

Prepared for:  
**Conectiv Delmarva Generation**  
**Wilmington, Delaware**

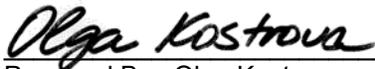


# Revised Source-Specific Best Available Retrofit Technology (BART) Determination: Edge Moor Units 4 & 5

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ENSR Corporation  
July 2008  
Document No.: 01855-056-0400

# Revised Source-Specific Best Available Retrofit Technology (BART) Determination: Edge Moor Units 4 & 5



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# Contents

**Executive Summary .....1**

**1.0 Introduction ..... 1-1**

    1.1 Location of Source vs. Relevant Class I Areas ..... 1-1

    1.2 Organization of Report Document ..... 1-1

**2.0 Inputs to CALPUFF Model ..... 2-1**

    2.1 Meteorological Database..... 2-1

    2.2 Model Selection and Features ..... 2-1

    2.3 Modeling Domain and Receptors..... 2-1

    2.4 Technical Options Used in the Modeling ..... 2-1

    2.5 Air Quality Database (Background Ozone and Ammonia) ..... 2-2

    2.6 Natural Conditions and Monthly f(RH) at Class I Areas ..... 2-2

    2.7 Light Extinction and Haze Impact Calculations ..... 2-2

**3.0 Source Description and Baseline Emissions Data ..... 3-1**

**4.0 Evaluation of Air Pollution Control Technologies ..... 4-1**

    4.1 Particulate Controls ..... 4-1

        4.1.1 Fabric Filter Baghouse ..... 4-2

        4.1.2 Electrostatic Precipitator ..... 4-3

        4.1.3 Wet ESP ..... 4-4

        4.1.4 Compact Hybrid Particulate Collector ..... 4-4

        4.1.5 GE MAX-9 Hybrid ..... 4-5

        4.1.6 Multiple Cyclone Separator ..... 4-5

        4.1.7 Alternative Fuels ..... 4-6

    4.2 Sulfur Dioxide Controls ..... 4-6

        4.2.1 Dry Sorbent Injection and Fuel Oil Sulfur Content ..... 4-6

        4.2.2 Low Sulfur Fuel Oil ..... 4-7

    4.3 Nitrogen Oxides Controls ..... 4-7

        4.3.1 Selective Non-Catalytic Reduction ..... 4-7

        4.3.2 Staged Combustion ..... 4-8

    4.4 Technical Feasibility of PM Control Options ..... 4-8

    4.5 Effectiveness of Feasible PM Control Options ..... 4-8

    4.6 Impacts of Technically Feasible Options ..... 4-9

    4.7 Conclusions ..... 4-9

**5.0 CALPUFF Modeling Results**..... **5-1**

    5.1 Baseline CALPUFF Modeling Results..... 5-1

    5.2 CALPUFF Modeling Results for Feasible Control Options..... 5-1

    5.3 Cost of BART Control Options ..... 5-2

**6.0 Conclusions and BART Recommendations** ..... **6-1**

**7.0 References**..... **7-1**

## List of Appendices

Appendix A Relevant Excerpts from EPA’s “Additional Regional Haze Questions”

Appendix B Re-Calculating CALPOST Visibility Outputs with the New IMPROVE Algorithm

## List of Tables

Table 2-1 Sea Salt Concentrations and Rayleigh Scattering Coefficients..... 2-4

Table 3-1 Modeling Exhaust Stack Parameters ..... 3-2

Table 3-2 Baseline Emission Rates ..... 3-4

Table 4-1 Emissions for BART Control Option 1 ..... 4-10

Table 4-2 Emissions for BART Control Option 2 ..... 4-11

Table 5-1 Summary of Results – Edge Moor BART Modeling..... 5-2

Table 5-2 Cost of BART Control Options ..... 5-2

Table 6-1 Summary of BART Analysis..... 6-2

## List of Figures

Figure 1-1 Location of Class I Areas in Relation to Edge Moor Power Plant..... 1-2

Figure 2-1 Edge Moor CALPUFF Computational Grid in Relation to the VISTAS Subdomain #5 ..... 2-3

Figure 3-1 Aerial View of the Edge Moor Plant ..... 3-3

## Executive Summary

Conectiv Delmarva Generation, Inc, (Conectiv) an affiliate of Conectiv Energy, operates the Edge Moor Power Plant ("Edge Moor"), a coal and oil-fired electric generating station located in Wilmington, Delaware. Edge Moor has been identified by DNREC as a source that is eligible for consideration of BART controls for PM<sub>10</sub> (CAIR serves as BART for SO<sub>2</sub> and NO<sub>x</sub>). This document, an update to a BART report submitted in June 2007, summarizes the procedures by which a modeling analysis and a BART engineering review have been conducted for the Edge Moor Units 4 and 5.

The Regional Haze Rule requires Best Available Retrofit Technology (BART) for any BART-eligible source that "emits any air pollutant which may reasonably be anticipated to cause or contribute to any impairment of visibility" in any mandatory Class I federal area. The Environmental Protection Agency (EPA) has determined that implementation of the Clean Air Interstate Rule (CAIR) by electric generating unit (EGU) sources satisfies applicable BART requirements for SO<sub>2</sub> and NO<sub>x</sub> emissions from those sources (see Appendix A for specific EPA BART references in this regard). The Delaware Department of Natural Resources and Environmental Control (DNREC) has indicated that the federal CAIR program is employed in Delaware as part of a Federal Implementation Plan (FIP) process under which EGU sources will meet the State's CAIR emission reduction requirements. As such, CAIR satisfies BART for SO<sub>2</sub> and NO<sub>x</sub> for EGU sources in the State of Delaware. In addition, Delaware has promulgated a Multi-Pollutant Regulation for Electrical Generating Units that effectively serves the same purpose as CAIR, and which satisfies BART for SO<sub>2</sub> and NO<sub>x</sub> for EGU sources in the State of Delaware. Accordingly, this report focuses solely on performing BART modeling analyses and engineering reviews for primary particulate matter (PM<sub>10</sub>) emissions from Edge Moor Units 4 and 5.

The document entitled "Source-Specific Best Available Retrofit Technology (BART) Modeling and Engineering Review: Edge Moor Units 4 & 5" was submitted to DNREC in June 2007. The modeling analysis documented in that report was conducted in accordance with our understanding of the agreed-upon approach following a conference call with the DNREC in which the proposed procedures were discussed and approved for use. The results of the analysis indicated that the PM<sub>10</sub> emissions from the existing facility will have imperceptible impacts on regional haze at the two Class I areas within 300 km of the plant. The results indicated that PM<sub>10</sub> impacts would be at or below the MANE-VU 0.1 delta-deciview threshold for a level of visibility change not worth additional consideration. The report also documented substantial emission controls to be installed at Edge Moor in accordance with the Multi-Pollutant Regulation (MPR).

In April 2008, DNREC requested additional documentation on certain aspects of a more formal BART determination analysis for control options for Edge Moor beyond the MPR steps, even though the remaining visibility incremental improvement potentially possible is a small fraction of what is perceptible. This report provides the additional documentation requested.

Edge Moor Unit 4 is a dry-bottom, pulverized coal (primary fuel), tangentially-fired boiler equipped with an electrostatic precipitator (ESP) for the control of filterable particulates. Edge Moor Unit 5 is a residual oil-fired (primary fuel) boiler with a multiple cyclone (multiclone) for the control of filterable particulates.

