Air Quality Model Performance Evaluation and Comparison Study for Martins Creek Steam Electric Station

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AIR QUALITY
MODEL PERFORMANCE
EVALUATION AND COMPARISON STUDY
FOR MARTINS CREEK STEAM ELECTRIC STATION

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EXECUTIVE SUMMARY

A model performance comparison study was conducted to determine the most appropriate dispersion modeling approach for estimating sulfur dioxide (SO_2) ambient air quality impacts from Pennsylvania Power & Light Company's (PP&L) Martins Creek Steam Electric Station (MCSES) on elevated terrain in the vicinity of Scotts Mountain in Warren County, New Jersey. The United States Environmental Protection Agency (EPA) has designated that portions of the county are in nonattainment of the National Ambient Air Quality Standards (NAAQS). That designation is based on dispersion modeling analyses conducted with EPA's complex terrain screening models. This model comparison study was conducted because of concern that the screening models overpredict the actual air quality impacts from MCSES on Scotts Mountain. This report describes the study, which was designed based on the EPA's Interim Procedures for Evaluating Air Quality Models (Revised) (EPA, 1984) and was conducted in accordance with the Air Quality Model Performance Evaluation and Comparison Protocol for Martins Creek Steam Electric Station (Londergan, 1990).

The modeling protocol was approved by the Pennsylvania Department of Environmental Resources (DER), EPA and the New Jersey Department of Environmental Protection and Energy (NJDEPE). The protocol presented the study design, including the monitoring network; established the basis for judging model performance; and described the intended application of the winning model to estimate air quality impacts and establish emission limits for MCSES.

The study described in this report involves performance comparisons between the Large Area Power Plant Effluent Study (LAPPES) model and the Rough Terrain Diffusion Model (RTDM) in combination with the Multiple Point Gaussian Dispersion Algorithm with Terrain

Adjustment (MPTER) model. The models were evaluated using continuous hourly field measurement data collected from May 1, 1992 through May 19, 1993. During this period, PP&L monitored ambient SO_2 concentrations at seven sites in New Jersey and one background site in Pennsylvania; collected meteorological data at a tower and at a remote sensing acoustic sounder (SODAR) site near MCSES; and collected data needed to calculate hourly emissions data from MCSES. Emissions data from other nearby sources were provided by Metropolitan Edison (Portland Station), Hoffman LaRouche and the Warren County Resource Recovery Facility.

The results of the model performance evaluation are that:

1) LAPPES is the model which best simulates the air quality impacts of MCSES emissions at elevated terrain in the vicinity of Scotts Mountain in New Jersey.

2) LAPPES outperformed the reference model, RTDM/MPTER, and met the scoring criteria specified in the modeling protocol to be selected as the winning model.

3) LAPPES did not have a significant under- or overprediction bias and no model adjustment factors will be necessary.

TABLE OF CONTENTS

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TABLE OF CONTENTS (cont.)

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LIST OF TABLES

LIST OF TABLES (cont.)

LIST OF FIGURES

1.0 INTRODUCTION

The Martins Creek Steam Electric Station (MCSES), owned and operated by the Pennsylvania Power & Light Company (PP&L), is located in the Delaware River Valley near Martins Creek, Pennsylvania. Portions of adjacent Warren County, New Jersey have been designated as non-attainment for sulfur dioxide (SO_2) by the U. S. Environmental Protection Agency (EPA) based on the results of air quality dispersion modeling (EPA, 1987). The air quality dispersion modeling was conducted with EPA complex terrain screening models. Of particular concern to PP&L are predictions of MCSES stack emission impacts in high terrain portions of Warren County.

PP&L was concerned that the EPA's screening models overpredict actual concentrations from MCSES in complex terrain (terrain above stack top), particularly Scotts Mountain in Warren County, NJ. As a result of this concern, PP&L prepared the Air Quality Model Performance Evaluation and Comparison Protocol for Martins Creek Steam Electric Station (Londergan, 1990) to evaluate predictions on Scotts Mountain following the Interim Procedures for Evaluating Air Quality Models (Revised) (EPA, 1984). The protocol details an air quality monitoring program and a rigorous statistical model performance comparison between the EPA reference models and the candidate Large Power Plant Effluent Study (LAPPES) model. LAPPES was developed during a Western Pennsylvania field study (Schiermeirer and Niemeyer, 1970). The reference models are EPA's Rough Terrain Diffusion Model (RTDM) and Multiple Point Gaussian Dispersion Algorithm with Terrain Adjustment (MPTER) Model.

PP&L and TRC Environmental Corporation (TRC) conferred with the Pennsylvania Department of Environmental Resources (DER), EPA and New Jersey Department of

Environmental Protection and Energy (NJDEPE) to develop the protocol for the model evaluation study. The protocol was approved prior to the start of the study. It calls for one year of air quality, source emissions and meteorological monitoring to be conducted, followed by modeling of the monitoring locations using both the reference and candidate models. The air quality, emissions and meteorological monitoring period of record for this evaluation is May 1, 1992 through May 19, 1993. The abilities of the reference and candidate models to simulate the air quality situation around MCSES is judged using a set of statistical performance measures and the better model is selected using the agreed to model scoring scheme from the protocol.

This document overviews the model evaluation study design, the data base collected for the model comparison and the statistical comparison protocol. The results of the model comparisons, scoring and selection are presented in detail.

This model performance comparison report is based upon modeling performed using data provided to TRC by PP&L. The results of the model performance comparison study show that LAPPES is the superior model for determining the air quality impacts from MCSES on Scotts Mountain in New Jersey.

Section 2 of this report summarizes the relevant background regulatory issues, emission source and topography characterizations, a description of the models used and the project history. The databases used for the model comparison study is described in Section 3. The statistical measures used to evaluate model performance are summarized in Section 4. The model performance comparison results are contained in Section 5. The bootstrapping analysis, conducted to evaluate the model over/under prediction tendency, is found in Section 6, while the study conclusions and references are provided in Sections 7 and 8, respectively.

2.0 STUDY DESIGN

2.1 Regulatory Setting

The regulatory issues addressed by this study concern the effect of SO_2 emissions from MCSES and other nearby sources on the ambient air concentrations at elevated terrain locations on Scotts Mountain in Warren County, New Jersey. In December 1987, EPA designated part of Warren County as a non-attainment area for the short-term average SO_2 concentrations relative to the National Ambient Air Quality Standards (NAAQS), based on dispersion modeling results using EPA complex terrain screening models.

Because portions of Warren County are nonattainment, the appropriate regulatory agencies must determine allowable SO_2 emission limits for MCSES and the other sources in the area in order to bring the county into NAAQS attainment. PP&L believes that the screening models overpredict ambient impacts from MCSES. Pursuant to EPA guidelines, PP&L, using the avenue of the Interim Procedures for Evaluating Air Quality Models (Revised) (EPA, 1984), seeks to:

1) demonstrate that an alternative model, LAPPES, provides more realistic predictions of short-term SO_2 concentrations than the RTDM/MPTER regulatory reference models, and

2) have the LAPPES model approved for regulatory modeling for MCSES.

Following the guidance set forth in the Interim Procedures, PP&L prepared a protocol for the model comparison study. The protocol was reviewed, commented on and approved by the DER.

If the results of the model comparison and scoring determine that the EPA reference models (RTDM/MPTER) provide more accurate predictions of concentrations on Scotts Mountain resulting from MCSES emissions than the candidate model (LAPPES), the reference models meeting current EPA guidance will be used to determine emission limits needed to safeguard the NAAQS. If the candidate model is determined to be more accurate, then it will be used to evaluate emission limits for MCSES in the Scotts Mountain area, while emissions limits for other sources in the region will be evaluated using the EPA reference models.

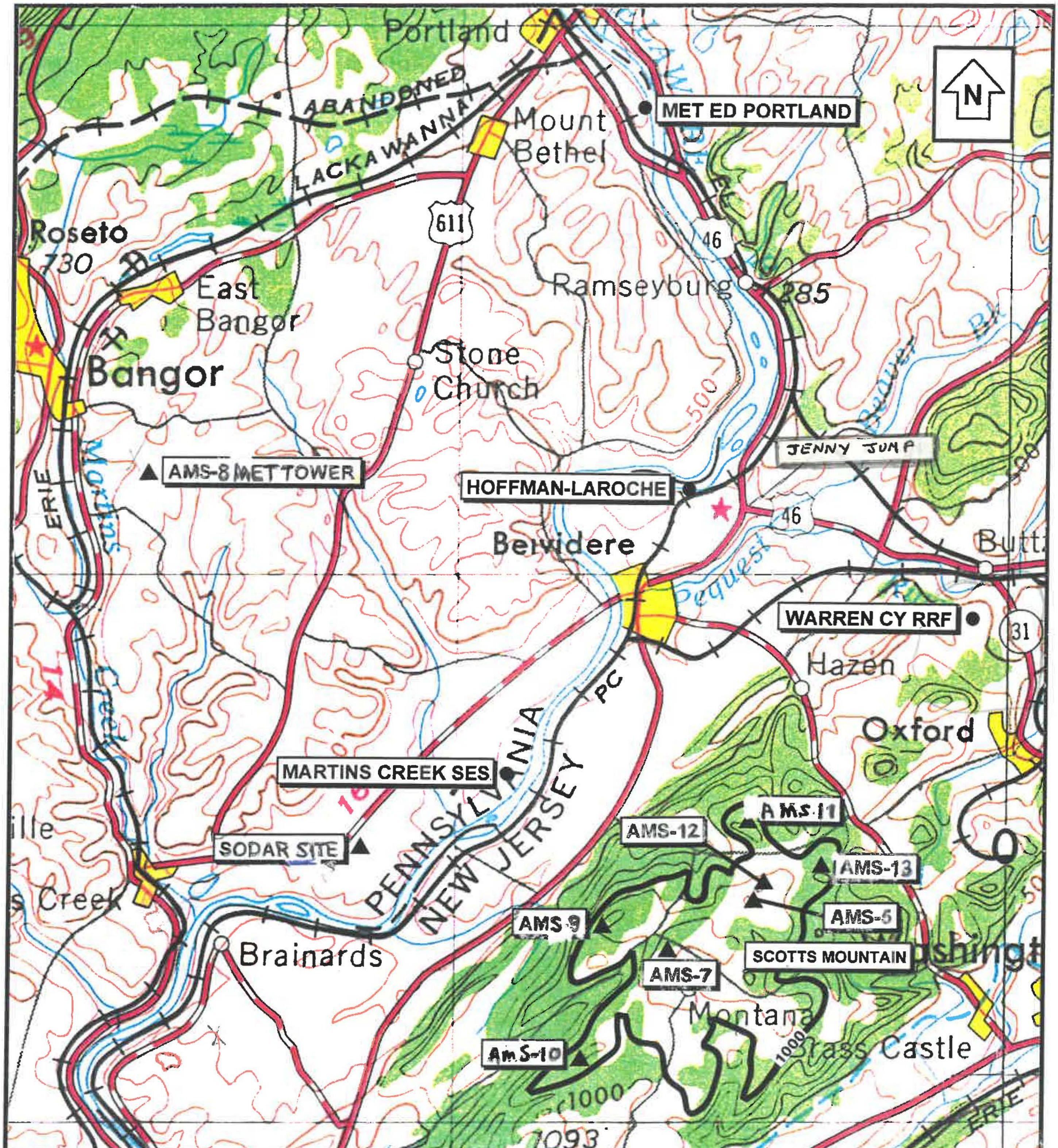
PP&L collected continuous hourly ambient SO_2, meteorological and MCSES emissions data from May 1, 1992 through May 19, 1993 for the model comparison study. The data were quality assured and provided to the DER, EPA and NJDEPE periodically during the study.

2.2 Sources and Topography

MCSES is located in the Delaware River Valley in Pennsylvania. PP&L operates two large coal-fired units (1&2) and two large No. 6 oil-fired units (3&4) at MCSES. The coal-fired units are 156 MegaWatts (MW) each and exhaust to a common 600 foot stack. The oil-fired units are 850 MW each and exhaust to separate 600 foot stacks. For the model comparison study, actual hourly average emissions data were collected for each of the units. Two, No. 2 oil-fired auxiliary boilers that operate primarily for start-up at the plant were not included in the evaluation.

Other, nearby sources of SO_2 that may contribute to ambient concentrations in the region are included in the study. These sources include the Hoffman-LaRoche facility in Belvidere, NJ (HL), Metropolitan Edison Company's Portland Station near Portland, PA (MetEd), and the Warren County Resource Recovery Facility near Oxford, NJ (WCRRF). For the model comparison study, hourly average emissions data were provided to PP&L.

Scotts Mountain and Jenny Jump are the areas where both the reference and candidate models predict the largest concentrations in Warren County, New Jersey resulting from MCSES's emissions. Scotts Mountain, a northeast to southwest oriented ridge, is located approximately 3 km southeast of MCSES. Scotts Mountain rises to a maximum elevation of 1,281 feet, more than 400 feet above the MCSES stack tops. Jenny Jump Mountain, about 10 km northeast of MCSES, reaches an elevation of 1,070 feet. In Pennsylvania, no terrain within 10 km of the MCSES exceeds the plant's stack top elevation. Jenny Jump is not part of the model evaluation study. Kittatinny Ridge, a northeast/southwest ridge beyond 10 km from MCSES in Pennsylvania and New Jersey, also is not part of the model evaluation study. Figure 2-1 shows the Warren County region, the location of MCSES, the additional sources and the surrounding terrain features.



LEGEND

- ● Emission Source
- ▲ Monitoring Site
- 1000-ft Elevation Contour

0 5

APPROXIMATE SCALE KM

FROM NEWARK, NJ, PA, NY, 1944
REVISED 1969, USGS TOPOGRAPHIC MAP

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FIGURE 2-1.

MONITORING NETWORK FOR MODEL COMPARISON

Date: 9/94 | Drawing No. 14715-07

2.3 Description of the Dispersion Models Used

The proposed candidate model for regulatory compliance evaluations of MCSES on Scotts Mountain is LAPPES. EPA has designated the complex terrain reference model as a combination of RTDM and MPTER. RTDM predictions were compared to MPTER predictions at each monitor for every hour and the higher concentration was selected. For the purposes of this analysis, this reference model approach in effect selects primarily RTDM predictions, because all monitors are above stack top.

2.3.1 Candidate model

The LAPPES model is based on data collected during the Large Power Plant Effluent Study (Schiermeier and Niemeyer, 1970) conducted in western Pennsylvania. LAPPES is a "non-guideline" model applicable to complex terrain situations and has been used in other ridge and valley modeling settings in Pennsylvania. Notable features of LAPPES include:

- Empirical dispersion coefficients based on Pasquill-Gifford;
- Class A stability is rolled back to Class B;
- Enhanced horizontal plume spread under stable conditions to account for plume meander;
- Briggs distance dependant plume rise;
- Enhanced initial plume growth due to buoyancy induced dispersion, and
- Plume height adjusted as a function of stability class and underlying terrain height.

In terms of final concentration predictions, the most significant feature of LAPPES is the treatment of plume height as the plume approaches complex terrain, i.e., terrain elevations higher than stack height. The plume height above the terrain is gradually reduced to a meteorologically dependant minimum height as the plume passes over elevated terrain. During non-stable conditions, the minimum height above the terrain is 50 percent of the unadjusted plume height above the stack base elevation. During stable conditions the minimum height above terrain is 35 percent of the unadjusted plume height.

Dispersion Coefficients - LAPPES employs a standard Gaussian formulation with full ground reflection. Vertical dispersion coefficients are unmodified Pasquill-Gifford (P-G) coefficients. Horizontal coefficients are also standard P-G coefficients for unstable and neutral conditions. For stable conditions the horizontal plume spread (σ_y) is enhanced by:

$$\sigma_y = \sigma_y(P-G)/(0.4 * u_E^{.3})$$

where:

$$\sigma_Y(P-G) = \text{Pasquill-Gifford } \sigma_Y$$

$$u_E = u - 0.5$$

$$u = \text{wind speed at stack top (m/s)}$$

If $u < 1$ m/s, $u_E = .5$ m/s
If $u > 9$ m/s, $u_E = 8.5$ m/s

The horizontal dispersion enhancement for stable meteorological conditions is based on an empirical adjustment observed during the LAPPES experiments. During stable conditions the P-G σ_y values are increased from 1.32 to 3.08 times, depending upon the wind speed. Stability class A was not considered appropriate for tall stack sources by the LAPPES model developers, based on empirical observations of plume behavior. Therefore LAPPES "roles back" all stability A hours to stability B.

Plume Rise - Plume rise is calculated using the BEH072 subroutine from the EPA UNAMAP models, modified to include a factor of 2.6 (instead of 2.4) for stable conditions.

Plume Height Adjustment - During unstable and neutral conditions, LAPPES employs a plume height adjustment factor of 0.5, the same as RTDM. With this adjustment, the vertical separation, H_A, between the plume centerline and the ground is given by:

$$H_A = h + \Delta H - 0.5z, \quad z \le h + \Delta H$$

$$H_A = 0.5(h + \Delta H), \quad z > h + \Delta H$$

where:

z = terrain elevation above stack base
h = stack height
ΔH = plume height

For stable conditions, the adjusted plume height is given by:

$$H_A = h + \Delta H - z, \quad z \le (h + \Delta H)/1.7$$

$$H_A = h + \Delta H - 0.65z, \quad (h + \Delta H)/1.7 < z \le (h + \Delta H)$$

$$H_A = 0.35(h + \Delta H), \quad z > h + \Delta H$$

For low terrain elevations, this treatment corresponds to full terrain subtraction. As the terrain elevation increases, the adjusted plume height reaches the minimum approach distance and then remains constant.

