9.0 Attainment Demonstration

9.1 Modeling Study Overview: Background and Objectives

The modeling study is designed to assess compliance with the fine particulate matter ($PM_{2.5}$) National Ambient Air Quality Standards (NAAQS). The standards include an annual standard of 15.0 micrograms per cubic meter ($\mu g/m^3$) based on the 3-year average of annual mean $PM_{2.5}$ concentrations, and a 24-hour standard of 65 $\mu g/m^3$ based on the 3-year average of the 98th percentile of 24-hour concentrations.

Section 1.1 provides a listing of the jurisdictions within the Washington, D.C. Metropolitan Statistical Area (MSA) that have been designated by EPA as nonattainment. Figure 1-1 provides a graphical representation of the Washington, D.C. MSA, including the locations of the FRM monitor locations that are being specifically evaluated in the modeling analysis.

This modeling study is designed to demonstrate attainment of the $PM_{2.5}$ standards by April 5, 2010. The procedures followed in the modeling analysis are consistent with the EPA's Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze (EPA-454/B-07-002, April 2007).

9.1.1 Relationship to Regional Modeling Protocols

The state members of the committees for this study are also members of the Ozone Transport Commission (OTC) and the Association for Southeastern Integrated Planning (ASIP) modeling committees. This membership has allowed them to coordinate the analyses performed for Washington, D.C. MSA with the regional modeling analyses conducted by OTC and ASIP. VADEQ, in consultation with the MDE, DDOE, and MWCOG, was responsible for conducting CMAQ runs for the Washington, D.C. domain. VADEQ's modeling runs were done in coordination with the OTC modeling for the 12-state Ozone Transport Region (OTR) and with the ASIP modeling, done for the southeastern states. Modeling centers for OTC included the New York State Department of Environmental Conservation (NYSDEC), the University of Maryland (UMD), Northeast States for Coordinated Air Use Management (NESCAUM) and VADEQ. Modeling inventories were developed, updated and shared among the regional modeling centers and provided by MARAMA, MANE-VU and VISTAS.

Installation of the models at VADEQ and all participating modeling centers was completed and diagnostic procedures were run successfully. The model has been benchmarked against other modeling platforms across the region to ensure accurate results.

The Policy Committee and the Technical Advisory Committee (TAC) oversaw the modeling work and made appropriate reports to the full MWAQC through regular briefings and offered other information in cases where specific technical decisions had policy implications. The Technical Committee members and members of other committees involved in the project who are also members of OTC and ASIP made sure to the extent practicable that there was consistency between the regional and urban modeling efforts.

9.1.2 Conceptual Model

EPA recommends that a conceptual description of the area's $PM_{2.5}$ problem be developed prior to the initiation of any air quality modeling study. A "conceptual description" is a qualitative way of characterizing the nature of an area's nonattainment problem. Within the conceptual description of a particular modeling exercise, it is recommended that the specific meteorological parameters that influence air quality be identified and qualitatively ranked in importance.

The conceptual model for this study consists of two documents. The first was prepared by NESCAUM for use by the OTC member States. The conceptual model document, The Nature of the Fine Particle and Regional Haze Air Quality Problems in the MANE-VU Region: A Conceptual Description (NESCAUM, November 2006), is provided in Appendix I, Attachment A. This document provides the conceptual description of the fine particle issues in the OTC states, consistent with the EPA's guidance.

The second conceptual model document that is included in Appendix I, Attachment A is The Development of $PM_{2.5}$ Forecasting Tools for Selected Cities in the MARAMA Region (ICF, September 2004). The primary objective of the Mid-Atlantic Regional Air Management Association, Inc. (MARAMA) $PM_{2.5}$ forecasting assistance project was to develop and evaluate statistical-based tools to support $PM_{2.5}$ forecasting for nine cities in the MARAMA region. The nine cities included Charlotte, North Carolina; Bristol, Roanoke, and Richmond, Virginia; Washington, D.C.; Baltimore, Maryland; Philadelphia, Pennsylvania; Wilmington, Delaware; and Newark/Elizabeth, New Jersey. The study included the analysis of $PM_{2.5}$ and meteorological data using Classification and Regression Tree (CART) analysis software and the development, testing, and evaluation of interactive forecasting tools for each area. Data and information gathered throughout the course of the project were used, together with the CART analysis results, to describe the relationships between meteorology and $PM_{2.5}$ concentration and, specifically, the conditions associated with high $PM_{2.5}$ events in each forecast area.

9.2 Domain and Database Issues

9.2.1 Episode Selection

Due to the fact that the attainment demonstration is being conducted using a resource intensive photochemical grid model, EPA accepts the use of a single, recent "representative" year to be used for an annual model simulation. Two factors were used in selecting 2002 as the "representative" year:

1. The observed annual mean concentrations of $PM_{2.5}$ are close to the 3-year observed design value at all, or most, monitoring sites.
2. The pattern of quarterly mean values is similar to the pattern of quarterly mean concentrations averaged over 3 years.

9.2.2 Size of the Modeling Domain

In defining the modeling domain, one must consider the location of the local urban area, the downwind extent of the elevated $PM_{2.5}$ levels, the location of large emission sources, and the availability of meteorological and air quality data. The domain or spatial extent to be modeled includes as its core the nonattainment area. Beyond this, the domain includes enough of the surrounding area such that major upwind sources fall within the domain and emissions produced in the nonattainment area remain within the domain throughout the day.

The boundary of the modeling domain is provided in Appendix I, Attachment B. This domain covers the Northeast region including northeastern, central and southeastern US as well as southeastern Canada. The final SIP modeling analysis utilized the modeling domain boundary established by OTC. The ASIP modeling domain boundary is provided for reference.

9.2.3 Horizontal Grid Size

The OTC platform used for the Washington, D.C. modeling analysis has a coarse grid continental United States (US) domain with a 36-kilometer (km) horizontal grid resolution. The CMAQ domain is nested in the MM5 domain. A larger MM5 domain was selected for both MM5 simulations to provide a buffer of several grid cells around each boundary of the CMAQ 36-km domain. This was designed to eliminate any errors in the meteorology from boundary effects in the MM5 simulation at the interface of the MM5 model. A 12-km inner domain was selected to better characterize air quality in OTC and surrounding Regional Planning Organization (RPO) regions. Appendix I, Attachment C contains the horizontal grid definitions for the MM5 and CMAQ modeling domains.

9.2.4 Vertical Resolution

The CMAQ vertical structure is primarily defined by the vertical grid used in the MM5 modeling. The MM5 model employed a terrain following coordinate system defined by pressure. The layer averaging scheme adopted for CMAQ is designed to reduce the computational cost of the CMAQ simulations. The effects of layer averaging have a relatively minor effect on the model performance metrics when compared to ambient monitoring data. Appendix I, Attachment D contains the vertical layer definitions for the MM5 and CMAQ modeling domains.

9.2.5 Initial and Boundary Conditions

The objective of a photochemical grid model is to estimate the air quality given a set of meteorological and emissions conditions. When initializing a modeling simulation, the exact concentration fields are unknown in every grid cell for the start time. Therefore, typically photochemical grid models are started with clean conditions within the domain and allowed to stabilize before the period of interest is simulated. In practice this is accomplished by starting the model several days prior to the period of interest.

The winds move pollutants into, out of, and within the domain. The model handles the movement of pollutants within the domain and out of the domain. An estimate of the quantity of pollutants moving into the domain is needed. These are called boundary conditions. To estimate the boundary conditions for the modeling study, three-hourly boundary conditions for the outer 36-km domain were derived from an annual model run performed by researchers at Harvard University using the GEOS-CHEM global chemistry transport model. The influence of boundary conditions was minimized by using a 15-day ramp-up period which is sufficient to establish pollutant levels that are encountered in the beginning of an air pollution episode.

9.2.6 Meteorological Model Selection and Configuration

The Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Meteorological Model (MM5) was selected for application in the Washington, D.C. MSA modeling analysis. MM5 is a non-hydrostatic, prognostic meteorological model routinely used for urban- and regional-scale photochemical regulatory modeling studies.
Based on model validation and sensitivity testing, the MM5 configurations provided in Attachment E were selected. Results of the University of Maryland's detailed performance evaluation of the MM5 modeling used in conjunction with the OTC platform are provided in Appendix I, Attachment E.

9.2.7 Emissions Model Selection and Configuration

Significant coordination efforts took place between MANE-VU and VISTAS in the development of the emissions inventories used in the modeling study. All analyses conducted in support of the Washington, D.C. modeling analysis were coordinated between the Technical and Policy Committees along with TAC.

These inventories include a base case (2002) which serves as the "parent" inventory off which all future year inventories (i.e., 2009) are based. The future year inventories include emissions growth due to any projected increase in economic activity as well as the implementation of control measures.

The Sparse Matrix Operator Kernel Emissions (SMOKE) Emissions Processing System was selected for application in the Washington, D.C. non-attainment modeling analysis.
SMOKE (Version 2.1) was used for the Washington DC attainment modeling demonstration. 2002 base case and 2009 future base case emissions data files were provided by OTC and ASIP. A detailed description of all SMOKE input files such as area, mobile, fire, point and biogenic emissions files is provided in Appendix I, Attachment F. The SMOKE model configuration is also provided.

9.2.8 Air Quality Model Selection and Configuration

EPA's Models-3/Community Multi-scale Air Quality (CMAQ) modeling system was selected for the attainment demonstration primarily because it is a "one-atmosphere" photochemical grid model capable of addressing $PM_{2.5}$ at regional scale and is considered one of the preferred models for regulatory modeling applications. The model is also recommended by the Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze (EPA-454/B-07-002, April 2007). The CMAQ configuration is provided in Appendix I, Attachment H.

9.2.9 Quality Assurance

All air quality, emissions, and meteorological data were reviewed to ensure completeness, accuracy, and consistency before proceeding with modeling. Any errors, missing data or inconsistencies, were addressed using appropriate methods that are consistent with standard practices. All modeling was benchmarked through the duplication of a set of standard modeling results.

Quality Assurance (QA) activities were carried out for the various emissions, meteorological, and photochemical modeling components of the modeling study. Emissions inventories obtained from the Regional Planning Organizations (RPO) were examined to check for errors in the emissions estimates. When such errors were discovered, the problems in the input data files were corrected.