Possible alternative BART PM<sub>10</sub> control technologies that have been preliminarily considered as being potentially feasible for further reducing PM emissions from Edge Moor Units 4 and 5 are as follows.

Control Option 1. This option involves adding dry sorbent injection (DSI) to Unit 4 to control SO<sub>2</sub> emissions, which also would reduce inorganic condensable PM<sub>10</sub> by about 50%. PM<sub>10</sub> emissions from Unit 5 would be reduced by about 9% by capping sulfur content of fuel oil at 0.5%. This control option will be implemented as a result of Delaware's Multi-Pollutant Regulation.

Control Option 2. This option is the same as Control Option 1 with the addition of fabric filter PM controls on Unit 4. The physical ability of accommodating a fabric filter baghouse at the Edge Moor Site near Unit 4 would

be particularly challenging, given the small amount of space available at this facility which directly abuts the Delaware River. PM<sub>10</sub> emissions from Unit 4, should a fabric filter baghouse be feasible, would be reduced by about 40%.

The BART analysis for PM<sub>10</sub> was conducted in accordance with the procedures contained in the Final BART Guidelines published by the EPA on July 6, 2005. Consistent with the BART Guidelines, the five steps for a case-by-case BART analysis were followed.

- Step 1– Identify all available control technologies for the unit including improvements to existing control equipment or installation of new add-on control equipment.
- Step 2– Eliminate technically infeasible options considering the commercial availability of the technology, space constraints, operating problems and reliability, and adverse side effects on the rest of the facility.
- Step 3– Evaluate the control effectiveness of the remaining technologies based on current pollutant concentrations, flue gas properties and composition, control technology performance, and other factors.
- Step 4– Evaluate the annual and incremental costs of each feasible option in accordance with approved EPA methods, as well as the associated energy and non-air quality environmental impacts.
- Step 5- Determine the visibility impairment associated with baseline emissions and the visibility improvements provided by the control technologies considered in the engineering analysis.

The modeling procedures used in this analysis are the same as those used in 2007, and are consistent with those outlined in the updated final VISTAS common BART modeling protocol (Revision 3.2, dated August 31, 2006), available at [http://www.vistassesarm.org/documents/BARTModelingProtocol\\_rev3.2\\_31Aug06.pdf](http://www.vistassesarm.org/documents/BARTModelingProtocol_rev3.2_31Aug06.pdf). This report references relevant portions of the common VISTAS report. Also, recent initiatives have been made by VISTAS to incorporate the new IMPROVE equation with CALPUFF results. Because of the inherent benefits of the new IMPROVE equation, ENSR has used that equation in its BART modeling.

As a result of this additional analysis, ENSR and Conectiv recommend that Control Option 1 (DSI on Unit 4 and 0.5% sulfur oil for Unit 5) as the Best Available Retrofit Technology alternative for the Edge Moor Generating Station. The controls associated with this selected BART option will be implemented as a result of Delaware's Multi-Pollutant Regulation. The MPR controls also involve emission reductions from non-BART Unit 3, which will provide beneficial visibility improvements that are in addition to those from the Edge Moor BART-eligible units. BART Control Option 2 with a fabric filter on Unit 4 was rejected due to the very small incremental improvement in visibility at high cost. As mentioned above, the other candidate BART control options are infeasible, and were therefore not further considered.

## 1.0 Introduction

The Edge Moor Power Plant, operated by Conectiv, has been identified by DNREC as a source that is eligible for consideration of BART controls for PM<sub>10</sub> (CAIR serves as BART for SO<sub>2</sub> and NO<sub>x</sub>). This document summarizes the procedures by which a modeling analysis and a BART engineering review have been conducted for the Edge Moor Units 4 and 5.

The Regional Haze Rule requires a BART assessment for any BART-eligible source that “emits any air pollutant which may reasonably be anticipated to cause or contribute to any impairment of visibility” in any mandatory Class I federal area. Delaware has promulgated a Multi-Pollutant Regulation for Electrical Generating Units that effectively serves the same purpose as CAIR, and which satisfies BART for SO<sub>2</sub> and NO<sub>x</sub> for EGU sources in the State of Delaware. Accordingly, this report focuses solely on performing BART modeling analyses and engineering reviews for primary particulate matter (PM<sub>10</sub>) emissions from Edge Moor Units 4 and 5.

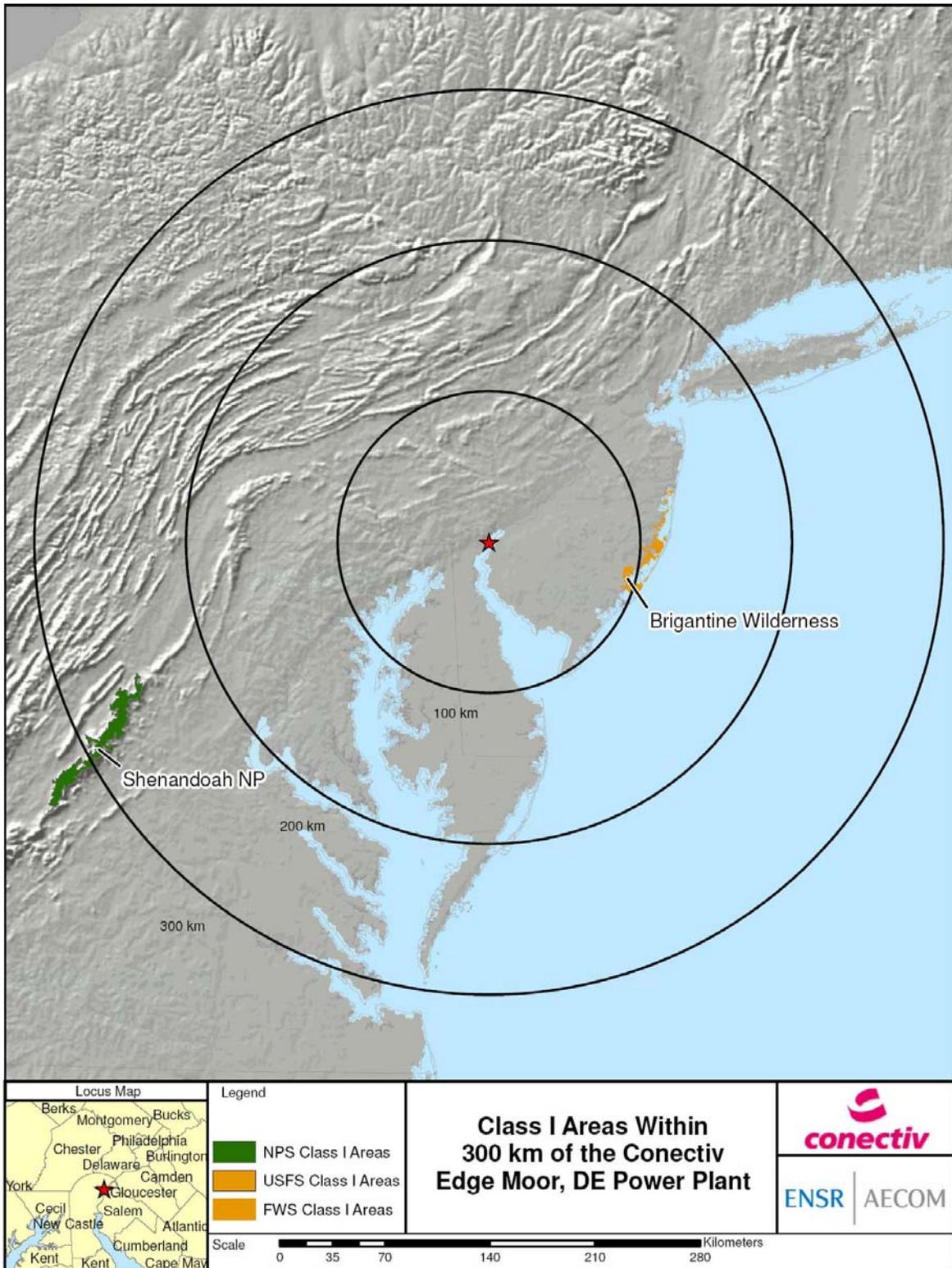
### 1.1 Location of Source vs. Relevant Class I Areas