2.3.2 RTDM Reference model

The RTDM model is fully described in the User's Guide to the Rough Terrain Diffusion Model (RTDM) Rev. 3.2 (Paine and Egan, 1987). The default version of RTDM is recommended by EPA as a screening model for complex terrain applications using on-site meteorological data. RTDM was identified as the appropriate complex terrain reference model for this model performance evaluation. Specific default model features of RTDM include:

- Reflection of the plume mass from the ground is limited by the second law of thermodynamics, so that the maximum concentrations cannot increase with distance downwind;
- During stable conditions, a critical height (H_{crit}) is computed from the wind speed, terrain height and the thermal stability. Plumes below H_{crit} are allowed to impinge on the terrain;
- The effects of entrainment can be accounted for in calculating plume rise;
- Transitional plume rise may be employed until the equilibrium plume rise is reached;
- During neutral and unstable conditions, or for plume heights above H_{crit} in stable conditions, a "half-height" plume elevation is used;
- Stack tip downwash can be induced;
- Horizontal dispersion causes uniform crosswind concentration distribution over a 22.5 degree sector;
- Plume rise is calculated using stack top wind speed and plume dilution is calculated using plume height wind speed, and
- Vertical dispersion is based on ASME dispersion coefficients.

With the "partial reflection" option employed in RTDM, the concentration at a receptor point depends on the predicted upwind concentrations as well as the source-receptor geometry. RTDM requires detailed terrain profiles in 10° radial intervals.

2.3.3 MPTER Reference Model

The MPTER model is intended for multi-source applications in rural areas with flat to moderately rolling (terrain elevations up to stack height) terrain. MPTER employs a standard Gaussian formulation using Pasquill-Gifford dispersion coefficients for both horizontal and vertical dispersion. In the regulatory mode, MPTER includes the following features:

- Final plume rise (distance independent) based on Briggs' formulation;
- Enhanced initial plume growth due to buoyancy induced dispersion;
- Stack tip downwash, and
- Full terrain subtraction for all stabilities. Predictions are not made at elevations above stack top. For receptors with elevations greater than stack top, MPTER defaults to the stack top elevation.

2.4 Modeling for Monitoring Network Design

The candidate and reference models were used in the design of the air quality monitoring network for this model evaluation. Model predictions were made for a spectrum of typical MCSES operating load conditions while assuming that all other significant SO_2 sources in the region were operating at full load and maximum emissions. MCSES Units 1 and 2 were modeled at 33 percent, 50 percent and full load conditions. Units 3 and 4 were modeled at 50 percent, 75 percent, 95 percent and full load. MCSES emission rates and exit velocities were treated as direct functions of load and exit temperature was held constant. This spectrum of operating conditions ensured that the variability in magnitude and location of the predicted maximum concentrations would be fully characterized. Onsite meteorological input data from 1986 and 1987 were used for the network design modeling.

Ultimately the monitoring array shown in Figure 2-1 was chosen based on the locations of the predicted high concentrations from the reference and candidate models. Seven monitors were sited to cover the region of high predicted 3 and 24-hour average concentrations. Air Monitoring Station 8 (AMS-8) was added to contribute to the assessment of background concentrations. Meteorological data are available from the Sound Detection And Ranging (SODAR) unit at 30 m increments between 60 and 600 m above grade and from the tower at AMS-8 at 10 and 20 m above grade. Backup data are available from the Allentown-Bethlehem-Easton (ABE) Airport weather station. The network design is discussed in detail in the Air Quality Model Performance Evaluation and Comparison Protocol for Martins Creek Steam Electric Station (Londergan, 1990).

3.0 DATABASE FOR MODEL COMPARISON

The performance evaluation compared predicted concentrations from MCSES and other nearby sources using the reference and candidate models with ambient SO_2 measurements on Scotts Mountain. As specified in the protocol, actual hourly emissions, meteorological data and ambient SO_2 data were collected continuously for the period of the study. The model evaluation data base includes the period from May 1, 1992 through May 19, 1993. The "extra days" of the monitoring period (May 1 through May 19, 1993) have been included because MCSES Units 3 and 4, which operated infrequently for much of the monitoring year, were online during this period.

3.1 Emissions data

Hourly emissions data for the model evaluation period were recorded for MCSES, MetEd, WCRRF, and HL. Hourly SO_2 emission rates, exit velocities and stack temperatures were determined for these facilities. Table 3-1 summarizes the fixed stack parameters for the facilities.

3.1.1 MCSES Emissions Data

Hourly SO_2 emissions from MCSES were determined for each hour of the study period. For the coal-fired Units 1 and 2, continuous emissions monitors (CEM's) provided hourly SO_2 emission rates (lb/MMBTU) for each unit. These data were used along with hourly load data (MW) and monthly average heat rates (MMBTU/MW) to calculate hourly SO_2 hourly emissions (lb/hr). For oil-fired Units 3 and 4, no CEM data were available. Hourly SO_2 emissions were

TABLE 3-1
SOURCE CHARACTERISTICS

Source	UTM Coordinates (km)	Base Elevation (feet)	Stack Height (feet)	Stack Diameter (meters)
MCSES Units 1 and 2	491.02 (E) 4,515.91 (N)	240	600 (182.9 m)	5.30 28.4 m/s 422 °K
MCSES Unit 3	491.08 (E) 4,516.00 (N)	240	600	6.90 33.5 m/s 422 °K
MCSES Unit 4	491.12 (E) 4,516.08 (N)	240	600	33.5 m/s 6.90 422 °K
		Nad 83		
MetED Unit 1	493.35 (E) 4,528.37 (N)	493.353 4528.717 300	400	3.10
MetEd Unit 2	493.35 (E) 4,528.37 (N)	300	400	3.60
Unit 3				
HL	494.05 (E) 4,521.04 (N)	340	195	2.67
WCRRF Unit 1	498.95 (E) 4,518.50 (N)	570	250	1.87
WCRRF Unit 2	498.95 (E) 4,518.50 (N)	570	250	1.87

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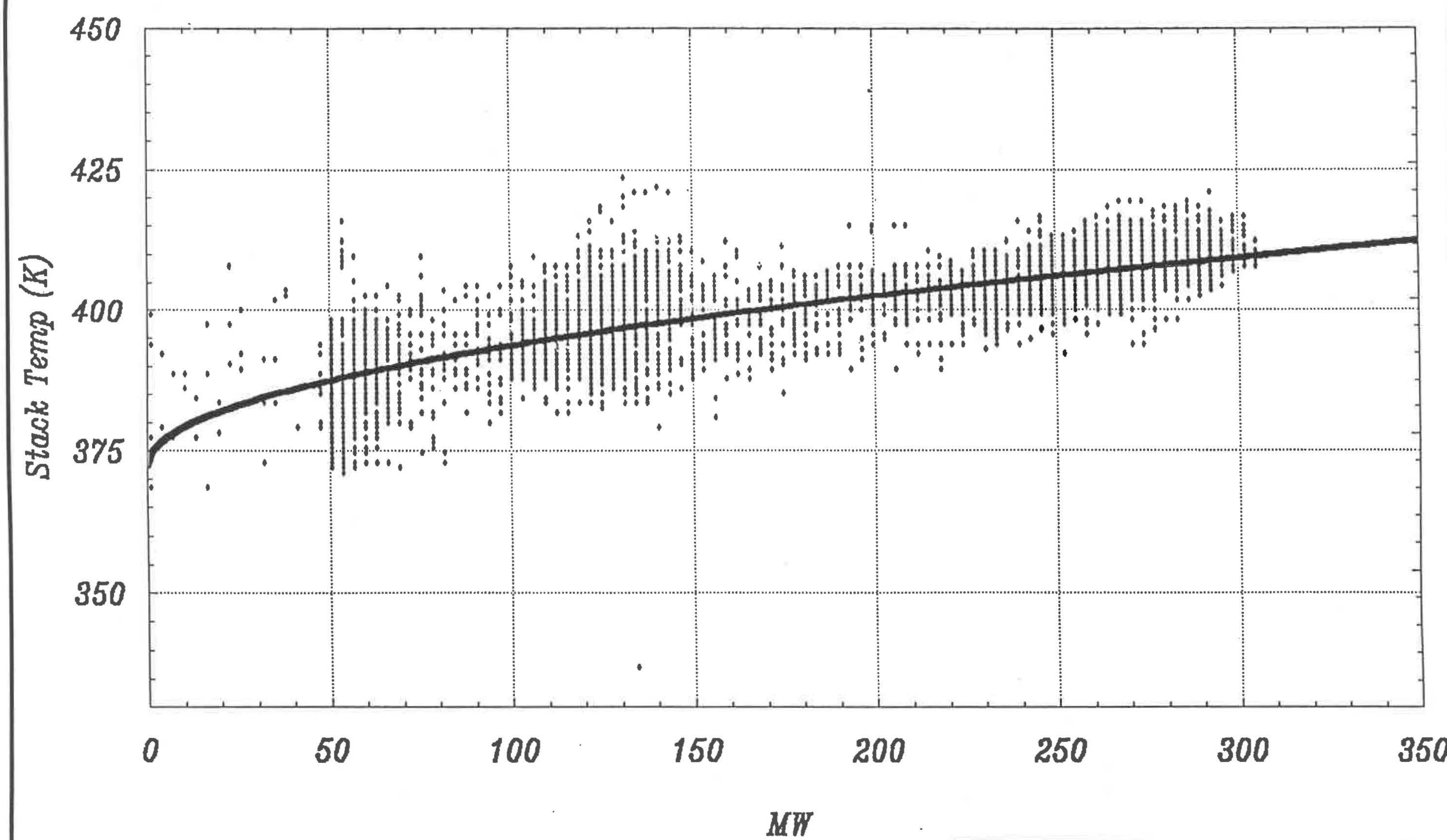
calculated from hourly load data (MW) and monthly average fuel sulfur content (percent), fuel heat content (MMBTU/gal) and heat rates (MMBTU/MW).

Stack gas exit velocities were assumed to be directly proportional to operating load. For Units 1 and 2, which exhaust to the same stack, exit velocities attributable to each unit were combined to determine the total exit velocity for the stack. If CEM data was missing for either Unit 1 or Unit 2, available data from adjacent hours were used. There was no missing operating load data that would effect the calculation of emissions or exit velocity; therefore, no hours of missing SO_2 emissions or exit velocities.

Hourly exit temperatures were measured in the exhaust ducts at the base of each stack. For Units 1 and 2, the temperatures were combined as a weighted average based on the operating load of each unit. If four hours or less of stack temperature data were missing, the missing hourly stack temperatures were estimated using linear interpolation from the hours with data. For Units 1 and 2, a total of 16 hours of missing temperature data were interpolated; for Unit 3, a total of 16 hours were interpolated and for Unit 4 a total of 44 hours were interpolated. For periods with more than four continuous hours of missing stack temperature data, temperatures were estimated based on statistical fits between observed stack temperatures and load. Figures 3-1 through 3-3 present scattergrams of measured temperature versus load. Statistical curve fitting techniques were used to find equations to estimate temperatures for those hours with missing data. The equations and correlation coefficients are shown on Figures 3-1 through 3-3. For Units 1 and 2, 849 hourly stack temperatures were estimated based on statistical fitting; for Unit 3, 182 hours were estimated and for Unit 4, 312 hours were estimated. For partial operating hours (hours during which the units went on- or off-line), if the



T = 372.41 + (2.14*SQRT(MW))
R = 0.83

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FIGURE 3-1.
FITTED TEMPERATURE FOR UNITS 1 AND 2

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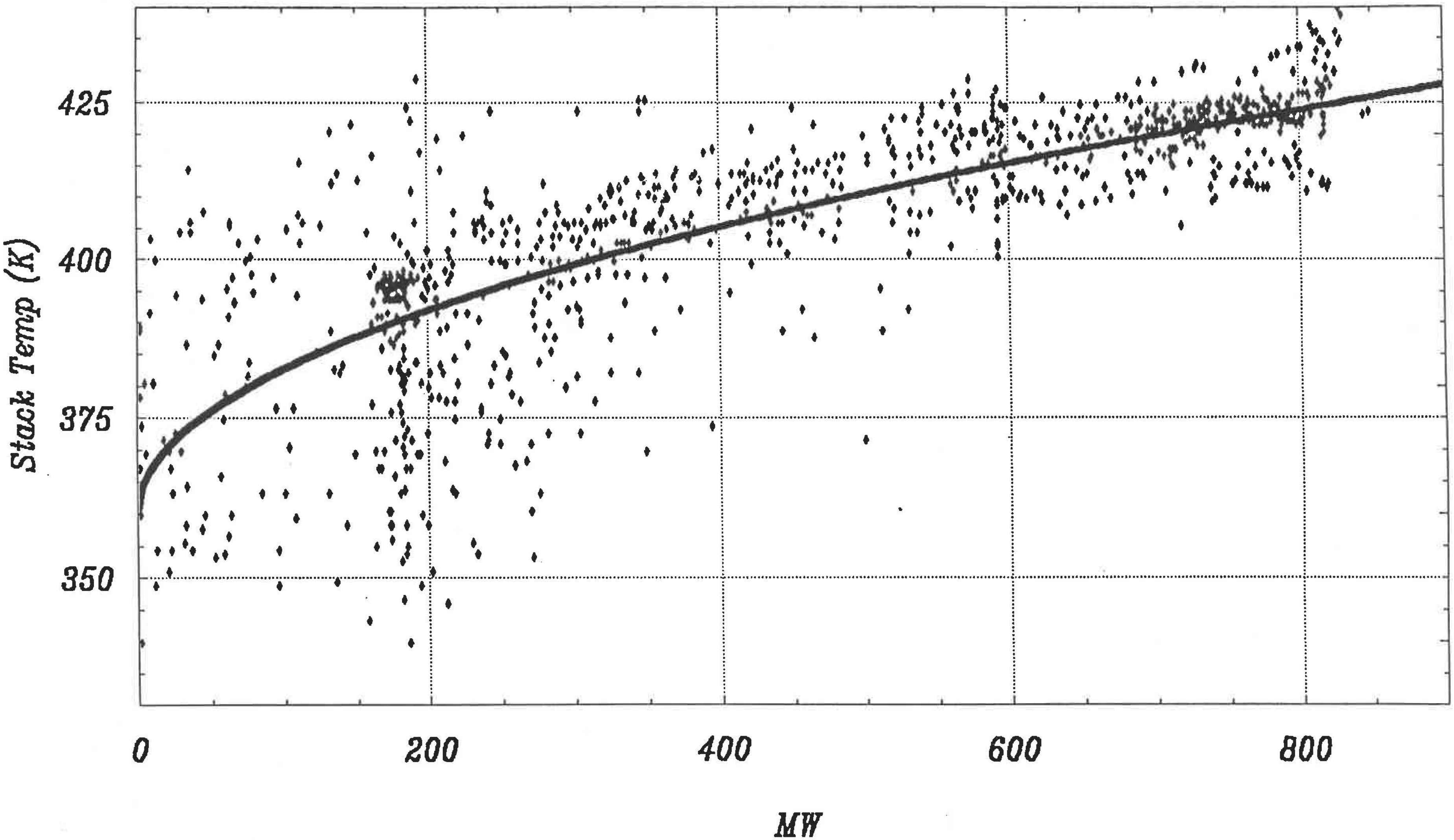

T = 360.08 + (2.26*SQRT(MW))
R = 0.79

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FIGURE 3-2.

