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Results of the Independent Evaluation of ISCST3 and ISC-PRIME

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REPORT SUMMARY

Background

Aerodynamic building downwash is a phenomenon caused by eddies created by air movement around building obstacles. Through the use of the Industrial Source Complex (ISCST3) model, EPA modeling guidelines have incorporated these effects for predicting ground-level concentration calculations. Unfortunately, the ISCST3 model retains numerous discontinuities.

In 1992, the Electric Power Research Institute (EPRI) decided to embark upon a program (project PRIME: Plume Rise Model Enhancements) to design a new downwash model to correct the deficiencies in the ISC model. The resulting downwash module, PRIME, has been installed in the ISCST3 model by Earth Tech as a replacement for the current algorithm; the resulting model is referred to as "ISC-PRIME". As part of the study, EPRI contracted with ENSR to prepare existing data bases for use in model development as well as an independent ("hands-off') model evaluation study. This report describes in detail the results of the evaluation of ISCST3 and ISC-PRIME with data bases reserved for the independent model evaluation study.

Objectives

There are many steps involved in obtaining regulatory approval of a new air dispersion modeling technique. One of the important steps is demonstrating that the new algorithm shows equivalent or superior prediction performance over a variety of applications settings. EPRI has maintained discussions with the U.S. Environmental Protection Agency (EPA) throughout the PRIME project to negotiate a model evaluation protocol and keep the agency informed regarding the PRIME model formulation as well as progress in the model evaluation program. This will help to facilitate promulgation of the new model as an approved guideline technique.

Approach

After an extensive search, ENSR identified 14 candidate data bases for the model evaluation. These data bases consisted of 8 tracer experiments, 3 long-term (1-year) data sets, and 3 wind tunnel studies.

Four of the data sets were reserved for the independent model evaluation:

1. a conventional 1-year monitoring network near the Bowline Point Station, New York (source type: electric utility; two 600-MW units, each with an 86.9-m stack; monitor coverage consisted of four close-in sites at distances from 251 to 848 meters

2. a tracer experiment conducted by the American Gas Association (AGA) in Texas and Kansas (source type: gas compressor station stacks; 63 hours available; tracer sampler coverage from 50 to 200 meters)

3. a tracer experiment at the EOCR Test Reactor Building in Idaho (source type: nonbuoyant releases at 30 m, 25 m, and ground level; 22 release hours;

4. a wind tunnel study of the Lee Power Plant (source type: 64.8-m steam boiler stacks, each 64.8 meters high; numerous cases studied: in neutral conditions, 78 combinations of wind direction, wind speed, and plume buoyancy; in stable conditions, 14 combinations of wind direction and plume buoyancy; tracer sampler coverage at six distances ranging from 150-900 meters)

For the Bowline Point 1-year data base, each model was run for the fun year with hourly emissions, and concentration predictions were obtained at four dose-in monitors. Products resulting from the evaluation include tabulations of the top several observed and predicted concentrations at each monitor, quantile-quantile (Q-Q) plots of ranked 1-hour predicted versus observed concentrations at each monitor (for all cases as well as certain meteorological classes), and other assorted concentration scatterplots and residual plots of the ratio of the predicted to the observed concentration (C_p / C_o versus variables such as wind speed.

For the tracer data bases (ECCR and AGA), the observed data values for each hour and arc of monitors were carefully analyzed to determine the locations of the peak concentrations on the monitoring arcs. The models were then run with the plume directed toward the peak observed concentration. There were a total of 214 arc-hours available from the EOCR data set, and 78 arc-hours from the AGA data set. For these two data bases, concentration scatterplots as well as several residual plots of C_p / C_o against variables such as distance and stability class were prepared.

The wind tunnel observed concentrations (Lee Power Plant) were available in the form of one "centerline" concentration at various distances. The models were run by advecting the plume directly toward the line of monitors. A total of 1,062 "arc-hours" were available for the Lee data set. Concentration scatterplots and residual plots similar to those produced for the tracer data bases were produced.

Other evaluation procedures for all of the data bases involved computing test statistics from the observed and predicted concentrations. For full-year data bases with only a few monitors such as the Bowline Point data base, an appropriate test statistic is the robust highest concentration (RHC) estimate, which is based upon the highest 25 concentrations. For the two tracer data bases and the wind tunnel data base, a test statistic based upon the median of the upper quartile of the predictions and observations has been used for each evaluation subset, or "regime".

Results

Evaluation results are provided in tabular and in graphical form with considerable detail. The report employs 31 appendices to provide a comprehensive record of the model evaluation results.

The overall conclusions from the performance evaluation are as follows:

- ISC-PRIME is generally unbiased or overpredicts, so its use is protective of air quality.
- ISCST3 is especially conservative in stable conditions, and ISC-PRIME performs much better under these conditions. This disparity between model performance appears to be most notable for buoyant point sources. This result is consistent with the findings of other investigators.
- Under neutral conditions, the performance of the two models is more comparable, but ISC-PRIME is somewhat better. The relatively good performance of the ISCST3 in neutral conditions is expected because the model was formulated based upon wind tunnel experiments carried out in neutral, high wind conditions. This results is consistent with the findings of other investigators.
- ISC-PRIME has a statistically better performance result for each data base in the independent evaluation.
- In some cases, as noted above, the use of the current ISCST3 model will produce extremely conservative results under stable conditions for applications involving highly buoyant plumes.

- Under the terms of the model evaluation protocol, ISC-PRIME has a technically superior formulation and has consistently demonstrated a better performance evaluation result.

EPRI Perspective

(to be completed by EPRI)

Interest Categories

(to be completed by EPRI)

ACKNOWLEDGMENTS

ENSR's production of the evaluation data bases, the model evaluation protocol, and the evaluation results were sponsored by the Electric Power Research Institute (Project RP 3527-02) with Dr. Charles Hakkarinen as the project director.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1

PROJECT OVERVIEW

Aerodynamic building downwash is a phenomenon caused by eddies created by air movement around building obstacles. Since the early 1980's with the release of the Industrial Source Complex (ISC) model (Bowers et al., 1979), EPA guideline models have incorporated these effects in ground-level concentration calculations. Unfortunately, the current ISC model, ISCST3 (USEPA, 1995a) retains numerous discontinuities in the present collection of building downwash algorithms.

For several permit applications, air dispersion modelers have found that their "design" concentrations (those that determine the emission limits) are based upon modeled downwash concentrations. Numerous background sources recently have been and will be modeled that have never had building downwash impacts considered in the determination of their emission limits. An accurate determination of building downwash effects is now and will increasingly become more important. Unfortunately, few evaluation studies have been conducted in this area.

In view of the importance of the building downwash modeling algorithm, the Electric Power Research Institute (EPRI) decided in 1992 to embark upon a program to design a new downwash model to correct the deficiencies mentioned above. The EPRI project is referred to as PRIME, for Plume Rise Model Enhancements. Earth Tech developed a new PRIME algorithm to replace the current plume rise and downwash model in ISCST3 (see Schulman et al., 1998). As part of the study, EPRI contracted with ENSR to prepare existing data bases for use in model development as well as an independent ("hands-off') model evaluation study. This report describes in detail the data bases used for the independent model evaluation study and the results of the model performance evaluation.

In 1995, a model evaluation protocol (Paine, 1995) was negotiated with EPA, with significant input from a standing workgroup on downwash modeling. The protocol described the models to be run, the data bases, and the type of evaluation tests to be conducted. This report provides evaluation results consistent with the protocol.

Section 2 of this report reviews the results of the evaluation data base search. The model evaluation tests are described in Section 3. A technical overview of the PRIME module and a description of recent updates to the ISC-PRIME model are discussed in Section 4. Results for the four separate independent data bases, Bowline Point, American Gas Association, EOCR, and the Lee Power Plant, are provided in Sections 5, 6, 7, and 8, respectively. An overall summary of the evaluation results And study conclusions are given in Section 9.

2

SUMMARY OF EVALUATION DATA BASES

Much of the progress that has been made to date in designing building downwash models has been based upon wind tunnel studies (e.g., Huber and Snyder, 1982; Huber, 1984; Ramsdell, 1990; Snyder, 1993). The advantage of these experiments in model development is their ability to set up hypothetical conditions involving building and receptor configurations that test numerous scenarios that could not be tested in the real world. For the PRIME project, significant assistance was provided by EPA's Fluid Modeling Facility (Snyder, 1992) and by Monash University in Australia (Melbourne and Taylor, 1994a,b). The data provided by these facilities, which include both neutral and stable conditions, were used in the development of ISC-PRIME. The model development focus was upon visualization of the plume dynamics and checking horizontal and vertical profiles as well as testing the model against measured ground-level concentrations.

In its search of data bases for the model evaluation, ENSR also focused upon previously conducted real-world field experiments for this independent evaluation study. Although EPRI had gathered some new field data for evaluating downwash models (Sayreville, NJ), these data had few ground-level concentration measurements and were best used for model development purposes. EPRI also recognized that the use of existing data bases would be important to supplement the EPRI field effort. Early in the search process, it was clear that the available data bases would have to be a mixture of tracer studies, fluid modeling studies, and conventional 1-year data bases. While the wind tunnel studies had the advantage of using different physical scenarios, the field studies avoided boundary conditions and other limitations that wind tunnel studies have to deal with for simulating real-world conditions.

After an extensive search, ENSR identified 14 candidate data bases for the model evaluation, as discussed by Paine (1995). These data bases, consisting of 8 tracer experiments, 3 long-term (1 year) data sets, and 3 wind tunnel studies, are briefly summarized below.

1. Tracer Site #1: Alaska North Slope
    - Source type: Highly buoyant gas turbine, stack is 39 meters high
    - Number of hours available: 44

- Tracer sampler coverage: from 20 to 3000 meters downwind

2. Tracer Site #2: American Gas Association (AGA) Experiments (Texas and Kansas)
   - Source type: Gas compressor station stacks; stack height to building height ratio ranging from 0.95 to 2.52
   - Number of hours available: 63
   - Tracer sampler coverage: from 50 to 200 meters
3. Tracer Site #3: Duane Arnold Energy Center (DAEC), (Iowa)
   - Source type: Non-buoyant releases at heights of 46 m, 24 m, and ground level
   - Number of hours available: 12 from 46 m, 16 from 24 m, 11 from ground level
   - Tracer sampler coverage: 300 and 1000 meters
4. Tracer Site #4: EOCR Test Reactor Building (Idaho)
   - Source type: Non-buoyant releases at 30 m, 25 m, and ground level
   - Number of hours available: 22 elevated release hours
   - Tracer sampler coverage: 37, 68, 187, 386, 794, 1200, and 1600 meters
5. Tracer Site #5: Rancho Seco Nuclear Power Station (California)
   - Source type: Non-buoyant releases of two tracer gases at 43 m, 16.5 m, and ground level
   - Number of hours available: 19 with simultaneous releases at two heights
   - Tracer sampler coverage: from 100, 200, 400, and 800 meters
6. Tracer Site #6: University of Vermont/Burlington
   - Source type: Buoyant release from Central Heating Plant stack
   - Number of hours available: 4
   - Tracer sampler coverage: from 90 to 180 meters

7. Tracer Site #7: Millstone Nuclear Power Station (Connecticut)
    - Source type: Slightly buoyant release from reactor and turbine buildings
    - Number of hours available: 36
    - Tracer sampler coverage: 350, 800, and 1500 meters
8. Tracer Site #8: Downtown Minneapolis (Minnesota)
    - Source type: Buoyant plumes from steam boilers in an urban core of very tall buildings
    - Number of hours available: 43
    - Tracer sampler coverage: adjacent to source, and at distances of 200, 350, 600, and 1000 meters
9. Conventional Network #1: Bowline Point Station, New York
    - Source type: electric utility; two 600-MW units, each with an 86.9-m stack
    - Length of period: 1 year
    - Monitor coverage: four close-in sites at distances from 251 to 848 meters
10. Conventional Network #2: (Confidential)
    - Source type: electric utility; stacks at heights ranging from 117.3 to 152.4 meters
    - Length of period: 1 year
    - Monitor coverage: three sites at distances ranging from 0.9 to 3.3 kilometers
11. Conventional Network #3: (Confidential)
    - Source type: electric utility; stacks at heights ranging from 38.7 to 87.8 meters
    - Length of period: 1 year
    - Monitor coverage: four sites at distances ranging from 1.8 to 3.4 kilometers
12. Wind Tunnel Study #1 (Snyder; EPA Fluid Modeling Facility)
    - Source type: steam boiler and combustion turbine stacks