Figure 1-1 shows the location of the Edge Moor Power Plant relative to nearby Class I areas. There are two Class I areas within 300 km of the plant: (1) Brigantine Wilderness and (2) Shenandoah National Park. The nearest point of the Brigantine Wilderness is approximately 92 kilometers east of the Edge Moor Power Plant, while the nearest point of the Shenandoah National Park is approximately 248 kilometers southwest of the Edge Moor Power Plant. The BART modeling analysis has been conducted for both of these Class I areas in accordance with the referenced VISTAS common BART modeling protocol and the procedures described in the referenced source-specific BART modeling protocol.

### 1.2 Organization of Report Document

Section 2 describes the input data that has been used for the modeling including the modeling domain, terrain and land use, and meteorological data. Section 3 of this report describes the source emissions that have been used as input to the BART modeling demonstration. An engineering review of the effects of anticipated visibility-affecting emission reductions is provided in Section 4. Section 5 discusses the CALPUFF modeling results. BART recommendations and conclusions are provided in Section 6. References are provided in Section 7. Appendix B describes the implementation of the new IMPROVE equation in the VISTAS states, as approved by the Federal Land Managers.

Figure 1-1 Location of Class I Areas in Relation to Edge Moor Power Plant



## 2.0 Inputs to CALPUFF Model

### 2.1 Meteorological Database

Although MANE-VU has processed a single year of data for use in BART assessments, a better (3-year) database is available for Delaware (including the Edge Moor Power Station), which lies within the VISTAS modeling domain. VISTAS has developed five sub-regional 4-km CALMET meteorological databases for three years (2001-2003). The sub-regional modeling domains are strategically designed to cover all potential BART-eligible sources within VISTAS states and all PSD Class I areas within 300 km of those sources. The extents of the 4-km sub-regional domains are shown in Figure 4-4 of the VISTAS common BART modeling protocol. The BART modeling for Edge Moor has been done using the easternmost 4-km subdomain that encompasses all of Delaware, as shown in Figure 4-4 of the VISTAS BART protocol (subdomain #5).

Three years of MM5 data (2001-2003) were used by VISTAS to generate the 4-km sub-regional meteorological datasets. See Sections 4.3.2 and 4.4.2 in the VISTAS common BART modeling protocol for more detail on these issues.

USGS 90-meter Digital Elevation Model (DEM) files were used by VISTAS to generate the terrain data at 4-km resolution for input to the 4-km sub-regional CALMET run. Likewise, USGS 90-meter Composite Theme Grid (CTG) files were used by VISTAS to generate the land use data at 4-km resolution for input to the 4-km sub-regional CALMET run.

### 2.2 Model Selection and Features

As noted in the VISTAS protocol, VISTAS used the BART-specific versions of CALMET and CALPUFF that have been posted at [http://www.src.com/calpuff/download/download.htm#VISTAS\\_VERSION](http://www.src.com/calpuff/download/download.htm#VISTAS_VERSION). These versions contain enhancements funded by the Minerals Management Service (MMS) and VISTAS. They are maintained on TRC's Atmospheric Studies Group CALPUFF website for public access.

The major features of the CALPUFF modeling system, including those of CALMET and the post processors (CALPOST and POSTUTIL) are referenced in Section 3 of the VISTAS protocol.

### 2.3 Modeling Domain and Receptors

All of the modeling for the Edge Moor Power Plant used the 4-km subdomain #5. A smaller computational grid within the VISTAS subdomain #5 was designed to minimize computation time and output file size. The Edge Moor computational grid domain covers distances of 452 km W-E and 352 km N-S and is shown in Figure 2-1. This domain includes two Class I areas with a 50-km buffer, plus a nearly 100-km buffer around the source (up to the limit of the VISTAS sub-domain northern boundary).

The receptors used for each of the Class I areas are based on the National Park Service database of Class I receptors, as recommended by VISTAS.

### 2.4 Technical Options Used in the Modeling

CALMET modeling for the VISTAS-provided 4-km subdomains had already been conducted by the VISTAS contractor, and this modeling was reviewed and approved by the Federal Land Managers.

For CALPUFF model options, the Edge Moor Power Plant followed the VISTAS common BART modeling protocol, which states that we should use IWAQM (EPA, 1998) guidance. The VISTAS protocol also notes that building downwash effects are not required to be included, and we followed this guidance for this application as well. The Edge Moor Power Plant is several tens of kilometers from the nearest Class I area,

and therefore building downwash effects can be expected to have little effect on the results of the CALPUFF modeling.

## 2.5 Air Quality Database (Background Ozone and Ammonia)

Hourly measurements of ozone from all non-urban monitors, as generated by VISTAS and available on the VISTAS CALPUFF page on the TRC web site ([http://www.src.com/calpuff/download/sample\\_files.htm](http://www.src.com/calpuff/download/sample_files.htm)), have been used as input to CALPUFF. Currently, VISTAS advises sources to use a background ammonia concentration of 0.5 ppb, which has been used for this analysis. However, since there are no NO<sub>x</sub> emissions being considered in this application, the results are not sensitive to the ammonia concentration used.

## 2.6 Natural Conditions and Monthly f(RH) at Class I Areas

There are two Class I areas (Brigantine Wilderness Area and Shenandoah National Park) that were modeled for Edge Moor. For these Class I areas, natural background conditions have been established in order to determine a change in natural conditions related to a source's emissions. For the modeling described in this document, ENSR used the natural background light extinction of 7.44 deciviews for Brigantine W and 7.41 deciviews for Shenandoah NP, modified as noted below with site-specific considerations, and corresponding to the annual average (EPA 2003, Appendix B), consistent with the July 19, 2006 EPA guidance to Region 4 on this issue ("Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determinations", Joseph W. Paise/ EPA OAQPS to Kay Prince/Branch Chief).

The input to CALPOST is computed by converting the deciviews to extinction using the equation:

$$\text{Extinction (Mm}^{-1}\text{)} = 10 \exp(\text{deciviews}/10).$$

For example, for Brigantine, 7.44 deciviews is equivalent to an extinction of 11.04 inverse megameters (Mm<sup>-1</sup>). This extinction does not include the default 10 Mm<sup>-1</sup> for Rayleigh scattering. The remaining extinction of 11.04 Mm<sup>-1</sup> is due to naturally occurring particles, and should be held constant for the entire year's simulation. Therefore, the data provided to CALPOST for Brigantine is the total natural background extinction minus 10 (expressed in Mm<sup>-1</sup>), or 11.04 Mm<sup>-1</sup>. This is most easily input as a fine soil concentration of 11.04 µg/m<sup>3</sup> in CALPOST, since the extinction efficiency of soil (PM-fine) is 1.0 and there is no f(RH) component. The concentration entries for all other particle constituents were set to zero, and the fine soil concentrations were kept the same for each month of the year. The monthly values for f(RH) that CALPOST used were taken from "Guidance for Tracking Progress Under the Regional Haze Rule" (EPA, 2003) Appendix A, Table A-3.