The MM5 meteorological and CMAQ air quality model inputs and outputs were plotted and examined to ensure accurate representation of the observed data in the model-ready fields, and temporal and spatial consistency and reasonableness. Both MM5 and CMAQ underwent operational and scientific evaluations in order to facilitate the quality assurance review of the meteorological and air quality modeling procedures and are discussed in greater detail throughout this document.

9.3 Model Performance Evaluation

A critical component of every air quality modeling study is the model performance evaluation where the modeled estimates for the current year base case are compared against observed values to assess the model's accuracy and provide an indication of its reliability. This section lays out the procedures and results of the evaluation. It should be noted that the other parts of the modeling process, the emissions and meteorology, also undergo an evaluation. It is with this knowledge and the desire to keep the report concise, that the air quality model became the primary focus of this section.

The first step in the modeling process is to verify the model's performance in terms of its ability to predict the $PM_{2.5}$ and its individual components (i.e., sulfate, nitrate, ammonium, organic carbon, elemental carbon and other $PM_{2.5}$) in the right locations and at the right levels. To do this, the model predictions for the base year simulation are compared to the ambient data observed in the historical episode. This verification is a combination of statistical and graphical evaluations. If the model appears to be producing $PM_{2.5}$ in the right locations for the right reasons, then the model can be used as a predictive tool to evaluate various control strategies and their effects on $PM_{2.5}$.

The results of a model performance evaluation were reviewed prior to using modeling to support the attainment demonstration. The New York State DEC, Division of Air Resources, conducted a performance evaluation of the 2002 base case CMAQ simulation on behalf of the OTC member States. Appendix I (Attachment I) provides comprehensive operational and diagnostic evaluation results, including spreadsheets containing the assumptions made to compute statistics. Highlights of this evaluation are provided in the following sections.

9.3.1 Diagnostic and Operational Evaluation

The issue of model performance goals for $PM_{2.5}$ is an area of ongoing research and debate. To evaluate model performance, EPA recommends that several statistical metrics be developed for air quality modeling. Performance goals refer to targets that a good performing model should achieve, whereas performance benchmarks are based on historical model performance measures for the best performing simulations. Performance goals are necessary in order to provide consistency in model applications and expectations across the country and to provide standardization in how much weight may be accorded modeling study results in the decision-making process.

When EPA's guidance was first developed nearly four (4) years ago, an interim set of fine particulate modeling performance goals were suggested for aggregated mean normalized gross error and mean normalized bias as defined in Table 9-1.

Table 9-1. EPA $PM_{2.5}$ Modeling Performance Goals

Pollutant	Gross Error	Normalized Bias
$PM_{2.5}$	~30-50%	~10%
Sulfate	~30-50%	~20-30%
Nitrate	~20-70%	~15-50%
EC	~15-60%	NA
OC	~40-50%	~38%

Because regional-scale $PM_{2.5}$ modeling is an evolving science, and considerable practical application and performance testing has transpired in the intervening years since these goals were postulated, they are considered as general guidelines.

It may also be possible to adopt levels of model performance goals for bias and gross error as listed in Table 9-3 (as developed by VISTAS) to help evaluate model performance.

Table 9-2. VISTAS $PM_{2.5}$ Modeling Performance Goals

Fractional Bias	Fractional Error	Comment
≤±15%	≤35%	Ozone model performance goal for which $PM_{2.5}$ model performance would be considered good.
≤±30%	≤50%	A level of model performance that we would hope each $PM_{2.5}$ species could meet.
≤±60%	≤75%	At or above this level of performance indicates fundamental problems with the modeling system.

It does not mean that these performance goals should be generally adopted or that they are the most appropriate goals to use. Rather, the goals are being used to frame and put the $PM_{2.5}$ model performance into context and to facilitate model performance across episodes, species, models and sensitivity tests.

As noted in EPA's $PM_{2.5}$ modeling guidance, less abundant $PM_{2.5}$ species should have less stringent performance goals. Accordingly, performance goals that are a continuous function of average observed concentrations such as those proposed by Dr. James Boylan at the Georgia Department of Natural Resources have the following features:

- Asymptotically approaching proposed performance goals or criteria when the mean of the observed concentrations are greater than 2.5 $\mu g/m^3$.

- Approaching 200% error and ±200% bias when the mean of the observed concentrations are extremely small.

The above goals and criteria are not regarded as a pass/fail test, but rather as a basis of inter-comparing model performance across studies, sensitivity tests and models.

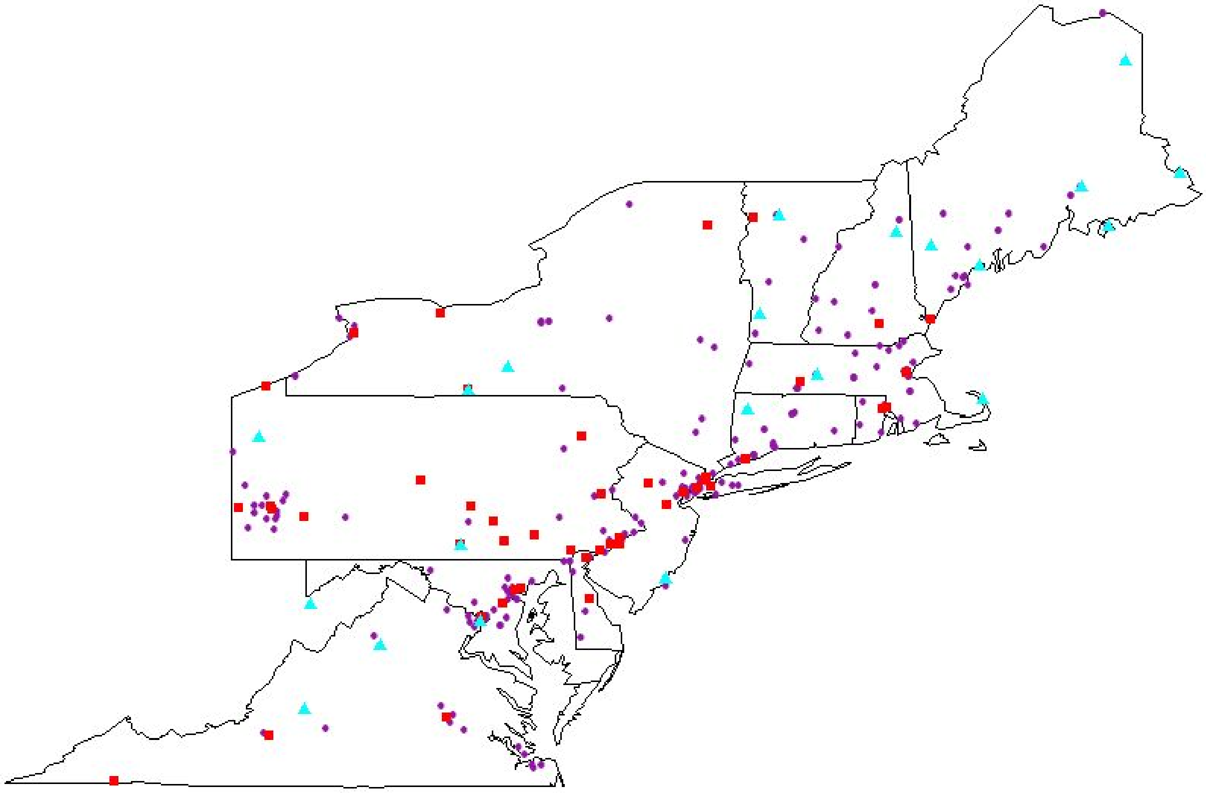
The OTC model performance evaluation was initially conducted by NYSDEC on the summer ozone season data only. VADEQ has extended the evaluation to include the entire year of 2002 observations. Four statistical parameters, two recommended by EPA (Table 9-1) and two adopted by VISTAS (Table 9-2), pertinent to model performance evaluation were computed for FRM $PM_{2.5}$ mass and for individual species of SO_4, NO3, NH_4, EC, OM (1.8* blank-corrected OC), soil or crustal material (sum of oxides of Ca, Fe, Si, and Ti). The statistics were organized into two categories: a) by date and b) by site.

For statistics by date, the parameters were calculated on a given day for any valid pairs of observed/predicted data across all FRM and speciation monitors that fall within the OTR modeling domain plus all of Virginia monitors (referred to as OTR+). Data collected from three different monitoring networks, FRM, STN, and IMPROVE, were used in the statistics. A subset of these "time-based composite monitor" statistics focusing only on the Washington, D.C. MSA monitors was also generated. It is important to note that predicted data used for the model performance evaluation were extracted from CMAQ outputs at the exact grid cells where monitors are located. This is in contrast to the design value calculations where predictions are based on the average of the surrounding nine grid cells (see Section 9.4).

For statistics by site, parameters were computed at a given FRM, STN, or IMPROVE monitor for any valid pairs of observed/predicted data over a period of one calendar year. Again, the full year of 2002 data was used in this “monitor-based composite period" analysis, except for the dates between July 6 and July 9 due to the exceptional event caused by the Quebec forest fires.

Figure 9-1 depicts the location of the FRM, STN and IMPROVE monitor locations used for the model evaluation across the OTR+ region.

Figure 9-1. FRM (●, 264), STN (■, 50), and IMPROVE (▲, 21) Locations Used for the Model Evaluation Across the OTR+ Region



A composite FRM time series across the OTR+ region (264 monitors) is provided in Figure 9-2. This figure indicates that there is an overall mean bias of approximately 4 ug/m^3. There is a general over-prediction during winter months and an under-prediction during summer months. There is excellent agreement during the mid-August air pollution episode.