FITTED TEMPERATURE FOR UNIT 3

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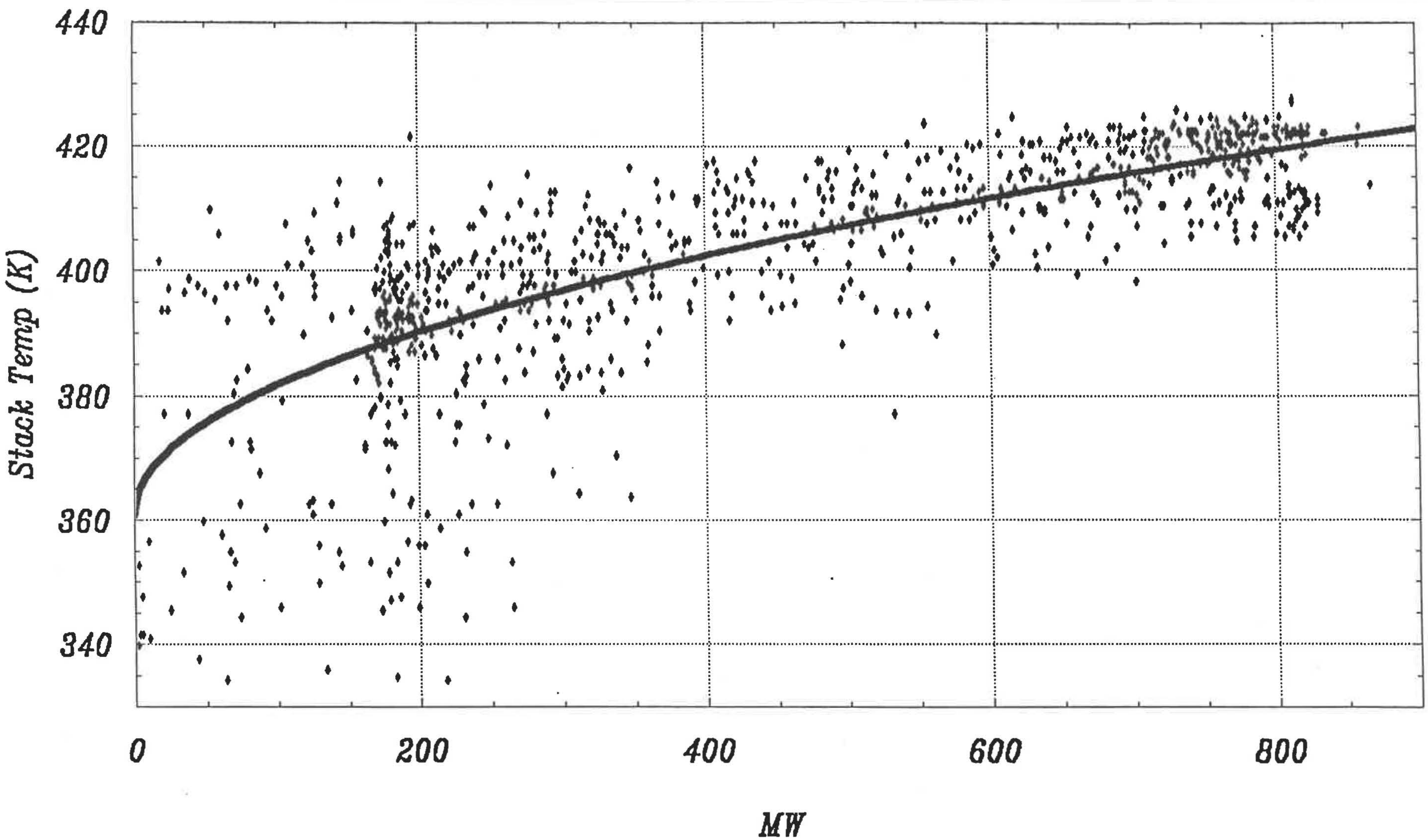

T = 361.14 + (2.06*SQRT(MW))
R = 0.76

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FIGURE 3-3.

FITTED TEMPERATURE FOR UNIT 4

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hourly average temperature or velocity was unrealistically low because of averaging within the off-line period, it was set equal to the value for the adjacent on-line hour.

3.1.2 Emissions Data from Nearby Sources

Hourly SO_2 emissions, exit velocities (or volume flow rates) and exit temperatures were provided for WCRRF, HL and MetEd. If there were missing emission, exit velocity or temperature data for less than four hours, linear interpolation was used to fill in the missing data. A total of 25 hours of missing data were interpolated for WCRRF and no interpolations were needed for HL or MetEd. If more than four continuous hours of data were missing for these sources, the average observed emission, stack temperature or velocity for each source during operational hours was substituted for the missing value. For HL, a total of 121 hours used average stack data. For WCRRF, a total of 1,127 hours used average stack data. MetEd had no missing data.

MetEd did not continue to collect hourly emissions data after May 1, 1993. Thus for the period from May 1 through May 19, 1993 it was necessary to calculate hourly SO_2 emissions for MetEd based on daily average CEM SO_2 data and hourly load data.

3.2 Meteorological data

Meteorological data for the model comparison were collected from on site instruments and National Weather Service (NWS) observations. Primary wind speed and wind direction data were collected at 30 meter intervals between 60 and 600 meters by a SODAR unit. Sigma theta and ambient temperature measurements were collected at the 10 and 20 meter elevation levels on a meteorological tower at Air Monitoring Site 8 (AMS-8). AMS-8 wind speeds and directions were used as backup data if the SODAR data were unavailable. During the last three months of the study the 20-meter tower level was replaced by a 60-meter level. NWS surface wind, temperature and cloud clover observations were available from Allentown-Bethlehem-Easton Airport (ABE) and upper air observations were taken from Albany, NY. Mixing heights were calculated using Albany, NY upper air data and ABE surface temperature. The meteorological sites are shown in Figure 2-1.

SODAR plume height wind speed and wind direction measurements plus stability categories based on sigma theta and air temperature measurements from the 10-meter level of AMS-8 are the primary set of meteorological inputs for the modeling. Stack top wind speeds were taken from the SODAR level closest to the stack top elevation of each source being modeled. The stack top wind speed was used to calculate plume rise for both RTDM and LAPPES. The stack top wind speed was used as the dilution wind speed for LAPPES. A second level of SODAR winds, representative of plume height, was used as the dilution wind speed for RTDM. Thus, a separate set of meteorological data was developed for each source, based on meteorological observations at the stack top elevations and plume height elevations.

Base elevation sodar 320 ft amsl

Recognizing that missing data periods would occur, a data substitution hierarchy, shown in Table 3-2 was implemented. For example, the first choice for plume height wind speed for MCSES was the 420 m level from the SODAR. If data at 420 m was missing, wind data from the closest available lower level was substituted down to a minimum height of 180 m. If no valid SODAR wind speeds at 180 m were available, the AMS-8 20m level wind speed was substituted. If the AMS-8 20m level was not available, ABE hourly wind speeds were

TABLE 3-2

SUBSTITUTION HIERARCHY FOR METEOROLOGICAL INPUTS

Emission Source	Stack Top Wind Speed	Transport Wind Speed*	Transport Wind Direction	Stability Class**
MCSES	180m AMS-8(20) ABE	420-180m AMS-8(20) ABE	420-180m AMS-8(20) AMS-8-(10) ABE	AMS-8(10) AMS-8(20) ABE
MetEd	120-90m AMS-8(20) ABE	300-180m AMS-8(20) ABE	300-180m AMS-8(20) AMS-8(10) ABE	AMS-8(10) AMS-8(20) ABE
WCRRF	150-90m AMS-8(20) ABE	210-180m AMS-8(20) ABE	210-180m AMS-8(20) AMS-8(10) ABE	AMS-8(10) AMS-8(20) ABE
HL	90m AMS-8(20) ABE	210-180m AMS-8(20) ABE	210-180m AMS-8(20) AMS-8(10) ABE	AMS-8(10) AMS-8(20) ABE

* Used for RTDM only.
** Stability class by sigma theta from AMS-8 and by Turner's method from ABE.

KEY:

"420-180m" refers to the SODAR 420m level, with missing data first substituted for with data from the closest lower level, down to a minimum height of 180m

"AMS-8(20)" refers to the 20m level of AMS-8.

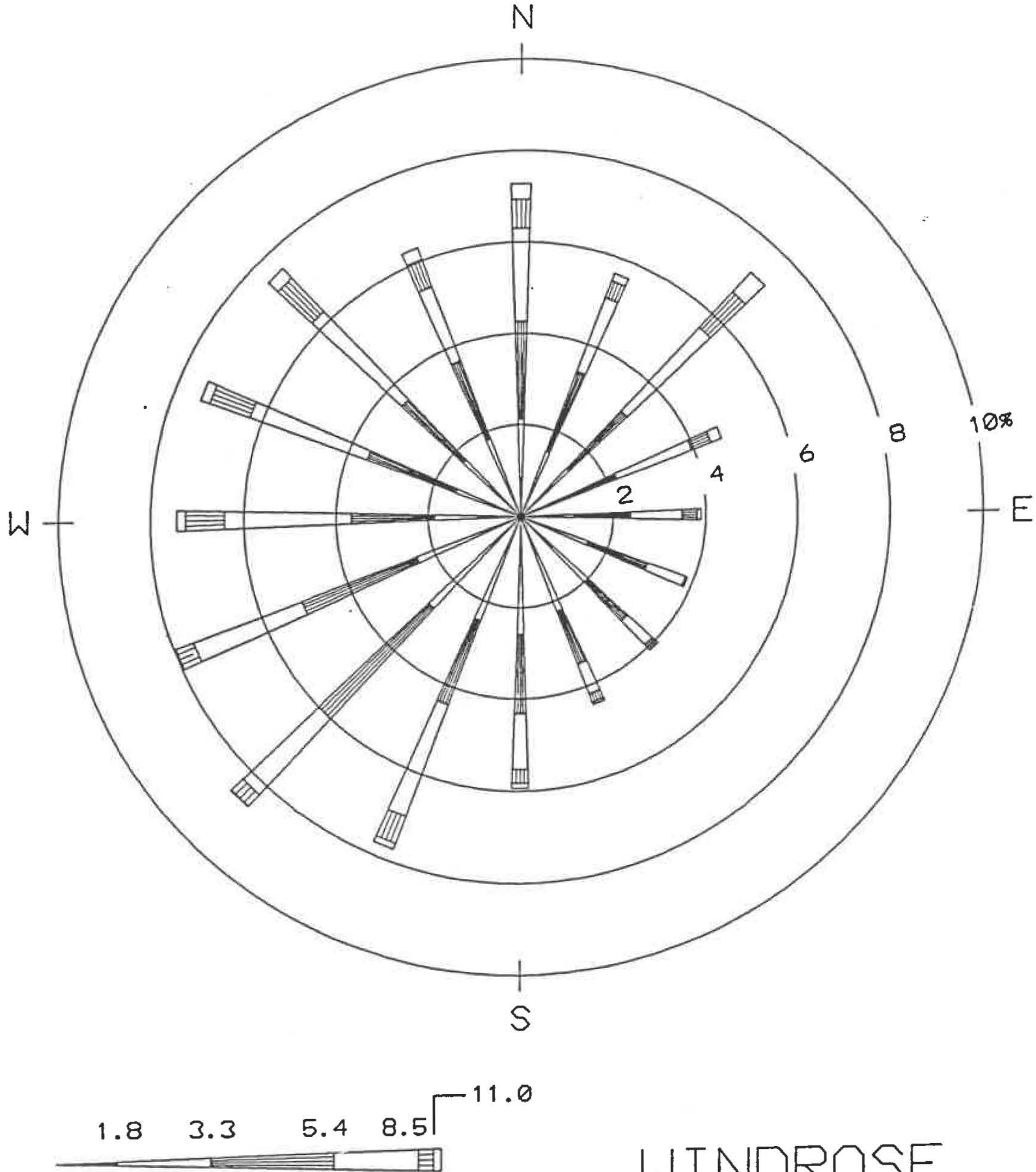
substituted. Temperature data were taken from AMS-8, or from ABE if AMS-8 temperature data were missing. Table 3-3 presents a source by source tabulation of the number of modeling hours for which each data source was used. Figure 3-4 displays the wind rose for the processed meteorological data for MCSES (stack top wind speed and plume height wind direction).

3.2.1 Stability Classification

Sigma theta measurements from the 10-meter level of the AMS-8 meteorological tower were used as the primary stability classification technique. Classification was based on EPA guideline procedures, including day/night and wind speed corrections. Also, the recommended sampling height corrections were made for hours that data were substituted from the 20-meter tower level. A site-specific roughness length (z_o) of 100 cm was used rather than the default value of 15 cm. The site is located on a hill surrounded by rolling terrain, farms, tree clusters and tree lines. A z_o of 100 cm increased the frequency of stability class F from 2.7 percent to 6.5 percent and yielded a stability distribution in which the extreme stabilities (A and F), were closer to the frequency of occurrence to the NWS frequencies. Table 3-4 provides a comparison of the stability frequency distributions. Stability classification using sigma theta measurements from the 20-meter level of AMS-8 were the first back-up and ABE data was the final back-up. After substituting for missing data, stability classes were smoothed so that the stability did not change by more than one category from one hour to the next.

TABLE 3–3
OCCURRENCE OF METEOROLOGICAL HIERARCHY

Data Source	Stack Top Wind Speed	Transport Wind Speed	Transport Wind Direction	Ambient Temperature	Data Source	Atmospheric Stability
		Number of Hours for MCSES				
SODAR	8,761	8,771	8,771	–	TW10	8,535
TW20	431	421	412	–	TW20	68
TW10	–	–	2	9,093	NWS	613
NWS	24	24	31	123		
		Number of Hours MetED				
SODAR	8,912	8,771	8,771	–	TW10	8,535
TW20	287	421	412	–	TW20	68
TW10	–	–	2	9,093	NWS	613
NWS	17	24	31	123		
		Number of Hours HL				
SODAR	8,912	8,763	8,763	–	TW10	8,535
TW20	287	429	418	–	TW20	68
TW10	–	–	2	9,093	NWS	613
NWS	17	24	33	123		
		Number of Hours WCRRF				
SODAR	8,912	8,763	8,763	–	TW10	8,535
TW20	287	429	418	–	TW20	68
TW10	–	–	2	9,093	NWS	613
NWS	17	24	33	123		



WIND SPEED CLASS BOUNDARIES
(METERS/SECOND)

NOTES:
DIAGRAM OF THE FREQUENCY OF OCCURRENCE FOR EACH WIND DIRECTION. WIND DIRECTION IS THE DIRECTION FROM WHICH THE WIND IS BLOWING. EXAMPLE - WIND IS BLOWING FROM THE NORTH 7.3 PERCENT OF THE TIME.

WINDROSE

MCSES, PA.
PERIOD: 1992-93

Plume Ht. 420 meter (direction)
Stack Top 180 " (speed)

Bowman Environmental Engineering

TRC
TRC Environmental Corporation
5 Waterside Crossing
Windsor, CT 06095
(203) 289-8631

PENNSYLVANIA POWER & LIGHT COMPANY

FIGURE 3-4. WINDROSE OF THE METEOROLOGICAL DATA

Date: 9/94 | Drawing No. 14715-07

TABLE 3–4
ATMOSPHERIC STABILITY CLASS FREQUENCY DISTRIBUTIONS

Stability Class	Number of Hours by Year							
	Final Substitution*		Turner Method ABE		On site with 100 cm z_o		On site with 15 cm z_o	
	Hours	Percentage	Hours	Percentage	Hours	Percentage	Hours	Percentage
1 (A)	89	1.0%	65	0.7%	169	2.0%	380	4.5%
2 (B)	233	2.5%	482	5.2%	163	1.9%	339	4.0%
3 (C)	503	5.5%	865	9.4%	335	3.9%	855	10.0%
4 (D)	4,874	52.9%	5,090	55.2%	4,528	53.1%	4,793	56.2%
5 (E)	2,959	32.1%	1,099	11.9%	2,787	32.7%	1,936	22.7%
6 (F)	558	6.1%	1,615	17.5%	553	6.5%	232	2.7%

* Final stability classification, based on onsite sigma theta (100 cm z_o) with ABE Turner as back–up. Stability classes were smoothed.

3.2.2 Wind Speed Extrapolation

Wind speed extrapolations with height were required to adjust observed wind speeds to stack top and plume height winds for periods when there were missing data. Adjustment factors were developed for four different wind speed substitution possibilities:

- SODAR winds between 180 and 420 m,
- SODAR winds between 90 and 180 m,
- Substitution of AMS-8 20 m winds for 180 m SODAR
- Substitution of ABE winds for 180 m SODAR

For wind speed extrapolation between SODAR levels, different wind profile exponents were calculated for each stability class based on the observed data. The exponents were calculated by substituting the wind speeds at the end of each range (180 and 420 m, and 90 and 180 m) into the equation:

$$\left(\frac{u_2}{u_1}\right)=\left(\frac{z_2}{z_1}\right)^p$$

where:

u_1, u_2 = wind speeds at levels 1 and 2

z_1, z_2 = elevations of levels 1 and 2

p = wind speed profile exponent

The median exponent value calculated for each stability class was selected for wind profile calculations.

The third and fourth substitution adjustments are much simpler. For each hour, the ratio of the two wind speeds was computed. The hourly ratios were then sorted by stability class and the median ratio was chosen for each class. Each wind speed value from AMS-8 or ABE that was substituted for the SODAR 180 m level was multiplied by the median ratio value for the appropriate stability class. When meteorological data from AMS-8 or ABE were used, the wind speeds were first adjusted to the 180 m level, and then scaled upward or downward using the SODAR extrapolation profiles. Table 3-5 displays the wind speed profile exponents and wind speed ratios used in the meteorological data processing.

3.2.3 Calm Processing

Identification of calm hours for modeling purposes was done considering the characteristics of meteorological instrumentation. Winds were considered calm if the SODAR reported wind speeds were less than to 0.3 m/s. If SODAR data were missing, and it became necessary to use substitute wind speed data, the winds were considered calm if AMS-8 reported wind speeds less than 0.3 m/s, the starting threshold of the anemometer. If ABE NWS winds were less than or equal to 1 m/s and the reported direction was persistent, these data were treated as calms in accordance with EPA guidance. The determination of calms for both the candidate and reference models was based on the transport level wind speed only, e.g. the 420 m SODAR level for MCSES or substituted data if the specified level was missing. If substituted data were used, the calm determination was made prior to applying the wind profile extrapolation. Any wind speed less than 1 m/s after being extrapolated to either stack top or transport wind height was set equal to 1 m/s.