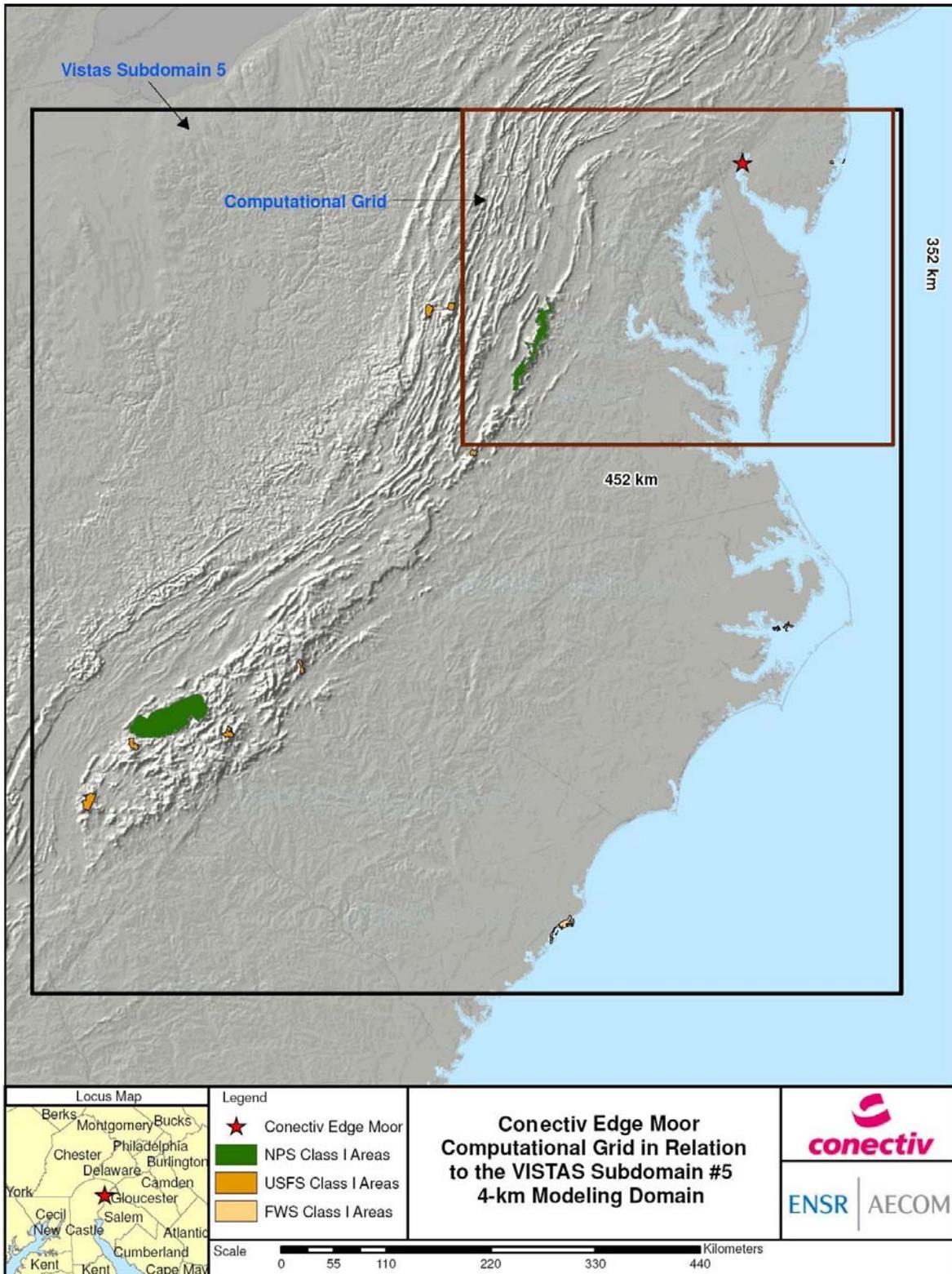
## 2.7 Light Extinction and Haze Impact Calculations

The CALPOST postprocessor was used as prescribed in the VISTAS protocol for the calculation of the impact of the modeled source's primary and secondary particulate matter concentrations on light extinction. The formula that is used in CALPOST is the existing IMPROVE/EPA formula, which is applied to determine a change in light extinction due to increases in the particulate matter component concentrations. Using the notation of CALPOST, the formula is the following:

$$b_{\text{ext}} = 3 f(\text{RH}) [(\text{NH}_4)_2\text{SO}_4] + 3 f(\text{RH}) [\text{NH}_4\text{NO}_3] + 4[\text{OC}] + 1[\text{Soil}] + 0.6[\text{Coarse Mass}] + 10[\text{EC}] + b_{\text{Ray}}$$

The concentrations, in square brackets, are in µg/m<sup>3</sup> and b<sub>ext</sub> is in units of Mm<sup>-1</sup>. The Rayleigh scattering term (b<sub>Ray</sub>) has a default value of 10 Mm<sup>-1</sup>, as recommended in EPA guidance for tracking reasonable progress (EPA, 2003a).

Figure 2-1 Edge Moor CALPUFF Computational Grid in Relation to the VISTAS Subdomain #5



Dr. Ivar Tombach, consultant to VISTAS, has provided a spreadsheet calculation system (see Appendix B) that incorporates the revised IMPROVE equation for determining light extinction from particulate concentration estimates. The VISTAS BART modeling protocol indicates that the unrevised IMPROVE algorithm does not incorporate the effects of naturally occurring sea salt on background visibility. The Brigantine Wilderness is significantly affected by this omission because it is off the coastline of New Jersey and surrounded by salt water. Therefore, we incorporated this effect into the present CALPUFF framework by using the guidance provided by Dr. Tombach, as presented in Appendix B. Table 2-1 lists sea salt concentrations and Rayleigh coefficients that were used in Dr. Tombach’s new IMPROVE equation.

**Table 2-1 Sea Salt Concentrations and Rayleigh Scattering Coefficients**

	<b>Brigantine W</b>	<b>Shenandoah NP</b>
Sea Salt Concentration (µg/m <sup>3</sup> )	0.22	0.02
Raleigh Scattering Coefficient (Mm <sup>-1</sup> )	12	10

The assessment of visibility impacts at the Class I areas used CALPOST Method 6. Each hour’s source-caused extinction was calculated by first using the hygroscopic components of the source-caused concentrations, due to ammonium sulfate and nitrate (not relevant for EGUs in CAIR states except for H<sub>2</sub>SO<sub>4</sub> emissions), and monthly Class I area-specific f(RH) values. The contribution to the total source-caused extinction from ammonium sulfate and nitrate was then added to the other, non-hygroscopic components of the particulate concentration (from coarse and fine soil, secondary organic aerosols, and elemental carbon) to yield the total hourly source-caused extinction.