Figure 9-2. Composite FRM Time Series across the OTR+ Region (264 monitors)

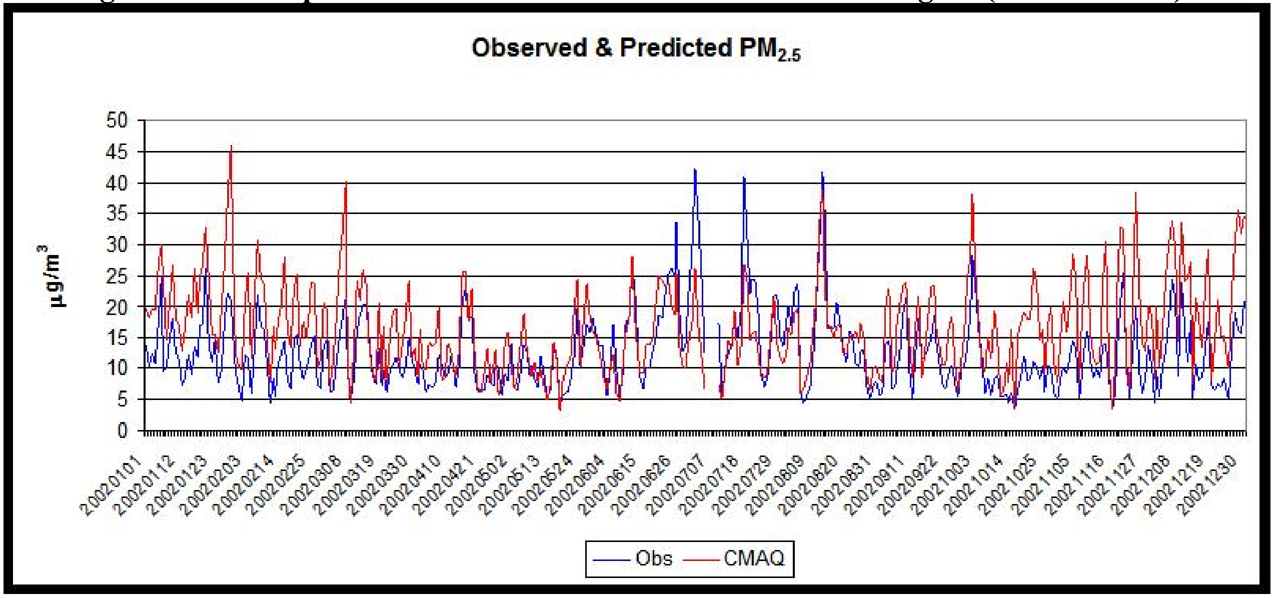
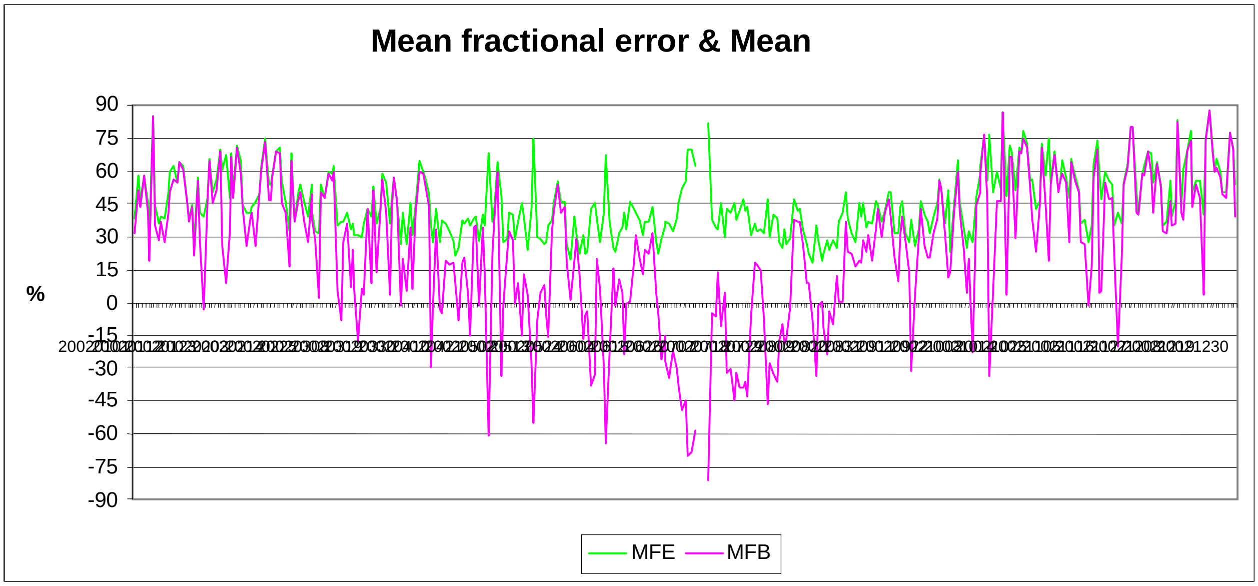


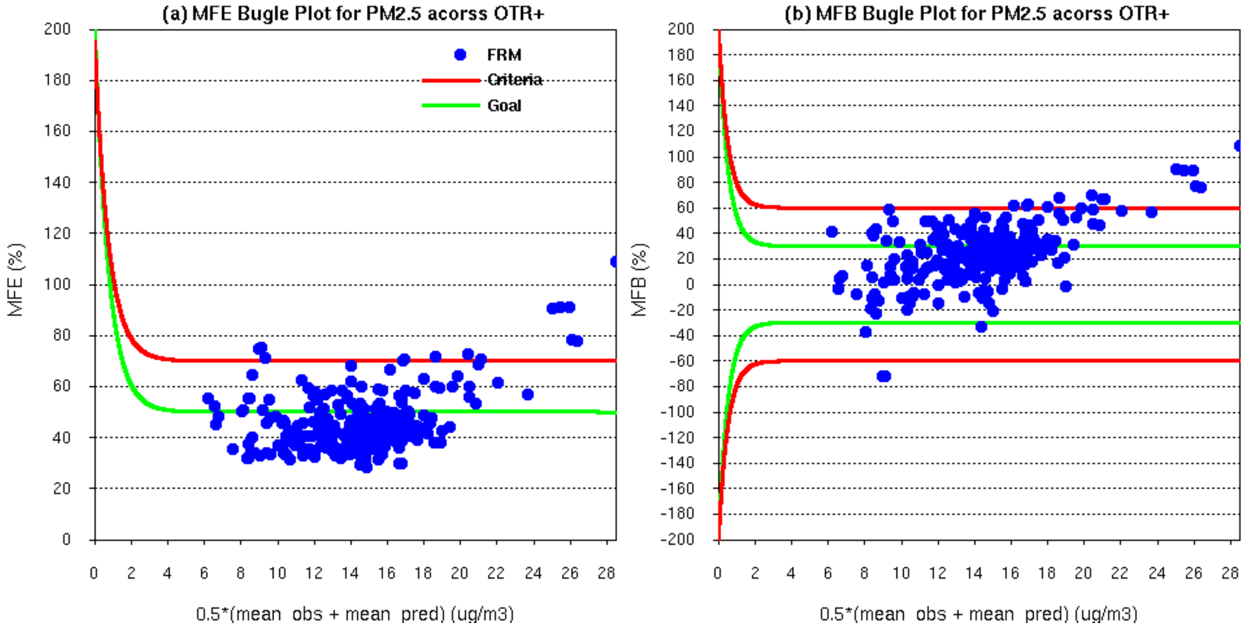
Figure 9-3 is a plot of the FRM mean fractional error (MFE) and mean fractional bias (MFB) across the OTR+ region. MFE ranges from 17% to 88% with an average of approximately 45%. MFB ranges from -82% to +88% with an average of approximately +24%. These values are generally consistent with similar studies listed in the Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze (EPA-454/B-07-002, April 2007).

Figure 9-3. MFE and MFB Time Series for FRM $PM_{2.5}$ across the OTR+ Region



A bugle plot for FRM $PM_{2.5}$ monitors across the OTR+ region is provided in Figure 9-4. “Goal” curves are the best a model can be expected to achieve while the “criteria” curves are considered acceptable for model performance. The overall model performance for $PM_{2.5}$ is fairly good, with greater than 50% of the 264 FRM sites meeting the goals and greater than 95% meeting the criteria on an annual average basis.

Figure 9-4. Bugle Plot for FRM $PM_{2.5}$ across OTR+ Region



MFE bugle plots were also generated for SO_4, NO_3, and NH_4, EC, OM, and soil/crustal across OTR+ region and are provided in Figures 9-5 through 9-10. As can be seen from the results, the performance for individual species is generally consistent with the criteria necessary for acceptable model performance.