Calm hours were processed for each source in accordance with EPA guidance. Because each source has its own meteorological data file, based on different stack heights and plume

TABLE 3-5
WIND SPEED PROFILE EXPONENTS AND RATIOS

Stability Class	420m/180m Median Wind Profile Exponents	180m/90m Median Wind Profile Exponents	180m/AMS 20m Median Wind Speed Ratio	180m/NWS Median Wind Speed Ratio
1 (A)	0.453	0.241	1.000	0.778
2 (B)	0.561	0.206	1.083	0.842
3 (C)	0.479	0.202	1.111	0.850
4 (D)	0.484	0.280	1.213	1.210
5 (E)	0.679	0.585	1.390	1.722
6 (F)	0.773	0.784	1.288	1.643

TRC

heights, some sources may have calm hours while others do not. Concentrations for each averaging period for each source were evaluated using EPA's calm processing procedures. Predicted concentrations from each source were combined to determine the total concentration for each averaging period.

3.3 Ambient SO_2 Measurements

Hourly ambient SO_2 measurements were collected from a network of seven monitoring stations sited to provide measurements of peak short-term concentrations attributable to MCSES on Scotts Mountain and one background site (AMS-8). Figure 2-1 shows the locations of the monitoring stations and Table 3-6 displays the locations and elevations of the eight monitoring stations. AMS-5, 7, 9, 10, 11, 12 and 13 are located on Scotts Mountain in Warren County, NJ. AMS-8 is located 6 km to the northwest of MCSES in Pennsylvania.

3.4 Background Concentrations

Background SO_2 concentrations were determined hourly from the monitoring network. The lowest hourly reported station(s) concentration was used as the hourly background concentration. Consequently, the background values used generally reflected regional-scale contributions from distant source regions, rather than from local contributions. The hourly background concentration was subtracted from the observed hourly concentrations at all stations to construct the observed SO_2 concentration data set used for comparison against predicted concentrations for the model evaluation. Table 3-7 provides a summary of the measured SO_2 concentration data obtained from PP&L's monitoring network during the period May 1, 1992

TABLE 3-6
LOCATIONS FOR MARTINS CREEK STEAM
ELECTRIC STATION SO2 MONITORING NETWORK

Monitor Name	Monitor Number	UTM Coordinates (Km) East	UTM Coordinates (Km) North	Elevation (ft)
AMS05	1	495.51	4,513.68	1,160
AMS07	2	493.90	4,513.20	1,236
AMS08	3	486.50	4,519.75	800
AMS09	4	492.70	4,513.44	1,215
AMS10	5	492.44	4,511.19	1,116
AMS11	6	495.40	4,515.18	1,170
AMS12	7	495.30	4,513.88	1,200
AMS13	8	496.43	4,514.50	1,120

TABLE 3–7
BACKGROUND CONCENTRATIONS FOR THE
SO_2 AIR MONITORING STATIONS

Monitor Name	Number of Hours*: Available	Number of Hours*: Percent Data Capture	Number of Hours*: Used for Background**	Average for the Available Hours ($\mu g/m^3$)	Average for the Background Hours ($\mu g/m^3$)	Highest 1–Hour for the Available Hours ($\mu g/m^3$)	Highest 1–Hour for the Background Hours ($\mu g/m^3$)
AMS05	9,080	98.5%	1,547	11.9	9.60	692	86.5
AMS07	9,038	98.1%	1,323	12.3	9.60	571	65.5
AMS08	8,903	96.6%	3,152 34.2%	12.7	11.9	820	105
AMS09	8,995	97.6%	2,805 3[illegible].4%	10.4	10.4	689	81.2
AMS10	9,115	98.9%	2,557 27.7%	12.8	12.8	718	126
AMS11	9,090	98.6%	1,624	13.0	7.40	742	96.9
AMS12	9,091	98.6%	2,675 29%	12.1	10.4	1,362	102
AMS13	9,093	98.7%	1,558	13.1	13.6	1,824	89.1

* The total number of hours for the study was 9,216 hours
(May 1, 1992 through May 19, 1993).

** If two or more stations had equal, low concentrations,
then both stations were counted as measuring the background concentration.

through May 19, 1993. The table shows, for each monitoring site:

- The number of hours of available SO_2 data,
- The number of hours used to define background,
- The average SO_2 concentration for the available hours,
- The average background SO_2 concentration for the available background hours,
- The highest 1-hour average SO_2 concentration,
- The highest 1-hour average background SO_2 concentration.

Table 3-7 shows that the monitor with the most available hours of SO_2 data was AMS-10 (9,115 hours), while the monitor used most often to determine background was AMS-8 (3,152 hours). The total number of hours for the study was 9,216 hours (May 1, 1992 through May 19, 1993).

Table 3-7 also presents the data recovery statistics for the monitoring network for the period of the model evaluation study. The lowest reported data recovery (AMS-8, 8,903 hours) exceeds 96 percent data capture. The air monitoring network provided excellent data recovery.

3.5 Model Options

Tables 3-8 through 3-10 summarize the regulatory options and related input data used for the RTDM, MPTER and LAPPES model comparison analyses. Tables 3-8 through 3-10 present the model options in the RTDM, MPTER and LAPPES models, respectively. All the options were run in accordance with EPA guidance.

Since LAPPES is a non-regulatory model there is no specific EPA guidance to reference with respect to the model inputs. However, model options were chosen to follow the general specifications for RTDM. The most distinguishing feature of LAPPES is the treatment of

TABLE 3-8

RTDM MODEL OPTIONS

Model Parameters:

PR0001: Horizontal Scale is 1000.000 Meters Per User Unit

PR0002: Vertical Scale is .305 Meters Per User Unit

PR0003: Wind Speed Scale is .447 m/sec Per User Unit

PR0004: Anemometer #1 Height Above ZA (Used for Plume Rise) is (see Table 3-2)
If Available, Anemometer #2 Height Above ZA (Used for Plume Dilution) is (see Table 3-2)
Dilution Wind Speed Option is (see Table 3-5) (If 0, One Wind Speed--at Stack Height--is Used for Plume Rise and Dilution
If 1, Wind Speed at Level #1 is Extrapolated to Stack-Top Height for Plume Rise and to Plume Height for Dilution
If 2, Wind Speed at Level #1 is Extrapolated to Stack-Top Height for Plume Rise, and the Speed at Level #2 is Extrapolated to Plume Height for Dilution)
ZA (Height in Meters Above Stack Base Elevation where the Wind Speed Profile is Assumed to Originate) = .000

PR0005: Default Wind Speed Profile Exponents as a Function of Stability Class (1-6, respectively): (see Table 3-5)

PR006: Dispersion Coefficients are Briggs Rural/ASME-1979 (Unless Replaced by On-Site Turbulence Data)

PR009: Partial Plume Penetration of Mixing Lids is Not Being Used

PR010: Buoyancy-Enhanced Plume Dispersion is Used; Parameter Alpha is: 3.162

PR011: Unlimited Mixing Height Used for Stable Condition

PR012: Transitional Plume Rise is Used

PR013: Plume Path Coefficients for Stability Classes 1-6: .500, .500, .500, .500, .500, .500

PR014: Default Vertical Potential Temperature Gradients Used for Stable Plume Rise (Classes 5 & 6): .0200, .0350

PR015: Stack-Tip Downwash is Used

PR016: Y-Component Turbulence Intensity Values are Not Provided; Stability Class is Used to Obtain Sigma-Y.

PR017: Z-Component Turbulence Intensity Values are Not Provided; Stability Class is Used to Obtain Sigma-Z.

PR018: Hourly Vertical Potential Temperature Gradients are Not Provided to Determine Stable Plume Rise; Use Default Values (see PR014)

PR019: Hourly Vertical Potential Temperature Gradients are Not Provided to Determine HCRIT; Use Default Values (see PR014)

PR020: Wind Direction Shear is Not Used in Computation of Sigma-Y.

PR021: Hourly Values of Wind Speed Profile Exponent are Not Provided; Use Defaults (see PR005)

PR022: Partial Reflection Algorithm is Being Used; Keyword Terrain Must be Used to Read in Terrain

PR023: Sector Averaging is Used for All Stabilities
Sector Widths (Deg) for Stabilities 1-6 are: 22.50, 22.50, 22.50, 22.50, 22.50, 22.50

PR024: Hourly Emissions Data are Available and Will Replace the Constant Values Specified in the Stacks Section

PR025: Detailed Information About Each Case will Not Be Printed

TABLE 3-9

MPTER MODEL OPTIONS

Option	Option List	Option Specification 0 = Ignore Option 1 = Use Option
	Technical Options	
1	Terrain Adjustments	1
2	Do Not Include Stack Downwash Calculations	0
3	Do Not Include Gradual Plume Rise Calculations	1
4	Calculate Initial Plume Size	1
	Input Options	
5	Read Met Data from Cards	0
6	Read Hourly Emissions	1
7	Specify Significant Sources	0
8	Read Radial Distances to Generate Receptors	0
	Printed Output Options	
9	Delete Emissions with Height Table	1
10	Delete Met Data Summary for Average Period	1
11	Delete Hourly Contributions	1
12	Delete Met Data on Hourly Contributions	1
13	Delete Final Plume Rise Calc on Hourly Contributions	1
14	Delete Hourly Summary	1
15	Delete Met Data on Hourly Summary	1
16	Delete Final Plume Rise Calc on Hourly Summary	1
17	Delete Avg-Period Contributions	1
18	Delete Averaging Period Summary	1
19	Delete Avg Concentrations and Hi-5 Tables	0
	Other Control and Output Options	
20	Run is Part of a Segmented Run	0
21	Write Partial Conc to Disk or Tape	0
22	Write Hourly Conc to Disk or Tape	1
23	Write Avg-Period Conc to Disk or Tape	0
24	Punch Avg-Period Conc onto Cards	0
	Default Option	
25	Use Default Option	0

Anemometer Height is: (see Table 3-2)
Exponents for Power-Law Wind Increase with Height are: (see Table 3-5)
Terrain Adjustments are: .000, .000, .000, .000, .000, .000

TABLE 3-10

LAPPES MODEL OPTIONS

Option	List	Option Specification 0 = Ignore Option 1 = Use Option
	Technical Options	
1	Terrain Adjustments	1
2	Do Not Include Stack Downwash Calculations	0
3	Do Not Include Gradual Plume Rise Calculations	1
4	Calculate Initial Plume Size	1
	Input Options	
5	Read Met Data from Cards	0
6	Read Hourly Emissions	1
7	Specify Significant Sources	0
8	Read Radial Distances to Generate Receptors	0
	Printed Output Options	
9	Delete Emissions with Height Table	1
10	Delete Met Data Summary for Average Period	1
11	Delete Hourly Contributions	1
12	Delete Met Data on Hourly Contributions	1
13	Delete Final Plume Rise Calc on Hourly Contributions	1
14	Delete Hourly Summary	1
15	Delete Met Data on Hourly Summary	1
16	Delete Final Plume Rise Calc on Hourly Summary	1
17	Delete Avg-Period Contributions	1
18	Delete Averaging Period Summary	1
19	Delete Avg Concentrations and Hi-5 Tables	0
	Other Control and Output Options	
20	Run is Part of a Segmented Run	0
21	Write Partial Conc to Disk or Tape	0
22	Write Hourly Conc to Disk or Tape	1
23	Write Avg-Period Conc to Disk or Tape	0
24	Punch Avg-Period Conc onto Cards	0
25	Complex Terrain Option	6

Anemometer Height is: (see Table 3-2)

Exponents for Power-Law Wind Increase with Height are: (see Table 3-5)

Terrain Adjustments are: .500, .500, .500, .500, .000, .000

Zmin is: 10.0

.35 ?

✓

terrain. The LAPPES terrain adjustment was selected by setting model option number 25 to 6.

4.0 STATISTICAL EVALUATION

The statistical protocol for model comparison defines an objective procedure to determine the abilities of the candidate and reference models to predict short-term average SO_2 concentrations in the vicinity of MCSES. The statistical protocol is detailed in the Air Quality Model Performance Evaluation and Comparison Protocol for Martins Creek Steam Electric Station (Londergan, 1990). Statistical performance measures are used to assess the ability of each model to predict the concentrations observed on the monitoring array. A scoring scheme was employed to award points to each model based on the model's statistical performance. The statistical protocol and scoring scheme emphasizes the ability of the model to predict the magnitude of highest, second high 3- and 24-hour average concentrations, the spatial and temporal pattern of concentrations, and the meteorological conditions under which the concentrations occur. Ultimately the model scoring the most combined points for all the performance measures is recognized as the better performing model.

4.1 Performance Measures

The performance measures and associated point scores are presented in Table 4-1. The scoring scheme emphasizes model performance for predicting the peak short-term concentrations because the preliminary modeling indicated that the emissions limits were controlled by the 3- and 24-hour averaging period air quality standards. The "top N" values referred to in Table 4-1 are the top values of the respective frequency distribution, where N=25 for 1-hour averages, N=15 for 3-hour averages and N=5 for 24-hour averages.

TABLE 4-1

PERFORMANCE SCORING

	Performance Measure	Score
1.	Highest Second High Values	
	3-hour average	18
	24-hour average	12
2.	Second High by Station, Paired by Location	
	a. Average Difference (fractional bias)	
	1-hour	6
	3-hour	18
	24-hour	12
	b. Mean Square Error (normalized)	
	1-hour	1
	3-hour	3
	24-hour	2
	c. Correlation Coefficient	
	1-hour	1
	3-hour	3
	24-hour	2
3.	Top N Values - Fraction Bias on Average Values	
	a. 1-hour (N=25)	4
	b. 3-hour (N=15)	12
	c. 24-hour (N=5)	8
4.	Second High by Meteorological Category	
	(1-hour only - three categories)	
	Fractional Bias - Each Category	12
5.	Top N Values by Meteorological Category	
	(1-hour only - three categories)	
	N = one percent of hours in category	
	10 < = N < = 25	
	Fractional Bias on Average Values - Each Category	6
6.	All Values Paired in Time and Location (1-hour)	
	a. Average Difference - Fractional Bias	7
	b. MS Error (normalized)	3
	TOTAL	130

4.2 Performance Scoring

The method for awarding points to the models for the statistical performance measures is summarized in Table 4-2. The scoring scheme relies on:

Fractional Bias - FB

$$FB=(Obs-Pred)/0.5(Obs+Pred)$$

Absolute Fractional Bias - AFB

$$AFB=|(Obs-Pred)/0.5(Obs+Pred)|$$

Absolute Average Difference - AAD

$$AAD = \frac{1}{N}\Sigma|(O_i-P_i)|$$

where:

O_i, P_i = one pair of observed and predicted values, and
N = the number of data pairs

Pearson Correlation Coefficient - R

$$R=\frac{1}{\sqrt{[\Sigma(O_i-\bar{O})^2][\Sigma(P_i-\bar{P})^2]}}\Sigma(O_i-\bar{O})(P_i-\bar{P})$$

where:

$\bar{O},\bar{P}$ = average observed and predicted values

Normalized Root Mean Square Error (NRMSE)

$$NRMSE = \frac{\sqrt{\frac{1}{N}\Sigma(O_i-P_i)^2}}{\bar{O}}$$

TABLE 4-2

PERFORMANCE SCORE CALCULATION METHODS

1. HIGHEST SECOND HIGH VALUES - ABSOLUTE FRACTIONAL BIAS (AFB)

Score = P (1-1.5 AFB), AFB $\leq$ 2/3
Score = 0 , AFB > 2/3
Where P = maximum possible score

2. SECOND HIGH BY STATION

Average difference - AFB same as above

Normalized average absolute difference (NAAD)
Score = P (1 - NAAD), NAAD $\leq$ 1
Score = 0 , NAAD > 1
Where P = maximum possible score

Correlation coefficient
Score = 4P (R - 0.75), R $\geq$ 0.75
Score = 0 , R < 0.75

3. TOP N VALUES - FRACTIONAL BIAS OF AVERAGE VALUES
Score = P (1 - 2.5 AFB), AFB $\leq$ 0.4
Score = 0 , AFB > 0.4

4. SECOND HIGH BY METEOROLOGICAL CATEGORY - AFB
Same as item 1.

5. TOP N VALUES BY METEOROLOGICAL CATEGORY - AFB on average of N values
Same as item 3.

6. ALL VALUES PAIRED IN TIME AND LOCATION

Average difference - AFB (same equation as item 3)

Normalized RMS error (NRMSE)
Score = P (1 - 0.5 NRMSE), NRMSE $\leq$ 2
Score = 0 , NRMSE > 2

4.3 Scoring at AMS-5 and AMS-12

Two of the air monitoring stations, AMS-5 and AMS-12, are located very close together and frequently respond similarly to plume events. The scoring from these two stations is specially weighted so that similarity of results from these sites does not unduly influence the model scoring and selection process. The following weighting is used for results from AMS-5 and AMS-12:

- For comparisons where overall highest second-high values are selected, no special weighting is applied.
- For comparison other than correlation coefficients where individual stations are evaluated (performance measures 2 and 6), a weighting of 0.75 times the score will be given to the results. For the correlation coefficients of the highest second-highest predicted and measured concentrations at each station, AMS-5 and AMS-12 will be evenly weighted with the other monitoring sites.
- For the evaluation of the "Top N" values (performance measures 3 and 5), each plume event is considered only once. If both sites have high predicted (observed) values during the same event, the higher predicted (observed) value is selected for inclusion in the "Top N" values. This criteria is also applied in the bootstrapping evaluation used to determine adjustment factors.