- Number of cases studied: 24 scenarios with a steam boiler stack, 18 with a combustion turbine influenced by the turbine structure, and 24 with a combustion turbine influenced by the steam boiler building

- Tracer sampler coverage: vertical concentration profile at 15 building heights downwind for all cases; 4 cases with vertical profiles at additional distances

13. Wind Tunnel Study #2 (Melbourne and Taylor; Monash U.; Lee Power Plant)

- Source Type: steam boiler stack, 64.8 meters high

- Number of cases studied: in neutral conditions, 78 combinations of wind direction, wind speed, and plume buoyancy; in stable conditions, 14 combinations of wind direction and plume buoyancy

- Tracer sampler coverage: ground-level concentrations at six distances ranging from the cavity zone to beyond the wake (150-900 meters)

14. Wind Tunnel Study #3 (Melbourne and Taylor; Monash U.; Sayreville Power Plant)

- Source Type: combustion turbine stack, 12 meters high

- Number of cases studied: in neutral conditions, 20 combinations of wind speed and plume buoyancy; in stable conditions, 6 cases with varying wind directions

- Tracer sampler coverage: ground-level concentrations at six distances ranging from the cavity zone to beyond the wake (10 - 100 meters)

After further analysis into the condition and availability of these data bases, EPRI decided to process the data for nine of the twelve mentioned above; data bases #5, #8, #10, #12, and #14 were given a lower priority based upon availability of resources as well as specific drawbacks for these data bases: representation of nonbuoyant releases by another data base (#5), site complexity (#8), difficulties in data archive retrieval (#11), and preference for ambient field data (#12, #14).

After several discussions among the EPRI project team members, a plan for dividing the currently processed data bases into those used for model development (by Earth Tech) and those used for an independent "hands-off" evaluation (by ENSR) was finalized in 1995. The strategy for allocating the data bases between the two groups was to provide a large range of stack heights to building heights as well as plume buoyancies, for the independent evaluation, while maximizing the availability of data available for the EPRI model development. The final assignments of data bases to these two groups are listed below.

Model Development Phase:

- Conventional network #2,
- University of Vermont/Burlington,
- Alaska North Slope,
- Millstone Nuclear Power Station, and
- DAEC data base.

The model development work also involved data obtained from the February 1994 field experiment in Sayreville, NJ (featuring a gas turbine) as well as available wind tunnel data.

Independent Model Evaluation Phase:

- Bowline Point (Conventional Network #1), see Figures 2-1 and 2-2;
- American Gas Association experiments (Tracer Site #2); see Figures 2-3 and 2-4;
- EOCR Test Reactor Building (Tracer Site #4), see Figure 2-5 and 2-6; and
- Lee Power Plant (Wind Tunnel Study #2), see Figures 2-7 and 2-8.

The first two data bases listed for the independent evaluation involve buoyant plumes and were previously used in the evaluation of the current ISCST3 model. The Bowline Point data base represents a full year of data for a moderately buoyant source reflective of electric utility plants, which tested the models under a wide variety of meteorological conditions. The American Gas Association experiments feature a much more buoyant plume with a wide variety of stack height to building height ratios. The inclusion of these two data bases for the independent evaluation provided historical continuity with the API study (which included the AGA and the Bowline Point data; see Schulman and Hanna, 1986), while actually giving ISCST3 a slight advantage in the model competition over the contending model, ISC-PRIME, because the Scire-Schulman algorithm has already been evaluated with these data bases. This advantage was somewhat offset by providing to the model development team one half of the Bowline Point data base (needed because certain key elements of the conventional data base #2 listed above were not available). The EOCR data base represented a nonbuoyant release, which is an important class of sources for consideration of air toxics releases. The Lee Power Plant data base considered a steam boiler stack in both neutral and stable conditions at six distance ranges. As such, the inclusion of this wind tunnel data base significantly widened the scope of the evaluation tests, since it is recognized that the use of real-world data bases restricts model testing in terms of building aspect ratios and building stack orientations.

Table 2-1 provides a list of the stack exhaust parameters used in the independent evaluation for the Bowline Point, AGA, and Lee Power Plant data bases. The EOCR releases were non-buoyant in nature, from small roof top or ground-level point sources.

Table 2-1
Exhaust Parameters for Buoyant Releases: PRIME Independent Model Evaluation

Site	Stack Height (m)	Stack Gas Temperature (°K)	Stack Gas Exit Velocity (m/sec)	Stack Diameter (m)
Bowline Point	87	370-400	10-30	5.7
AGA	10, 25	620-640	8-9	0.6
Lee	65	440	17	2.5

Figure 2-1 Photograph taken in early 1980's of Bowline Point plant.

Figure 2-2 Location of the Bowline Point plant and air quality monitors.

Figure 2-3 Plan view of the natural gas compressor station at Site I, AGA field study.

Figure 2-4 Plan view of the locations of tracer samplers at Site I AGA field study.

Figure 2-5 Plot plan of the innermost arcs of the EOCR grid.

Figure 2-6 Terrain map of the entire EOCR grid.

Figure 2-7 Plan view of the Lee Power Plant model and nearby buildings showing the Power Station Units and the zero reference position used in the Monash wind tunnel tests.

Figure 2-8 Photograph of the 1:150 scale model in the 4-m high by 12-m wide by 40-m long Monash wind tunnel working section.

3

MODEL EVALUATION PROCEDURE

For the Bowline Point 1-year data base, both models being evaluated (ISCST3 and ISC-PRIME) were run for the full year with hourly emissions, and concentration predictions were obtained at four near-field monitors. (Results from two of the monitors were subsequently set aside as representing too few significant concentrations; more details are presented in Section 5.) Products resulting from the evaluation include tabulations of the top several observed and predicted concentrations at each monitor, quantile-quantile (Q-Q) plots of ranked 1-hour predicted versus observed concentrations at each monitor (for all cases as well as certain meteorological classes), and other assorted concentration scatterplots and residual plots of the ratio of the predicted to the observed concentration (C_p / C_o) versus variables such as wind speed.

For the tracer data bases (EOCR and AGA), the observed data for each hour and arc of monitors were plotted (for example, see Figure 3-1) and carefully analyzed to determine the locations of the peak concentrations on the monitoring arcs. The models were then run with the plume directed toward the peak observed concentration. There were a total of 214 arc-hours available from the EOCR data set, and 78 arc-hours from the AGA, data set. Consistent with procedures developed by Irwin (1996), a Gaussian fit to the arcwise observed concentrations in the vicinity of the peak location was computed and was used as the appropriate observed value for comparing predicted values against. For these two data bases, concentration scatterplots as well as several residual plots of C_p / C_o against variables such as distance and stability class were prepared.

The wind tunnel observed concentrations (Lee Power Plant) were available in the form of one "centerline" concentration at various distances. The models were run by advecting the plume directly toward the line of monitors. A total of 1,062 "arc-hours" were available for the Lee data set. Concentration scatterplots and residual plots similar to those produced for the tracer data bases were produced.

Other evaluation procedures involved computing test statistics from the observed and predicted concentrations. The evaluation process made use of EPA procedures (Cox, 1988; Cox and Tikvart, 1990; Lee and Irwin, 1995; see Paine, 1995 for details) and those introduced by Hanna (1989). A summary of the procedure is given here, with specific references to the current application involving several diverse data bases and two or more models.

Figure 3-1 Plot concentration arcs for an EOCR experiment.

For full-year data bases with only a few monitors such as the Bowline Point data base, an appropriate test statistic is the robust highest concentration estimate, which was based upon the highest 25 concentrations (Cox, 1988; Cox and Tikvart, 1990). The robust highest concentration is based on a tail exponential fit to the upper end of the concentration distribution, and is computed as:

RHC = X(N) + SLOPE*log((3N-l)/2), where

SLOPE = XBAR - X(N)

XBAR = Average of the N-1 largest values

X(N) = Nth largest value

N = the number of values exceeding a threshold value, or 26, whichever is less.

For consistency among all data bases, only 1-hour averages were evaluated for the Bowline Point data base. In each evaluation regime, the highest predicted and observed RHC value among all receptors was selected for comparison.

For the tracer data bases or the wind tunnel experiments, arc maxima (denoted by Lee and Irwin as the "maximum arc-wise concentration", or MAC) defined one sample point for an observation or prediction. For the EOCR and AGA experiments, a maximum arcwise concentration based on a <u>Gaussian fit</u> to the concentration values along the receptor arc was used. For these data bases, a test statistic based upon the median of the upper quartile of the predictions and observations was used for each evaluation regime. For all data bases except the Bowline Point site (which featured two stacks with some considerable separation), the concentrations were normalized by dividing by the emission rate; the resulting units are micro-seconds per cubic meter.

For each data set within each evaluation regime, the primary statistic was the Fractional Bias (FB), defined as:

$FB = [\, 2*(C_o - C_p) \;/\; (C_o + C_p)]$, where

C_o is. the average of the observed concentration test statistics,

Cp is the average of the predicted concentration test statistics, and

The fractional bias is negative for overpredicting models and positive for underpredicting models. A conversion from FB to the predicted to observed ratio of concentrations is: pre/obs ratio = (2.0 - FB)/(2.0 + FB). The absolute value of the fractional bias, or AFB, ranges in magnitude from 0.0 for a perfect model to a value approaching 2.0 for a model with no skill. Therefore, the model with the lower AFB value is the best performer.

The evaluation data bases were categorized into several regimes. For the evaluation process, the defined regimes were based on stack height to building height ratio, wind speed, stability class and downwind distance.

Three downwind distance regimes of concern were based upon the value of L_b, which is the lesser of the building height and width. The distance regimes were the:

- cavity zone (up to $3*L_b$ downwind),
- wake zone (from 3 to 10 L_b downwind), and
- region beyond the wake zone (greater than $10*L_b$ downwind).

Three meteorological regimes of concern were based on stability class and the 10-meter wind speed. The meteorological regimes were:

- stable (stability classes 5 or 6) and the 10-m wind speed less than or equal to 4 m/sec,
- unstable or neutral (stability classes 1-4) and the 10-m wind speed less than or equal to 4 m/sec, and
- any stability with the 10-m wind speed greater than 4 m/sec.

The two stack height/building height ratio regimes were based on the nature of the available data. A ratio of 1.25 was chosen to divide the data into tall stack/buoyant releases versus low stack or non-buoyant releases.

For the AGA and EOCR tracer study data bases, each case (ambient sampler arc) was placed in one of the three distance regimes. Each case was then further categorized into the three meteorological regimes and two stack height/building height ratio regimes, if a sufficient number of cases were present in each category.

As with the AGA and EOCR studies, the Lee wind tunnel tracer study cases were placed in one of the three distance regimes, and then further categorized into the three meteorological regimes. The cases were also analyzed based on operating load (100%, 75% and 50% of maximum load), and based on emitting sources (Units 1 and 2, Unit 3). All cases fell into the tall stack/buoyant release regime.

The tracer study observation data bases (EOCR and AGA) on each sampler arc were processed with a gaussian fitting program, PLMFIT (as supplied by Irwin, 1996) to determine an alternative to the peak observed value on each arc, consistent with the model evaluation protocol (Paine, 1995).