Figure 9-5. Bugle Plot for SO_4 across OTR+ Region

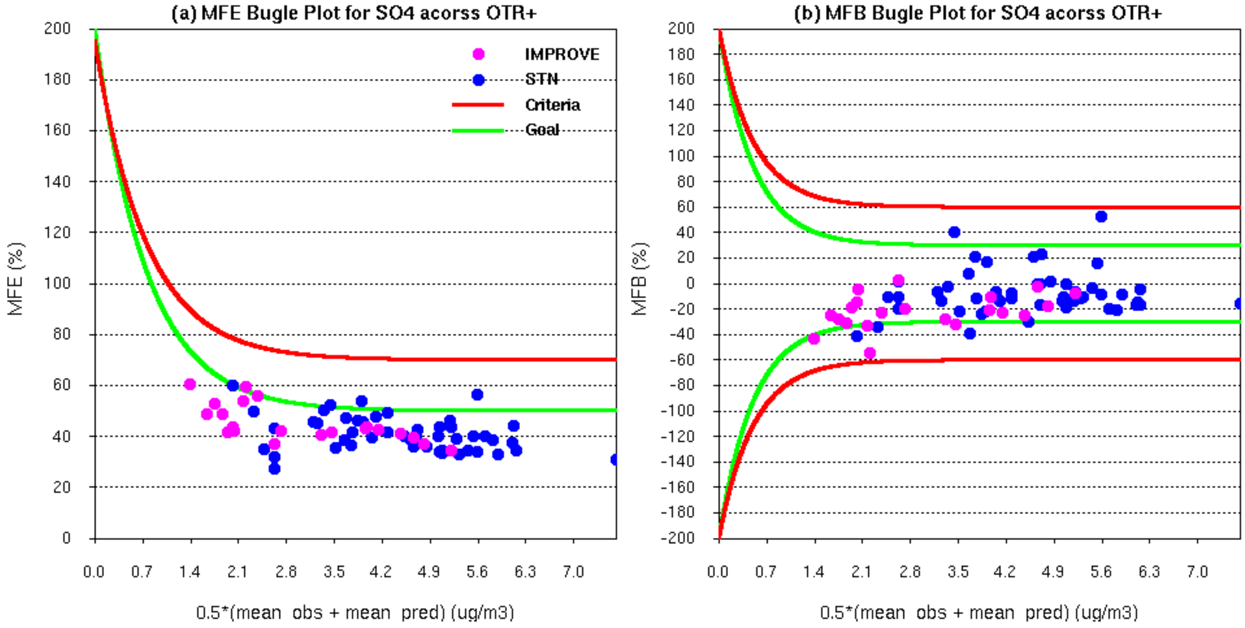


Figure 9-6. Bugle Plot for NO_3 across OTR+ Region

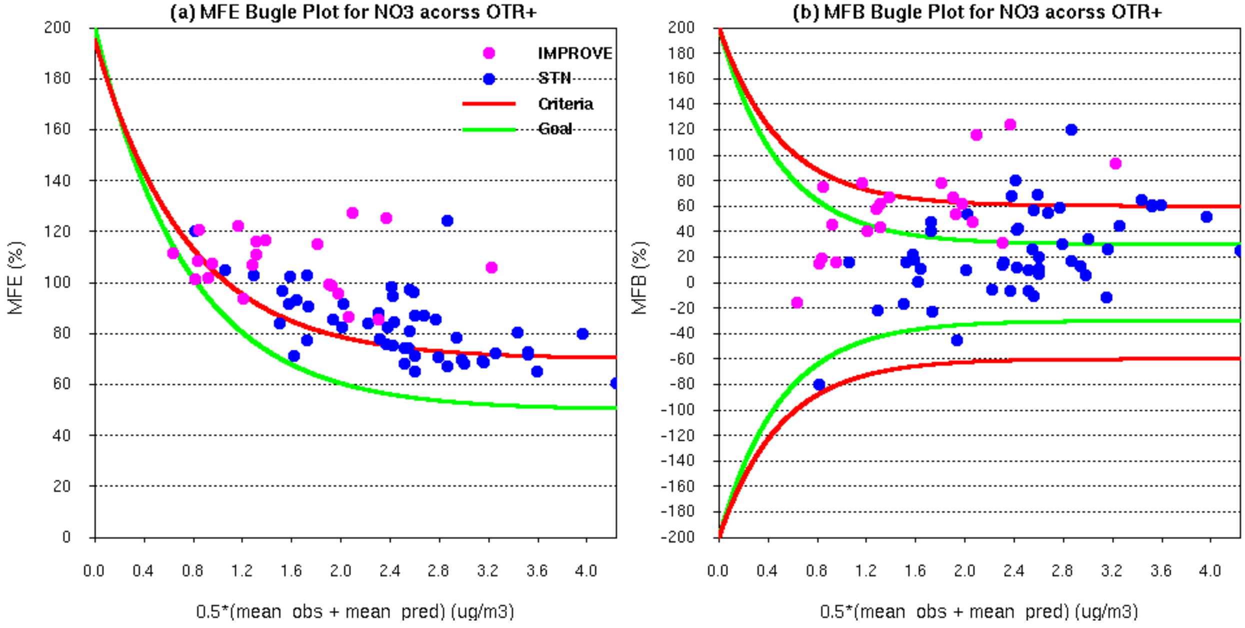
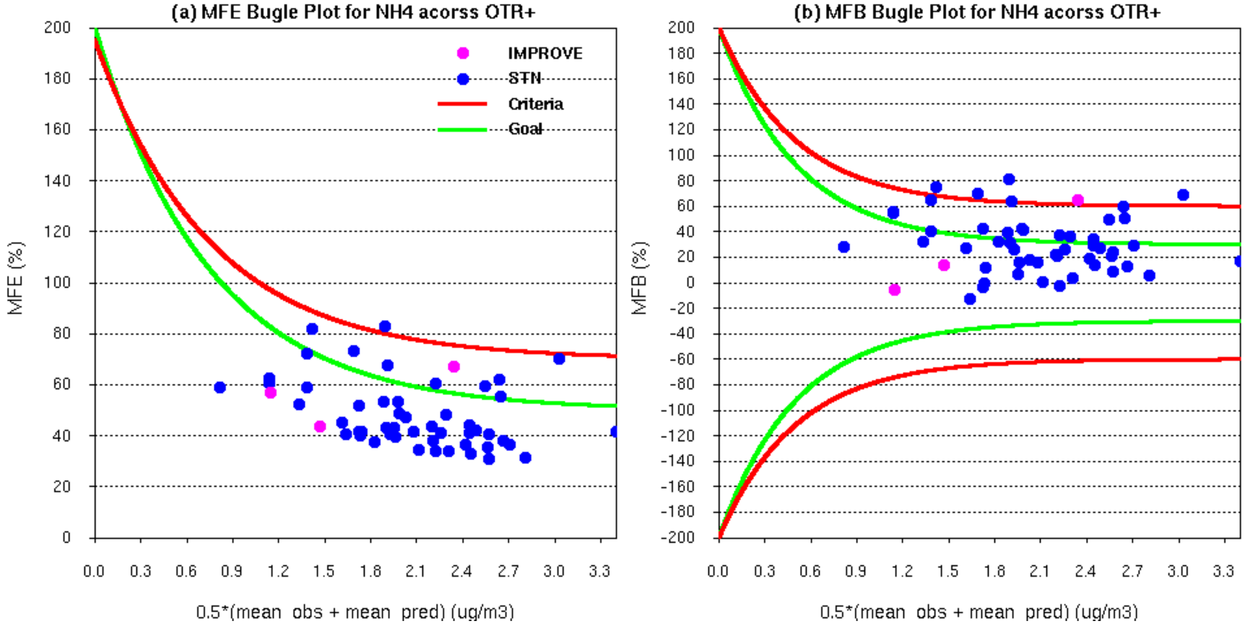


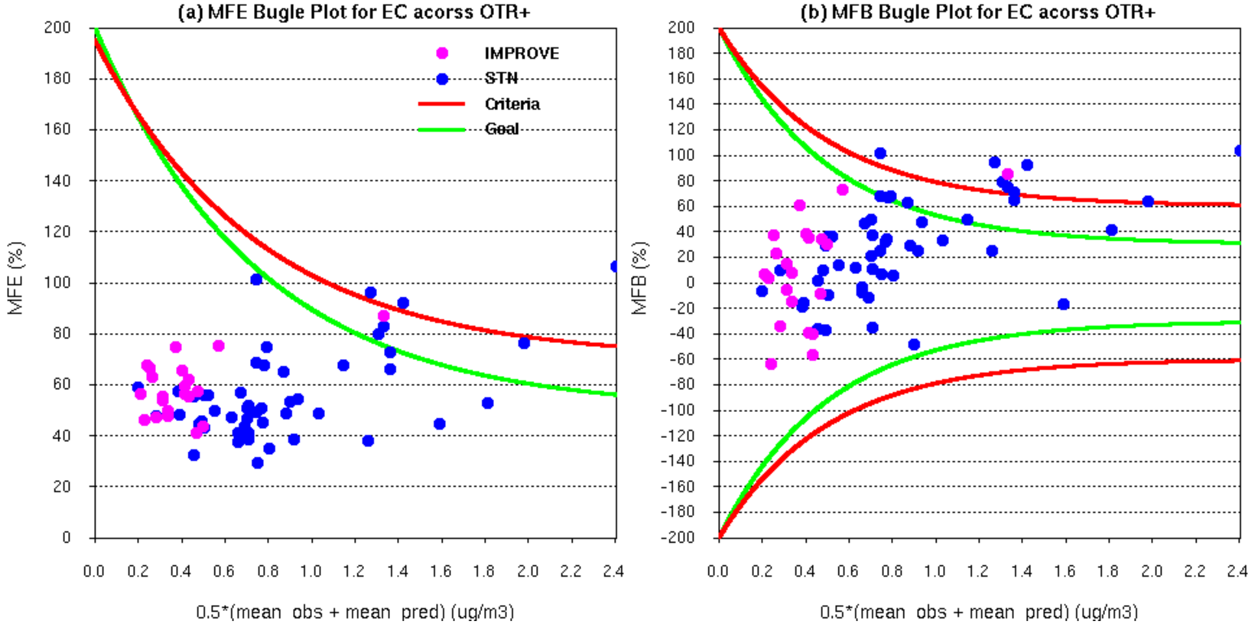
Figure 9-7. Bugle Plot for NH_4 across OTR+ Region



(a) MFE Bugle Plot for NH4 acorss OTR+

(b) MFB Bugle Plot for NH4 acorss OTR+

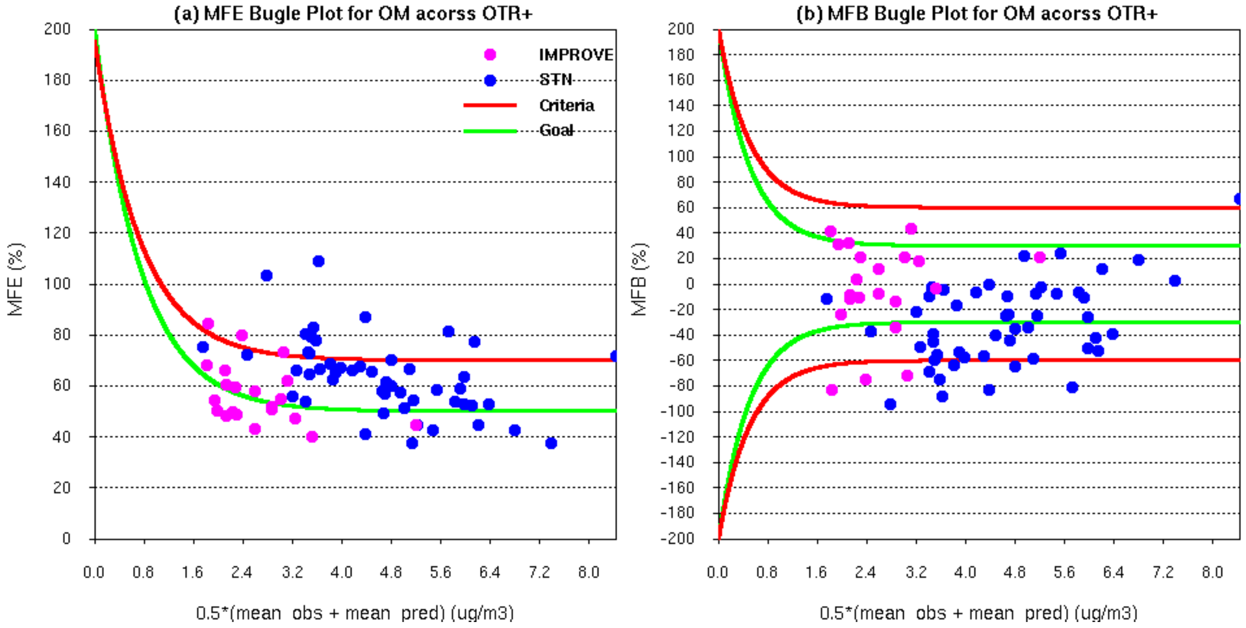
Figure 9-8. Bugle Plot for EC across OTR+ Region



