.2)	45.6 (±9.3)	29.8 (±10.3)	52.3 (±10.0)
2.5 to 5 m/sec	3873	100.7	46.6 (±9.0)	59.0 (±7.8)	19.4 (±9.8)	74.3 (±7.7)	68.6 (±7.3)	66.2 (±7.3)	78.3 (±7.0)	69.0 (±7.7)
> 5 m/sec	466	119.1	15.1 (±30.1)	50.7 (±22.0)	-17.2 (±31.2)	80.8 (±22.6)	77.4 (±20.6)	77.4 (±20.7)	108.8 (±20.0)	68.1 (±22.1)
b. Stability Group										
Class A & B	544	111.2	-28.0 (±35.0)	-29.4 (±31.9)	-40.7 (±36.0)	-10.9 (±32.0)	-7.6 (±23.7)	-7.6 (±23.7)	-36.5 (±21.5)	-8.3 (±31.1)
Class C	1229	111.1	-6.9 (±21.7)	-4.4 (±19.3)	-28.3 (±24.0)	25.1 (±17.4)	16.8 (±15.1)	16.8 (±15.1)	10.0 (±11.9)	30.2 (±16.0)
Class D	3513	107.0	70.6 (±7.6)	67.0 (±7.1)	37.6 (±8.4)	99.1 (±6.4)	94.0 (±6.4)	94.0 (±6.4)	108.0 (±6.3)	92.6 (±6.6)
Class E & F	1237	58.6	30.9 (±9.4)	63.4 (±5.4)	10.7 (±12.6)	58.3 (±6.0)	56.5 (±6.0)	45.4 (±7.0)	62.3 (±5.9)	46.1 (±8.0)

* Due to the effects of imposing a threshold cutoff value, the number of events and the average observed value differ slightly from model to model. The values listed are those for MPTER.

TABLE 7b. AVERAGE DIFFERENCE BETWEEN OBSERVED AND PREDICTED CONCENTRATION VALUES EVENT-BY-EVENT (PAIRED IN TIME)
CLIFTY CREEK (1976) AVERAGING TIME: 3 HOURS

Data Sets	Number of Events*	Average Observed Value $\bar{C}_o$* ($\mu g/m^3$)	Difference of Averages $(\overline{C_o - C_p})$ For Each Model ($\mu g/m^3$)							
			MPTER	MPSDM	COMPTER	SCSTER	3141	4141	TEM-8A	MULTIMAX
1. Highest concentration, event-by-event (A-1)	1478	105.6	39.5 (±8.7)	42.4 (±7.8)	9.1 (±9.2)	68.7 (±7.5)	69.8 (±6.8)	66.8 (±6.9)	73.3 (±7.5)	64.0 (±7.3)
2. All concentrations, all stations (paired in time and location) (B-3)	2525	81.6	33.5 (±6.6)	35.9 (±5.8)	10.8 (±7.1)	55.2 (±5.7)	51.3 (±5.2)	49.3 (±5.3)	50.8 (±5.4)	51.5 (±5.7)
3. All concentrations, by station (B-1)										
Station 1	598	81.8	34.1 (±15.2)	45.9 (±12.6)	22.2 (±16.4)	56.4 (±13.1)	52.5 (±11.9)	49.0 (±12.2)	60.0 (±12.3)	51.8 (±13.3)
Station 2	460	86.7	49.3 (±12.6)	48.6 (±10.8)	27.4 (±13.0)	64.2 (±11.8)	60.5 (±11.0)	60.4 (±9.2)	57.2 (±10.8)	63.2 (±11.5)
Station 3	428	70.8	7.6 (±20.1)	5.6 (±18.1)	-34.2 (±19.0)	34.4 (±16.1)	32.9 (±14.2)	32.9 (±14.1)	33.8 (±13.2)	33.2 (±15.3)
Station 4	526	82.6	8.7 (±14.8)	22.7 (±13.3)	-15.0 (±15.5)	49.0 (±14.3)	42.2 (±12.8)	37.0 (±12.3)	45.8 (±15.4)	30.2 (±13.7)
Station 5	372	66.0	48.1 (±11.4)	25.5 (±13.5)	21.5 (±14.4)	55.6 (±10.0)	52.3 (±10.3)	52.3 (±10.3)	44.7 (±11.5)	55.8 (±9.8)
Station 6	341	94.5	74.4 (±11.2)	65.1 (±10.6)	69.7 (±11.2)	74.5 (±11.1)	72.1 (±10.9)	72.1 (±10.9)	58.3 (±11.4)	75.1 (±11.1)
4. By meteorological conditions, all stations (B-4)										
a. Wind Speed										
< 2.5 m/sec	591	76.0	33.4 (±12.7)	9.0 (±12.3)	13.1 (±13.3)	44.5 (±10.7)	38.8 (±10.0)	37.0 (±10.0)	20.2 (±10.9)	43.8 (±10.8)
2.5 to 5 m/sec	1533	81.5	34.7 (±8.8)	44.5 (±7.4)	12.1 (±9.4)	55.8 (±7.6)	52.5 (±6.9)	50.0 (±6.9)	56.1 (±6.7)	51.9 (±7.5)
> 5 m/sec	401	90.5	28.7 (±17.1)	46.4 (±13.2)	2.2 (±18.4)	69.4 (±13.5)	66.7 (±13.0)	66.5 (±12.9)	85.5 (±12.4)	61.9 (±13.6)
b. Stability Group										
Class A & B	209	89.6	-12.1 (±31.3)	-16.4 (±29.6)	-24.2 (±33.4)	1.0 (±26.9)	3.0 (±21.9)	3.0 (±21.8)	-16.2 (±18.3)	3.3 (±26.7)
Class C	476	87.0	6.3 (±19.4)	2.3 (±16.2)	-9.4 (±21.2)	26.1 (±16.0)	19.4 (±13.6)	19.4 (±13.7)	11.6 (±12.4)	29.4 (±15.7)
Class D	1394	87.9	48.5 (±6.0)	49.7 (±6.7)	22.0 (±8.8)	74.5 (±6.6)	70.8 (±6.3)	70.1 (±6.3)	78.8 (±6.4)	69.6 (±6.7)
Class E & F	446	52.7	36.6 (±9.4)	55.0 (±6.0)	11.5 (±11.8)	54.5 (±6.3)	53.3 (±6.4)	43.6 (±7.2)	56.9 (±6.4)	43.1 (±8.0)