A post-processing program called "BOOT25" was developed as a modified version of BOOT, a statistical program based on bootstrap resampling that was documented and supplied by Hanna (1989). BOOT25 used the median of the upper quartile of values for calculation of the fractional bias (FB), as recommended by Lee and Irwin (1995), for each of 1000 simulations. The fractional bias was also determined for the various regimes mentioned. The output of BOOT25 included two types of 95% confidence intervals as discussed by Hanna (1989), using the "seductive" and the "robust" methods. In accordance with Hanna's recommendations, the seductive interval was selected for reporting results for this evaluation procedure. For the tracer and wind tunnel data bases, the models were judged not to be significantly different if the 95% confidence interval of the difference in FB values overlapped zero. Otherwise, the model with the lower FB range was judged to have a significantly better performance.

In the process of selecting evaluation regimes, it was important to maintain a minimum number of cases within each regime that was assessed. Lee and Irwin (1995) recommended a minimum number of about 20 cases from any one experiment if the upper quartile statistic is used for comparison purposes. The number of case hours for each regime is shown in Table 3-1. Due to the limited number of hours in the downwash tracer experiments, the number of case hours for some regimes was slightly less than the recommended 20 hours. For evaluation purposes, the following regime combinations were assessed:

Table 3-1
Number of Experimental Data Points with Observations in Various Model Evaluation Regimes

Met Class	Stable, 10-m ws ≤ 4 m/s	Unstable/Neutral 10-m w/s ≤ 4 m/s	Any Stability, 10-m ws > 4 m/s
Stack:Building Height Ration ≤ 1.25			
Cavity Region (x ≤ 3Lb)	EOCR-17	EOCR-7	EOCR-10
Wake Region (3Lb < x ≤ 10Lb)	EOCR - 27	AGA - 7 EOCR - 7	AGA - 33 EOCR - 18
Beyond Wake Region (x > 10Lb)	EOCR - 64	AGA - 4 EOCR - 21	AGA - 16 EOCR - 43
Stack:Building Height Ratio > 1.25			
Cavity Region (x ≤ 3Lb)			
Wake Region (3Lb < x ≤ 10Lb)	AGA - 2 Lee - 126	AGA - 2 Lee - 24	AGA - 1 Lee - 204
Beyond Wake Region (x>10Lb)	AGA - 4 Lee - 252	AGA - 6 Lee - 48	AGA - 3 Lee - 408

EOCR Experiments:

All samples were included in the stack:building height < 1.25 regime

- All samples (214) based on 1 regime;
- All samples (214) based on 9 regimes;
- Cavity samples (34) based on 3 meteorological regimes;
- Wake region samples (52) based on 3 meteorological regimes;
- Beyond the wake region samples (128) based on 3 meteorological regimes;
- Stable, low wind speed samples (108) based on 3 downwind distance regimes;

- Unstable / neutral, low wind speed samples (35) based on 3 downwind distance regimes; and
- High wind speed samples (71) based on 3 downwind distance regimes.

AGA Experiments:

- All samples (78) based on 1 regime;
- All samples (78) based on 9 regimes;
- Wake region samples for stack:building height ≤ 1.25 (40) based on 2 meteorological regimes;
- Beyond the wake region samples for stack:building height < 1.25 (20) based on 2 meteorological regimes;
- Stack:building height ratio ≤ 1.25 (60) based on 2 meteorological and 2 distance regions; and
- Stack:building height ratio > 1.25 (18) based on 3 meteorological and 2 distance regions.

Lee Wind Tunnel Experiments:

All samples were included in the stack:building height > 1.25 regime

All Experiments, Regardless of Load or Unit

- All samples (1062) based on 1 regime;
- All samples (1062) based on 6 regimes;
- Wake region samples (354) based on 3 meteorological regimes;
- Beyond the wake region samples (708) based on 3 meteorological regimes;
- Stable, low wind speed samples (378) based on 2 downwind distance regimes;
- Unstable / neutral, low wind speed samples (72) based on 2 downwind distance regimes; and
- High wind speed samples (612) based on 2 downwind distance regimes.

All Experiments for 100% Load Conditions, Regardless of Unit

- All samples (354) based on 1 regime;
- All samples (354) based on 6 regimes;
- Wake region samples (118) based on 3 meteorological regimes;
- Beyond the wake region samples (236) based on 3 meteorological regimes;
- Stable, low wind speed samples (126) based on 2 downwind distance regimes;
- Unstable/neutral, low wind speed samples (24) based on 2 downwind distance regimes;
- High wind speed samples (204) based on 2 downwind distance regimes;

All Experiments for 75% Load Conditions, Regardless of Unit

- All samples (312) based on 1 regime;
- All samples (312) based on 5 regimes (no unstable/neutral, low wind speed cases in the wake region);
- Wake region samples (104) based on 2 meteorological regimes;
- Beyond the wake region samples (208) based on 3 meteorological regimes;
- Stable, low wind speed samples (84) based on 2 downwind distance regimes;
- Unstable/neutral, low wind speed samples (24) based on 2 downwind distance regimes;
- High wind speed samples (204) based on 2 downwind distance regimes;

All Experiments for 50% Load Conditions, Regardless of Unit

- All samples (396) based on 1 regime;
- All samples (396) based on 6 regimes;
- Wake region samples (132) based on 3 meteorological regimes;
- Beyond the wake region samples (264) based on 3 meteorological regimes;

- Stable, low wind speed samples (168) based on 2 downwind distance regimes;
- Unstable/neutral, low wind speed samples (24) based on 2 downwind distance regimes; and
- High wind speed samples (204) based on 2 downwind distance regimes.

All Experiments for Units 1 & 2, Regardless of Load Condition

- All samples (552) based on 1 regime;
- All samples (552) based on 6 regimes;
- Wake region samples (184) based on 3 meteorological regimes;
- Beyond the wake region samples (368) based on 3 meteorological regimes;
- Stable, low wind speed samples (210) based on 2 downwind distance regimes;
- Unstable/neutral, low wind speed samples (36) based on 2 downwind distance regimes; and
- High wind speed samples (306) based on 2 downwind distance regimes.

All Experiments for Unit 3, Regardless of Load Condition

- All samples (510) based on 1 regime;
- All samples (510) based on 6 regimes;
- Wake region samples (170) based on 3 meteorological regimes;
- Beyond the wake region samples (340) based on 3 meteorological regimes;
- Stable, low wind speed samples (168) based on 2 downwind distance regimes;
- Unstable/neutral, low wind speed samples (36) based on 2 downwind distance regimes; and
- High wind speed samples (306) based on 2 downwind distance regimes.

The Model Evaluation Methodology (MEM) system (Strimaitis et al., 1993) implements the statistical routines required for the evaluation procedures involving a full-year data base such as Bowline Point. The MEM software (used for Bowline Point only) calculated a "composite performance measure" (CPM) over the three meteorological regimes, similar to the statistics generated by the Hanna software. The MEM software also determined differences in the CPM between the two models being evaluated. This difference is referred to as the model comparison measure (MCM):

$$MCM_{1,2} = CPM_1 - CPM_2,$$

where:

CPM_1 = Composite Performance Measure for Model 1, and

CPM_2 = Composite Performance Measure for Model 2.

If a value of $MCM_{i,j}$ within a confidence bound of 95% was not expected to include the value of zero, then the differences in model performances were considered to be statistically significant. To determine the statistical significance, a bootstrap method was employed within MEM to resample the observations and predictions for a large number of simulations (1000). This resampling process was used for each data base simulation to compute new test statistics (RHCs), the absolute fractional biases, new CPMS, and a new MCM.

The model evaluation protocol (Paine, 1995) stated that

> "ISCST3 is the current reference model, but the new EPRI model being evaluated incorporates more complete simulation of the physics of downwash. If this new model shows clear performance improvements..., then the downwash algorithms in ISCST3/SCREEN3 should be replaced by the PRIME model. If there is no statistical significance between the performance of ISCST3/SCREEN3 and ISC-PRIME, but the [evaluation results] show at least comparable performance by ISC-PRIME, then a comparison of the technical features of the models should be used to determine the better model. In this case, with its technical improvements over ISCST3/SCREEN3, ISC-PRIME would be selected as the better model."

The results of the statistical tests described above, in conjunction with several types of residual and quantile-quantile plots displaying various aspects of the evaluation results, were used to determine the overall outcome of this evaluation process.

4

OVERVIEW OF ISC-PRIME

General Technical Description of PRIME

This section presents an overview of the technical formulation of PRIME. More details are described by Schulman et al. (1998). The following text presents excerpts from that paper.

The Industrial Source Complex (ISCST3) model was largely developed with data that represented neutral stability, moderate to high wind speeds, winds perpendicular to the building face, and nonbuoyant or low buoyancy plumes. The ISCST3 model does not include several important features: the stack location with respect to the building, the influence of streamline deflection on plume trajectory, the effect of wind angle on wake structure and the effects of plume buoyancy and vertical wind speed shear on plume rise near buildings. Proper treatment of all of these factors are essential characteristics of the enhanced plume rise and building downwash model that is part of PRIME.

PRIME explicitly treats the trajectory of the plume near the building and uses the position of the plume relative to the building to calculate interactions with the building wake. The trajectory of the rising plume downwind of a building is the result of two processes: (1) descent of the air containing the plume material, and (2) rise of the plume relative to the streamlines due to buoyancy or momentum effects. For a given source-building configuration, the dominant effect depends on the wind direction relative to the building face (affecting the amount of streamline descent) and the wind speed (controlling the rate of rise of the plume.) PRIME calculates the local slope of the mean streamlines as a function of building shape and wind angle, and coupled with a numerical plume rise model, determines the change in plume centerline location with downwind distance.

This approach in PRIME addresses the current deficiencies in the downwash algorithm of the ISCST3 model. Since the plume position relative to the building is used to calculate the plume trajectory, the stack location is an important input parameter. Plumes released upwind of a building will initially have an ascending component, and then, as the plume travels downwind of the building, a descending component. The magnitude of the streamline deflection decreases both laterally and vertically from the building, so that a plume released to the side of a building will be less affected than a plume released on or directly downwind of a building.

The formulation for the slope of the mean streamlines near an obstacle is based on the location and maximum height of the roof-top recirculation cavity, the length of the downwind recirculation cavity (near wake) and a building length scale. In general, the mean streamlines follow the shape of the near wake. For example, for a very wide building, the descent of the mean streamlines is not as steep as for a narrow building of the same height and length. For two buildings of the same height and width, the descent of the mean streamlines is steeper for the building with the shortest length. For example, the magnitude of the descent is a strong function of the wind angle relative to the building face. For example, the amount of descent in PRIME is greater for a 45-degree angle approach to the building face than for perpendicular winds.

Plume rise in the PRIME model is computed using a numerical solution of the mass, energy and momentum conservation laws. The model allows arbitrary ambient temperature stratification, arbitrary unidirectional wind stratification, and arbitrary initial plume size. It includes radiative heat losses and could be run optionally in a non-Boussinesq mode. The implementation of the model in PRIME allows for streamline ascent/descent effects to be considered, as well as the enhanced dilution due to building induced turbulence. A key feature of the model is its ability to include vertical wind shear effects, which are important for many buoyant releases from short stacks.

PRIME predicts concentrations in both the near and far wakes. Currently, the ISCST3 model is only valid for the far wake (defined in ISCST3 as beyond the lesser of three building heights or building widths). A separate model, SCREEN3 (U.S. EPA, 1995b), is recommended by EPA for near-wake concentrations. PRIME uses one of two nearwake algorithms depending on whether a source, after any initial momentum and buoyant rise, is inside or outside of the near wake. For sources outside the near-wake, that fraction of the plume captured by the near wake is well-mixed within the cavity. Emissions released inside the cavity are assumed to be well mixed as they circulate in the near wake. The plume material exits through the top of cavity, where it is modeled as a volume source. For a source released outside the cavity, the far wake concentrations are the sum of the fraction of the “primary” plume that is not captured by the near wake, and the fraction entrained into the cavity that is re-emitted from the cavity as a volume source. For a source released inside the cavity, the far-wake concentrations are determined from the cavity-top volume source.