(a) MFE Bugle Plot for EC acorss OTR+

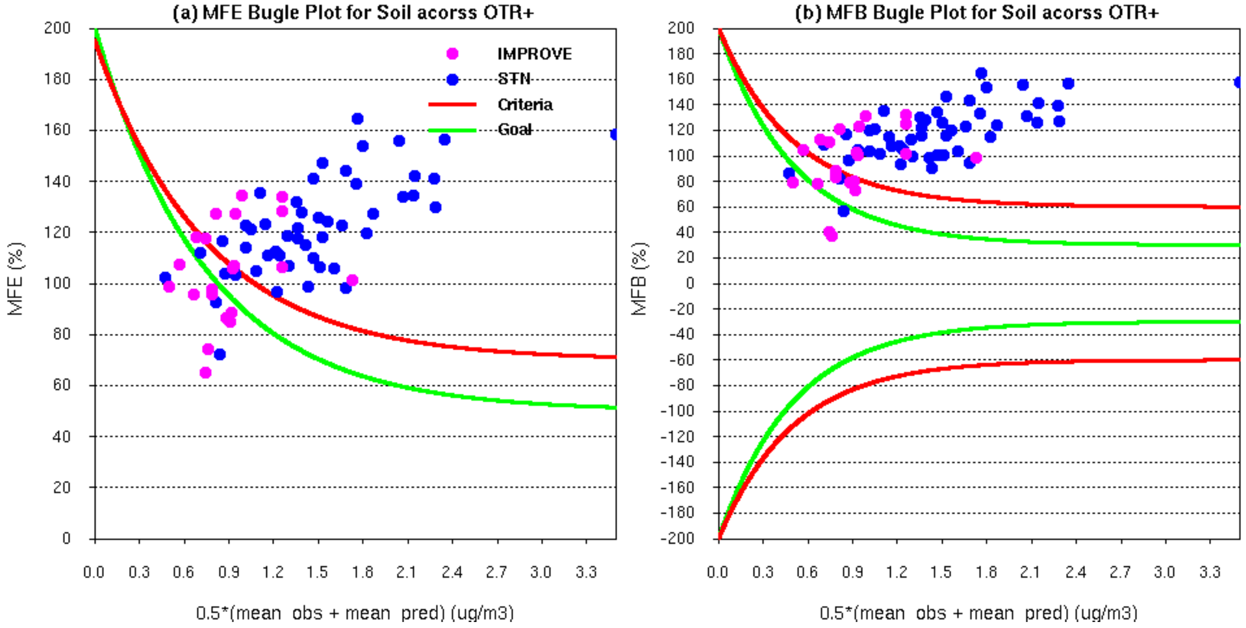
(b) MFB Bugle Plot for EC acorss OTR+

Figure 9-9. Bugle Plot for OM across OTR+ Region


(a) MFE Bugle Plot for OM acorss OTR+

(b) MFB Bugle Plot for OM acorss OTR+

Figure 9-10. Bugle Plot for Soil/Crustal across OTR+ Region

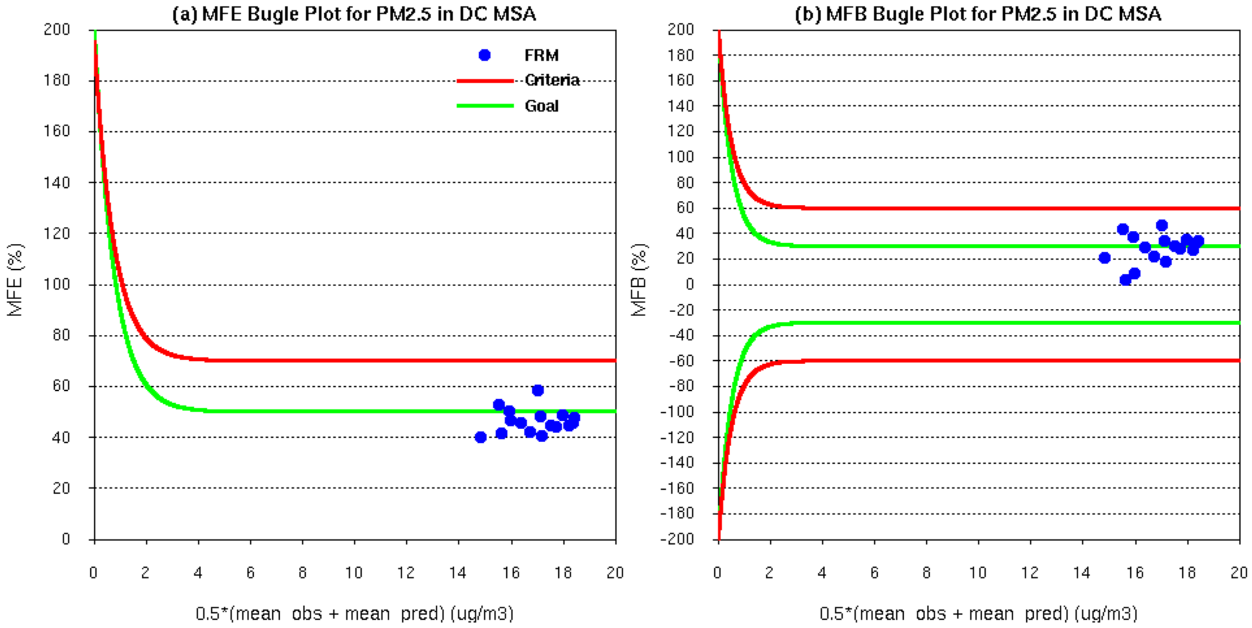

(a) MFE Bugle Plot for Soil acorss OTR+

(b) MFB Bugle Plot for Soil acorss OTR+

In terms of individual $PM_{2.5}$ components, model performance for sulfate is excellent, with a great majority of the data points meeting the goals, and all of the data points meeting the criteria. The good performance is likely attributed to accurate estimates of SO_2 emissions, less complex sulfate chemistry than other component species, and high spatial homogeneity of sulfate. On the other hand, model performs poorly for nitrate, with more than half of the data points fail to meet the criteria. Nitrate, in general, exhibits an overestimated (i.e., positive bias) trend. Similar to sulfate, performance of ammonium is fairly good as well, with only a few data points falling outside of the criteria. Performance for organic compounds is considered fair, as a number of data points fail to meet the criteria. Contrary to nitrate, poorly-performed data points of organic compounds appear mostly under-predicted (i.e., negative bias). Elemental carbon, which makes up only a small portion of total $PM_{2.5}$, has a similarly good model performance as ammonium. Finally, model performance for soil compounds is quite poor, with a great majority of data points falling outside of the criteria, caused largely by over-prediction.

A separate evaluation focusing on total $PM_{2.5}$ for the FRM monitors in the Washington D.C. MSA is presented in Figure 9-11. CMAQ performs well for DC FRM monitors with all of the monitors meeting the criteria for acceptable model performance.

Figure 9-11. Bugle Plot for FRM $PM_{2.5}$ in Washington, D.C. MSA



The following is a list of several $PM_{2.5}$ statistics for the OTC domain that have also been provided in Appendix I, Attachment J.

1. Statistical evaluation of daily average $PM_{2.5}$ mass from FRM sites across the OTR+ domain. Statistics are computed by date and by site (across the OTR+).

2. Statistical evaluation of daily average $PM_{2.5}$, SO_4, NO_3, NH_4, EC, OM, and crustal/soil mass at EPA STN sites. Statistics are computed by date and by site (across the OTR+).

3. Statistical evaluation of daily average $PM_{2.5}$, SO_4, NO_3, EC, OM, and crustal/soil mass at IMPROVE sites. Statistics are computed by date and by site (across the OTR+).

4. Statistical evaluation of daily average $PM_{2.5}$ mass from FRM sites in the Washington, D.C. MSA sub-domain. Statistics are computed by date and by site.

9.3.2 Summary of Model Performance

CMAQ was employed to simulate $PM_{2.5}$ for the calendar year 2002. A review of $PM_{2.5}$ and its individual species was conducted for the study domain. Documentation for the Model Performance tests is provided in Appendix I Attachment I (CMAQ Model Performance).

The CMAQ model performance for surface $PM_{2.5}$ is good with acceptable bias and error. Several observations can be made with respect to overall model performance, including the following:

1. Approximately 80-90% of OM is in the primary fraction. Observed OM has distinct maximum during summer when secondary formation is highest; CMAQ exhibits substantial under-prediction in secondary organic aerosols (SOA). The predicted primary OM is highest during the winter.
2. CMAQ captures seasonal variation in SO_4 well.
3. CMAQ appears to overestimate primary $PM_{2.5}$ components (EC, soil, primary OM), especially during colder months.
4. CMAQ appears to underestimate secondary OM during the summer.

These issues are not of great regulatory concern since attainment tests are based on the application of relative response factors. In summary, the regional and local model performance is acceptable for $PM_{2.5}$. While there are some differences between the spatial data between sub-regions, there is nothing to suggest a tendency for the model to respond in a systematically different manner between regions. Examination of the statistical metrics by sub-region confirms the absence of significant performance problems arising in one area but not in another, building confidence that the CMAQ modeling system is operating consistently across the full OTC domain. This confidence in the modeling results allows for the modeling system to be used to support the State Implementation Plan to meet the 1997 $PM_{2.5}$ NAAQS.

9.4 Attainment Demonstration

As previously mentioned, the Washington, D.C. MSA has been classified as a nonattainment area for $PM_{2.5}$ with an attainment date of April 5, 2010. The $PM_{2.5}$ NAAQS include an annual standard of 15.0 $\mu g/m^3$ based on the 3-year average of annual mean $PM_{2.5}$ concentrations, and a 24-hour standard of 65 $\mu g/m^3$ based on the 3-year average of the 98th percentile of 24-hour concentrations.