* Due to the effects of imposing a threshold cutoff value, the number of events and the average observed value differ slightly from model to model. The values listed are those for MPTER.

TABLE 7c. AVERAGE DIFFERENCE BETWEEN OBSERVED AND PREDICTED CONCENTRATION VALUES EVENT-BY-EVENT (PAIRED IN TIME)
CLIFTY CREEK (1976) AVERAGING TIME: 24 HOURS

Data Sets	Number of Events*	Average Observed Value $\bar{C}_o$* ($\mu g/m^3$)	Difference of Averages ($\overline{C_o - C_p}$) For Each Model ($\mu g/m^3$)							
			MPTER	MPSIM	COMPTER	SCSTER	3141	4141	TEM-8A	MULTIMAX
1. Highest concentration, event-by-event (A-1)	355	46.0	38.0 (±4.0)	20.3 (±3.7)	7.4 (±4.5)	29.2 (±3.9)	29.9 (±3.6)	29.2 (±3.5)	31.3 (±4.3)	27.9 (±3.7)
2. All concentrations, all stations (paired in time and location) (B-3)	1165	26.2	12.7 (±2.1)	13.4 (±1.8)	6.4 (±2.4)	18.5 (±1.9)	17.5 (±1.8)	17.0 (±1.8)	17.6 (±1.9)	17.6 (±1.9)
3. All concentrations, by station (B-1)										
Station 1	245	28.7	13.7 (±5.2)	17.4 (±4.6)	10.2 (±5.7)	20.6 (±4.8)	19.6 (±4.6)	18.5 (±4.4)	21.4 (±4.7)	19.3 (±4.9)
Station 2	231	26.3	16.8 (±3.8)	16.9 (±3.6)	11.6 (±4.0)	20.7 (±3.6)	19.7 (±3.5)	19.6 (±3.5)	19.5 (±3.5)	20.4 (±3.5)
Station 3	188	23.9	5.8 (±6.4)	5.4 (±5.2)	-7.6 (±7.0)	13.0 (±5.0)	13.0 (±4.6)	13.0 (±4.6)	13.8 (±4.4)	12.6 (±4.8)
Station 4	215	29.5	5.2 (±4.6)	9.5 (±4.4)	-2.8 (±5.0)	17.6 (±5.4)	15.4 (±4.8)	14.1 (±4.7)	16.6 (±6.1)	14.5 (±4.9)
Station 5	122	15.8	12.6 (±2.5)	8.7 (±2.6)	7.7 (±3.4)	14.0 (±2.3)	13.3 (±2.4)	13.3 (±2.4)	12.1 (±2.6)	14.0 (±2.3)
Station 6	162	28.3	23.3 (±3.9)	20.9 (±3.4)	22.0 (±3.8)	23.3 (±3.9)	22.6 (±3.8)	22.6 (±3.8)	19.1 (±3.8)	23.4 (±3.8)

* Due to the effects of imposing a threshold cutoff value, the number of events and the average observed value differ slightly from model to model. The values listed are those for MPTER.