4.4 Selection Criteria

After the point scores are calculated, the total performance scores for the reference model and the candidate model are compared. To be selected, the candidate model must achieve a performance score of at least 30 points and must score higher than the reference model.

5.0 MODEL COMPARISON RESULTS

5.1 Overview

The candidate model (LAPPES) and the reference models (MPTER/RTDM) described in Section 2 were run using the input emissions and meteorological data sets described in Section 3. LAPPES was only evaluated for MCSES. The resulting sets of predicted SO_2 concentrations were compared to the observed concentrations using the statistical performance measures and scoring scheme discussed in Section 4. The objective of the statistical performance evaluation is to select the model that is the best predictor of impacts from MCSES on peak short-term (3- and 24-hour average) SO_2 concentrations on Scotts Mountain.

Tables 5-1 through 5-3 provide a summary of the highest and second highest predictions and measurements of SO_2 concentrations at each monitor. Further details are provided in Appendix A. Appendix B provides a detailed breakdown of the statistical scoring evaluation.

5.2 MCSES Contribution

Although LAPPES is only being evaluated for MCSES, it is necessary to conduct the evaluation by comparing total predictions from all sources modeled with the ambient SO_2 measurements, because the monitored data includes contributions from all sources. In all cases, other sources were modeled with RTDM. The Top N predicted and measured 1-hour, 3-hour and 24-hour concentrations (including source contributions) are presented in Appendix A with Tables A-1 through A-3 for MCSES modeled with RTDM and with Tables A-4 through A-6 for MCSES modeled with LAPPES. As can be seen, particularly when MCSES is modeled with LAPPES, several of the Top N predicted concentrations are caused by sources other than MCSES. For comparison, Tables A-7 through A-9 present a list of the Top N predictions for

TABLE 5–1
Highest and Second Highest Predicted and Observed
1–Hour Concentrations ($\mu g/m^3$) at Each Monitor

Monitor	Observed*		LAPPES		RTDM/MPTER	
	Highest	2nd Highest	Highest	2nd Highest	Highest	2nd Highest
AMS–05	692	671	1,217 7%	~~1,176~~ 1137 (100%)	2,325	2,049
AMS–07	571	548	1,241 (6%)	1,182 6%	3,397	2,109
AMS–09	689	542	912 0%	911 (5%)	4,625	2,775
AMS–10	718	430	1,122 (100%)	843	1,940	1,467
AMS–11	742	555	1,196 3%	1,087 0%	2,242	2,183
AMS–12	1,362	603	1,211 13%	~~1,157~~ 1055 (100%)	2,426	2,187
AMS–13	1,824	637	1,160 7%	1,034 (100%)	2,083	1,593

* Observed less background

TRC

TABLE 5–2
Highest and Second Highest Predicted and Observed
3–Hour Concentrations ($\mu g/m^3$) at Each Monitor

Monitor	Observed*		LAPPES		RTDM/MPTER	
	Highest	2nd Highest	Highest	2nd Highest	Highest	2nd Highest
AMS–05	277	273	467	436	1,185	1,098
AMS–07	328	292	619	427	1,474	886
AMS–09	395	272	469	414	1,542	1,298
AMS–10	288	254	485	455	1,121	679
AMS–11	300	218	593	518	1,127	786
AMS–12	630	421	515	473	1,246	1,148
AMS–13	710	331	588	524	820	694

* Observed less background

TRC

TABLE 5–3
Highest and Second Highest Predicted and Observed
24–Hour Concentrations ($\mu g/m^3$) at Each Monitor

Monitor	Observed*		LAPPES		RTDM/MPTER	
	Highest	2nd Highest	Highest	2nd Highest	Highest	2nd Highest
AMS–05	73.1	57.6	96.8	95.5	185	159
AMS–07	119	89.0	102	90.6	198	135
AMS–09	107	65.6	95.9	90.8	204	201
AMS–10	59.8	58.2	130 47%	112 76%	166	157
AMS–11	101	91.3	109	103	213	183
AMS–12	89.5	80.6	110 9%	105	196	168
AMS–13	101	70.4	117 0%	112 26%	151	143

* Observed less background

which MCSES contributes at least 50 percent. The frequency distributions of Top N predictions from all sources versus from all sources for which MCSES contributes at least 50 percent are similar, although the requirement that MCSES contribute at least 50 percent gives corresponding values throughout the distribution that are generally about 10 percent lower for the 3- and 24-hour averages and about 20 percent lower for the 1-hour averages and generally closer to the Top N monitored values.

As specified in the protocol, the model performance evaluation was conducted by comparing predictions from all sources with the monitored data, without regard to the MCSES contribution. However, as specified in the protocol, the MCSES contribution was considered in the evaluation of possible model adjustment factors (see Section 6.0).

5.3 Highest Second Highs

The abilities of the models to successfully predict the highest from among all monitors of the second highest concentration at each monitor over the study period (highest second high, or H2H) regardless of location or time are important performance measures from a regulatory standpoint. It is the H2H concentration that is evaluated for compliance with the SO_2 NAAQS. The H2H performance measures have been allocated 30 out of a total of 130 possible points in the model scoring scheme as shown in Table 4-1. The results for the H2H comparisons, scoring test 1, are presented in Appendix B on page B-1. The observed H2H concentrations, the candidate model predicted concentrations and the reference model predicted concentrations for both 3- and 24-hour averaging periods are presented. As shown in Table 4-2, the abilities of the models to predict the H2H are judged using the Absolute Fractional Bias (AFB) statistics and points are awarded as a function of the AFB. For the H2H performance measure, LAPPES performs much better than MPTER/RTDM, i.e. the LAPPES predicted 3- and 24-hour H2H concentrations are much closer to the observed concentrations. LAPPES received 20.5 points for this measure and MPTER/RTDM received 0 points.

5.4 Second Highs By Station

The second highest concentration over the study period (second high) by station, scoring test 2, is a measure of the ability of the model to predict the peak concentrations at specific locations. The results for 1-, 3- and 24-hour averaging times are presented in Appendix B on pages B-2 through B-7. A total of 48 points are available for the second high by station. The performance is judged and scored using the AFB of the average difference, the Normalized Absolute Average Difference (NAAD) and the Pearson Correlation Coefficients (PCC). As specified in the protocol and Section 4.3 above, the results for stations AMS-5 and AMS-12, because of their proximity, were weighted by a factor of 0.75 for calculation of the averages. LAPPES had some success for the 3- and 24-hour averaging periods and a marginal success for 1 hour averaging. LAPPES scored a total of 14.7 points for the second high by station. MPTER/RTDM scored no points for these measures.

5.5 Top N Values

The highest 25, 15 and 5 (N) concentrations measured and predicted over the study period for 1-, 3- and 24-hour averages, respectively, are presented on Tables A-1 through A-6 of Appendix A. As described in Section 4-3, because of the proximity of AMS-5 and AMS-12, in determining the Top N concentrations only the highest concentrations from between these two monitors is considered for each event. The averages of the Top N concentrations are the basis for scoring test 3 presented on pages B-8 through B-10. A total of 24 points is assigned to the abilities of the models to predict the Top N values. This performance measure is judged and scored using the AFB of the average predicted and observed concentrations. LAPPES had success at predicting the average of the Top N values for the 3- and 24-hour averaging periods, and scored a total of 7.6 points for this performance measure. MPTER/RTDM scored no points for predicting the Top N values.

5.6 Second High by Meteorological Category

The second high by meteorological category, scoring test 4, measures the ability of the model to predict the second high concentrations as a function of meteorological conditions. The predicted and observed data sets were binned as:

- Unstable and neutral dispersion conditions,
- Stable dispersion conditions and MCSES stack top wind speed less than 4 m/s, and
- Stable dispersion conditions and wind speed greater than or equal to 4 m/s.

The distribution of hours by meteorological category are as follows: category 1; 5,699, category 2; 1,633 and category 3; 1,884. The second high observed and predicted concentrations for 1 hour averages only were compared and scored using the AFB. The results are presented on page B-11. LAPPES scored 1.8 points for this performance measure and MPTER/RTDM scored no points.

5.7 Top N by Meteorological Category

The top predicted and observed N values for each meteorological bin defined in Section 5.6 were compared as scoring test 5. In this case, N was defined to be 1 percent of the total number of hours in each category, but restricted to be $10 \leq N \leq 25$. The results of the Top N by meteorological category are presented on pages B-12 through B-14. The AFB of the average predicted and observed concentrations for the Top N was used to judge and score model performance. Neither LAPPES nor MPTER/RTDM scored any points for these comparisons.

5.8 All Values Paired in Time and Space

The final comparison of predicted and observed concentrations is the most difficult for models. These performance measures assess the abilities of the models to predict concentrations hour by hour at specific locations. Scoring test 6 employs the AFB of the individual hour by hour observed and predicted concentrations from LAPPES and MPTER/RTDM, as well as the Normalized Root Mean Square Error (NRMSE), to judge and score model performance. The results of these comparisons are shown on page B-15. Neither model scored any points on these comparisons.

5.9 Statistical Results

The performance of both the candidate model, LAPPES, and the reference models, MPTER/RTDM, were judged and scored using a series of statistically based model evaluation performance measures. The performance measures were designed to assess the capabilities of the models for successfully predicting concentrations important to the regulatory and scientific issues associated with the air quality situation in the study region. The relative importance of the ability of the models to successfully execute each performance measure was weighted by means of a scoring scheme. The candidate model, LAPPES, scored 44.6 points out of a total possible score of 130 points. The reference models, MPTER/RTDM, scored no points. Thus, LAPPES has scored more points than RTDM/MPTER and has scored greater than the minimum required 30 points to be chosen as the best performing model.

6.0 BOOTSTRAP ANALYSIS/ADJUSTMENT FACTORS

The model evaluation protocol calls for testing the LAPPES model to determine if it predicts the upper end of the frequency distribution within defined confidence intervals. If the LAPPES model either significantly under- or over-predicts the observed concentrations, model adjustment factors would be developed to adjust the predicted concentrations. The adjustment factors would be calculated separately for 3- and 24-hour averaging periods.

According to the protocol, adjustment factors would be employed if the difference between the observed and predicted values were significant, based on two criteria:

> 1) "The average of the "Top N" predicted and observed values will be compared, using the bootstrap technique, to determine whether the difference is significant at a 95 percent confidence level. The data set will be randomly resampled 1,000 times to determine the 95 percent confidence interval.
>
> 2) If the average of the "Top N" predicted values is less than 90 percent of the observed average, the difference will be considered significant regardless of the statistical test."

For the purpose of evaluating model adjustment factors, the predicted and measured data were reviewed to identify periods of high concentrations that were caused by sources other than MCSES. As the protocol notes, such periods should be excluded from the evaluation of adjustment factors. Tables 6-1 through 6-3 present the Top N LAPPES predicted concentrations for the 1-, 3-, and 24-hour averaging periods for the modeled year. The tables show the top observed and predicted concentrations, the time and location of each event, and the contribution of each source to the predicted top events. A review of the tables shows that the one-hour predicted concentrations are frequently dominated by sources other than MCSES. To ensure that

TABLE 6-1
TOP 25 1-HOUR IMPACTS (MCSES WITH LAPPES)

Rank	Observed Impact (μg/m^3)	Year	Julian Day	Observed Event and Location: Hour	Receptor	Monitor	Total Modeled Impact (μg/m^3)	Year	Julian Day	Modeled Event and Location: Hour	Receptor	Monitor	MCSES Impact (μg/m^3)	METED Impact (μg/m^3)	H-L & WCRRF Impact (μg/m^3)	MCSES Percent of Total (%)
1	1,824	92	281	10	8	AMS13	1,241	93	19	21	2	AMS07	81.9	1,159	0.00	7%
2	1,362	92	316	24	7	AMS12	1,217	92	339	7	1	AMS05	0.00	1,092	125	0%
3	742	92	164	1	6	AMS11	1,211	92	337	21	7	AMS12	158	1,053	0.00	13%
4	718	93	98	10	5	AMS10	1,196	92	337	21	6	AMS11	36.0	1,160	0.00	3%
5	692	92	215	7	1	AMS05	1,182	92	177	21	2	AMS07	0.00	1,182	0.00	0%
6	689	92	164	8	4	AMS09	1,160	92	337	21	8	AMS13	77.0	1,083	0.00	7%
7	671	92	219	3	1	AMS05	1,137	92	210	22	1	AMS05	0.00	1,005	131	0%
8	637	92	316	24	8	AMS13	1,122	92	301	19	5	AMS10	1,122	0.00	0.00	100%
9	600	92	219	2	7	AMS12	1,087	92	210	22	6	AMS11	0.00	982	105	0%
10	571	92	164	8	2	AMS07	1,078	92	339	7	6	AMS11	0.00	957	121	0%
11	555	92	219	3	6	AMS11	1,050	92	160	20	7	AMS12	1,050	0.00	0.10	100%
12	548	92	164	1	2	AMS07	1,036	92	337	21	2	AMS07	10.4	1,025	0.00	1%
13	542	92	164	11	4	AMS09	1,034	92	193	19	8	AMS13	1,034	0.00	0.00	100%
14	542	92	316	24	2	AMS07	1,023	92	193	19	6	AMS11	1,023	0.00	0.00	100%
15	498	92	192	3	7	AMS12	1,013	92	350	6	6	AMS11	0.00	1,013	0.00	0%
16	495	92	143	2	7	AMS12	1,010	92	291	23	6	AMS11	0.00	1,003	6.60	0%
17	477	92	215	7	8	AMS13	1,009	92	339	6	8	AMS13	0.00	927	81.8	0%
18	474	92	275	8	8	AMS13	998	92	191	20	6	AMS11	998	0.00	0.00	100%
19	456	92	316	23	7	AMS12	966	93	16	20	7	AMS12	0.00	966	0.00	0%
20	430	92	219	3	8	AMS13	949	92	350	6	8	AMS13	0.00	949	0.00	0%
21	430	92	189	5	5	AMS10	940	92	291	23	1	AMS05	0.00	897	42.9	0%
22	430	92	280	16	4	AMS09	931	92	350	6	7	AMS12	0.00	931	0.00	0%
23	424	92	336	7	7	AMS12	922	93	51	22	2	AMS07	0.00	921	1.00	0%
24	406	92	276	8	8	AMS13	912	92	350	6	4	AMS09	0.30	911	0.00	0%
25	401	92	149	9	5	AMS10	911	92	301	20	4	AMS09	911	0.00	0.00	100%

TABLE 6-2
TOP 15 3-HOUR IMPACTS (MCSES WITH LAPPES)

Rank	Observed Impact (µg/m^3)	Year	Julian Day	Hour	Receptor	Monitor	Total Modeled Impact (µg/m^3)	Year	Julian Day	Hour	Receptor	Monitor	MCSES Impact (µg/m^3)	METED Impact (µg/m^3)	H-L & WCRRF Impact (µg/m^3)	MCSES Percent of Total (%)
		Observed Event and Location						Modeled Event and Location								
1	710	92	281	12	8	AMS13	619	92	192	3	2	AMS07	619	0.00	0.00	100%
2	630	92	316	24	7	AMS12	593	93	50	21	6	AMS11	593	0.00	0.00	100%
3	421	92	219	3	7	AMS12	588	93	50	21	8	AMS13	588	0.00	0.00	100%
4	395	92	164	9	4	AMS09	524	93	33	24	8	AMS13	233	291	0.00	45%
5	331	92	316	24	8	AMS13	518	92	350	6	6	AMS11	0.00	518	0.00	0%
6	328	92	164	3	2	AMS07	515	93	18	21	7	AMS12	0.00	506	8.90	0%
7	314	92	192	3	7	AMS12	502	93	34	9	8	AMS13	502	0.00	0.00	100%
8	300	92	164	3	6	AMS11	485	92	343	24	5	AMS10	485	0.00	0.00	100%
9	292	92	164	9	2	AMS07	483	92	350	6	8	AMS13	0.00	483	0.00	0%
10	292	92	164	3	7	AMS12	473	92	350	6	7	AMS12	0.00	473	0.10	0%
11	288	93	98	12	5	AMS10	469	92	191	24	4	AMS09	469	0.00	0.00	100%
12	283	92	143	3	7	AMS12	468	92	233	21	7	AMS12	0.00	441	27.5	0%
13	272	92	164	12	4	AMS09	455	92	295	21	5	AMS10	455	0.00	0.00	100%
14	272	92	280	18	4	AMS09	455	92	301	21	5	AMS10	455	0.00	0.00	100%
15	263	92	215	9	1	AMS05	442	92	233	21	6	AMS11	0.00	430	12.1	0%

TABLE 6-3
TOP 5 24-HOUR IMPACTS (MCSES WITH LAPPES)

Rank	Observed Impact (µg/m^3)	Observed Event and Location: Year	Julian Day	Hour	Receptor	Monitor	Total Modeled Impact (µg/m^3)	Modeled Event and Location: Year	Julian Day	Hour	Receptor	Monitor	MCSES Impact (µg/m^3)	METED Impact (µg/m^3)	H-L & WCRRF Impact (µg/m^3)	MCSES Percent of Total (%)
1	119	92	164	24	2	AMS07	130	92	313	24	5	AMS10	61.2	68.6	0.63	47%
2	107	92	164	24	4	AMS09	117	92	210	24	8	AMS13	0.00	101	15.6	0%
3	101	92	281	24	8	AMS13	112	93	33	24	5	AMS10	85.2	25.3	1.10	76%
4	101	92	164	24	6	AMS11	112	93	33	24	8	AMS13	29.2	80.6	1.75	26%
5	91.3	92	342	24	6	AMS11	110	93	18	24	7	AMS12	9.47	98.4	2.43	9%

the Top N predicted values were in fact attributable to MCSES, the data set was screened to eliminate individual modeled hours for which MCSES contributed less than 50 percent of the predicted concentration. Observed events for which MCSES was not a significant contributor were eliminated only if MCSES was completely off-line during that hour and the previous hour, i.e., there were no MCSES emissions and thus no significant contribution was possible. These periods included Julian day 219 at hours 1, 2, 3 and 9 and Julian day 236 at hour 1.