This section summarizes the procedures that were used to demonstrate attainment of the NAAQS in the State Implementation Plan (SIP) package. As described in EPA's Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze (EPA-454/B-07-002, April 2007), an attainment demonstration consists of (a) analyses which estimate whether selected emissions reductions will result in ambient concentrations that meet the NAAQS, and (b) an identified set of control measures which will result in the required emissions reductions. The necessary emission reductions for both of these attainment demonstration components may be determined by relying on results obtained with air quality models.

EPA guidance recommends applying a modeled attainment test to the air quality modeling results to determine if the $PM_{2.5}$ NAAQS will be met. Additional technical or corroboratory analyses may also be used as part of a “supplemental analysis” or a more stringent “weight of evidence” determination to supplement the modeled attainment test and to further support a demonstration of attainment of the NAAQS.

The modeled attainment test and additional corroborative analyses are described in further detail in the remaining portions of this section.

9.4.1 Model Attainment Test

The purpose of a modeling assessment determine if control strategies currently being implemented (“on the books”) and proposed control strategies will lead to attainment of the NAAQS for $PM_{2.5}$ by the attainment year of 2009. The modeling is applied in a relative sense, similar to the 8-hour ozone attainment test. However, The $PM_{2.5}$ attainment test is more complicated and reflects the fact that $PM_{2.5}$ is a mixture. In the test, ambient $PM_{2.5}$ is divided into major components, with a separate relative response factor (RRF) and future design value (DVF) calculated for each of the $PM_{2.5}$ components. Since the attainment test is calculated on a per species basis, the attainment test for $PM_{2.5}$ is referred to as the Speciated Modeled Attainment Test (SMAT). The following sections outline the process to determine 2009 projections of $PM_{2.5}$ will meet the NAAQS from regional modeling, as suggested in EPA’s guidance.

9.4.1.1 Determine Baseline Design Values

The first step in any attainment test process is to determine the baseline design value (DVB). EPA guidance recommends using a DVB that is the average of the three design value periods that straddle the baseline inventory year (i.e., the average of the 2000-2002, 2001-2003, and 2002-2004 design value periods for a 2002 baseline inventory year). This works out to a 5-year weighted average, with the baseline year having the heaviest weight (i.e., {[2000] + 2*[2001] + 3*[2002] + 2*[2003] + [2004]}/9).

For the SMAT process, a mean $PM_{2.5}$ DVB is determined, as well as component specific DVB for each quarter. The following section will detail the calculation of baseline design values needed for the $PM_{2.5}$ attainment test.

9.4.1.1.1 Mean $PM_{2.5}$ Baseline Design Values

To begin the SMAT process, a mean $PM_{2.5}$ DVB is calculated on a quarterly basis for each Federal Reference Method (FRM) monitor in the $PM_{2.5}$ nonattainment areas. Concentrations are calculated based on calendar quarters (Q1: January - March; Q2: April - June; etc.) as the NAAQS is calculated for a calendar year, and the quarters need to fit evenly within a year. Also, calculating the attainment test on a quarterly basis allows states to examine the differences in $PM_{2.5}$ composition that occur during the different seasons.

9.4.1.1.2 Speciated Baseline Conditions

The monitored attainment test for $PM_{2.5}$ utilizes both $PM_{2.5}$ and individual $PM_{2.5}$ component species. A separate RRF is calculated for each $PM_{2.5}$ species. In order to perform the recommended modeled attainment test, States should divide observed mass concentrations of $PM_{2.5}$ into 7 components (plus passive mass):

1. Mass associated with sulfates (SO_4)
2. Mass associated with nitrates (NO_3)
3. Mass associated with ammonium (NH_4)
4. Mass associated with organic carbon (OC)
5. Mass associated with elemental carbon (EC)
6. Mass associated with particle bound water (PBW)
7. Mass associated with “other” primary inorganic particulate matter (Crustal)
8. And passively collected mass or the mass of the blank filter

The second part of the process is to use the quarterly mean $PM_{2.5}$ DVBs (as calculated in Section 9.4.1.1.1) with speciated data to calculate the quarterly mean concentrations of these 7 components at the FRM sites. This need to speciate the FRM data presents two issues:

1. FRM measurements and speciated $PM_{2.5}$ measurements do not always measure the same mass.
2. Not all FRM monitoring sites have co-located STN speciation monitors.

The following sections will explain how these issues were overcome to produce the speciated values needed for this attainment demonstration.

9.4.1.1.2.1 SANDWICH

As EPA guidance notes, recent data analyses have noted that the FRM monitors do not measure the same components and do not retain all of the $PM_{2.5}$ that is measured by routine speciation samplers and therefore cannot be directly compared to speciation measurements from the Speciation Trends Network (STN). By design, the FRM mass measurement does not retain all ammonium nitrate and other semi-volatile materials (negative sampling artifacts) and includes particle bound water associated with sulfates, nitrates and other hygroscopic species (positive sampling artifacts). This results in concentrations (and percent contributions to $PM_{2.5}$ mass), which may be different than the ambient levels of some $PM_{2.5}$ chemical constituents.

To resolve the differences between FRM and STN total mass, EPA recommends using the “sulfate, adjusted nitrate, derived water, inferred carbonaceous material balance approach” or SANDWICH approach. With the SANDWICH approach, nitrate mass is adjusted to account for volatilization based on hourly meteorology parameters. Subsequently, quarterly average nitrate, sulfate, elemental carbon, and crustal mass can be calculated, as well as the Degree of Neutralization (DON) of sulfates. Quarterly average NH_4 can then be calculated from adjusted the adjusted nitrate mass, sulfate mass, and DON of sulfate. Next the mass of particle bound water can be calculated from the previously obtained DON, sulfate, nitrate, and ammonium values. Finally, organic carbon is calculated by taking the difference between the total $PM_{2.5}$ mass as measured at the FRM monitor, and the calculated component mass (i.e., OC from mass balance ([OCMmb] = $PM2.5_{FRM}$:{[EC] + [SO4] + [NO3] + [NH4] + [water] + [crustal material] + [passive mass]}).

9.4.1.1.2.2 Speciated Profiles

While the SANDWICH method reconciles the differences between FRM and STN, a lingering issue is that not all FRM monitoring sites have co-located STN monitors to provide speciated data. EPA guidance suggests four measures that can be taken to resolve the lack of speciated data:

1. Use of concurrent data from a near by speciated monitor
2. Use of representative data (from a different time period)
3. Use of interpolation techniques to create a spatial field using ambient speciation data
4. Use of interpolation techniques to create spatial fields, and gridded modeling outputs to adjust the species concentrations

Of the four methodologies, the EPA recommends using one of the spatial interpolation techniques to estimate species concentrations at FRM sites that do not have speciation data (numbers 3 and 4 above). To assist in this task, the EPA is developing software tool called “Modeled Attainment Test Software” (or MATS) that will perform the spatial analysis of described options number 3 and 4. However, the MATS tool is not available at this time. In trying to pursue the EPA recommended course of action, speciated profiles from the Clean Air Interstate Rule (CAIR) SMAT tool, which is the predecessor for the MATS program, were used as an alternative.

The CAIR SMAT tool uses data from both the Interagency Monitoring of Protected Visual Environments (IMPROVE) and the US EPA’s Speciation Network (ESPN) to derive mean concentrations for six $PM_{2.5}$ components. Quarterly average concentrations between Jan 2002 to December 2002 were retained for sites that had at least 11 monitored values per quarter for each of the major $PM_{2.5}$ species. Major species for ESPN include EC, OC, NH4, SO_4, NO_3, and crustal material (which include the five trace elements aluminum, calcium, iron, silicon, and titanium). The major species for IMPROVE are the same except for NH_4, which is not routinely measured in the IMPROVE protocol.

The quarterly average species concentrations at the IMPROVE and ESPN monitors were used to interpolate concentrations at the $PM_{2.5}$ FRM monitoring sites using a technique called Voronoi Neighbor Averaging (VNA). Appendix I Attachment J contains the document entitled Procedures for Estimating Future $PM_{2.5}$ Values for the CAIR Final Rule by Application of the (Revised) Speciated Modeled Attainment Test (SMAT) Updated- 11/8/04, which describes the interpolation process, and the data speciation process in detail.

As a result of the CAIR SMAT process, quarterly species fractions were generated (see Attachment J). These fractions were then applied to Observed Quarterly Mean $PM_{2.5}$ values to determine quarterly component specific concentrations. The estimated future mass of NH_4 and PBW are determined by the estimated future mass of SO_4 and NO_3, as was done in the CAIR SMAT tool using equations provided in Appendix I, Attachment J.

9.4.1.2 Relative Response Factor Calculations

The calculation of relative response factors (RRFs) for this study was performed using the EPA recommended method for "nearby" grid cells for a 12-kilometer horizontal grid resolution, with a 3x3 grid cell array for 12-km resolution modeling. The relative response factor used in the modeled attainment test is computed by taking the ratio of the mean of the predictions in the future to the mean predictions with baseline emissions, over all relevant days.

For the 24-hour and annual $PM_{2.5}$ NAAQS, the spatially averaged value of the nearby predictions (mean value of the grid cell array) was used. Each component-specific RRF was used in the modeled attainment test by taking the ratio of the mean of the spatially averaged daily predictions in the future to the mean of the spatially averaged daily predictions with current emissions.

The basis for this approach is as follows:

1. Consequence of a control strategy may be "migration" of a predicted peak. If a State were to confine its attention only to the cell containing a monitor, it might underestimate the RRF (i.e., overestimate the effects of a control strategy).
2. Uncertainty in the formulation of the model and the model inputs is consistent with recognizing some leeway in the precision of the predicted location of concentrations.
3. Standard practice in defining a gridded modeling domain is to start in the southwest corner of the domain, and determine grid cell location from there. Considering several cells "near" a monitor rather than the single cell containing the monitor diminishes the likelihood of inappropriate results which may occur from the geometry of the superimposed grid system.
4. The area does not exhibit strong spatial concentration gradients of observed primary $PM_{2.5}$.

9.4.1.3 Annual SMAT Results

Table 9-3 presents the results of the annual SMAT results for the Washington, D.C. MSA. The SMAT results demonstrate that the projected average annual arithmetic mean $PM_{2.5}$ concentration calculated at each FRM monitor attains the 1997 $PM_{2.5}$ NAAQS. Specifically, all future design value (DVF) calculations are less than15.0 $\mu g/m^3$.