The EPA BART rule’s recommended significance threshold for contribution to visibility impairment is 0.5 delta deciviews. For reference purposes, ENSR compared the PM<sub>10</sub> visibility impacts to both the EPA-recommended 0.5 delta deciview threshold and the very low “significance” threshold of 0.1 delta deciviews for MANE-VU (98<sup>th</sup> percentile impacts), especially for the non-sulfate portion of the PM<sub>10</sub> emissions which will not be affected by CAIR emission reductions.

### 3.0 Source Description and Baseline Emissions Data

The baseline emissions data used to assess the visibility impacts at the selected Class I areas are discussed in this section. As noted earlier, implementation of CAIR by EGUs satisfies BART requirements for SO<sub>2</sub> and NO<sub>x</sub>. Therefore, as requested by DNREC, this report focuses only on PM<sub>10</sub> control options. Because the various components of PM<sub>10</sub> emissions have different visibility extinction efficiencies, the PM<sub>10</sub> emissions are divided, or “speciated,” into several components. The EPA guidance on BART modeling encourages the use of source-specific emissions and speciation factors. Otherwise, values from EPA’s AP-42 reference document can be used as the default. PM<sub>10</sub> was speciated in a manner that is consistent with EPA and National Park Service guidance.

Edge Moor Unit 4 is a nominal 175 MW dry-bottom, pulverized coal (primary fuel), tangentially-fired boiler equipped with an electrostatic precipitator (ESP) for the control of filterable particulates. Edge Moor Unit 5 is a nominal 445 MW residual oil-fired (primary fuel) boiler with a multiple cyclone (multiclone) for the control of filterable particulates. An aerial view of Edge Moor Units 4 and 5 is shown in Figure 3-1.

The PM<sub>10</sub> emissions and speciation approach used for the baseline modeling are described in the bullets below.

- Total PM<sub>10</sub> is comprised of filterable and condensable emissions.
- Total filterable PM for Unit 4 is determined from the relationship "0.08A lb/ton" (where A is the ash content in % wt.) based on AP-42, Table 1.1-4. The filterable PM is subdivided by size category consistent with the default approach from the AP-42 Document, Table 1.1-6. For coal-fired utility boilers equipped with an ESP, 67% of the filterable PM emissions are filterable PM<sub>10</sub> and 29% of the filterable PM emissions are fine filterable PM<sub>10</sub> emissions (less than 2.5 microns in size). For coal-fired utility boilers, elemental carbon is expected to be 3.7% of fine PM<sub>10</sub> based on the best estimate for electric utility coal combustion in Table 6 of “Catalog of Global Emissions Inventories and Emission Inventory Tools for Black Carbon”, William Battye and Kathy Boyer, EPA Contract No. 68-D-98-046, January 2002.
- Total filterable PM for Unit 5 is determined from the relationship "0.83(1.12S+0.37) lb/Mgal" (where S is the sulfur content in % wt.) based on AP-42, Table 1.3-4. The filterable is subdivided by size category consistent with the default approach from the AP-42 Document, Table 1.3-4. For uncontrolled oil-fired utility boilers, 71% of the filterable PM emissions are filterable PM<sub>10</sub> and 52% of the filterable PM emissions are fine filterable PM<sub>10</sub> emissions (less than 2.5 microns in size). For oil-fired utility boilers, elemental carbon is expected to be 7.4% of fine PM<sub>10</sub>, based on the best estimate for electric utility petroleum combustion in Table 6 of “Catalog of Global Emissions Inventories and Emission Inventory Tools for Black Carbon”, William Battye and Kathy Boyer, EPA Contract No. 68-D-98-046, January 2002.
- Condensable PM<sub>10</sub> consists of inorganic and organic compounds. The inorganic portion is assumed to consist of H<sub>2</sub>SO<sub>4</sub>; the organic portion is modeled as secondary organic aerosols.
- For Unit 4, H<sub>2</sub>SO<sub>4</sub> emissions are based on "Estimating Total Sulfuric Acid Emissions from Coal Fired Power Plants", Keith Harrison, Larry Monroe and J. Edward Cichanowicz (Southern Company Services and Southern Research Institute, Revision 3, October 2005). This procedure is consistent with the method used by Conectiv for the data provided to DNREC as part of the Company’s Toxic Release Inventory (TRI) reports. Before control, H<sub>2</sub>SO<sub>4</sub> is determined by the relationship  $0.008 \times \%S/100 \times 10^6/HHV \times HIR \times 98.06/32.07$ . H<sub>2</sub>SO<sub>4</sub> control is 49% for an air pre-heater and 49% for a cold-side ESP.

- For Unit 5 (oil-fired), H<sub>2</sub>SO<sub>4</sub> emissions are based on the AP-42 Document, Table 1.3-2, where total condensable PM<sub>10</sub> is 1.5 lb/Mgal. The inorganic portion of PM<sub>10</sub> is 85% of the total condensable PM<sub>10</sub>, while the organic portion is 15% of the total condensable PM<sub>10</sub>.

In practice, CALPUFF allows for the user to input certain components of PM<sub>10</sub> as separate species and separate sizes, which will result in more accurate wet and dry deposition velocity results and also more accurate effects on light scattering from the different PM<sub>10</sub> species. As noted above, the particle size distribution information is provided in the AP-42 Document, Tables 1.1-6 and Table 1.3-4, and has been used for the BART modeling analysis.

A summary of the modeling stack parameters used in the BART CALPUFF modeling is presented in Table 3-1. A summary of the modeling emission parameters, as determined by the source emission factors mentioned above, is presented in Table 3-2.

**Table 3-1 Modeling Exhaust Stack Parameters**

	<b>Units</b>	<b>Unit 4</b>	<b>Unit 5</b>
UTM-X, Zone 18, NAD83	Meters	456891.942	4398832.728
UTM-Y, Zone 18, NAD83	Meters	456891.693	4398788.334
Stack Height	Meters	67.06	83.82
Base Elevation	Meters	3.96	3.96
Stack Diameter	Meters	4.11	6.40
Gas Exit Velocity	m/s	25.91	22.86
Stack Gas Exit Temperature	Deg K	407.59	413.15

Figure 3-1 Aerial View of the Edge Moor Plant



**Table 3-2 Baseline Emission Rates**

Facility	Unit	Description	Nominal Maximum Heat Input	Higher Heating Value	Higher Heating Value	Ash Content	Fuel Sulfur Content	Maximum Filterable PM Emissions			Filterable PM10					Condensable PM10			Total PM10
											total	coarse	Fine			total	SO4	organic	
													fine total	fine soil	EC				
MMBtu/hr (a)	Btu/gal (b)	Btu/lb (b)	% wt. (c)	% wt. (c)	lb/MMBtu	lb/hr	Basis	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr			
Edge Moor Power Plant	4	Unit 4, Coal, 175 MW, PC Tangential, Dry Bottom, ESP	1,793	N.A.	12,567	9.12	0.75	0.0290 (d)	52.05	AP-42	35.13 (e)	19.52	15.61 (e)	15.04	0.58 (f)	22.42	6.28 (g)	16.14 (h)	57.55
Edge Moor Power Plant	5	Unit 5, #6 Oil, 445 MW, Multiple Cyclone	4,551	152,655	N.A.	0.00	0.62	0.0579 (i)	263.38	AP-42	187.22 (j)	50.77	136.45 (j)	126.35	10.10 (k)	44.72 (l)	38.01 (l)	6.71 (l)	231.94

(a) Nominal maximum heat input is based on information received from Conectiv on April 5, 2007.

(b) Higher heating values are based on the average values for calendar years 2001 through 2006.