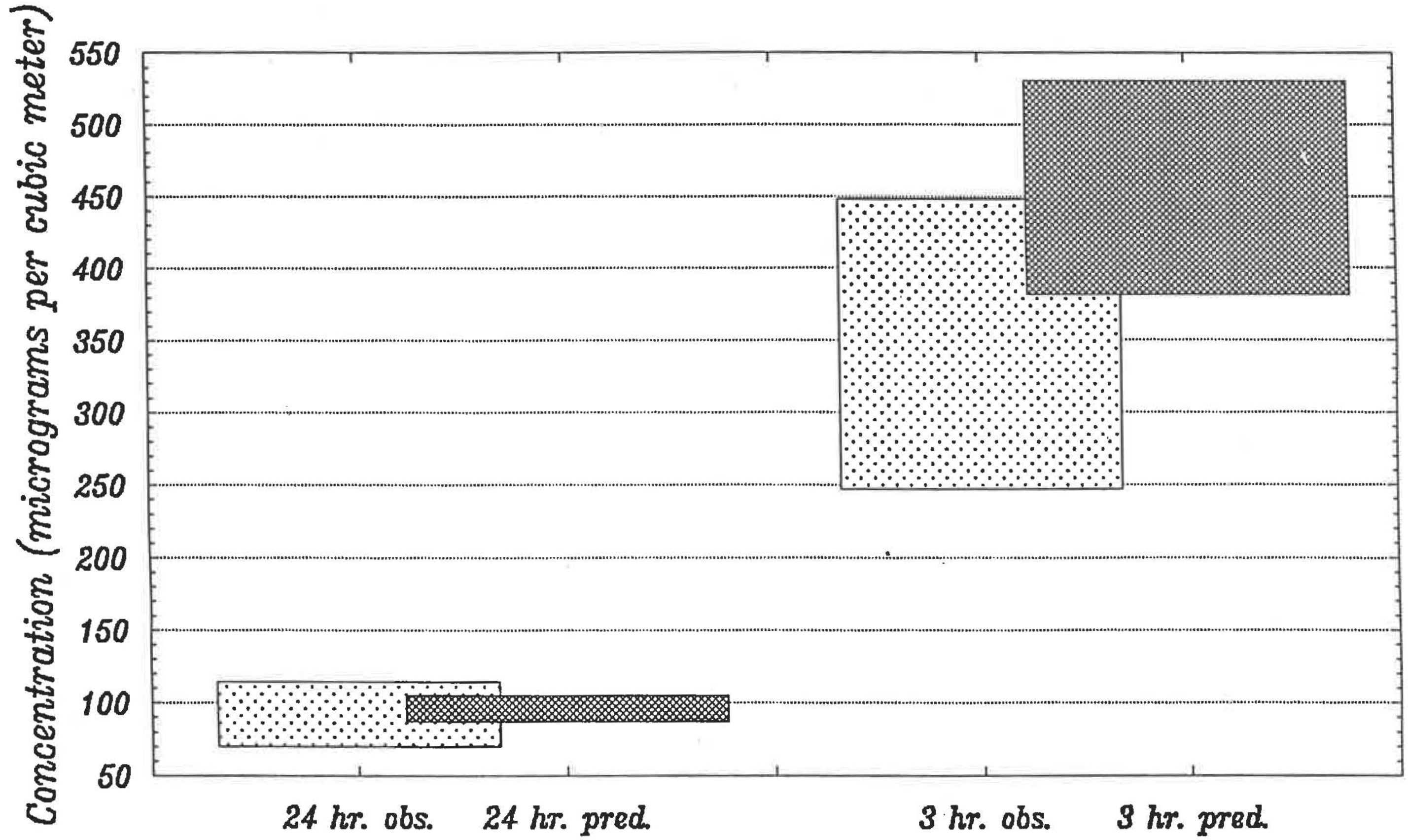
The statistical bootstrapping procedure was run by randomly sampling 3-day block periods by season, with replacement, to obtain 1000 simulations of 8760 hours each. The medians of the simulated Top N predicted and measured 3- and 24-hour concentrations were calculated for each simulated year. The results are presented in Figure 6-1 which presents the 95 percent confidence intervals for the 1,000-year bootstraps of the Top N predicted and observed 3- and 24-hour average (median) concentrations. For both averaging periods, the confidence intervals overlap, and thus the observed and predicted Top-N values are not statistically significantly different at the 95 percent confidence level.

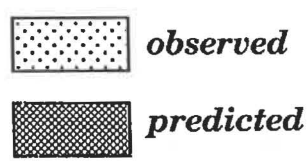
The average of the Top N 3-hour predicted values (medians) is 129.5 percent of the observed (453.14 $\mu g/m^3$ predicted versus 349.96 $\mu g/m^3$ observed) and the average of the Top N 24-hour predicted values is 94.4 percent of the observed (96.26 $\mu g/m^3$ predicted versus 101.96 $\mu g/m^3$ observed). The average of the Top N predicted values is greater than 90 percent of the average of the observed values for both averaging periods. Secondly, the average of the Top N predicted values are not more than two times the observed average.

Thus, by both evaluation criteria, the conclusion is that no under- or over-prediction corrections need to be applied to the LAPPES model results when predicting ambient concentrations impacts from MCSES on Scotts Mountain.

how were missing hrs included in 3, 24-hr avg.? why?

TRC





TRC
TRC Environmental Corporation
5 Waterside Crossing
Windsor, CT 06095
(203) 289-8631

PENNSYLVANIA POWER & LIGHT COMPANY

FIGURE 6-1.
95 PERCENT CONFIDENCE INTERVALS FOR TOP N OBSERVED AND PREDICTED CONCENTRATIONS

Date: 9/94 | Drawing No. 14715-07

7.0 SUMMARY AND CONCLUSIONS

MCSES is located in the Delaware River Valley near Martins Creek, Pennsylvania. Portions of adjacent Warren County, New Jersey have been designated as non-attainment for SO_2 by the EPA based on the results of air quality dispersion modeling. Of particular concern to PP&L are predictions of MCSES stack emission impacts in high terrain portions of Warren County.

PP&L was concerned that the EPA's screening models overpredict actual concentrations from MCSES in complex terrain (terrain above stack top), particularly Scotts Mountain in Warren County, NJ. As a result of this concern, PP&L prepared the Air Quality Model Performance Evaluation and Comparison Protocol for Martins Creek Steam Electric Station (Londergan, 1990) to evaluate predictions on Scotts Mountain following the Interim Procedures for Evaluating Air Quality Models (Revised) (EPA, 1984). The protocol details an air quality monitoring program and a rigorous statistical model performance comparison between the EPA reference models and the LAPPES model. The reference models are the RTDM and MPTER models.

Air quality, emissions and meteorological monitoring data were collected for this evaluation from May 1, 1992 through May 19, 1993. The abilities of the reference and candidate models to simulate the air quality situation on Scotts Mountain are judged using a set of statistical performance measures and the better model is selected using the agreed to model scoring scheme from the protocol.

This model performance comparison report is based upon modeling performed using data provided to TRC by PP&L. The results of the model performance comparison study are summarized as follows;

1) LAPPES is the model which best simulates the air quality impacts of MCSES at elevated terrain in the vicinity of Scotts Mountain in New Jersey,

2) LAPPES outperformed RTDM/MPTER and met the scoring criteria specified in the modeling protocol to be selected as the winning model, and

3) LAPPES did not contain a significant under or over prediction bias and no adjustment factors will be necessary.

8.0 REFERENCES

Cox, W. (1987) Protocol for Determining the Best Performing Model, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

EPA (1980), User's Guide for MPTER- A Multiple Point Gaussian Dispersion Algorithm with Terrain Adjustment, EPA-600/8-80-016, OAQPS, Research Triangle Park, NC.

EPA (1984), Interim Procedures for Evaluating Air Quality Models (Revised), EPA-450/4-84-023, OAQPS, Research Triangle Park, NC.

EPA (1987), Federal Register 52, December 31, 1987, p. 49408.

Londergan, R.J. (1990) Air Quality Model Performance Evaluation and Comparison Protocol for Martins Creek Steam Electric Station, TRC Project No. 7661-R61, TRC Environmental Consultants, Inc., East Hartford, CT.

Paine, R.J. and B.A. Egan, User's Guide to the Rough Terrain Diffusion Model (RTDM) (Rev. 3.20), Doc. No. P-D535-585, ER&T, Acton, MA.

Schiermeier, F.A. and L.E. Niemeyer (1970) Large Power Plant Effluent Study (LAPPES), Vol. I - Instrumentation, Procedures and Data Tabulations (1968), APTD 70-2, U.S. Dept. of Health, Education and Welfare, Raleigh, NC.

APPENDIX A

TOP N PREDICTIONS FOR RTDM AND LAPPES

TABLE A-1
TOP 25 1-HOUR IMPACTS (ALL SOURCES WITH RTDM)

Rank	Observed Impact (µg/m^3)	Year	Observed Event and Location Julian Day	Hour	Receptor	Monitor	Total Modeled Impact (µg/m^3)	Year	Modeled Event and Location Julian Day	Hour	Receptor	Monitor	MCSES Impact (µg/m^3)	METED Impact (µg/m^3)	H-L & WCRRF Impact (µg/m^3)	MCSES Percent of Total (%)
1	1,824	92	281	10	8	AMS13	4,625	92	1.5 m/s 337 46°, F	20	4	AMS09	4,625	0.00	0.00	100%
2	1,362	92	316	24	7	AMS12	3,397	92	1.4 " 337	20	2	AMS07	3,397	0.00	0.00	100%
3	742	92	164	1	6	AMS11	2,775	92	2.5 2.3 357 56°, E	21	4	AMS09	2,775	0.00	0.00	100%
4	718	93	98	10	5	AMS10	2,527	93	2.2/2.5 8 40°, F	7	4	AMS09	2,527	0.00	0.00	100%
5	692	92	215	7	1	AMS05	2,426	92	1.4 m/s 337 32°, F	21	7	AMS12	1,373	1053	0.00	57%
6	689	92	164	8	4	AMS09	2,242	92	1.6 301	21	6	AMS11	2,242	0.00	0.00	100%
7	671	92	219	3	1	AMS05	2,187	92	193	20	7	AMS12	2,187	0.00	0.00	100%
8	637	92	316	24	8	AMS13	2,183	92	3.3 197	5	6	AMS11	2,183	0.00	0.00	100%
9	600	92	219	2	7	AMS12	2,145	93	30 54°, E	22	4	AMS09	2,145	0.00	0.00	100%
10	571	92	164	8	2	AMS07	2,109	92	321	8	2	AMS07	2,109	0.00	0.00	100%
11	555	92	219	3	6	AMS11	2,103	93	131	20	4	AMS09	2,103	0.00	0.00	100%
12	548	92	164	1	2	AMS07	2,103	92	301	20	4	AMS09	2,103	0.00	0.00	100%
13	542	92	164	11	4	AMS09	2,083	92	337	21	8	AMS13	1,000	1,083	0.00	48%
14	542	92	316	24	2	AMS07	2,071	92	303	20	6	AMS11	2,071	0.00	0.00	100%
15	498	92	192	3	7	AMS12	1,942	92	357	21	2	AMS07	1,942	0.00	0.00	100%
16	495	92	143	2	7	AMS12	1,940	92	350	5	5	AMS10	1,940	0.00	0.00	100%
17	477	92	215	7	8	AMS13	1,902	92	321	8	4	AMS09	1,902	0.00	0.00	100%
18	474	92	275	8	8	AMS13	1,855	92	193	22	4	AMS09	1,855	0.00	0.00	100%
19	456	92	316	23	7	AMS12	1,854	93	65	8	2	AMS07	1,854	0.00	0.00	100%
20	430	92	219	3	8	AMS13	1,838	93	8	7	2	AMS07	1,838	0.00	0.00	100%
21	430	92	189	5	5	AMS10	1,745	93	33	20	4	AMS09	1,745	0.00	0.00	100%
22	430	92	280	16	4	AMS09	1,737	92	301	22	2	AMS07	1,737	0.00	0.00	100%
23	424	92	336	7	7	AMS12	1,627	92	160	20	7	AMS12	1,627	0.00	0.00	100%
24	406	92	276	8	8	AMS13	1,623	92	303	20	7	AMS12	1,623	0.00	0.00	100%
25	401	92	149	9	5	AMS10	1,619	92	293	7	6	AMS11	1,619	0.00	0.00	100%

TABLE A-2
TOP 15 3-HOUR IMPACTS (ALL SOURCES WITH RTDM)

		Observed Event and Location						Modeled Event and Location								
Rank	Observed Impact (µg/m^3)	Year	Julian Day	Hour	Receptor	Monitor	Total Modeled Impact (µg/m^3)	Year	Julian Day	Hour	Receptor	Monitor	MCSES Impact (µg/m^3)	METED Impact (µg/m^3)	H-L & WCRRF Impact (µg/m^3)	MCSES Percent of Total (%)
1	710	92	281	12	8	AMS13	1,542	92	337	21	4	AMS09	1,542	0.00	0.00	100%
2	630	92	316	24	7	AMS12	1,474	92	337	21	2	AMS07	1,133	342	0.00	77%
3	421	92	219	3	7	AMS12	1,298	92	357	21	4	AMS09	1,250	47.2	0.00	96%
4	395	92	164	9	4	AMS09	1,246	92	337	21	7	AMS12	1,246	0.00	0.00	100%
5	331	92	316	24	8	AMS13	1,148	92	193	21	7	AMS12	1,148	0.00	0.00	100%
6	328	92	164	3	2	AMS07	1,127	92	197	6	6	AMS11	1,127	0.00	0.00	100%
7	314	92	192	3	7	AMS12	1,121	92	350	6	5	AMS10	860	261	0.00	77%
8	300	92	164	3	6	AMS11	1,100	93	131	21	4	AMS09	1,100	0.00	0.00	100%
9	292	92	164	9	2	AMS07	975	93	51	21	4	AMS09	975	0.00	0.00	100%
10	292	92	164	3	7	AMS12	886	92	357	21	2	AMS07	886	0.00	0.00	100%
11	288	93	98	12	5	AMS10	846	92	321	9	2	AMS07	846	0.00	0.00	100%
12	283	92	143	3	7	AMS12	842	93	8	9	4	AMS09	842	0.00	0.10	100%
13	272	92	164	12	4	AMS09	833	92	321	9	4	AMS09	833	0.00	0.00	100%
14	272	92	280	18	4	AMS09	820	93	50	21	8	AMS13	820	0.00	0.00	100%
15	263	92	215	9	1	AMS05	815	93	33	21	4	AMS09	815	0.00	0.00	100%

TABLE A-3
TOP 5 24-HOUR IMPACTS (ALL SOURCES WITH RTDM)

Rank	Observed Impact (μg/m^3)	Observed Event and Location: Year	Julian Day	Hour	Receptor	Monitor	Total Modeled Impact (μg/m^3)	Modeled Event and Location: Year	Julian Day	Hour	Receptor	Monitor	MCSES Impact (μg/m^3)	METED Impact (μg/m^3)	H-L & WCRRF Impact (μg/m^3)	MCSES Percent of Total (%)
1	119	92	164	24	2	AMS07	213	92	197	24	6	AMS11	203	9.61	0.03	95%
2	107	92	164	24	4	AMS09	204	92	274	24	4	AMS09	203	0.00	0.14	100%
3	101	92	281	24	8	AMS13	201	92	301	24	4	AMS09	200	0.81	0.21	99%
4	101	92	164	24	6	AMS11	198	92	337	24	2	AMS07	154	42.7	1.12	78%
5	91.3	92	342	24	6	AMS11	196	92	193	24	7	AMS12	196	0.00	0.00	100%

TABLE A-4
TOP 25 1-HOUR IMPACTS (MCSES WITH LAPPES)