The PRIME model has a modular design. It has been initially incorporated into the ISCST3 model, but can easily be used to modify other existing or future air quality models.

Status of ISC-PRIME Updates

During the course of running ISC-PRIME the first time for the independent model evaluation, ENSR found a few cases with anomalous model predictions that had not been encountered in the developmental evaluation and which warranted further investigation. These included, for the EOCR data, some very high concentrations for some ground-level releases next to the building. For the Lee wind tunnel data, PRIME appeared to underpredict for certain concentration events for the closest receptors for some directions and units. Earth Tech found that the EOCR issues were caused by (1) a logic error in the numerical plume rise algorithm and (2) possible shortcomings of the BPIP model as used for PRIME. The Lee Power Plant underpredictions may have been the result of using rural dispersion coefficients for the neutral wind tunnel cases where a good argument could be made for using urban dispersion coefficients (this is discussed further in Section 8).

Earth Tech found that the plume rise logic error was a problem for sources with near-zero momentum and buoyancy and was causing the model to not invoke the enhanced wake dispersion even when the source was in the cavity. This, in turn, caused very high concentrations and sometimes the failure to predict at a receptor. This has been corrected in the revised version of PRIME, denoted in subsequent sections of this report as “ISC-PRIME^2" (as opposed to the initial and now obsolete release, "ISC-PRIME^1”), or as "ISC-PRIME" when overall conclusions about the model performance are discussed.

Other high predictions in EOCR cases for ground level sources may be due, according to Schulman (1997), to the shortcomings of the EPA BPIP processor, as linked to the PRIME model. BPIP was designed to calculate the building height and projected width for each wind direction and for each stack for the building tier that leads to the highest GEP stack height. BPIP assumes that the influence of a building tier is the same for any location within the building's region of influence. In PRIME, as well as in the real world, the building influence decreases with downwind distance from the building. In addition, for multiple building or complex tier situations, the selection of the dominant tier by the current version of BPIP can be incorrect. For example, a building 101 feet tall and 101 feet wide that is 450 feet from a source will be incorrectly determined by BPIP to have a larger downwash influence than a building 100 feet tall and 500 feet wide that is 10 feet from the source. The logic used by BPIP for multiple buildings should be modified. In the EOCR case, the ground level source was adjacent to a low tier and further from a taller tier on the same building. Schulman (1997) noted that BPIP selected the taller tier as dominant for some directions, but according to PRIME, this source was outside of the wake of the taller tier. In those cases, BPIP did not give PRIME any information on the adjacent, lower tier. If the lower tier had been selected, the source would be in the wake of that tier and the predicted concentrations would be much lower. Until BPIP is modified, user intervention may be needed. Such cases were modeled both ways in the evaluation to illustrate the problem. (In the case of

EOCR, these cases were few in number and did not materially alter the evaluation outcome.)

In addition to the above model corrections, which were made in response to questions raised during the initial run of the independent evaluation, a coding error was uncovered by Earth Tech that affected the magnitude of most of the earlier predicted concentrations. This error was also in the numerical plume rise algorithm and caused the wrong streamline slope to modify the plume height. It has been corrected and tested as part of ISC-PRIME. Schulman (1997) reports that the developmental data sets still perform quite well with the revised model.

The re-issued ISC-PRIME model has been run with all of the independent evaluation data bases. The next four sections of this report describe the results of the model evaluation with both ISC-PRIME^1 and ISC-PRIME^2. The results using ISC-PRIME^2 are considered the valid results of the independent evaluation.

5

BOWLINE POINT EVALUATION RESULTS

Model Input Data

Data requirements for the evaluation of the Bowline Point data base included:

- building and stack location data,
- meteorological data,
- emissions data, and
- monitored SO_2, data.

These data were used in the API-funded study conducted over 10 years ago (see Schulman and Hanna, 1986), and were retrieved for use in this analysis. The positions of buildings and stacks used in the Building Profile Input Program (BPIP) analysis are shown in Figure 5-1. The dominant building tier is 65.2 meters high, resulting in a stack height to building height ratio of 1.33.

An on-site meteorological tower instrumented at the 10-, 50-, and 100-m levels was operated during the field study period. The 100-m tower level is the most representative level for the 86.9-m stacks; each of the models evaluated used this level for meteorological input. Missing data hours (about 5% of the total period) were ignored by the post-processing procedures.

Emissions data (SO_2, output, stack gas temperature, and stack gas exit velocity) were available on an hourly basis for the two identical 600-MW units. Due to the separation distance between the two stacks, actual SO_2 emissions rather than normalized emissions were modeled for this data base. The few periods for which the plant was completely offline were modeled with zero emissions. These periods were not of interest for the model evaluation because there is no skill in predicting a zero concentration when there are no emissions. In any case, the zero predictions that resulted did not significantly affect the evaluation results because the peak concentrations dominated the statistics.

Figure 5-1 Depiction of locations of building tiers and stacks used for the BPIP Processing for the Bowline Point Data Base

The monitored SO_2 data at the closest four stations were considered for comparison to modeled concentrations (see a map of the Bowline Point network in Figure 2-2). Three of the stations were in the wake zone, and one was beyond the wake region. Consistent with EPA guideline procedures (Appendix W to CFR Part 51, 1996), background concentrations were calculated using monitored values from sites not within the 90° downwind sector. These background concentrations were subtracted from each measured hourly value to produce a set of hourly concentrations due to plant impacts only.

The land use within 3 kilometers of the source is predominately rural, so rural dispersion coefficients were used in the ISCST3 and ISC-PRIME runs.

Evaluation Results

Of the four monitors used in the model evaluation runs, we found that elevated background concentration events dominated most of the top 50 concentration tables for two of the monitors ("Met Tower" and "Parking Lot"). Appendix A provides a listing of the top 50 predicted and observed concentrations for the four monitors, with predictions from the ISC-PRIME model before final revisions ("ISC-PRIME^1") as well as the latest version ("ISC-PRIME^2”) included. The results indicate relatively minor changes between ISC-PRIME^1 and ISC-PRIME^2 results. Two of the sites ("Parking Lot" and "Met Tower") had very few significant concentration events and were dropped from further consideration. Tables 5-1 and 5-2 provide a listing of the top 50 observations and predictions (unpaired in time) for the two remaining monitoring sites ("Bowline Point" and "Boat Ramp").

It is evident in the tables that the observed high concentration cases are dominated by neutral events. ISC-PRIME does a much better job at predicting the number of stable versus neutral cases in the top 50 list than does ISCST3, especially in Table 5-1. In this table, the number of stable cases in the observed column is only 4, versus 5 for ISC-PRIME, and 21 for ISCST3. A similar result, although not as extreme, is seen in Table 5-2. This result indicates that ISCST3 incorrectly overemphasizes stable conditions as high concentration prediction events for this building downwash modeling application.

It is evident from the listed values from Tables 5-1 and 5-2 that both ISCST3 and ISC-PRIMIE predict the top 50 concentrations fairly well, although ISC-PRIME shows a lower bias than ISCST3 does over the whole list in both cases. The ranked concentrations (paired in space, but unpaired in time) are also depicted on quantile-quantile (Q-Q) plots in Figures 5-2 and 5-3. In both figures, it is evident that the curve for ISCST3 crosses the solid line, indicating unbiased predictions at higher concentration levels than does the curve for ISC-PRME. This indicates an underprediction tendency for ISCST3 at these lower concentration levels, and it shows that ISC-PRIME predictions are within a factor of 2 (dashed lines) for a larger portion of the concentration domain. The model underpredictions at very low concentration levels are not of concern because those concentrations are in the "noise" level for background concentration calculations.

Supplemental scatterplots of modeled versus observed concentrations are provided for completeness in Appendix B for ISCST3, Appendix C for ISC-PRIME^1, and Appendix D for ISC-PRIME^2. These plots include:

Table 5-1
Top 50 Observed and Modeled Concentrations at Bowline Point Monitor, Unpaired in Time

Rank	Observed					Rank	ISCST3					Rank	ISC3-PRIME (2)				
#	**Conc.**	**Day**	**Hr**	**WS**	**Stab**	**#**	**Conc.**	**Day**	**Hr**	**WS**	**Stab**	**#**	**Conc.**	**Day**	**Hr**	**WS**	**Stab**
1	823.5	68	19	4.20	5	1	923.0	197	1	4.60	6	1	692.8	92	12	15.20	4
2	652.7	68	20	5.30	5	2	803.0	196	24	4.90	6	2	643.0	5	10	16.40	4
3	651.2	5	10	16.40	4	3	782.8	188	6	5.30	6	3	640.9	92	10	14.30	4
4	549.7	73	16	14.10	4	4	673.1	99	24	7.60	5	4	633.8	92	11	14.80	4
5	538.7	5	11	13.40	4	5	648.6	364	4	8.30	5	5	545.7	92	14	12.10	4
6	526.1	92	12	15.20	4	6	631.6	252	21	7.60	6	6	535.8	189	12	3.90	1
7	429.8	43	7	8.70	4	7	595.1	357	20	7.10	6	7	534.0	5	7	4.10	
8	27.8	73	9	11.40	4	8	575.7	5	10	16.40	4	8	530.8	5	11	13.40	4
9	425.9	73	19	12.70	4	9	565.2	196	23	5.70	5	9	525.3	192	14	4.00	1
10	409.6	10	17	11.30	4	10	563.6	229	2	5.30	5	10	513.0	96	16	12.70	4
11	399.1	96	16	12.70	4	11	559.0	189	12	3.90	1	11	507.6	29	16	11.20	4
12	370.0	73	20	9.20	4	12	547.8	192	14	4.00	1	12	497.7	5	8	15.50	4
13	365.7	10	16	11.60	4	13	514.9	92	12	15.20	4	13	476.8	73	9	11.40	4
14	358.5	363	9	9.80	4	14	514.3	196	2	4.90	5	14	473.33	30	16	10.70	4
15	355.5	56	13	9.90	4	15	510.8	92	10	14.30	4	15	466.6	195	12	10.30	4
16	353.0	43	9	9.20	4	16	506.6	363	8	8.50	5	16	463.5	92	13	11.40	4
17	344.5	56	11	11.70	4	17	501.3	195	12	10.30	4	7	458.4	30	14	11.20	4
18	339.0	92	13	11.40	4	18	494.3	29	16	11.20	4	18	454.0	73	19	12.70	4
19	337.7	76	18	11.50	4	19	476.7	20	5	6.20	5	19	444.8	29	18	11.60	5
20	327.9	73	8	9.90	4	20	470.0	73	9	11.40	4	20	439.5	56	11	11.70	4
21	322.2	92	9	11.00	4	21	465.4	30	16	10.70	4	21	438.3	229	12	9.70	4
22	320.7	340	21	16.00	4	22	465.4	56	11	11.70	4	22	427.5	363	9	9.80	4
23	314.9	73	17	13.90	4	23	460.8	43	3	9.80	4	23	415.1	29	17	10.30	4
24	305.9	267	17	10.80	4	24	456.3	228	16	8.30	3	24	413.5	56	12	10.90	4
25	304.7	350	6	10.30	4	25	447.7	156	5	6.40	5	25	411.8	228	16	8.30	3
26	301.3	340	20	15.70	4	26	447.0	229	12	9.70	4	26	405.7	10	17	11.30	4
27	298.2	43	4	10.50	4	27	446.8	5	7	14.10	4	27	404.9	73	16	14.10	4
28	296.4	56	12	10.90	4	28	446.2	229	22	5.70	5	28	401.7	357	20	7.10	6
29	294.2	350	10	14.30	4	29	445.8	73	8	9.90	4	29	398.0	43	3	9.80	4
30	293.0	42	24	8.10	4	30	435.3	100	6	4.30	6	30	396.8	196	24	4.90	6
31	292.2	68	21	5.00	5	31	434.8	73	19	12.70	4	31	393.7	73	8	9.90	4
32	288.7	340	12	13.00	4	32	426.5	29	18	11.60	5	32	390.4	99	24	7.60	5
33	286.4	43	5	9.90	4	33	426.1	136	23	8.30	5	33	386.4	86	14	11.40	4