TABLE 8a. COMPARISON OF MAXIMUM OBSERVED AND MAXIMUM PREDICTED CONCENTRATION VALUES
CLIFTY CREEK (1975) AVERAGING TIME: 1 HOUR

Model	Highest observed value over all events and locations $C_O max$ ($\mu g/m^3$)	Highest predicted value over all events and locations $C_P max$ ($\mu g/m^3$)	Difference of maximum values $C_O - C_P$ ($\mu g/m^3$)	Average of maximum values observed at each station $\overline{C}_O$ ($\mu g/m^3$)	Average of maximum values predicted at each station $\overline{C}_P$ ($\mu g/m^3$)	Average difference $\overline{C_O - C_P}$ ($\mu g/m^3$)
MPTER (CRSTER, PLUME5)	1672.7	1492.5	180.2	994.5	1207.9	-213.4
MPSDM	1672.7	2940.0	-1267.3	994.5	1592.0	-597.5
COMPTER	1672.7	1529.0	143.7	994.5	1228.0	-233.5
SCSTER	1672.7	1374.4	298.2	994.5	1027.3	-32.8
3141	1672.7	727.8	944.9	994.5	591.3	403.2
4141	1672.7	727.8	944.9	994.5	591.3	403.2
TEM-8A	1672.7	1793.2	-120.5	994.5	1043.0	-48.5
MULTIMAX	1672.7	1383.7	289.0	994.5	1020.3	-25.8

TABLE 8b. COMPARISON OF MAXIMUM OBSERVED AND MAXIMUM PREDICTED CONCENTRATION VALUES
CLIFTY CREEK (1975) AVERAGING TIME: 3 HOUR

Model	Highest observed value over all events and locations $C_O max$ ($\mu g/m^3$)	Highest predicted value over all events and locations $C_P max$ ($\mu g/m^3$)	Difference of maximum values $C_O - C_P$ ($\mu g/m^3$)	Average of maximum values observed at each station $\bar{C}_O$ ($\mu g/m^3$)	Average of maximum values predicted at each station $\bar{C}_P$ ($\mu g/m^3$)	Average difference $\overline{C_O - C_P}$ ($\mu g/m^3$)
MPTER (CRSTER, PLUMES)	794.0	741.1	52.9	543.3	540.3	- 3.0
MPSDM	794.0	1560.9	-766.9	543.3	693.3	-150.0
COMPTER	794.0	760.9	33.1	543.3	602.3	-59.0
SCSTER	794.0	702.3	91.7	543.3	476.3	-67.0
3141	794.0	450.3	343.7	543.3	314.7	228.6
4141	794.0	450.3	343.7	543.3	314.7	228.6
TEM-8A	794.0	939.2	-145.2	543.3	508.3	35.0
MULTIMAX	794.0	692.6	101.4	543.3	465.5	77.8

TABLE 8c. COMPARISON OF MAXIMUM OBSERVED AND MAXIMUM PREDICTED CONCENTRATION VALUES
CLIFTY CREEK (1975) AVERAGING TIME: 24 HOUR

Model	Highest observed value over all events and locations $C_o max$ ($\mu g/m^3$)	Highest predicted value over all events and locations $C_p max$ ($\mu g/m^3$)	Difference of maximum values $C_o - C_p$ ($\mu g/m^3$)	Average of maximum values observed at each station $\bar{C}_o$ ($\mu g/m^3$)	Average of maximum values predicted at each station $\bar{C}_p$ ($\mu g/m^3$)	Average difference $\overline{C_o - C_p}$ ($\mu g/m^3$)
MPTER (CRSTER, PLUMES)	209.5	171.1	38.4	151.8	135.5	16.3
MPSDM	209.5	195.2	14.3	151.8	130.1	21.7
COMPTER	209.5	241.6	-32.1	151.8	171.2	-19.4
SCSTER	209.5	106.6	102.9	151.8	83.1	68.7
3141	209.5	96.8	112.7	151.8	74.6	77.2
4141	209.5	96.8	112.7	151.8	74.6	77.2
TEM-8A	209.5	142.1	67.3	151.8	92.4	59.4
MULTIMAX	209.5	104.9	104.6	151.8	85.7	66.1