412 434

Rank	Observed Impact (µg/m^3)	Year	Julian Day	Observed Event and Location: Hour	Observed Event and Location: Receptor	Monitor	Total Modeled Impact (µg/m^3)	Year	Julian Day	Modeled Event and Location: Hour	Modeled Event and Location: Receptor	Monitor	MCSES Impact (µg/m^3)	METED Impact (µg/m^3)	H-L & WCRRF Impact (µg/m^3)	MCSES Percent of Total (%)
1	1,824	92	281	10	8	AMS13	1,241	93	19	21	2	AMS07	81.9	1,159	0.00	7%
2	1,362	92	316	24	7	AMS12	1,217	92	339	7	1	AMS05	0.00	1,092	125	0%
3	742	92	164	1	6	AMS11	1,211	92	337	21	7	AMS12	158	1,053	0.00	13%
4	718	93	98	10	5	AMS10	1,196	92	337	21	6	AMS11	36.0	1,160	0.00	3%
5	692	92	215	7	1	AMS05	1,182	92	177	21	2	AMS07	0.00	1,182	0.00	0%
6	689	92	164	8	4	AMS09	1,160	92	337	21	8	AMS13	77.0	1,083	0.00	7%
7	671	92	219	3	1	AMS05	1,137	92	210	22	1	AMS05	0.00	1,005	131	0%
8	637	92	316	24	8	AMS13	1,122	92	301	19	5	AMS10	1,122	0.00	0.00	100%
9	600	92	219	2	7	AMS12	1,087	92	210	22	6	AMS11	0.00	982	105	0%
10	571	92	164	8	2	AMS07	1,078	92	339	7	6	AMS11	0.00	957	121	0%
11	555	92	219	3	6	AMS11	1,050	92	160	20	7	AMS12	1,050	0.00	0.10	100%
12	548	92	164	1	2	AMS07	1,036	92	337	21	2	AMS07	10.4	1,025	0.00	1%
13	542	92	164	11	4	AMS09	1,034	92	193	19	8	AMS13	1,034	0.00	0.00	100%
14	542	92	316	24	2	AMS07	1,023	92	193	19	6	AMS11	1,023	0.00	0.00	100%
15	498	92	192	3	7	AMS12	1,013	92	350	6	6	AMS11	0.00	1,013	0.00	0%
16	495	92	143	2	7	AMS12	1,010	92	291	23	6	AMS11	0.00	1,003	6.60	0%
17	477	92	215	7	8	AMS13	1,009	92	339	6	8	AMS13	0.00	927	81.8	0%
18	474	92	275	8	8	AMS13	998	92	191	20	6	AMS11	998	0.00	0.00	100%
19	456	92	316	23	7	AMS12	966	93	16	20	7	AMS12	0.00	966	0.00	0%
20	430	92	219	3	8	AMS13	949	92	350	6	8	AMS13	0.00	949	0.00	0%
21	430	92	189	5	5	AMS10	940	92	291	23	1	AMS05	0.00	897	42.9	0%
22	430	92	280	16	4	AMS09	931	92	350	6	7	AMS12	0.00	931	0.00	0%
23	424	92	336	7	7	AMS12	922	93	51	22	2	AMS07	0.00	921	1.00	0%
24	406	92	276	8	8	AMS13	912	92	350	6	4	AMS09	0.30	911	0.00	0%
25	401	92	149	9	5	AMS10	911	92	301	20	4	AMS09	911	0.00	0.00	100%

TABLE A-5
TOP 15 3-HOUR IMPACTS (MCSES WITH LAPPES)

		Observed Event and Location						Modeled Event and Location								
Rank	Observed Impact (µg/m^3)	Year	Julian Day	Hour	Receptor	Monitor	Total Modeled Impact (µg/m^3)	Year	Julian Day	Hour	Receptor	Monitor	MCSES Impact (µg/m^3)	METED Impact (µg/m^3)	H-L & WCRRF Impact (µg/m^3)	MCSES Percent of Total (%)
1	710	92	281	12	8	AMS13	619	92	192	3	2	AMS07	619	0.00	0.00	100%
2	630	92	316	24	7	AMS12	593	93	50	21	6	AMS11	593	0.00	0.00	100%
3	421	92	219	3	7	AMS12	588	93	50	21	8	AMS13	588	0.00	0.00	100%
4	395	92	164	9	4	AMS09	524	93	33	24	8	AMS13	233	291	0.00	45%
5	331	92	316	24	8	AMS13	518	92	350	6	6	AMS11	0.00	518	0.00	0%
6	328	92	164	3	2	AMS07	515	93	18	21	7	AMS12	0.00	506	8.90	0%
7	314	92	192	3	7	AMS12	502	93	34	9	8	AMS13	502	0.00	0.00	100%
8	300	92	164	3	6	AMS11	485	92	343	24	5	AMS10	485	0.00	0.00	100%
9	292	92	164	9	2	AMS07	483	92	350	6	8	AMS13	0.00	483	0.00	0%
10	292	92	164	3	7	AMS12	473	92	350	6	7	AMS12	0.00	473	0.10	0%
11	288	93	98	12	5	AMS10	469	92	191	24	4	AMS09	469	0.00	0.00	100%
12	283	92	143	3	7	AMS12	468	92	233	21	7	AMS12	0.00	441	27.5	0%
13	272	92	164	12	4	AMS09	455	92	295	21	5	AMS10	455	0.00	0.00	100%
14	272	92	280	18	4	AMS09	455	92	301	21	5	AMS10	455	0.00	0.00	100%
15	263	92	215	9	1	AMS05	442	92	233	21	6	AMS11	0.00	430	12.1	0%

TABLE A-6
TOP 5 24-HOUR IMPACTS (MCSES WITH LAPPES)

Rank	Observed Impact (µg/m^3)	Observed Event and Location: Year	Julian Day	Hour	Receptor	Monitor	Total Modeled Impact (µg/m^3)	Modeled Event and Location: Year	Julian Day	Hour	Receptor	Monitor	MCSES Impact (µg/m^3)	METED Impact (µg/m^3)	H-L & WCRRF Impact (µg/m^3)	MCSES Percent of Total (%)
1	119	92	164	24	2	AMS07	130	92	313	24	5	AMS10	61.2	68.6	0.63	47%
2	107	92	164	24	4	AMS09	117	92	210	24	8	AMS13	0.00	101	15.6	0%
3	101	92	281	24	8	AMS13	112	93	33	24	5	AMS10	85.2	25.3	1.10	76%
4	101	92	164	24	6	AMS11	112	93	33	24	8	AMS13	29.2	80.6	1.75	26%
5	91.3	92	342	24	6	AMS11	110	93	18	24	7	AMS12	9.47	98.4	2.43	9%

TABLE A-7
TOP 25 1-HOUR Impacts (MCSES WITH LAPPES)
WERE MCSES CONTRIBUTES AT LEAST 50%

Rank	Observed Impact (µg/m^3)	Year	Julian Day	Observed Event and Location Hour	Receptor	Monitor	Total Modeled Impact (µg/m^3)	Year	Julian Day	Modeled Event and Location Hour	Receptor	Monitor	MCSES Impact (µg/m^3)	METED Impact (µg/m^3)	H-L & WCRRF Impact (µg/m^3)	MCSES Percent of Total (%)
1	1,824	92	281	10	8	AMS13	1,122	92	301	19	5	AMS10	1,122	0.00	0.00	100%
2	1,362	92	316	24	7	AMS12	1,050	92	160	20	7	AMS12	1,050	0.00	0.00	100%
3	742	92	164	1	6	AMS11	1,034	92	193	19	8	AMS13	1,034	0.00	0.00	100%
4	718	93	98	10	5	AMS10	1,023	92	193	19	6	AMS11	1,023	0.00	0.00	100%
5	692	92	215	7	1	AMS05	998	92	191	20	6	AMS11	998	0.00	0.00	100%
6	689	92	164	8	4	AMS09	911	92	301	20	4	AMS09	911	0.00	0.00	100%
7	671	92	219	3	1	AMS05	895	92	191	21	4	AMS09	895	0.00	0.00	100%
8	637	92	316	24	8	AMS13	851	93	34	8	8	AMS13	851	0.00	0.00	100%
9	600	92	219	2	7	AMS12	843	92	203	19	5	AMS10	843	0.00	0.00	100%
10	571	92	164	8	2	AMS07	831	92	301	22	2	AMS07	831	0.00	0.00	100%
11	555	92	219	3	6	AMS11	809	92	197	20	6	AMS11	809	0.00	0.00	100%
12	548	92	164	1	2	AMS07	744	92	160	20	8	AMS13	744	0.00	0.00	100%
13	542	92	164	11	4	AMS09	721	92	191	20	8	AMS13	721	0.00	0.00	100%
14	542	92	316	24	2	AMS07	715	93	50	20	6	AMS11	715	0.00	0.00	100%
15	498	92	192	3	7	AMS12	711	93	50	19	8	AMS13	711	0.00	0.00	100%
16	495	92	143	2	7	AMS12	696	92	191	22	4	AMS09	696	0.00	0.00	100%
17	477	92	215	7	8	AMS13	687	93	50	21	8	AMS13	687	0.00	0.00	100%
18	474	92	275	8	8	AMS13	684	92	303	21	7	AMS12	684	0.00	0.00	100%
19	456	92	316	23	7	AMS12	676	92	300	22	8	AMS13	676	0.00	0.00	100%
20	430	92	219	3	8	AMS13	674	93	55	20	2	AMS07	674	0.00	0.00	100%
21	430	92	189	5	5	AMS10	667	93	131	21	4	AMS09	667	0.00	0.00	100%
22	430	92	280	16	4	AMS09	664	92	321	9	5	AMS10	664	0.00	0.00	100%
23	424	92	336	7	7	AMS12	662	93	33	20	4	AMS09	662	0.00	0.00	100%
24	406	92	276	8	8	AMS13	659	93	56	18	5	AMS10	659	0.00	0.00	100%
25	401	92	149	9	5	AMS10	657	93	61	8	6	AMS11	657	0.00	0.00	100%

TABLE A-8
TOP 15 3-HOUR Impacts (MCSES WITH LAPPES)
WERE MCSES CONTRIBUTES AT LEAST 50%

Rank	Observed Impact (µg/m^3)	Year	Julian Day	Observed Event and Location Hour	Receptor	Monitor	Total Modeled Impact (µg/m^3)	Year	Julian Day	Modeled Event and Location Hour	Receptor	Monitor	MCSES Impact (µg/m^3)	METED Impact (µg/m^3)	H-L & WCRRF Impact (µg/m^3)	MCSES Percent of Total (%)
1	710	92	281	12	8	AMS13	619	92	192	3	2	AMS07	619	0.00	0.00	100%
2	630	92	316	24	7	AMS12	593	93	50	21	6	AMS11	593	0.00	0.00	100%
3	421	92	219	3	7	AMS12	588	93	50	21	8	AMS13	588	0.00	0.00	100%
4	395	92	164	9	4	AMS09	502	93	34	9	8	AMS13	502	0.00	0.00	100%
5	331	92	316	24	8	AMS13	485	92	343	24	5	AMS10	485	0.00	0.00	100%
6	328	92	164	3	2	AMS07	469	92	191	24	4	AMS09	469	0.00	0.00	100%
7	314	92	192	3	7	AMS12	455	92	295	21	5	AMS10	455	0.00	0.00	100%
8	300	92	164	3	6	AMS11	455	92	301	21	5	AMS10	455	0.00	0.00	100%
9	292	92	164	9	2	AMS07	441	92	160	21	7	AMS12	350	88.1	3.10	79%
10	292	92	164	3	7	AMS12	414	93	131	21	4	AMS09	414	0.00	0.00	100%
11	288	93	98	12	5	AMS10	412	93	61	9	6	AMS11	412	0.00	0.00	100%
12	283	92	143	3	7	AMS12	393	92	303	21	7	AMS12	393	0.00	0.00	100%
13	272	92	164	12	4	AMS09	370	92	191	21	6	AMS11	370	0.00	0.00	100%
14	272	92	280	18	4	AMS09	359	93	70	24	4	AMS09	359	0.00	0.00	100%
15	263	92	215	9	1	AMS05	358	92	193	21	8	AMS13	358	0.00	0.00	100%

TABLE A-9
TOP 5 24-HOUR IMPACTS (MCSES WITH LAPPES)
WERE MCSES CONTRIBUTES AT LEAST 50%

Rank	Observed Impact (µg/m^3)	Observed Event and Location: Year	Julian Day	Hour	Receptor	Monitor	Total Modeled Impact (µg/m^3)	Modeled Event and Location: Year	Julian Day	Hour	Receptor	Monitor	MCSES Impact (µg/m^3)	METED Impact (µg/m^3)	H-L & WCRRF Impact (µg/m^3)	MCSES Percent of Total (%)
1	119	92	164	24	2	AMS07	112	93	33	24	5	AMS10	85.2	25.3	1.10	76%
2	107	92	164	24	4	AMS09	109	93	61	24	6	AMS11	109	0.00	0.00	100%
3	101	92	281	24	8	AMS13	103	92	197	24	6	AMS11	92.9	9.60	0.00	91%
4	101	92	164	24	6	AMS11	101	92	301	24	5	AMS10	100	0.65	0.15	99%
5	91.3	92	342	24	6	AMS11	95.9	92	191	24	4	AMS09	95.9	0.00	0.00	100%

APPENDIX B

PERFORMANCE SCORING

PERFORMANCE SCORING FOR MARTINS CREEK STEAM ELECTRIC STATION

Scoring Test 1
HIGHEST SECOND-HIGH CONCENTRATION VALUES : ABSOLUTE FRACTIONAL BIAS

	Concentrations in $\mu g/m^3$		Absolute Fractional Bias	
	3-HOUR	24-HOUR	3-HOUR	24-HOUR
SO2 OBS.	421	91.3		
LAPPES	524	112	0.218	0.200
RTDM	1,298	201	1.02	0.752

POSSIBLE SCORE : 18 FOR 3-HOUR, 12 FOR 24-HOUR	SCORE:	3-HOUR	24-HOUR
= P(1-1.5 AFB), AFB<= 2/3	LAPPES	12.1	8.40
= 0.00, AFB> 2/3	RTDM	0.00	0.00

Running Subtotal:

LAPPES	20.5
RTDM	0.00

PERFORMANCE SCORING FOR MARTINS CREEK STEAM ELECTRIC STATION

Scoring Test 2
1–HOUR HIGHEST–SECOND HIGH CONCENTRATION VALUES BY STATION:

	M1 AMS05	M2 AMS07	M4 AMS09	M5 AMS10	M6 AMS11	M7 AMS12	M8 AMS13
	Concentrations in $\mu g/m^3$						
SO2 OBS.	671	548	542	430	555	603	637
LAPPES	1,176	1,182	911	843	1,087	1,157	1,034
RTDM	2,049	2,109	2,775	1,467	2,183	2,187	1,593
SO2 OBS. – LAPPES	–505	–634	–369	–413	–532	–554	–397
SO2 OBS. – RTDM	–1378	–1561	–2233	–1037	–1628	–1585	–956

564

Scoring Test 2a
1–HOUR AVERAGE DIFFERENCE

	M1 AMS05	M2 AMS07	M4 AMS09	M5 AMS10	M6 AMS11	M7 AMS12	M8 AMS13	AFB
	FB: (observed–predicted) / (0.5(observed+predicted)							
LAPPES	–0.547	–0.733	–0.507	–0.649	–0.647	–0.630	–0.476	0.599
RTDM	–1.01	–1.18	–1.35	–1.09	–1.19	–1.14	–0.858	1.12

POSSIBLE SCORE : 6	SCORE:	
= P(1–1.5 AFB), AFB<= 2/3	LAPPES:	0.606
= 0.00, AFB> 2/3	RTDM:	0.000

Running Subtotal:	
LAPPES	21.1
RTDM	0.00

PERFORMANCE SCORING FOR MARTINS CREEK STEAM ELECTRIC STATION

Scoring Test 2b
1-HOUR ABSOLUTE AVERAGE DIFFERENCE

	M1 AMS05	M2 AMS07	M4 AMS09	M5 AMS10	M6 AMS11	M7 AMS12	M8 AMS13	AAD	NAAD
	Concentrations in $\mu g/m^3$								
LAPPES	505	634	369	413	532	554	397	483	0.894 0.856
RTDM	1,378	1,561	2,233	1,037	1,628	1,585	956	1,483	2.63

0.7804

POSSIBLE SCORE: 1
= P(1-NAAD), NAAD<= 1
= 0.00, NAAD> 1

SCORE:	
LAPPES:	0.144
RTDM:	0.00

Running Subtotal:

LAPPES	21.3
RTDM	0.00

Scoring Test 2c
1-HOUR CORRELATION COEFFICIENT

	M1 AMS05	M2 AMS07	M4 AMS09	M5 AMS10	M6 AMS11	M7 AMS12	M8 AMS13
	Concentrations in $\mu g/m^3$						
	(Oi-OAVG)						
SO2 OBS.	101	-21.7	-27.0	-140	-13.9	33.3	67.4
	(Pi-PAVG)						
LAPPES	120	126	-145	-213	31.3	101.4	-21.7
RTDM	1,023	1,083	1,749	441	1,157	1,161	567
	(Oi-OAVG)*(Pi-PAVG)						
LAPPES	12,197	-2734	3,903	29,680	-434	3,377	-1465
RTDM	103,705	-23483	-47208	-61541	-16070	38,684	38,236