(c) Ash and sulfur contents are based on the values cited in the latest complete emission statement submitted to DNREC in 2004.

(d) Total filterable PM is determined from the relationship "0.08A lb/ton" (where A is the ash content in % wt.) based on AP-42, Table 1.1-4.

(e) Total filterable PM10 is 67% of filterable PM and fine filterable PM10 is 29% of filterable PM based on AP-42, Table 1.1-6.

(f) Elemental carbon is 3.7% of fine PM based on the best estimate for electric utility coal combustion in Table 6 of "Catalog of Global Emissions Inventories and Emission Inventory Tools for Black Carbon", William Battye and Kathy Boyer, EPA Contract No. 68-D-98-046, January 2002.

(g) H2SO4 emissions are based on "Estimating Total Sulfuric Acid Emissions from Coal Fired Power Plants," Keith Harrison, Larry Monroe and J. Edward Cichanowicz, Southern Company Services and Southern Research Institute, Revision 3, October 2005. Before control, H2SO4 is determined from the relationship "0.008(%S/100)(10\*6/HHV)(HIR)(98.06/32.07)" (where S is the sulfur content in % wt., HHV, the higher heating value in Btu/lb, and HIR, the heat input rate in MMBtu/hr). H2SO4 control is 0.49 for an air preheater and 0.49 for a cold-side ESP.

(h) Condensable organic PM10 is determined from the relationship, "0.20(0.1S-0.03 lb/MMBtu)" (where S is the sulfur content in % wt.) based on AP-42, Table 1.1-5.

(i) Total filterable PM is determined from the relationship "0.83(1.12S+0.37) lb/Mgal" (where S is the sulfur content in % wt.) based on AP-42, Table 1.3-4.

(j) Total filterable PM10 and fine filterable PM10 is 71% of filterable PM fine PM10 is 52% of filterable PM based on AP-42, Table 1.3-4.

(k) Elemental carbon is 7.4% of fine PM based on the best estimate for electric utility petroleum combustion in Table 6 of "Catalog of Global Emissions Inventories and Emission Inventory Tools for Black Carbon", William Battye and Kathy Boyer, EPA Contract No. 68-D-98-046, January 2002.

(l) Total condensable PM10 is 1.5 lb/Mgal based on AP-42, Table 1.3-2. Inorganic and inorganic fractions are 85% and 15% of total condensable PM10, respectively.

## 4.0 Evaluation of Air Pollution Control Technologies

The DNREC has promulgated Regulation 1146, the Electric Generating Unit Multi-Pollutant Regulation, effective December 11, 2006. This regulation establishes SO<sub>2</sub> and NO<sub>x</sub> emission limits for coal and residual oil-fired EGUs with a nameplate capacity rating of 25 MW or greater. According to this regulation, NO<sub>x</sub> emissions from coal and residual oil fired EGUs must not exceed 0.15 lb/MMBtu from May 1, 2009 through December 31, 2011, and 0.125 lb/MMBtu on or after January 1, 2012, on a 24-hour rolling average basis. For coal-fired EGUs, SO<sub>2</sub> emissions must not exceed 0.37 lb/MMBtu from May 1, 2009 through December 31, 2011, and 0.26 lb/MMBtu on or after January 1, 2012, also on a 24-hour rolling average basis. For residual oil-fired units, EGUs must not receive residual oil with a sulfur content in excess of 0.5% by weight on or after January 1, 2009.

Edge Moor Unit 4 is a nominal 175 MW dry-bottom, pulverized coal (primary fuel), tangentially-fired boiler equipped with low-NO<sub>x</sub> coal burners (LNB) and overfire air (OFA) for the control of NO<sub>x</sub> emissions and an electrostatic precipitator (ESP) for the control of filterable particulate emissions. Unit 4 is currently permitted to burn coal with a sulfur content of 1.0% wt. To comply with DNREC's Multi-Pollutant Regulation, Unit 4 will be retrofitted with a dry-sorbent injection system using a sodium-based sorbent to further reduce SO<sub>2</sub> emissions. For NO<sub>x</sub> control, Unit 4 will be undertake the addition/enhancement/optimization of low-NO<sub>x</sub> burner (LNB), overfire air (OFA), and an enhanced selective non-catalytic reduction system (SNCR).

Edge Moor Unit 5 is a nominal 445 MW residual oil-fired (primary fuel) boiler with oil LNB and OFA for the control of NO<sub>x</sub> emissions and a multiclone for the control of filterable particulates. Unit 5 is also currently permitted to burn oil with a sulfur content of 1.0% wt. To comply with DNREC's Multi-Pollutant Regulation, Unit 5 will receive residual oil for use at the facility with a maximum sulfur content of no more than 0.5% by weight to reduce SO<sub>2</sub> emissions. NO<sub>x</sub> additions/enhancements/optimizations will be employed will also include the use of a flue gas recirculation system, boosted over air system, and an enhanced SNCR system to further control NO<sub>x</sub> emissions.

Edge Moor Unit 3 (a coal-fired unit) is not a BART-eligible unit because it was placed into service before August 7, 1962. However, the Delaware Multi-Pollutant Regulation (and CAIR) will result in emission reductions at this unit as well. Since the baseline period (2000-2004), Conectiv has installed enhanced LNBs and has also installed supplemental OFA on this unit. Conectiv also plans on improving the SNCR system at this unit by making it operational year-round, and installing multi-level lances for injection, to assist the unit comply with the provisions of the Multi-Pollutant Regulation. These controls will extend the EGU-related emission reductions at Edge Moor to the only non-BART unit at the plant.

The remainder of this section discusses the BART determination factors related to PM<sub>10</sub> controls and evaluates the effectiveness of existing and proposed air pollution control technologies in reducing direct PM<sub>10</sub> emissions. In addition, the MPR controls that affect SO<sub>2</sub> and NO<sub>x</sub> emissions are described for supplemental information.

### 4.1 Particulate Controls

Currently, Edge Moor Unit 4 is equipped with an ESP to control particulate emissions. By 2009, the unit will also be equipped with dry sorbent injection to control SO<sub>2</sub> emissions. The dry sorbent injection system will provide the added benefit of controlling sulfates, a principal constituent of condensable PM<sub>10</sub>. Edge Moor Unit 5 is equipped with a multiple cyclone separator to control particulate emissions. By 2009, the unit will fire residual fuel oil with a lower sulfur content of 0.5% wt. This will also result in a reduction in the emissions of sulfates and hence condensable PM<sub>10</sub>.

The PM control technologies that were identified as available for retrofit to the Edge Moor Units 4 and 5 include the following:

- Fabric Filter Baghouse
- Electrostatic Precipitator (ESP)
- Wet ESP
- Compact Hybrid Particulate Collector
- GE MAX-9 Hybrid
- Multiple Cyclone Separator
- Alternative Fuels

These control technologies are reviewed below in the context of their effectiveness in further reducing PM emissions from Edge Moor Units 4 and 5.

#### **4.1.1 Fabric Filter Baghouse**

In a fabric filter, flue gas passes through a tightly woven or felted fabric, causing particles in the gas to be collected on the fabric by sieving, electrostatic attraction, and other mechanisms. Fabric filters may be in the form of sheets, cartridges or, most commonly, bags. The dust cake that forms on the filter from the collected PM can significantly increase collection efficiency. Fabric filters are frequently referred to as baghouses because the fabric is usually configured in cylindrical bags. Groups of bags are placed in isolable compartments to allow cleaning of the bags or replacement of some of the bags without shutting down the entire fabric filter.