TABLE 9a. COMPARISON OF MAXIMUM OBSERVED AND MAXIMUM PREDICTED CONCENTRATION VALUES
CLIFTY CREEK (1976) AVERAGING TIME: 1 HOUR

Model	Highest observed value over all events and locations $C_o max$ ($\mu g/m^3$)	Highest predicted value over all events and locations $C_p max$ ($\mu g/m^3$)	Difference of maximum values $C_o - C_p$ ($\mu g/m^3$)	Average of maximum values observed at each station $\overline{C}_o$ ($\mu g/m^3$)	Average of maximum values predicted at each station $\overline{C}_p$ ($\mu g/m^3$)	Average difference $\overline{C_o - C_p}$ ($\mu g/m^3$)
MPTER (CRSTER, PLUME5)	950.8	1422.4	-471.6	858.1	1118.1	-260.0
MPSDM	950.8	1512.1	-561.3	858.1	1152.9	-294.8
COMPTER	950.8	1438.8	-488.0	858.1	1160.3	-302.2
SCSTER	950.8	1422.2	-471.4	858.1	1023.3	-165.2
3141	950.8	841.3	109.5	858.1	626.2	231.9
4141	950.8	841.3	109.5	858.1	626.2	231.9
TEM-8A	950.8	1309.9	-359.1	858.1	953.0	94.9
MULTIMAX	950.8	1398.7	-447.9	858.1	1025.9	-167.8

TABLE 9b. COMPARISON OF MAXIMUM OBSERVED AND MAXIMUM PREDICTED CONCENTRATION VALUES CLIFTY CREEK (1976) AVERAGING TIME: 3 HOUR

Model	Highest observed value over all events and locations $C_o$max ($\mu g/m^3$)	Highest predicted value over all events and locations $C_p$max ($\mu g/m^3$)	Difference of maximum values $C_o - C_p$ ($\mu g/m^3$)	Average of maximum values observed at each station $\overline{C}_o$ ($\mu g/m^3$)	Average of maximum values predicted at each station $\overline{C}_p$ ($\mu g/m^3$)	Average difference $\overline{C_o - C_p}$ ($\mu g/m^3$)
MPTER (CRSTER, PLUMES)	623.7	856.0	-232.3	525.6	579.5	-53.9
MPSDM	623.7	947.1	-323.4	525.6	562.0	-36.4
COMPTER	623.7	1008.4	-384.7	525.6	660.4	-140.8
SCSTER	623.7	657.0	-33.3	525.6	488.2	37.4
3141	623.7	453.4	170.3	525.6	324.1	201.5
4141	623.7	453.4	170.3	525.6	324.1	201.5
TLM-8A	623.7	763.7	-140.1	525.6	443.0	82.6
MULTIMAX	623.7	616.0	7.6	525.6	463.2	62.4

TABLE 9c. COMPARISON OF MAXIMUM OBSERVED AND MAXIMUM PREDICTED CONCENTRATION VALUES
CLIFTY CREEK (1976) AVERAGING TIME: 24 HOUR

Model	Highest observed value over all events and locations $C_o max$ ($\mu g/m^3$)	Highest predicted value over all events and locations $C_p max$ ($\mu g/m^3$)	Difference of maximum values $C_o - C_p$ ($\mu g/m^3$)	Average of maximum values observed at each station $\overline{C_o}$ ($\mu g/m^3$)	Average of maximum values predicted at each station $\overline{C_p}$ ($\mu g/m^3$)	Average difference $\overline{C_o - C_p}$ ($\mu g/m^3$)
MPTER (CRSTER, PLUMES)	181.2	248.7	-67.5	132.8	133.3	-0.5
MPSDM	181.2	178.7	2.5	132.8	107.1	25.7
COMPTER	181.2	274.9	-93.7	132.8	159.6	-26.8
SCSTER	181.2	203.8	-22.5	132.8	100.1	32.7
3141	181.2	129.1	52.2	132.8	74.3	58.5
4141	181.2	129.1	52.1	132.8	75.5	57.3
TEM-8A	181.2	102.2	79.0	132.8	74.8	58.0
MULTIMAX	181.2	196.0	-14.8	132.8	99.2	33.6

APPENDIX 3

(WORKSHEETS FOR WORKBOOK COMPARISON OF TEN AIR-QUALITY MODELS)