Rank	Observed					Rank	ISCST3					Rank	ISC3-PRIME (2)				
#	Conc.	Day	Hr	WS	Stab	#	Conc.	Day	Hr	WS	Stab	#	Conc.	Day	Hr	WS	Stab
34	286.3	43	3	9.80	4	34	425.3	73	6	9.20	4	34	384.6	76	22	11.30	4
35	284.5	43	13	9.40	4	35	423.9	92	11	14.80	4	35	384.3	10	16	11.60	4
36	283.2	62	9	9.70	4	36	419.0	30	14	11.20	4	36	383.0	30	12	10.70	4
37	270.0	76	22	11.30	4	37	418.5	43	1	9.20	4	37	381.8	350	6	10.30	4
38	268.2	43	8	8.40	4	38	399.3	188	14	3.00	1	38	376.4	62	12	11.10	4
39	262.6	340	9	13.60	4	39	396.7	197	13	2.90	1	39	370.8	56	13	9.90	4
40	260.8	340	19	16.20	4	40	396.0	230	6	4.90	5	40	370.8	62	11	11.60	4
41	256.6	73	14	15.50	4	41	391.0	156	3	7.60	5	41	369.9	364	4	8.30	5
42	256.3	363	10	9.60	4	42	384.2	73	3	8.80	4	42	365.5	43	1	9.20	4
43	251.0	30	14	11.20	4	43	382.2	211	5	7.20	5	43	362.7	62	13	10.90	4
44	247.5	350	9	16.50	5	44	382.1	56	12	10.90	4	44	362.4	340	21	16.00	4
45	246.6	40	13	8.90	4	45	378.7	43	2	9.40	4	45	362.0	73	6	9.20	4
46	241.6	76	17	11.00	4	46	376.6	363	9	9.80	4	46	359.9	197	13	2.90	1
47	239.4	73	13	14.10	4	47	373.8	73	5	9.30	4	47	359.6	30	17	9.40	4
48	238.5	73	18	14.40	4	48	371.0	196	3	7.60	4	48	356.4	92	15	10.30	4
49	237.4	267	9	11.90	4	49	371.0	252	24	6.70	5	49	354.5	5	9	17.80	4
50	234.2	56	15	10.90	4	50	370.9	73	7	9.20	4	50	352.1	76	18	11.50	4

Table 5-2
Top 50 Observed and Modeled Concentrations at Boat Ramp Monitor, Unpaired in Time

Rank	Observed					Rank	ISCST3					Rank	ISC3-PRIME (2)				
#	Conc.	Day	Hr	WS	Stab	#	Conc.	Day	Hr	WS	Stab	#	Conc.	Day	Hr	WS	Stab
1	513.9	5	7	14.10	4	1	560.9	56	1	8.90	5	1	579.3	92	11	14.80	4
2	504.8	350	9	16.50	5	2	546.6	2	11	10.70	5	2	554.6	92	12	15.20	4
3	499.3	73	16	14.10	4	3	529.8	5	9	17.80	4	3	510.1	5	9	17.80	4
4	493.4	350	10	14.30	4	4	482.3	5	10	16.40	4	4	494.6	5	10	16.40	4
5	429.5	43	8	8.40	4	5	465.1	76	18	11.50	4	5	492.4	5	8	15.50	4
6	428.7	42	23	7.80	4	6	462.4	115	11	9.80	5	6	459.7	92	10	14.30	4
7	393.8	40	12	10.40	4	7	458.1	56	11	11.70	4	7	423.9	5	7	14.10	4
8	381.9	2	12	9.80	4	8	454.8	208	5	8.00	4	8	416.3	5	11	13.40	4
9	380.8	73	9	11.40	4	9	454.5	208	6	9.00	4	9	411.2	92	14	12.10	4
10	365.7	73	8	9.90	4	10	454.3	29	16	11.20	4	10	410.5	76	18	11.50	4
11	360.7	43	9	9.20	4	11	452.0	43	5	9.90	4	11	406.0	30	14	11.20	4
12	351.8	43	7	8.70	4	12	450.9	43	4	10.50	4	12	404.7	29	16	11.20	4
13	349.5	350	7	11.60	4	13	450.3	132	24	8.40	5	13	400.4	29	15	10.70	4
14	346.4	92	12	15.20	4	14	449.5	2	15	11.60	4	14	396.6	96	16	12.70	4
15	341.5	39	22	16.10	4	15	448.5	229	12	9.70	4	15	389.5	56	12	10.90	4
16	337.0	7	23	10.60	4	16	447.5	56	12	10.90	4	16	382.3	30	16	10.70	4
17	323.7	73	19	12.70	4	17	447.4	364	4	8.30	5	17	381.1	340	20	15.70	4
18	319.7	92	9	11.00	4	18	447.2	340	22	14.80	4	18	376.4	340	21	16.00	4
19	317.2	76	18	11.50	4	19	443.8	30	15	10.30	4	19	372.1	229	12	9.70	4
20	313.3	43	4	10.50	4	20	440.1	115	17	10.70	4	20	371.5	73	9	11.40	4
21	313.0	40	3	13.00	4	21	438.5	29	15	10.70	4	21	367.6	350	6	10.30	4
22	310.1	350	8	13.40	4	22	436.9	30	14	11.20	4	22	366.2	56	11	11.70	4
23	304.7	363	9	9.80	4	23	436.3	56	2	10.10	4	23	365.2	340	22	14.80	4
24	290.2	76	17	11.00	4	24	433.5	340	21	16.00	4	24	363.8	340	19	16.20	4
25	288.2	43	5	9.90	4	25	433.0	43	3	9.80	4	25	363.4	208	6	9.00	4
26	285.2	43	6	9.50	4	26	432.9	73	19	12.70	4	26	362.4	73	19	12.70	4
27	276.9	267	17	10.80	4	27	432.4	350	6	10.30	4	27	360.7	92	13	11.40	4
28	276.2	267	10	11.10	4	28	431.9	5	8	15.50	4	28	356.8	30	15	10.30	4
29	271.2	56	11	11.70	4	29	431.1	56	3	11.20	4	29	354.8	86	14	11.40	4
30	262.4	267	9	11.90	4	30	430.3	2	16	10.30	4	30	354.6	195	10	8.70	3
31	260.7	2	11	10.70	5	31	430.1	30	16	10.70	4	31	350.2	73	16	14.10	4
32	259.3	56	13	9.90	4	32	429.8	73	9	11.40	4	32	349.5	10	17	11.30	4
33	254.4	56	12	10.90	4	33	429.3	7	23	10.60	4	33	348.9	363	9	9.80	4

Rank		Observed				Rank		ISCST3				Rank		ISC3-PRIME (2)			
#	Conc.	Day	Hr	WS	Stab	#	Conc.	Day	Hr	WS	Stab	#	Conc.	Day	Hr	WS	Stab
34	249.6	2	16	10.30	4	34	429.3	56	4	9.60	4	34	348.8	340	11	13.60	4
35	247.8	195	15	10.00	4	35	427.7	7	19	11.00	4	35	345.5	350	10	14.30	4
36	243.4	73	13	14.10	4	36	426.7	267	9	11.90	4	36	344.8	340	12	13.00	4
37	242.1	73	14	15.50	4	37	426.4	267	17	10.80	4	37	344.5	56	4	9.60	4
38	241.1	42	24	8.10	4	38	424.6	340	20	15.70	4	38	342.8	62	12	11.10	4
39	236.6	43	3	9.80	4	39	424.2	43	6	9.50	4	39	341.9	43	4	10.50	4
40	235.3	195	11	10.60	3	40	423.9	29	18	11.60	5	40	341.6	195	12	10.30	4
41	234.9	2	17	10.70	4	41	422.7	2	12	9.80	4	41	340.7	340	13	12.40	4
42	229.2	39	23	16.50	4	42	422.6	340	9	13.60	4	42	340.0	340	14	12.50	4
43	228.6	73	20	9.20	4	43	421.4	73	2	8.50	4	43	338.9	56	3	11.20	4
44	226.4	10	17	11.30	4	44	417.1	92	11	14.80	4	44	336.8	228	16	8.30	3
45	225.3	2	22	7.50	4	45	415.0	5	7	14.10	4	45	336.5	2	16	10.30	4
46	222.2	73	17	13.90	4	46	414.6	73	6	9.20	4	46	336.5	29	17	10.30	4
47	221.0	96	16	12.70	4	47	414.4	43	2	9.40	4	47	334.4	62	13	10.90	4
48	220.7	76	19	8.30	4	48	413.7	195	6	9.20	4	48	332.0	76	22	11.30	4
49	211.8	108	16	12.10	4	49	413.3	137	8	9.00	5	49	330.3	281	11	11.50	4
50	211.4	136	24	11.70	4	50	412.9	73	5	9.30	4	50	329.9	17	21	11.90	4

- predicted versus observed concentrations at each monitor for all hours,
- predicted versus observed concentrations for three wind speed categories, and
- predicted versus observed concentrations for different stability categories.

Due to the limited number of monitors and the sensitivity of the modeled prediction for any given hour to the wind direction provided to the model, a large scatter in these plots is expected.

The result of the MEM software application for statistical significance for the model performances is summarized in Table 5-3, and is provided for ISC-PRIME[1] in Appendix E and for ISC-PRIME[2] in Appendix F. Only the diagnostic component of MEM was exercised for this application, and it involved the computation of robust highest concentrations for three meteorological classes:

1. Unstable / neutral cases with 10-m wind speeds up to 4 m / sec,
2. Stable cases with 10-m wind speeds up to 4 m / sec, and
3. Any stability with 10-m wind speeds above 4 m / sec.

The results of the MEM testing for each of these diagnostic categories indicate a general result of lower or nearly equivalent absolute fractional biases (AFBs) for ISC-PRIME relative to ISCST3.

An examination of the data displayed in this section and in Appendices A-F provide additional conclusions about the models' performances for the Bowline Point data base.

- ISC-PRIME in general shows less random scatter about the 1:1 line on the scatterplots than does ISCST3.
- The highest ISCST3 predictions are for stable conditions, while the highest ISC-PRIME and observed concentrations occur in neutral conditions.
- In the MEM output, it is evident that while both models overpredict for the light wind speed categories, ISC-PRIME exhibits a lower bias.
- For high wind speed cases, both models do well.
- The ISC-PRIME[1] results show a higher overprediction bias than the ISC-PRIME[2] results. Consequently, the MEM results for the model comparison measure (MCM) indicate no significant difference between the ISCST3 and

ISC-PRIME^1 results (barely), while a significant difference is indicated for the ISCST3 versus ISC-PRIME^2 results.

Table 5-3
Results of Statistical Post-Processing of Bowline Point Data Using MEM

Using MEM

		ISCST^3		ISC-PRIME^1		ISC-PRIME^2	
Regime	Monitor	fb	pre/obs ratio	fb	pre/obs ratio	fb	pre/obs ratio
Neutral, 10-m wind speed ≤4 m/sec	Bowline Pt.	-1.00	3.00	-0.85	2.48	-0.84	2.45
	Boat Ramp	-0.76	2.23	-0.71	2.10	-0.58	1.82
Stable 10-m wind speed ≤4 m/sec	Bowline Pt.	-1.35	5.15	-1.16	3.76	-1.11	3.49
	Boat Ramp	-0.83	1.66	-0.16	1.88	-0.52	1.70
Any Stability 10-m wind speed >4 m/sec	Bowline Pt.	+0.027	0.97	-0.13	1.14	-0.071	1.07
	Boat Ramp	+0.15	0.86	-0.062	1.06	+0.021	0.98

Composite Performance Measure*

	ISCST3	ISC-PRIME^1	ISC-PRIME^2
Mean	0.344	0.294	0.262
95% Confidence Interval	+0.0685	+/-0.0682	+/-0.0680

Model Comparison Measure Results

ISCST3 vs. ISC-PRIME^1: 0.052 +/- 0.06553 (barely intersects zero)

ISCST3 vs. ISC-PRIME^2: 0.0828 +/- 0.06513 (does not intersect zero)

*Based upon weighted absolute fractional biases.