Pulse-jet fabric filtration (PJFF) is the preferred cleaning method for coal-fired boilers because it can treat high dust loadings, operate at constant pressure drop, and occupy less space than other types of fabric filters. Practical application of pulse-jet fabric filters requires the use of a large fabric area in order to avoid an unacceptable pressure drop across the fabric. The total fabric area is determined by the maximum economic compartment size, total gas volume rate, air-to-cloth (A/C) ratio, and cleaning method. The air-to-cloth ratio, in turn, depends on the particulate loading and particle characteristics. A high particulate loading will require the use of a larger baghouse in order to avoid forming too heavy a dust cake, which would result in an excessive pressure drop across the unit.

In pulse-jet fabric filters, the flue gas typically enters the compartment hopper and passes from the outside of the bag to the inside, depositing particulate on the outside of the bag. To prevent the collapse of the bag, a metal cage is installed on the inside of the bag. The flue gas passes up through the center of the bag into the outlet plenum. The filter unit is typically divided into compartments, which allows online maintenance or bag replacement. The number of compartments is determined by maximum economic compartment size, total volumetric flow rate, air-to-cloth (A/C) ratio, and cleaning system design. Extra compartments for maintenance or offline cleaning increase the reliability at the expense of capital cost and real estate utilization.

Cleaning is performed by initiating a downward pulse of air into the top of the bag. The pulse causes a ripple effect along the length of the bag. This releases the dust cake from the bag surface, which then falls into the hopper. This cleaning may occur with the compartment online or offline. Care must be taken during design to ensure that the upward velocity between the bags is minimized so that particulate is not re-entrained during the cleaning process. The PJFF cleans bags in sequential, usually staggered, rows. During online cleaning, part of the dust cake from the row being cleaned may be captured by the adjacent rows. Despite this apparent shortcoming, PJFF have successfully implemented online cleaning on many large units.

Fabric filter baghouses are now the most common PM control device being applied to new large-scale, coal-fired boilers in the country. These devices in general provide highest collection efficiencies for both coarse and fine particulates and are relatively insensitive to fluctuations in gas stream conditions. In addition, the efficiency and pressure drop are relatively unaffected by large changes in inlet dust loadings for continuously cleaned filters. Despite physical site constraints, the BART analysis therefore focuses on the effectiveness and economic impacts associated with the retrofit of a fabric filter on Edge Moor Unit 4.

Because of the sticky and hygroscopic nature of residual oil fly ash, fabric filters have almost never been applied to oil-fired units, unless the bags are first pre-conditioned by means of dry sorbent injection upstream of the baghouse for SO<sub>2</sub> control. A fabric filter baghouse, therefore, is not considered technically feasible for application to Unit 5.

#### **4.1.2 Electrostatic Precipitator**

Unit 4 is equipped with an ESP to control filterable particulate matter discharged from the boiler. The ESP uses electrical forces to move particles entrained within the exhaust stream onto collector plates. The entrained particles are given an electrical charge when they pass through the corona, a region where gaseous ions flow. Electrodes in the center of the gas stream are maintained at high voltage and generate the electrical field that forces the particles to the collector plates. The collector plates are periodically knocked or "rapped" by various mechanical means to dislodge the particulate, which slides downward into a hopper where they are collected. The collection hopper is evacuated periodically, as it becomes full. The particulate is removed through a rotary valve into an ash-handling system, such as a pneumatic conveyor, and is then disposed of.

The voltage applied to the electrodes causes the gas between the electrodes to break down electrically, an action known as a "corona." The electrodes are usually given a negative polarity because a negative corona supports a higher voltage than does a positive corona before sparking occurs. The ions generated in the corona follow electric field lines from the wires to the collecting plates. Therefore, each wire establishes a charging zone through which the particles must pass. As larger particles absorb many times more ions than small particles, the electrical forces are much stronger on larger particles.

Certain design features and particle characteristics affect the control efficiency of an ESP. The rapping that dislodges the accumulated layer also releases some of the particles back into the gas stream. These re-entrained particles are then collected again in later sections, but the particles re-entrained in the last section are not collected and escape the unit. Further, part of the gas may flow around the charging zones through the clearances required for non-electrified internal components at the top of the ESP. This is called "sneakage" and places an upper limit on the collection efficiency. On Unit 4, the ESP has been designed to maintain the gas flow through at a relatively low velocity to minimize particle re-entrainment and to prevent gas flow around the charging zone to minimize sneakage.

Another major factor in the ESP's performance is the resistivity of the particles discharged from the boiler. Because the particles form a continuous layer on the ESP plates, all of the ion current must pass through the layer to reach the ground plates, creating an electric field in the layer. At high resistivities, this current can become strong enough to cause local electrical breakdown known as "back corona." At low resistivities, the particles are held on the plates so loosely that particle re-entrainment becomes much more severe. On Unit 4, ESP performance has been optimized for the relatively constant particle properties associated with the coal commonly fired in the boiler. It should also be noted that sodium based sorbent injection technology, planned for use by Conectiv for compliance with Delaware's Multi-pollutant Regulation is commonly used by ESP operators to reduce fly ash resistivity to improve the capture efficiency of particulate matter in such control devices.

ESPs are the most widely applied particulate control device to existing coal-fired utility boilers in the country. Based on performance tests conducted in December 1989, the Unit 4 ESP was demonstrated to limit filterable particulate emissions to 0.018 lb/MMBtu. These performance levels are much better than the MACT standard of 0.07 lb/MMBtu. As stated in the preamble to the BART Guidelines, "...unless there are new technologies

subsequent to the MACT standards which would lead to cost effective increases in the level of control, States may rely on the MACT standards for purposes of BART". Because no new technologies have become available since issuance of the MACT standard, the existing ESPs may be considered representative of BART. Furthermore, the performance levels are comparable to those specified for ESPs being applied to new coal-fired utility boilers around the country. Because of the particle size distribution of the PM emission from the existing unit, another ESP in series with the existing control device would provide little to no additional PM reduction and hence is not considered technically feasible for Unit 4. However, as part of implementation of the Multi-pollutant effort, Conectiv has also received permission from DNREC to improve the anodes in the Unit 4 existing precipitator design to a "pipe and spike" electrode to further enhance collection performance, and to replace 24 sonic horns to improve collection plate ash removal performance.

Although ESPs have also been applied to oil-fired utility boilers, they have experienced problems in dislodging the particles on the collection plates because of the sticky and hygroscopic nature of the fly ash. Further, the fine particulates exiting the existing multiclone may be more easily re-entrained in the flue gas or may flow around the charging zone resulting in sneackage. Because of these potential problems and severe site constraints, an ESP is not considered technically feasible for application to Unit 5.

#### **4.1.3 Wet ESP**

A wet ESP collects particles based on the same theory as a dry ESP, where negatively charged particles are collected on positively charged surfaces. In a wet ESP, however, the collecting surfaces are wet instead of dry and are flushed with water to remove the particulate. Typically, a wet ESP is installed downstream of an existing wet FGD system where the flue gas is already saturated to minimize water consumption. The particulate collection efficiency is enhanced by preventing re-entrainment after contact with the wet walls, compared with re-entrainment due to rapping on a dry ESP. Due to this feature, wet ESPs are well suited for the removal of fine particulate or acid mist from the gas stream.