	AVERAGE	SIGMA O	SIGMA P	PEARSON CORRELATION
SO2 OBS.	569	72.5		
LAPPES	1,056		124	0.705
RTDM	2,052		399	0.160

POSSIBLE SCORE: 1
= 4P(PCC-0.75), PCC>= 3/4
= 0.00, PCC< 3/4

SCORE:	
LAPPES:	0.00
RTDM:	0.00

Running Subtotal:

LAPPES	21.3
RTDM	0.00

PERFORMANCE SCORING FOR MARTINS CREEK STEAM ELECTRIC STATION

Scoring Test 2
3–HOUR HIGHEST–SECOND HIGH CONCENTRATION VALUES BY STATION

	M1 AMS05	M2 AMS07	M4 AMS09	M5 AMS10	M6 AMS11	M7 AMS12	M8 AMS13
	Concentrations in $\mu g/m^3$						
SO2 OBS.	273	292	272	254	218	421	331
LAPPES	436	427	414	455	518	473	524
RTDM	1,098	886	1,298	679	786	1,148	694
SO2 OBS. – LAPPES	–164	–136	–142	–201	–300	–52.4	–193
SO2 OBS. – RTDM	–826	–594	–1026	–425	–568	–727	–363

Scoring Test 2a
3–HOUR AVERAGE DIFFERENCE

	M1 AMS05	M2 AMS07	M4 AMS09	M5 AMS10	M6 AMS11	M7 AMS12	M8 AMS13	AFB
	FB: (observed–predicted) / (0.5(observed+predicted)							
LAPPES	–0.462	–0.377	–0.414	–0.567	–0.814	–0.117	–0.451	0.470
RTDM	–1.20	–1.01	–1.31	–0.911	–1.13	–0.926	–0.709	1.03

POSSIBLE SCORE: 18	SCORE:	
= P(1–1.5 AFB), AFB<= 2/3	LAPPES:	5.30
= 0.00, AFB> 2/3	RTDM:	0.00

Running Subtotal:

LAPPES	26.6
RTDM	0.00

Scoring Test 2b
3–HOUR ABSOLUTE AVERAGE DIFFERENCE

	M1 AMS05	M2 AMS07	M4 AMS09	M5 AMS10	M6 AMS11	M7 AMS12	M8 AMS13	AAD	NAAD
	Concentrations in $\mu g/m^3$								
LAPPES	164	136	142	201	300	52.4	193	174	0.601
RTDM	826	594	1,026	425	568	727	363	637	2.19

170 0.754 0.9511

POSSIBLE SCORE: 3
= P(1– NAAD), NAAD<= 1
= 0.00, NAAD> 1

SCORE:	
LAPPES:	1.20
RTDM:	0.00

Running Subtotal:

LAPPES	27.8
RTDM	0.00

Scoring Test 2c
3–HOUR CORRELATION COEFFICIENT

	M1 AMS05	M2 AMS07	M4 AMS09	M5 AMS10	M6 AMS11	M7 AMS12	M8 AMS13
	Concentrations in $\mu g/m^3$						
			(Oi–OAVG)				
SO2 OBS.	–21.8	–2.63	–22.7	–40.1	–76.0	127	36.7
			(Pi–PAVG)				
LAPPES	–27.7	–36.8	–50.4	–8.6	54.0	9.4	59.8
RTDM	157	–55.7	356	–262	–155	206	–247
			(Oi–OAVG)*(Pi–PAVG)				
LAPPES	604	96.6	1,145	343	–4109	1,196	2,195
RTDM	–3426	147	–8097	10,507	11,795	26,152	–9056

	AVERAGE	SIGMA O	SIGMA P	PEARSON CORRELATION
SO2 OBS.	294	60.7		
LAPPES	464		40.2	0.086
RTDM	941		224	0.295

POSSIBLE SCORE: 3
= 4P(PCC–0.75), PCC>= 3/4
= 0.00, PCC< 3/4

SCORE:	
LAPPES:	0.00
RTDM:	0.00

Running Subtotal:

LAPPES	27.8
RTDM	0.00

PERFORMANCE SCORING FOR MARTINS CREEK STEAM ELECTRIC STATION

Scoring Test 2
24-HOUR HIGHEST-SECOND HIGH CONCENTRATION VALUES BY STATION

	M1 AMS05	M2 AMS07	M4 AMS09	M5 AMS10	M6 AMS11	M7 AMS12	M8 AMS13
	Concentrations in $\mu g/m^3$						
SO2 OBS.	57.6	89.0	65.6	58.2	91.3	80.6	70.4
LAPPES	95.5	90.6	90.8	112	103	105	112
RTDM	159	135	201	157	183	168	143
SO2 OBS. - LAPPES	-37.9	-1.60	-25.2	-53.4	-11.2	-24.0	-41.1
SO2 OBS. - RTDM	-102	-45.7	-136	-98.9	-91.3	-87.3	-73.0

Scoring Test 2a
24-HOUR AVERAGE DIFFERENCE

	M1 AMS05	M2 AMS07	M4 AMS09	M5 AMS10	M6 AMS11	M7 AMS12	M8 AMS13	AFB
	FB: (observed-predicted) / (0.5(observed+predicted)							(@ABS(Cn)+@ABS(Dn) + etc.)/(6.5)
LAPPES	-0.495	-0.0178	-0.322	-0.629	-0.116	-0.259	-0.452	0.323
RTDM	-0.938	-0.409	-1.02	-0.919	-0.667	-0.703	-0.683	0.758

POSSIBLE SCORE: 12	SCORE:	
= P(1-1.5 AFB), AFB<= 2/3	LAPPES:	6.18
= 0.00, AFB> 2/3	RTDM:	0.00

Running Subtotal:

LAPPES	**33.9**
RTDM	**0.00**

PERFORMANCE SCORING FOR MARTINS CREEK STEAM ELECTRIC STATION

Scoring Test 2b
24–HOUR ABSOLUTE AVERAGE DIFFERENCE

	M1 AMS05	M2 AMS07	M4 AMS09	M5 AMS10	M6 AMS11	M7 AMS12	M8 AMS13	AAD	NAAD
	Concentrations in $\mu g/m^3$								
LAPPES	37.9	1.60	25.2	53.4	11.2	24.0	41.1	27.5	0.374
RTDM	102	45.7	136	98.9	91.3	87.3	73.0	90.2	1.23

0.?41
0.733

POSSIBLE SCORE: 2
= P(1– NAAD), AFB<= 1
= 0.00, NAAD> 1

SCORE:
LAPPES: 1.25
RTDM: 0.00

Running Subtotal:
LAPPES 35.2
RTDM 0.00

Scoring Test 2c
24–HOUR CORRELATION COEFFICIENT

	M1 AMS05	M2 AMS07	M4 AMS09	M5 AMS10	M6 AMS11	M7 AMS12	M8 AMS13
	Concentrations in $\mu g/m^3$						
	(Oi–OAVG)						
SO2 OBS.	–15.6	15.8	–7.64	–15.0	18.1	7.36	–2.84
	(Pi–PAVG)						
LAPPES	–5.51	–10.4	–10.2	10.6	1.49	3.59	10.5
RTDM	–4.39	–29.1	37.6	–6.69	18.8	4.11	–20.4
	(Oi–OAVG)*(Pi–PAVG)						
LAPPES	86.3	–164	78.1	–159	26.8	26.4	–29.8
RTDM	68.6	–458	–287	101	340	30.3	58.0

	AVERAGE	SIGMA O	SIGMA P	PEARSON CORRELATION
SO2 OBS.	73.2	12.9		
LAPPES	101		8.28	–0.181
RTDM	164		21.1	–0.0781

POSSIBLE SCORE: 2
= 4P(PCC–0.75), PCC>= 3/4
= 0.00, PCC< 3/4

SCORE:
LAPPES: 0.00
RTDM: 0.00

Running Subtotal:
LAPPES 35.2
RTDM 0.00

PERFORMANCE SCORING FOR MARTINS CREEK STEAM ELECTRIC STATION

Scoring Test 3
. TOP N VALUES — FRACTIONAL BIAS ON AVERAGE VALUES

Scoring Test 3a
1 – HOUR TOP 25 VALUES

RANK	SO2 OBS.	LAPPES	RTDM
	Concentrations in $\mu g/m^3$		
1	1,824	1,241	4,625
2	1,362	1,217	3,397
3	742	1,211	2,775
4	718	1,196	2,527
5	692	1,182	2,426
6	689	1,160	2,242
7	671	1,137	2,187
8	637	1,122	2,183
9	600	1,087	2,145
10	571	1,078	2,109
11	555	1,050	2,103
12	548	1,036	2,103
13	542	1,034	2,083
14	542	1,023	2,071
15	498	1,013	1,942
16	495	1,010	1,940
17	477	1,009	1,902
18	474	998	1,855
19	456	966	1,854
20	430	949	1,838
21	430	940	1,745
22	430	931	1,737
23	424	922	1,627
24	406	912	1,623
25	401	911	1,619
Average Values	625	1,053	2,186

Fractional Bias On Average Values :

		POSSIBLE SCORE: 4	SCORE:	
LAPPES	0.511	= P (1 – 2.5 AFB), AFB <= 0.4	LAPPES	0.00
RTDM	1.11	= 0.0, AFB > 0.4	RTDM	0.00

Running Subtotal:

LAPPES	**35.2**
RTDM	**0.00**

PERFORMANCE SCORING FOR MARTINS CREEK STEAM ELECTRIC STATION

Scoring Test 3b
3 – HOUR TOP 15 VALUES

RANK	SO2 OBS.	LAPPES	RTDM
		Concentrations in $\mu g/m^3$	
1	710	619	1,542
2	630	593	1,474
3	421	588	1,298
4	395	524	1,246
5	331	518	1,148
6	328	515	1,127
7	314	502	1,121
8	300	485	1,100
9	292	483	975
10	292	473	886
11	288	469	846
12	283	468	842
13	272	455	833
14	272	455	820
15	263	442	815
Average Values	359	506	1,072

Fractional Bias On Average Values :

POSSIBLE SCORE: 12

LAPPES	0.339	= P (1 – 2.5 AFB), AFB <= 0.4	1.83
RTDM	1.00	= 0.0, AFB > 0.4	0.00

Running Subtotal:

LAPPES	37.0
RTDM	0.00

PERFORMANCE SCORING FOR MARTINS CREEK STEAM ELECTRIC STATION

Scoring Test 3c
24 – HOUR TOP 5 VALUES

RANK	SO2 OBS.	LAPPES	RTDM
	Concentrations in $\mu g/m^3$		
1	119	130	213
2	107	117	204
3	101	112	201
4	101	112	198
5	91.3	110	196
Average Values	104	116	202

Fractional Bias On Average Values :

		POSSIBLE SCORE: 8	SCORE:	
LAPPES	0.111	= P (1 – 2.5 AFB), AFB <= 0.4	LAPPES	5.79
RTDM	0.642	= 0.0, AFB > 0.4	RTDM	0.00

Running Subtotal:

LAPPES	42.8
RTDM	0.00

PERFORMANCE SCORING FOR MARTINS CREEK STEAM ELECTRIC STATION

Scoring Test 4
1–HOUR HIGHEST–SECOND HIGH BY METEOROLOGICAL CATEGORY

	Category 1	Category 2	Category 3
		Concentrations in $\mu g/m^3$	
SO2 Obs.	671	600	207
LAPPES	456	1,182	843
RTDM	313	2,775	1,340

UNDER-PREDICTED

Fractional Bias :	Category 1	Category 2	Category 3
LAPPES	0.382	0.653	1.21
RTDM	0.728	1.29	1.46

Score:	Category 1	Category 2	Category 3
LAPPES	1.71	0.0822	0.00
RTDM	0.00	0.00	0.00

POSSIBLE SCORE: 4 PER CATEGORY
= P (1 – 1.5 AFB), AFB <= 2/3
= 0.0, AFB > 2/3

SCORE:	
LAPPES	1.79
RTDM	0.00

?

CATEGORY 1 – UNSTABLE AND NEUTRAL (CLASS A,B,C AND D)
CATEGORY 2 – STABLE AND LOW WIND SPEED (CLASS E AND F, W.S. <= 4m/s)
CATEGORY 3 – STABLE AND HIGH WIND SPEED (CLASS E AND F, W.S. > 4m/s)

Running Subtotal:

LAPPES	44.6
RTDM	0.00

PERFORMANCE SCORING FOR MARTINS CREEK STEAM ELECTRIC STATION

Scoring Test 5
Top N Values by Meteorological Category

Number of Hours in Each Category		
Category	Hours	N
1	5699	25 *
2	1633	16
3	1884	19

* 10 <= N <= 25
N = one percent of hours in category but not greater than 25 or less than 10

Scoring Test 5a
1-HOUR TOP N VALUES BY METEORLOGICAL CATEGORY ONE

Category 1
Top 25 Hours
Concentration in $\mu g/m^3$

RANK	SO2 OBS.	LAPPES	RTDM
1	1,824	502	399
2	718	456	395
3	692	455	330
4	689	438	316
5	671	392	313
6	571	356	279
7	555	313	277
8	542	307	269
9	477	303	265
10	474	291	264
11	430	279	263
12	430	277	262
13	424	276	253
14	406	274	249
15	401	271	249
16	393	269	248
17	390	269	246
18	383	269	245
19	383	268	244
20	375	264	244
21	375	264	241
22	375	262	239
23	364	260	236
24	356	251	234
25	351	243	233
Average Values :	522	312	272

Fractional Bias on Average Values :

		POSSIBLE SCORE: 2	SCORE:	
LAPPES	0.502	= P (1 − 2.5 AFB), AFB <= 0.4	LAPPES	0.00
RTDM	0.630	= 0.0, AFB > 0.4	RTDM	0.00

Running Subtotal:

LAPPES	44.6
RTDM	0.00

Scoring Test 5b
1-HOUR TOP N VALUES BY METEOROLOGICAL CATEGORY TWO

Category 2
Top 16 Hours
Concentration in $\mu g/m^3$

RANK	SO2 OBS.	LAPPES	RTDM
1	1,362	1,241	4,625
2	742	1,217	3,397
3	637	1,211	2,775
4	600	1,196	2,527
5	548	1,182	2,426
6	542	1,160	2,242
7	498	1,137	2,187
8	495	1,087	2,183
9	456	1,078	2,145
10	388	1,050	2,109
11	362	1,036	2,103
12	356	1,034	2,103
13	356	1,023	2,083
14	354	1,013	2,071
15	343	1,010	1,942
16	341	1,009	1,940
Average Values :	524	1,105	2,429

Fractional Bias on Average Values :

		POSSIBLE SCORE: 2	SCORE:	
LAPPES	0.714	= P (1 − 2.5 AFB), AFB <= 0.4	LAPPES	0.00
RTDM	1.29	= 0.0, AFB > 0.4	RTDM	0.00

Running Subtotal:

LAPPES	44.6
RTDM	0.00

PERFORMANCE SCORING FOR MARTINS CREEK STEAM ELECTRIC STATION

Scoring Test 5c
1-HOUR TOP N VALUES BY METEOROLOGICAL CATEGORY THREE

Category 3
Top 19 Hours
Concentration in $\mu g/m^3$

RANK	SO2 OBS.	LAPPES	RTDM
1	430	1,122	1,593
2	335	998	1,437
3	207	895	1,340
4	204	851	1,321
5	183	843	1,198
6	181	721	1,197
7	181	715	1,185
8	176	711	1,151
9	173	703	1,115
10	162	696	1,052
11	162	687	1,031
12	160	678	1,023
13	160	678	975
14	149	676	956
15	147	675	938
16	147	674	937
17	144	667	933
18	142	662	927
19	139	659	913
Average Values :	189	753	1,117

Fractional Bias on Average Values :

		POSSIBLE SCORE: 2	SCORE:	
LAPPES	1.20	= P (1 − 2.5 AFB), AFB <= 0.4	LAPPES	0.00
RTDM	1.42	= 0.0, AFB > 0.4	RTDM	0.00

Running Subtotal:

LAPPES	44.6
RTDM	0.00

PERFORMANCE SCORING FOR MARTINS CREEK STEAM ELECTRIC STATION

Scoring Test 6
ALL 1–HOUR VALUES – PAIRED IN TIME AND LOCATION

a. Average Difference – fractional bias				
		POSSIBLE SCORE: 7	SCORE:	
THE AVERAGE FRACTIONAL BIAS FOR LAPPES IS :	1.63	= P (1 – 2.5 AFB), AFB <= 0.4	LAPPES	0.00
THE AVERAGE FRACTIONAL BIAS FOR RTDM IS :	1.63	= 0.0, AFB > 0.4	RTDM	0.00

b. MS Error (Normalized)				
		POSSIBLE SCORE: 3	SCORE:	
THE NRMSE FOR LAPPES IS :	4.81	= P (1 – 0.5 NRMSE), NRMSE <= 2	LAPPES	0.00
THE NRMSE FOR RTDM IS :	7.41	= 0.0, NRMSE > 2	RTDM	0.00

GRAND TOTALS :

LAPPES	44.6
RTDM	0.00