6

AGA EVALUATION RESULTS

Model Input Data

The basic elements of the AGA tracer data base are the same as in the case of Bowline Point: building and stack location data, meteorological data, emissions data, and tracer sampler concentrations. A plot of the building tiers and release locations used in the BPIP analysis is provided in Figure 6-1. The dominant building tier in each case was 10 meters high, resulting in a stack height to building height ratio ranging from 0.95 to 2.52.

One feature not in common with the conventional network (Bowline Point) is the arrangement of observed concentrations on rows or arcs of samplers that are generally at the same distance from the stack. The AGA experiments involved up to four arcs of receptors at distances of 50, 100, 150, and 200 meters from the source (see Figure 2-4). Plots of the receptor locations and observed concentrations for each AGA experiment hour are provided in Appendix G. Each model was run in the rural mode due to the predominant rural nature of the two field study sites involved in the AGA experiments.

Each model receptor was given an arc designation for purposes of the model evaluation. Each arc resulted in a single maximum observed and predicted concentration for each hour evaluated. Note from Appendix G the excellent resolution in the concentration field, allowing us to determine the position of the highest concentration with a high degree of confidence. Experiment hours for which the peak predictions were not evident (when the plume missed the tracer sampler network) were not included in this evaluation study. A gaussian fit to the observed concentration distribution on each arc was made using "PLMFIT" software provided by Dr. John Irwin of U.S. EPA (1996).

For each arc-hour, separate model runs were prepared and executed, with the wind direction input altered to advect the plume directly toward the monitor with the highest prediction. Sensitivity tests indicated that the receptor directly downwind of the source resulted in the highest predicted concentration, so the model predictions were limited to the centerline receptor for these runs. The single resulting peak/fitted observation, and the predicted concentration at the downwind receptor were tabulated in a spreadsheet for further analysis. The spreadsheet including ISC-PRIME^1 results is provided in Appendix H, and the one including ISC-PRIME^2 results is provided in Appendix I.

Figure 6-1a Depiction of locations of the building and stacks used for the BPIP processing for the AGA data base: Kansas site.

Figure 6-1b Depiction of locations of the building and stacks used for the BPIP processing for the AGA data base: Texas site.

Figure 6-2 Residual plot of predicted to observed concentration ratios versus distance for the AGA data base.

Evaluation Results

A concise summary of the AGA evaluation results can be shown in a series of "box plots" in which the ratio of the predicted to observed concentrations is plotted against an independent variable such as distance, wind speed, stability, and the stack height to building height ratio (see Figures 6-2 through 6-5, respectively). In each figure, a box/whisker plot is shown for portions of the x-axis region. The points that make up each portion of the x-axis are sorted in cumulative frequencies for the y-axis value. The box encloses the 25%-75% region (designated with circles at each end), with the 50% value inside the box denoted with a diamond symbol. The short horizontal bars at the lower and upper extremities along the y-axis of the "whisker" denote the 10% and 90% values, respectively. A series of box plots for the four independent variables mentioned above for ISCST3, ISC-PRIME^1, and ISC-PRIME^2 are provided in Appendices J, K, and L, respectively. For each box plot, the scatterplots of predicted to observed concentrations for the portion of the x-axis involved are provided as supplementary plots in the appendices.

The results shown in Figures 6-2 through 6-5 generally show an overprediction tendency for both ISCST3 and ISC-PRIME, but with ISC-PRIME showing a lower bias, in general. This pattern is evident across most of the range for distance, wind speed, and stability classes. Although the plots show prediction/observation ratios that appear to be overlapping between the two models, it should be noted that the y-axis is presented on a logarithmic scale, so that small displacements can actually be important differences between the model predictions.

Supplemental plots of modeled and observed concentrations as a function of the independent variables mentioned above are included in Appendix M.

As described in Section 3, an enhanced version of the bootstrapping software provided by Hanna (1989) was used to determine whether the differences in the model performances of ISCST3 and ISC-PRIME were statistically significant. A summary of the bootstrapping results are provided in Table 6-1. Complete output listings of the statistical evaluation are provided in Appendix N for ISC-PRIME^1 and in Appendix 0 for ISC-PRIME^2.

An inspection of the results presented in this section and in Appendices G through 0 provide general conclusions about the models' performance for the AGA data base.

- The highest observed concentrations occurred for stability class 3 (C, slightly unstable) conditions, while much lower observed concentrations were generally noted for stable conditions.

Figure 6-3 Residual plot of predicted to observed concentration ratio, versus 10-m wind speed for the AGA data base.

Figure 6-4 Residual plot of predicted to observed concentration ratios versus stability class for the AGA data base.

Figure 6-5 Residual plot of predicted to observed concentration ratios versus stack height to building height ratio for the AGA data base.

- For both models, an overprediction tendency existed over all stability classes, but for the unstable classes most of all (relatively little for neutral and stable conditions).

- No strong trend in model behavior as a function of downwind distance was evident.

- ISC-PRIME predictions fell within a narrower range of concentration values than did the ISCST3 predictions.

- Although the ISCST3 predictions were generally more conservative than those of ISC-PRIME, ISCST3 showed a slight underprediction tendency for cases with a stack height to building height ratio of at least 1.25. For these cases, ISC-PRIME consistently overpredicted.

- Both versions of ISC-PRIME showed a significant difference in the fractional bias relative to ISCST3. ISC-PRIME^2 had a slightly lower overprediction bias.

The results show that while both models overpredict, the 95% confidence intervals for the fractional biases for ISCST3 and ISC-PRIME do not intersect, and ISC-PRIME shows a lower bias. Therefore, the improved performance of ISC-PRIME for the AGA data base is statistically significant.

Table 6-1
Results of Statistical Post-processing for the AGA Data Base

	ISCST3 95% Confidence Interval		**ISC-PRIME^1 95% Confidence Interval**		**ISC-PRIME^2 95% Confidence Interval**	
Sampling Regime	**Fractional Bias**	**Pre/Obs Ratio**	**Fractional Bias**	**Pre/Obs Ratio**	**Fractional Bias**	**Pre/Obs Ratio**
All cases (unrestricted resampling)	-0.94 to -0.56	1.78 to 2.77	-0.58 to -0.14	1.15 to 1.82	-0.47 to -0.015	1.02 to 1.61
All cases (resampling restricted within regimes)	-0.94 to -0.54	1.74 to 1.77	-0.58 to -0.14	1.15 to 1.82	-0.47 to -0.05	1.0-2 to 1.61
Stack height/ building height <1.25	-0.94 to -0.50	1.67 to 2.77	-0.50 to -0.09	1.10 to 1.67	-0.37 to +0.36	0.96 to 1.45
Stack height/ building height >1.25	-0.067 to +0.290	0.82 to 1.07	-0.81 to -0.45	1.58 to 2.36	-0.80 to -0.51	1.68 to 2.33
Receptors within wake region	-1.00 to -0.42	1.53 to 3.00	-0.50 to +0.016	0.98 to 1.67	-0.37 to +0.15	0.86 to 1.45
Receptors beyond wake region	-0.83 to -0.24	1.27 to 2.42	-0 .55 to +0.095	0.91 to 1.76	-0.52 to +0.098	0.91 to 1.70

Difference in fractional bias for all cases (unrestricted resampling):

ISCST3 versus ISC-PRIME1: -0.56 to -0.25 (does not cross zero)

ISCST3 versus ISC-PRIME2: -0.70 to -0.41 (does not cross zero)

7

EOCR EVALUATION RESULTS

Model Input Data

The basic elements of the EOCR tracer data base are the same as in the case of the two data bases already discussed: building and stack location data, meteorological data, emissions data, and tracer sampler concentrations. A plot of the building tiers and release locations used in the BPIP analysis is provided in Figure 7-1. The dominant building tier was 25 meters high, and the source release heights were 1, 25, and 30 meters.

This experiment featured completely closed, circular arcs of observed concentrations. Except for the first (50-m) arc, which was in the "cavity" region, the predicted and observed peak concentrations were directly downwind. Some peak predictions at locations slightly displaced to one side of directly downwind were seen for ISC-PRIME. So as not to skip such peak predictions, we obtained modeling results at a number of sites on the arc before determining the peak prediction in each case. SCREEN3 was used to provide predictions for the first arc, since ISCST3 did not provide concentrations within the cavity region.

A total of 8 hours exhibited a phenomenon whereby very high concentrations were observed at the 50-m distance ring in an upwind direction. This happened often enough so that a tracer gas leak was probably not the cause. The inclusion of these cases did not substantially alter the overall results for this data base.

The EOCR experiments involved up to six arcs of receptors at distances of 50, 100, 400, and 800, 1200 and 1600 meters from the source (see Figure 2-6). Plots of the receptor locations and observed concentrations for each EOCR experiment hour are provided in Appendix P. Each model was run in the rural mode due to the predominant rural nature of the field study site involved in the EOCR experiments. For each arc-hour, separate model runs were prepared and executed, with the wind direction input altered to advect the plume directly toward the monitor with the highest prediction (except for the 50-m ring, for which predictions at several receptors were examined, as mentioned above).

As in the case of the AGA experiments, each model receptor was given an arc designation for purposes of the model evaluation. Each arc resulted in a single maximum observed and predicted concentration for each hour evaluated. A gaussian

Figure 7-1 Depiction of locations of the building tiers and stacks used for the EOCR data base.

fit to the observed concentration distribution on each arc was made using the PLMFIT software.

The spreadsheet including ISC-PRIME[1] results is provided in Appendix Q and the one including ISC-PRIME[2] results is provided in Appendix R. These appendices both list the observed fitted as well as the peak observed concentrations; only the fitted observed concentrations were used in the evaluation results.

Evaluation Results

A summary of the EOCR evaluation results can be shown in a series of residual plots in which the ratio of the predicted to observed concentrations is plotted against an independent variable such as distance, wind speed, and stability (see Figures 7-2 through 7-4, respectively). A series of box plots for the three independent variables mentioned above for ISCST3, ISC-PRIME[1], and ISC-PRIME[2] are provided in Appendices S, T, and U, respectively. For each box plot, the scatterplots of predicted to observed concentrations for the portion of the x-axis involved are provided as supplementary plots in the appendices.

The results shown in Figures 7-2 through 7-4 generally show an overprediction tendency for both ISCST3/SCREEN3 and ISC-PRIME (more so than for the AGA data base), with ISC-PRIME showing a lower bias, in general. This pattern is evident across most of the range for distance, wind speed, and stability classes.

Supplementary plots of modeled and observed concentrations as a function of the independent variables mentioned above are included in Appendix V.

The BOOT25 software used to determine whether the differences in the model performances of ISCST3/SCREEN3 and ISC-PRIME were statistically significant. A summary of the bootstrapping results are provided in Table 7-1. Complete output listings of the statistical evaluation are provided in Appendix W for ISC-PRIME[1] and in Appendix X for ISC-PRIME[2].

Several features are evident regarding the model evaluation results for EOCR from the exhibits mentioned above.

- The prediction/observation ratio for both ISCST3/SCREEN3 and ISC-PRIME does not vary appreciably over the range of distances and wind speeds.
- The ISC-PRIME overprediction ratio increases steadily across stability categories from A through G. The ISCST3/SCREEN3 overprediction ratio increases in a similar manner, but with less of a trend because the ISCST3/SCREEN3 overprediction ratio is higher for stability A than the ISC-PRIME ratio.

The highest observed concentrations were recorded for the lowest wind speeds, usually associated with ground-level releases. The models replicated this feature except for the SCREEN3 model, whose predictions were insensitive to the actual wind speed.