It is important to note that an attempt was made to calculate a DVF at each of the FRM monitors. EPA guidance is somewhat unclear as to what constitutes a valid number of quarters necessary to calculate a DVF. Special attention should be paid to this when reviewing the results in Table 9-3. Monitors with 19 or 20 valid quarters are generally considered to have a more reliable DVF than those with incomplete data. As previously mentioned, EPA is expected to release MATS in the next few months and at that time the values in this report will be verified.

Table 9-3. Annual SMAT Results for Washington, D.C. MSA
2009 Beyond-On-The-Way Control Measures and Virginia CAIR Rule [(a)]

AIRS ID	Site Name	Jurisdiction	State	2000-2004 DVB Q1	Q2	Q3	Q4	#Q	2009 DVF
11-001-0041	River Terrace	District of Columbia	---	14.85	14.91	18.76	14.16	20	12.6
11-001-0042	Park Services	District of Columbia	---	13.43	15.49	17.33	12.98	20	11.9
11-001-0043	McMillan	District of Columbia	---	13.65	15.28	18.10	13.55	20	12.1
24-031-3001	Rockville	Montgomery	MD	11.23	13.64	16.01	10.43	20	10.4
24-033-0001	Bladensburg	Prince George's	MD	14.53	16.72	22.00	14.93	11	13.9
24-033-0002	Greenbelt	Prince George's	MD	9.73	12.37	14.83	9.28	7	9.5
24-033-0030	Beltsville	Prince George's	MD	NA	NA	14.93	10.36	2	10.4
24-033-8001	Suitland	Prince George's	MD	12.04	15.61	15.66	11.62	8	11.0
24-033-8003	PG Equestrian Center	Prince George's	MD	11.61	15.72	17.26	10.87	11	11.3
51-013-0020	Aurora Hills	Arlington	VA	13.27	14.88	17.27	13.05	20	11.5
51-059-0030	Franconia	Fairfax	VA	11.59	14.01	16.95	12.02	19	10.4
51-059-1005	Annandale	Fairfax	VA	12.58	14.20	17.25	11.37	11	10.5
51-059-5001	Lewinsville	Fairfax	VA	12.63	14.05	17.80	12.37	19	10.7
51-107-1005	Ashburn	Loudoun	VA	11.38	14.14	17.32	11.71	20	10.1

(a) Includes NO_X reductions only.

Table 9-4 presents the results of the annual SMAT results for the Washington, D.C. MSA for a suite of regional modeling runs conducted by OTC and ASIP, each representing a level of emissions controls:

1. OTB/OTW – “On the Books, On the Way” control measures.
2. BOTW – “Beyond on the Way” represents control measures that Commissioners thought States might adopt. However, not all States have committed to adopt all of the BOTW measures that have been modeled.
3. BOTW + VA CAIR – The aforementioned “Beyond on the Way” control measures and the Virginia CAIR rule. This run only includes NO_X reductions and does not include SO_2 reductions for the Virginia CAIR rule.

Examination of the results confirms the absence of significant differences between the ASIP and OTC results, building confidence that the CMAQ modeling system is operating consistently across the RPO platforms. Additionally, all runs demonstrate compliance with the 1997 NAAQS.

Table 9-4. 2009 Annual SMAT Results Comparison for Regional Modeling Runs

AIRS ID	Site Name	Jurisdiction	State	2009 DVF OTC OTB/OTW	 OTC BOTW	 OTC BOTW +VA CAIR	 ASIP OTB/OTW
11-001-0041	River Terrace	District of Columbia	---	12.6	12.6	12.6	12.9
11-001-0042	Park Services	District of Columbia	---	11.9	11.9	11.9	12.2
11-001-0043	McMillan	District of Columbia	---	12.1	12.1	12.1	12.4
24-031-3001	Rockville	Montgomery	MD	10.4	10.4	10.4	10.4
24-033-0001	Bladensburg	Prince George's	MD	13.9	13.9	13.9	13.9
24-033-0002	Greenbelt	Prince George's	MD	9.5	9.5	9.5	9.4
24-033-0030	Beltsville	Prince George's	MD	10.4	10.4	10.4	10.1
24-033-8001	Suitland	Prince George's	MD	11.0	11.0	11.0	11.2
24-033-8003	PG Equestrian Center	Prince George's	MD	11.3	11.3	11.3	11.2
51-013-0020	Aurora Hills	Arlington	VA	11.5	11.5	11.5	12.0
51-059-0030	Franconia	Fairfax	VA	10.4	10.4	10.4	11.0
51-059-1005	Annandale	Fairfax	VA	10.5	10.5	10.5	11.3
51-059-5001	Lewinsville	Fairfax	VA	10.7	10.7	10.7	11.6
51-107-1005	Ashburn	Loudoun	VA	10.1	10.1	10.1	11.0

9.4.1.4 24-Hour SMAT Results

Table 9-5 presents the results of the 24-hour SMAT results for the Washington, D.C. MSA. The SMAT results demonstrate that the projected average annual arithmetic mean $PM_{2.5}$ concentration calculated at each FRM monitor attains the 24-hour $PM_{2.5}$ NAAQS. Specifically, all future design value (DVF) calculations are well below 65 µg/m^3.

Table 9-5. 24-Hour Modeling Attainment Test Using EPA SMAT Methodology 2009 Beyond-On-The-Way Control Measures and Virginia CAIR Rule [(a)]

AIRS ID	Site Name	Jurisdiction	State	24-Hour 98th Percentile DVB 2000	 2001	 2002	 2003	 2004	2009 DVF
11-001-0041	River Terrace	District of Columbia	---	41.20	44.80	47.80	39.00	38.40	33.6
11-001-0042	Park Services	District of Columbia	---	37.20	35.10	35.90	38.70	36.00	29.7
11-001-0043	McMillan	District of Columbia	---	38.60	43.70	40.00	35.20	34.80	32.0
24-031-3001	Rockville	Montgomery	MD	36.20	37.50	36.30	32.10	31.70	27.3
24-033-0001	Bladensburg	Prince George's	MD	40.90	38.90	35.20	NA	NA	29.2
24-033-0002	Greenbelt	Prince George's	MD	NA	NA	27.00	32.30	16.90	23.1
24-033-0030	Beltsville	Prince George's	MD	NA	NA	NA	NA	38.10	29.0
24-033-8001	Suitland	Prince George's	MD	36.50	35.20	NA	NA	NA	27.6
24-033-8003	PG Equestrian Center	Prince George's	MD	NA	NA	47.20	31.50	37.70	32.4
51-013-0020	Aurora Hills	Arlington	VA	37.70	37.20	35.60	39.20	35.70	29.7
51-059-0030	Franconia	Fairfax	VA	35.30	34.30	36.10	32.60	35.30	27.1
51-059-1005	Annandale	Fairfax	VA	NA	NA	35.00	36.70	34.00	25.8
51-059-5001	Lewinsville	Fairfax	VA	37.20	37.80	33.70	32.90	33.70	25.4
51-107-1005	Ashburn	Loudoun	VA	36.60	35.60	32.30	35.30	34.20	24.9

(a) Includes NO_X reductions only.

Table 9-6 presents the results of the 24-hour SMAT results for the Washington, D.C. MSA for the suite of regional modeling runs conducted by OTC and ASIP. Again, the comparison confirms the absence of significant differences between the OTC and ASIP results. All runs demonstrate attainment with the 24-hour NAAQS.

Table 9-6. 2009 24-Hour SMAT Results Comparison for Regional Modeling Runs

AIRS ID	Site Name	Jurisdiction	State	2009 DVF OTC OTB/OTW	OTC BOTW	OTC BOTW +VA CAIR	ASIP OTB/OTW
11-001-0041	River Terrace	District of Columbia	---	33.6	33.6	33.6	34.7
11-001-0042	Park Services	District of Columbia	---	29.7	29.7	29.7	30.3
11-001-0043	McMillan	District of Columbia	---	31.9	31.9	32.0	32.0
24-031-3001	Rockville	Montgomery	MD	27.3	27.3	27.3	27.2
24-033-0001	Bladensburg	Prince George's	MD	29.2	29.2	29.2	29.2
24-033-0002	Greenbelt	Prince George's	MD	23.0	23.0	23.1	22.7
24-033-0030	Beltsville	Prince George's	MD	29.0	28.9	29.0	28.4
24-033-8001	Suitland	Prince George's	MD	27.6	27.6	27.6	28.7
24-033-8003	PG Equestrian Center	Prince George's	MD	32.4	32.4	32.4	32.1
51-013-0020	Aurora Hills	Arlington	VA	29.7	29.7	29.7	31.1
51-059-0030	Franconia	Fairfax	VA	27.1	27.1	27.1	28.8
51-059-1005	Annandale	Fairfax	VA	25.8	25.8	25.8	28.1
51-059-5001	Lewinsville	Fairfax	VA	25.4	25.4	25.4	27.8
51-107-1005	Ashburn	Loudoun	VA	24.9	24.9	24.9	27.5

9.4.2 Unmonitored Area Analysis

The modeled attainment test does not address future air quality at locations where there is not an $PM_{2.5}$ monitor nearby. To guard against the possibility that air quality levels could exceed the standard in areas with limited monitoring, EPA suggests that additional review is necessary, particularly in nonattainment areas where the $PM_{2.5}$ monitoring network just meets or minimally exceeds the size of the network required to report data to Air Quality System (AQS). This review is intended to ensure that a control strategy leads to reductions in $PM_{2.5}$ and its constituent pollutants at other locations that could have baseline (and future) design values exceeding the NAAQS were a monitor deployed there. The test is called an "unmonitored area analysis". The purpose of the analysis is to use a combination of model output and ambient data to identify areas that might exceed the NAAQS if monitors were located there.

It is important to note that the Washington, D.C. MSA currently operates a network of 14 $PM_{2.5}$ monitors. Several of these monitors were established as State and Local Air Monitoring Stations (SLAMS). These SLAMS monitors were selected based on specific monitoring objectives (background concentration, area of highest concentration, high population, source impact, transport, and rural impact) as required by EPA and siting scales (micro, middle, neighborhood, urban, and regional) established by EPA.