- A few very high ISC-PRIME predictions may be related to the shortcomings of the BPIP output relative to ISC-PRIME needs. There were also a few unusual cases of very high observed values upwind from the release point. In both instances, however, these cases did not materially affect the overall statistics.
- ISCST3/SCREEN3 predictions are relatively unbiased in the cavity region (on average), but become more conservative in the wake and more so in the beyond wake regions.
- ISC-PRIME predictions are relatively unbiased in the cavity and wake regions, and overpredict the most in the beyond wake region.
- Both models overpredict for the light wind speed categories, but ISC-PRIME is less biased.
- ISCST3/SCREEN3 overpredicts for the high wind speed cases (but less than for the low wind speed cases), while ISC-PRIME exhibits a slight underprediction tendency for this category.
- Both versions of ISC-PRIME exhibit overall overprediction tendencies, with ISC-PRIME^2 overpredicting somewhat less.
- Both versions of ISC-PRIME show a lower overprediction bias relative to ISCST3/SCREEN3.

The overall results show that while both models overpredict, the 95% confidence intervals for the fractional biases for ISCST3/SCREEN3 and ISC-PRIME do not intersect, and ISC-PRIME shows a lower bias. Therefore, the improved performance of ISC-PRIME for the EOCR data base is statistically significant.

Figure 7-2 Residual plot of predicted to observed concentration ratios versus distance for the EOCR data base.

Figure 7-3 Residual plot of predicted to observed concentration ratios versus 10-m wind speed for the EOCR data base.

Figure 7-4 Residual plot of predicted to observed concentration ratios versus stability class for the EOCR data base.

Table 7-1
Results of Statistical Post-processing for the EOCR Data Base

	ISCST3/SCREEN3 95% Confidence Interval		**ISC-PRIME[1] 95% Confidence Interval**		**ISC-PRIME[2] 95% Confidence Interval**	
Sampling Regime	**Fractional Bias**	**Pre/Obs Ratio**	**Fractional Bias**	**Pre/Obs Ratio**	**Fractional Bias**	**Pre/Obs Ratio**
All cases (unrestricted resampling)	-1.5 to -1.1	3.4 to 7.0	-1.2 to -0.52	1.70 to 4.0	-0.98 to -0.036	1.03 to 2.92
All cases (resampling restricted within regimes)	-1.5 to -0.98	2.92 to 7.0	-1.2 to -0.44	1.56 to 4.0	-0.88 to -0.017	1.02 to 2.57
Unstable/neutral 10-m wind speed ≤4 m/sec	-1.8 to -1.5	7.0 to 19	-1.3 to -0.55	1.76 to 4.7	-1.4 to -0.49	1.65 to 5.7
Stable 10-m wind speed ≤4 m/sec	-1.6 to -0.80	2.33 to 9.0	-1.3 to -0.41	1.52 to 4.7	-1.0 to +0.026	0.97 to 3.0
All stabilities 10-m wind speed >4 m/sec	-1.5 to -0.39	1.48 to 7.0	-0.81 to +1.1	0.29 to 2.36	+0.077 to 1.2	0.25 to 0.93
Receptors within cavity region	-0.53 to +0.56	0.56 to 1.72	-1.4 to +0.64	0.52 to 5.7	-0.36 to +0.80	0.43 to 1.44
Receptors within wake region	-1.2 to -0.12	1.13 to 4.0	-1.7 to +0.52	0.59 to 12.	-0.52 to +0.67	0.53 to 1.70
Receptors beyond wake region	-1.3 to -0.85	2.48 to 4.7	-1.6 to -1.1	3.4 to 9.	-1.1 to -0.59	1.84 to 3.4

Difference in fractional bias for all cases (unrestricted resampling):

ISCST3 / SCREEN3 versus ISC-PRIME[1]: -0.66 to -0.25 (does not cross zero)

ISCST3 / SCREEN3 versus ISC-PRIME[2]: -1.10 to -0.52 (does not cross zero)

8

LEE POWER PLANT EVALUATION RESULTS

Model Input Data

The Lee Power Plant data base is unique in that it represents the results of wind tunnel tests. However, the basic elements of the Lee Power Plant data base include the usual elements: building and stack location data, meteorological data, emissions data, and tracer sampler concentrations (actually, dilution factors). A plot of the building tiers and release locations used in the BPIP analysis is provided in Figure 8-1. The dominant building tier height is 42.6 meters, resulting on a stack height to building height ratio of 1.52.

Note from Figure 8-1 that the stacks for Units 1 and 2 are adjacent to each other and are separate from the Unit 3 stack. The exhaust parameters from each stack are nearly identical. Several combinations of boiler load and unit combinations were tested in the wind tunnel: Units 1 and 2 together at 50%, 75%, and 100% load, and Unit 3 operating separately at these varying load levels.

This experiment featured just one row of samplers in the downwind direction. There was no arc of receptors, so no use of the PRIME software was considered for this data base. The samples represented a short-term (5-minute average), so that a multiplication factor of 0.61 was used to derive 1-hour average observed concentrations from the 1/5 time averaging power law (Turner, 1969). In the case of zero observed concentrations that were reported, a value of one-half the minimum detection limit was assigned to avoid computation problems in the statistical post-processing routines. The Lee Power Plant experiments involved up to six receptor (full-scale) distances of 50, 100, 400, and 800, 1200 and 1600 meters from the source.

The unique setting of the wind tunnel roughness and turbulence field resulted in a dispersion characteristic for neutral conditions that most resembles urban, rather than rural dispersion conditions. This is due to the fact that the vertical turbulence intensity (i_z) value was in the range of 0.15-0.20 for the wind tunnel runs. This corresponds well with the ISCST3 urban$_z$ values of 0.14 and 0.20 for stability classes D and C, respectively, and is somewhat higher than the rural i_z values of 0.08 and 0.11 for the same stability classes. In both rural and urban cases for neutral conditions, the temperature lapse rate is dry-adiabatic, which

Figure 8-1a Depiction of all building tiers and stacks used for the BPIP processing for the Lee Power Plant data base.

Figure 8-1b Depiction of the dominant 135-foot building tiers associated with the Lee Power Plant

was the case for the wind tunnel conditions. Therefore, the wind tunnel setup was more representative of urban, rather than rural, conditions for the neutral condition trials, in spite of the fact that the real power plant is in a rural setting from a land-use point of view. The ISC-PRIME^1 runs were conducted with the rural setting, as one would deduce from the land-use algorithm. However, the factors as discussed above were adequate justification to run ISCST3 and ISC-PRIME^1 with the urban dispersion option. Due to the considerable resources required to re-run the now obsolete ISC-PRIME^1 model for the 684 neutral, urban conditions (requiring individual model runs), reruns of ISC-PRIME^1 for neutral conditions were not conducted.

In stable conditions, however, the temperature lapse rate simulated in the wind tunnel corresponded to the stability F potential temperature lapse rate of 0.035 degrees Kelvin per meter. Since in urban areas, the lapse rate is actually neutral within the urban canopy even at night, the temperature lapse rate as simulated in the wind tunnel is not consistent with urban condition for the stable runs. Therefore, model runs conducted for stable conditions used the rural dispersion option.

The spreadsheet including ISC-PRIME^1 results (all rural runs) is provided in Appendix Y, and the one including ISC-PRIME^2 results is provided in Appendix Z.

Evaluation Results

A summary of the Lee Power Plant evaluation results can be shown in a series of residual plots in which the ratio of the predicted to observed concentrations is plotted against independent variable such as distance, wind speed, and stability (see Figures 8-2 through 8-5). A series of box plots for the independent variables mentioned above for ISCST3, ISC-PRIME^1, and ISC-PRIME^2 are provided in Appendices AA, BB, and CC, respectively. For each box plot, the scatterplots of predicted to observed concentrations for the portion of the x-axis involved are provided as supplementary plots in the appendices.

The results shown in Figures 8-2 through 8-5 generally show a slight underprediction tendency for both ISCST3 and ISC-PRIME in neutral conditions. The two model results are considerably different for stable conditions, which features nearly unbiased ISCP predictions versus ISCST3 overpredictions by a factor of more than 10 on average.

Supplementary plots of modeled and observed concentrations as a function of the independent variables mentioned above are included in Appendix DD.

The BOOT25 software used to determine whether the differences in the model performances of ISCST3 and ISC-PRIME were statistically significant. A summary of the bootstrapping results are provided in Table 8-1. Complete output listings of the statistical evaluation are provided in Appendix EE for ISC-PRIME[2].

Table 8-1
Results of Statistical Post-processing for the Lee Power Plant Data Base

	ISCST3 95% confidence Interval		**ISC-PRIME[2] 95% Confidence Interval**	
Sampling Regime	**Fractional Bias**	**Pre/Obs Ratio**	**Fractional Bias**	**Pre-Obs Ratio**
All Cases	0.17 to 0.34	0.71 to 0.84	0.15 to 0.27	0.76 to 0.86
Receptors within wake region (all units/loads)	0.35 to 0.62	0.53 to 0.70	0.022 to 0.27	0.76 to 0.98
Receptors beyond wake region (all units/loads)	0.016 to 0.25	0.78 to 0.98	0.097 to 0.25	0.78 to 0.91
Stable cases (all units/loads)	-1.8 to -1.7	large (no detectable observed concentrations)	-0.50 to -0.012	1.01 to 1.67
Neutral cases, 10-m wind speed ≤4 m/sec (all units/loads)	-2.0 to -1.9	large	-2.0 to -1.9	large
Neutral cases, 10-m wind speed >4 m/sec (all units/loads)	0.65 to 0.79	0.43 to 0.51	0.16 to 0.32	0.72 to 0.85
All 100% load cases	0.009 to 0.25	0.78 to 0.99	-0.14 to 0.16	0.85 to 1.15
Receptors within wake region (100% load)	0.11 to 0.71	0.48 to 0.90	-0.35 to 0.20	0.82 to 1.42
Receptors beyond wake region (100%load)	-0.11 to 0.17	0.84 to 1.12	-0.10 to 0.23	0.79 to 1.11
Stable cases (100% load)	-1.9 to -1.8	large	-1.0 to 0.13	0.88 to 3.0
Neutral cases 10-m wind speed ≤4 m/sec (100% load)	-2.0 to 2.0	large	-2.0 to -2.0	large
Neutral cases 10-m wind speed >4 m/sec (100% load)	0.44 to 0.72	0.47 to 0.64	-0.055 to 0.26	0.77 to 1.06

All 75% load cases	0.17 to 0.46	0.62 to 0.84	0.11 to 0.29	0.75 to 0.90
Receptors within wake region (75% load)	0.27 to 0.87	0.39 to 0.76	-0.097 to 0.39	0.67 to 1.10
Receptors beyond wake region (75% load)	-0.028 to 0.37	0.69 to 1.03	0.053 to 0.29	0.75 to 0.95
Stable cases (75% load)	-1.9 to -1.8	large	-0.86 to 0.15	0.86 to 2.51
Neutral cases 10-m wind speed ≤4 m/sec (75% load)	-2.0 to -1.9	large	-2.0 to -2.0	large
Neutral cases 10-m wind speed >4 m/sec (75% load)	0.59 to 0.86	0.40 to 0.54	0.064 to 0.37	0.69 to 0.94
All 50% load cases	0.01 to 0.31	0.73 to 0.99	0.18 to 0.41	0.66 to 0.83
Receptors within wake region (50% load)	0.13 to 0.60	0.54 to 0.88	0.036 to 0.51	0.59 to 0.96
Receptors beyond wake region (50% load)	-0.13 to 0.18	0.83 to 1.14	0.18 to 0.42	0.65 to 0.83
Stable cases (50% load)	-1.7 to -1.4	5.6 to 12	-0.28 to 0.55	0.57 to 1.33
Neutral cases 10- m wind speed >4 m/sec (50% load)	0.59 to 0.83	0.41 to 0.54	0.20 to 0.52	0.59 to 0.82
All cases, Units 1 and 2 only	0.18 to 0.37	0.69 to 0.83	0.098 to 0.26	0.77 to 0.91
Receptors within wake region (Units 1 and 2 only)	0.43 to 0.76	0.45 to 0.65	0.23 to 0.51	0.59 to 0.79
Receptors beyond wake region (Units 1 and 2 only)	0.01 to 0.22	0.80 to 0.99	0.18 to 0.33	0.72 to 0.83
Stable cases (Units 1 and 2 only)	-1.8 to -1.4	5.6 to 19	-0.60 to 0.33	0.72 to 1.86
Neutral cases 10-m wind speed ≤4 m/sec (Units 1 and 2 only)	-2.0 to -1.8	large	-2.0 to -1.9	large
Neutral cases 10-m wind speed >4 m/sec (Units 1 and 2 only)	0.73 to 0.88	0.29 to 0.46	0.26 to 0.40	0.07 to 0.77
All cases, unit 3 only	0.019 to 0.27	0.76 to 0.98	0.094 to 0.30	0.74 to 0.91
Receptors within wake region (Unit 3 only)	-0.077 to 0.62	0.53 to 1.08	-0.097 to 0.46	0.63 to 1.10
Receptors beyond wake region (Unit 3 only)	-0.0675 to 0.24	0.79 to 1.07	0.075 to0.34	0.71 to 0.93