It is believed that the density of the monitoring network relieves the necessity of applying this additional analysis. Despite being confident the monitoring network is robust enough to cover the Washington, D.C. MSA, once the final version of the MATS tool has been released, and after sufficient peer review and proper guidance documentation for the analysis of the results is provided, the TAC Modeling Committee will evaluate the MATS tool output.

9.4.3 Local Area Analysis

Based on review of final EPA modeling guidance, the Local Area Analysis (LAA) is designed to identify local primary $PM_{2.5}$ sources that are thought to be contributing to a monitor and causing non-attainment of the NAAQS. At this time, no monitors within the D.C. MSA are projected to exceed the NAAQS so it is not a necessary requirement in this circumstance to conduct the LAA. Furthermore, existing monitoring data suggests a uniform regional pattern with respect to $PM_{2.5}$ concentrations rather than any “hot spot” monitor.

Some concern was expressed by stakeholders about local $PM_{2.5}$ emissions and impacts from the Mirant Potomac River Generating Station (PRGS). Virginia remains committed to evaluating $PM_{2.5}$ impacts from this facility upon promulgation of appropriate and final implementation guidance from EPA and VADEQ. Based on a schedule and protocol to be established by VDEQ after US EPA promulgates final rules for $PM_{2.5}$ analysis, or US EPA promulgates revised implementation guidance or policy for PM2.5 analysis, or VDEQ establishes a more appropriate implementation methodology for $PM_{2.5}$, Mirant Potomac River Power Station shall conduct an ambient air quality analysis for the emissions of $PM_{2.5}$ from the facility. No later than 60 days after approval of the implementation methodology by the Virginia State Air Pollution Control Board, Mirant Potomac River Power Station shall provide to VDEQ a detailed protocol outlining how the facility will implement the approved methodologies. VDEQ will make this document available to the public by publishing this protocol on the VDEQ website.

It is important to note that none of the $PM_{2.5}$ monitors currently located at the PRGS meet the EPA siting criteria; therefore, these data cannot be directly used to evaluate the attainment status of the Washington, D.C. MSA.

9.4.4 Emissions Inventories

For areas with an attainment date of no later than 2010, the emission reductions need to be implemented no later than the beginning of 2009. A determination of attainment will likely be based on air quality monitoring data collected in 2007, 2008, and 2009. Therefore, the year to project future emissions should be no later than the last year of the three year monitoring period; in this case 2009.

The 2002 base year emissions inventory were projected to 2009 using standard emissions projection techniques. 2009 inventories provided by MANE-VU and VISTAS were used in the attainment demonstration.

Emission inventory guidance documents were followed for developing projection year inventories for point, area, mobile, and biogenic emissions. These procedures addressed projections of spatial, temporal, and chemical composition change between the base year and projection year.

The alternative control strategies for evaluation in the attainment demonstration were selected by MWAQC. These were selected from groups of strategies developed by the technical subcommittees responsible for identifying and developing the regulations and/or control measures.

Consideration was given to maintaining consistency with control measures likely to be implemented by other modeling domains. Also, technology-based emission reduction requirements mandated by the Clean Air Act were included in the future year model runs.

9.4.5 Supplemental Analyses and Weight of Evidence Determination

All models, including the CMAQ, model have inherent uncertainties. Over or under prediction may result from uncertainties associated with emission inventories, meteorological data, and representation of $PM_{2.5}$ chemistry in the model. Therefore, EPA modeling guidance provides for other evidence to address these model uncertainties so that proper assessment of the probability to attain the applicable standards can be made.

EPA modeling guidance states that those modeling analyses that show that attainment with the NAAQS will be reached in the future with some margin of safety (i.e., estimated concentrations below 14.5 $\mu g/m^3$ for annual $PM_{2.5}$ and 62 $\mu g/m^3$ for 24-hour $PM_{2.5}$) need more limited supporting material.

Due to the fact that the modeling results fall well below the aforementioned “weight of evidence” thresholds established by EPA, a limited supplemental analysis was deemed necessary to support the 2009 attainment demonstration.

9.4.5.1 Trend in $PM_{2.5}$ Design Values

Figure 9-12 and 9-13 below show trends in annual and daily $PM_{2.5}$ design values, respectively. It is clear from Figure 9-12 that there is a downward trend in annual $PM_{2.5}$ design value since the period 1999-2001. During the period 2003-2005, the design value was below the annual $PM_{2.5}$ standard and this trend continued through the period 2004-2006.

Figure 9-13 shows that there is also a downward trend in 24-hour $PM_{2.5}$ design value since the period 2000-2002, which has continued through the period 2004-2006.

A downward trend in both annual and daily $PM_{2.5}$ design values indicate that the control measures implemented during this period have been providing $PM_{2.5}$ reduction benefits. With more controls anticipated in coming years, this trend is expected to continue.

Figure 9-12. Trend in Annual $PM_{2.5}$ Design Values (1999-01 through 2004-06)

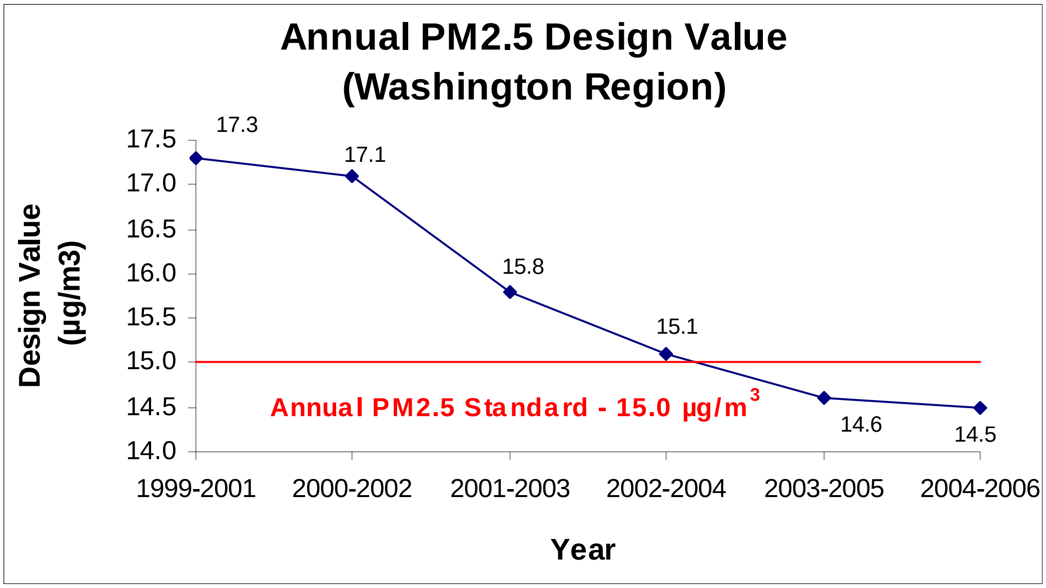
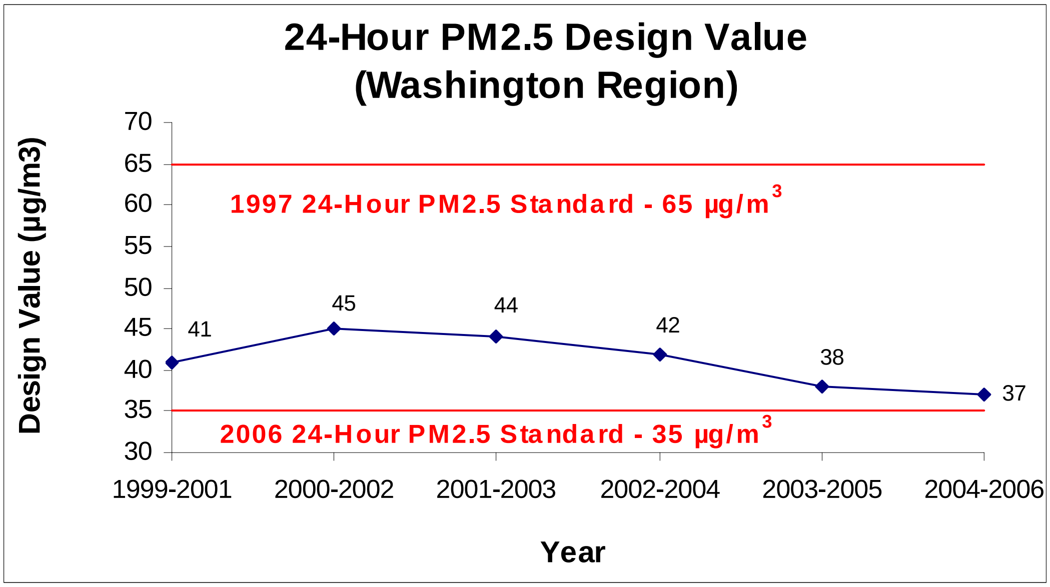


Figure 9-13. Trend in 24-Hour $PM_{2.5}$ Design Values (1999-01 through 2004-06)



9.4.6 Summary and Conclusions of Attainment Demonstration

The results from the modeling as well as the supplemental analyses present overwhelming evidence that the Washington D.C. MSA will attain the 1997 $PM_{2.5}$ NAAQS by the end of 2009. Based on air quality measurements and future predicted air quality modeling results the projected design values are below the NAAQS attainment criteria of 15.0 µg/m^3 for annual $PM_{2.5}$ and 65 µg/m^3 for 24-hour $PM_{2.5}$.

9.4.7 Procedural Requirements

9.4.7.1 Reporting

Documents, technical memorandums, and data bases developed in this study are available for distribution as appropriate. This report contains the essential methods and results of the conceptual model, episode selection, modeling protocol, base case model development and performance testing, future year and control strategy modeling, quality assurance, supplemental analyses, and calculation of $PM_{2.5}$ attainment via EPA's methodology.

9.4.7.2 Data Archival and Transfer of Modeling Files

All relevant data sets, model codes, scripts, and related software required by any project participants necessary to corroborate the study findings (e.g., performance evaluations, control strategy runs) will be provided in an electronic format approved by the Technical Committee within the framework of MWAQC. The Technical Committee has archived all modeling data relevant to this project. Transfer of data may be facilitated through the combination of a project website and the transfer of large databases via overnight mail. Database transfers will be accomplished using an ftp protocol for smaller datasets, and the use of IDE and Firewire disk drives for larger data sets.