Stable cases (Unit 3 only)	-1.9 to -1.8	large	-0.22 to 0.91	0.37 to 1.25
Neutral cases 10-m wind speed ≤4 m/sec (Unit 3 only)	-1.9 to -1.8	large	-2.0 to -1.8	large
Neutral cases 10-m wind speed > 4 m/sec (Unit 3 only)	0.62 to 0.82	0.42 to 0.53	0.18 to 0.44	0.64 to 0.83

Difference in fractional bias for all cases:

ISCST3 versus ISC-PRIME[2]: 0.27 to 0.40 (does not cross zero)

Difference in fractional bias for neutral, high wind cases:

ISCST3 versus ISC-PRIME[2]: 0.39 to 0.53 (does not cross zero)

Difference in fractional bias for stable cases:

ISCST3 versus ISC-PRIME[2]: -1.7 to -1.3 (does not cross zero)

Figure 8-2 Residual plot of predicted to observed concentration ratios versus distance for the Lee Power Plant data base, neutral (urban) cases only.

Figure 8-3 Residual plot of predicted to observed concentration ratios versus distance for the Lee Power Plant data base, stable (rural) cases only.

Figure 8-4 Residual plot of predicted to observed concentration ratios versus 10-m wind speed for the Lee Power Plant data base, neutral (urban) cases only.

Figure 8-5 Residual plot of predicted to observed concentration ratios versus stability category for the Lee Power Plant data base.

Several features not already mentioned above are evident regarding the model evaluation results for Lee Power Plant from the exhibits mentioned above.

- For neutral conditions, the prediction / observation ratio exhibited little variation with distance. Both models showed an overprediction tendency for low wind speeds and were nearly unbiased for high wind speeds. In many cases, there were no detectable observed concentrations at the ground for light wind neutral conditions.

- In stable conditions, ISCST3 consistently overpredicted by a large margin over all distances. In many cases, there were no detectable observed concentrations at the ground under these conditions. The ISC-PRIME concentrations were lower than observations for the first two distance categories. If a model that considered the actual turbulence levels measured in the wind tunnel (such as AERMOD) were to be linked to PRIME, then this underprediction tendency at short distances may be able to be corrected.

- ISC-PRIME predictions tended to become less conservative with lower operating load percentages, in general.

- ISCST3 predictions tended to become less unbiased (underpredicting less) in neutral conditions as the distance to the receptor increased.

The overall results show that the 95% confidence intervals for the fractional biases for ISCST3 and ISC-PRIME do not intersect for both the high wind speed neutral and the stable cases, and ISC-PRIME shows a lower bias (especially for the stable cases). Therefore, the improved performance of ISC-PRIME for the Lee Power Plant data base is statistically significant.

9

OVERALL CONCLUSIONS

For each data base, the ISC-PRIME predictions have consistently exhibited better agreement with observations than ISCST3 predictions. In most cases, ISC-PRIME predictions are conservative. Therefore, from a regulatory perspective, the use of ISC-PRIME would generally be expected to overstate the ground-level actual concentrations and thus be protective of air quality.

In general, ISCST3 predictions are relatively unbiased in neutral conditions. These findings have been independently verified by Guenther et al. (1989) and Thistle et al. (1995), and are consistent with the conditions under which the ISCST3 downwash algorithm was developed and previously evaluated. Even with the relatively good performance of ISCST3 in neutral conditions, ISC-PRIME appears to have a slightly better showing in neutral conditions.

ISCST3 appears to provide very conservative estimate for stable conditions. This appears to be the case especially for very buoyant sources such as electric steam power plants (Bowline Point and Lee Power Plant). This trend has also been independently verified by Thistle et al. (1995) for a case involving buoyant sources. These findings cast considerable doubt upon ISCST3 modeling results that indicate peak concentrations from downwashing stacks with buoyant plumes in flat terrain attributable to light wind, stable conditions. The poor showing of ISCST3 in such conditions may be grounds for disqualifying the model as being applicable for stable conditions. ISC-PRIME performs much better under stable conditions and appears to provide an appropriate selection of the number of critical stable versus neutral high concentration cases (e.g., in the case of Bowline Point).

Although the residual box plots appear to show that the ISCST3 and ISC-PRIME model performances considerably overlap, the reader should be cautioned that these plots have a logarithmic y-axis (predicted to observed ratio), so even slight differences can be important.

The statistical tests comparing the fractional biases of the two models in each case show a statistically better performance for ISC-PRIME in each of the four data bases. It is therefore concluded that ISC-PRIME shows a statistically better performance for the combined data sets taken as a whole. ISC-PRIME^2 appears to be slightly less conservative than the obsolete ISC-PRIME^1, but the overall performances of the two versions of ISC-PRIME are similar and probably not different in a statistically significant sense. Therefore, the code corrections to ISC-PRIME during the independent evaluation have led to performance improvements, but have not significantly altered the outcome of the evaluation.

The modeling protocol (Paine, 1995) refers to both the theoretical formulation and the performance evaluation results in determining whether ISC-PRIME should be considered as a replacement for the current ISCST3 model. This report demonstrates that both tests have been achieved in the independent evaluation. ISC-PRIME contains clear theoretical improvements in model formulation; and the independent model evaluation documents the improved performance of ISC-PRIME compared to ISCST3 when model calculations are compared with observed ground-level concentrations. The ISC-PRIME improvements are most noticeable in the simulation of ground-level concentrations under stable atmospheric conditions for highly buoyant plumes.

10

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A

TABULATIONS OF THE TOP OBSERVED AND PREDICTED 1-HOUR CONCENTRATIONS AT THE FOUR BOWLINE POINT MONITORS

B

SCATTERPLOTS AND RESIDUAL PLOTS INVOLVING OBSERVATIONS AND ISCST3 PREDICTIONS FOR BOWLINE POINT MONITORS

C

SCATTERPLOTS AND RESIDUAL PLOTS INVOLVING OBSERVATIONS AND ISC-PRIME[1] PREDICTIONS FOR TWO BOWLINE POINT MONITORS

D

SCATTERPLOTS AND RESIDUAL PLOTS INVOLVING OBSERVATIONS AND ISC-PRIME^2 PREDICTIONS FOR TWO BOWLINE POINT MONITORS

E

MODEL EVALUATION METHODOLOGY PROGRAM OUTPUT FOR THE BOWLINE POINT DATA BASE: ISCST3 VS. ISC-PRIME[1]

F

MODEL EVALUATION METHODOLOGY PROGRAM OUTPUT FOR THE BOWLINE POINT DATA BASE: ISCST3 VS. ISC-PRIME[2]

G

PLOTS OF OBSERVED CONCENTRATIONS AT TRACER SAMPLERS FOR EACH AGA DATA BASE EXPERIMENT HOUR USED IN THE EVALUATION STUDY

H

SPREADSHEET LISTING OF METEOROLOGICAL DATA AND OBSERVED AND PREDICTED CONCENTRATIONS FOR THE AGA DATA BASE: ISCST3 AND ISC-PRIME[1]

I

SPREADSHEET LISTING OF METEOROLOGICAL DATA AND OBSERVED AND PREDICTED CONCENTRATIONS FOR THE AGA DATA BASE: ISCST3 AND ISC-PRIME[2]

J

RESIDUAL PLOTS AND ASSOCIATED SCATTERPLOTS FOR THE AGA DATA BASE: ISCST3

K

RESIDUAL PLOTS AND ASSOCIATED SCATTERPLOTS FOR THE AGA DATA BASE: ISC-PRIME[1]

L

RESIDUAL PLOTS AND ASSOCIATED SCATTERPLOTS FOR THE AGA DATA BASE: ISC-PRIME[2]

M

SUPPLEMENTAL SCATTERPLOTS RELATING TO THE AGA DATA BASE EVALUATION

N

OUTPUT OF BOOT25 PROGRAM FOR ISCST3 AND ISC-PRIME[1] RESULTS FOR THE AGA DATA BASE

O

OUTPUT OF BOOT25 PROGRAM FOR ISCST3 AND ISC-PRIME[2] RESULTS FOR THE AGA DATA BASE

P

PLOTS OF TRACER SAMPLER LOCATIONS AND OBSERVED CONCENTRATIONS FOR THE EOCR DATA BASE

Q

SPREADSHEET LISTING OF METEOROLOGICAL DATA AND OBSERVED AND PREDICTED CONCENTRATIONS FOR THE EOCR DATA BASE: ISCST3 AND ISC-PRIME[1]

R

SPREADSHEET LISTING OF METEOROLOGICAL DATA AND OBSERVED AND PREDICTED CONCENTRATIONS FOR THE EOCR DATA BASE: ISCST3 AND ISC-PRIME[2]

S

RESIDUAL PLOTS AND ASSOCIATED SCATTERPLOTS FOR THE EOCR DATA BASE: ISCST3

T

RESIDUAL PLOTS AND ASSOCIATED SCATTERPLOTS FOR THE EOCR DATA BASE: ISC-PRIME[1]

U

RESIDUAL PLOTS AND ASSOCIATED SCATTERPLOTS FOR THE EOCR DATA BASE: ISC-PRIME^2

V

SUPPLEMENTAL SCATTERPLOTS RELATING TO THE EOCR DATA BASE EVALUATION

W

OUTPUT OF BOOT25 PROGRAM FOR ISCST3 AND ISC-PRIME[1] RESULTS FOR THE EOCR DATA BASE

X

OUTPUT OF BOOT25 PROGRAM FOR ISCST3 AND ISC-PRIME^2 RESULTS FOR THE EOCR DATA BASE

Y

SPREADSHEET LISTING OF METEOROLOGICAL DATA AND OBSERVED AND PREDICTED CONCENTRATIONS FOR ISCST3 AND ISC-PRIME[1]

Z

SPREADSHEET LISTING OF METEOROLOGICAL DATA AND OBSERVED AND PREDICTED CONCENTRATIONS FOR THE LEE POWER PLANT DATA BASE: ISCST3 AND ISC-PRIME^2

AA

RESIDUAL PLOTS AND ASSOCIATED SCATTERPLOTS FOR THE LEE POWER PLANT DATA

BASE: ISCST3

BB

RESIDUAL PLOTS AND ASSOCIATED SCATTERPLOTS FOR THE LEE POWER PLANT DATA BASE: ISC-PRIME[1]

CC

RESIDUAL PLOTS AND ASSOCIATED SCATTERPLOTS FOR THE LEE POWER PLANT DATA BASE: ISC-PRIME^2

DD

SUPPLEMENTAL SCATTERPLOTS RELATING TO THE LEE POWER PLANT DATA BASE EVALUATION

EE

OUTPUT FROM BOOT25 PROGRAM FOR ISCST3 AND ISC-PRIME[2] RESULTS FOR THE LEE POWER PLANT DATA BASE