Several major hurdles exist with the use of a wet ESP. First, the flue gas must be saturated with moisture prior to entering the wet ESP to allow the unit to work correctly. This requires that a quenching system be installed to add water to the flue gas to reduce the flue gas temperature to the saturation point or the wet ESP may be installed downstream of an existing wet FGD system. Without the presence of a wet FGD system, the wet ESP adds additional cost, increases water demand on the plant, and generates a visible moisture plume at the stack outlet. The removed particulate would also be contained in a wastewater stream that is generated by the wet ESP. In addition to this issue, the capital cost of a wet ESP is high as compared to other technologies due to the higher cost of the alloy materials required. A higher grade of material is required to withstand the highly corrosive conditions presented by the wet and acidic flue gas stream.

Because the flue gas must be saturated before entering a wet ESP, these devices are usually applied to combustion installations equipped with either a Venturi scrubber for PM control or a wet FGD system for acid gas control. Consequently, wet ESPs have seen extremely limited application to large-scale, coal-fired utility boilers and, therefore, are not considered technically feasible for application to Unit 4. Likewise, wet ESPs have almost never been applied to oil-fired boilers and, therefore, are not considered technically feasible for Unit 5.

#### **4.1.4 Compact Hybrid Particulate Collector**

Another control technology used for particulate control is a high A/C ratio fabric filter installed after an existing particulate control device (typically a cold side ESP). Commonly referred to as a Compact Hybrid Particulate Collector (COHPACTM), this technology was developed and trademarked by the Electric Power Research Institute (EPRI). The COHPAC filter typically operates at A/C ratios ranging from 6 to 8 ft/min, compared to a conventional fabric filter that typically operate at A/C ratios of about 4 ft/min. For a COHPAC system, the majority of the particulate is collected in the upstream particulate control device. Therefore, the performance requirements of a high A/C ratio fabric filter is reduced, allowing installation of this technology in a smaller footprint area, with less steel and filtration media to substantially lower both capital and operating costs compared to conventional fabric filters .

COHPAC collectors are designed to operate at filtration rates higher than normal pulse jet air-to-cloth ratios. These higher filtration rates provide many advantages over normal ratios, including lower capital cost, reduced real estate requirements, shorter system installation times, and associated outage times. While the type of pulse-jet cleaning technology is not the most critical factor to success, a pulse cleaning system must have the inherent capability to effectively clean long filter bags, while utilizing on-line filter cleaning and still be able to maintain reasonable pressure drops and deliver acceptable bag life.

To date, the COHPAC technology has limited experience on combustion type applications, having been applied to only four coal-fired boilers and two refuse fired combustors over the past ten years. Consequently, the COHPAC technology is not considered commercially available for application to Edge Moor Unit 4.

#### **4.1.5 GE MAX-9 Hybrid**

The Max-9 is a new technology for removing particulate matter from process gas streams. Basically, this technology is an electrostatic precipitator, but with fabric filter elements instead of collecting plates. When the dust particles are charged, they are attracted to the grounded metal cage inside the filter element, just as they would be attracted to the collecting plates in an ordinary ESP. Because the dust particles are all charged to the same polarity, they repel each other while trapped on the filter. This results in a very porous, permeable "dust cake." Accordingly, the pressure drop across the Max-9 is very low compared with that across a conventional baghouse – approximately 70% less than the typical high-efficiency baghouse.

Process gas enters the Max-9 from a hopper inlet duct. The gas then flows upward through the filters and out through the top of the filters. The area above the tube sheet is a clean gas plenum. Compressed air pulses are used to clean the filters. A brief, intense blast of air is fired through the purge air manifold; holes in the blowpipes located above the filters direct the cleaning air pulse down through the filters. The cleaning sequence is controlled by timers, which trigger solenoids. The high voltage system operates at very low current densities and at a steady state. There is no danger of fire caused by sparking, and the transformer/rectifier requires no voltage control.

To date, the GE Max-9 has not been applied to any large-scale, coal-fired boilers and, therefore, is not considered commercially available for application to Edge Moor Unit 4.

#### **4.1.6 Multiple Cyclone Separator**

Multiple cyclone separators, also known as "multiclones", consist of a number of small-diameter cyclones, operating in parallel and having a common gas inlet and outlet. Multiclones operate on the same principle as cyclones, creating a main downward vortex and an ascending inner vortex. Multiclones are more efficient than single cyclones because they are longer and smaller in diameter. The longer length provides longer residence time, while the smaller diameter creates greater centrifugal force. These two factors result in better separation of dust particles. The pressure drop of multiclone collectors is higher than that of single-cyclone separators.

Cyclone collectors are centrifugal collectors that rely on the particle density and velocity to separate the fly ash from the flue gas. The particulate-laden flue gas enters the top or the side of the cyclone. Vanes impart a rotational velocity to the flue gas, driving the fly ash to the edge of the cylinder. The flue gas then exits the center of the cyclone out the top, leaving the fly ash to fall out the bottom. At pressures near one atmosphere and 2 to 5 inches water gauge pressure differential, multiclones have been demonstrated to be capable of achieving a 40% to 60% reduction in filterable particulate emissions.

Unit 5 is equipped with a multiple cyclone separator to control filterable particulate matter discharged from the boiler. Based on performance tests conducted in December 1989, the Unit 5 multiclone was demonstrated to limit filterable particulate emissions to 0.020 to 0.024 lb/MMBtu. These performance levels are comparable to those specified for particulate control devices applied to new residual oil-fired boilers. Consequently, the existing multiclone is considered BART for PM emissions from Unit 5.

#### 4.1.7 Alternative Fuels

The only other means of reducing PM emissions from Unit 5 is converting from No. 6 residual fuel oil to “cleaner” fuels, such as No. 2 distillate fuel oil or natural gas. The advantages and disadvantages of converting to these alternative fuels is summarized below:

- No. 2 Distillate Fuel Oil. Converting to No. 2 distillate fuel oil with a lower sulfur content, say 0.3% wt., could reduce PM<sub>10</sub> emissions by up to 68% relative to baseline conditions, although it is very likely that the boiler would not be able to achieve full generating load capacity burning this type of fuel. The economic implications of converting to No. 2 fuel oil would also be difficult to determine because of the ever increasing price of this commodity. Further, this conversion would require the installation of new fuel oil storage tanks and handling system for the No. 2 fuel oil with the associated high capital expenditure. Because of physical site constraints, however, the space for the required storage tanks and handling system would be problematic.
- Natural Gas. Converting to pipeline quality natural gas could reduce PM<sub>10</sub> emissions by up to 85% relative to baseline conditions. Again, concerns would remain about the unit being able to accommodate this fuel and being able to reach full generating load capability. As with No. 2 oil, the economic implications of converting to natural gas would be difficult to determine because of the variability in prices in the future. Most importantly, however, Conectiv would not be unable to obtain a non-interruptible supply of natural gas from suppliers at the site due to existing supply infrastructure constraints.

Given these considerations, the conversion of Unit 5 from No. 6 residual fuel oil to either No. 2 distillate fuel oil or natural gas is not considered technically feasible as a means of further reducing PM emissions from that unit.

## 4.2 Sulfur Dioxide Controls

To comply with the DNREC’s Multi-Pollutant Regulation, Unit 4 will be retrofitted with a dry-sorbent injection system using a sodium-based sorbent to reduce SO<sub>2</sub> emissions. Likewise, Unit 5 will be converted to firing residual fuel oil with a lower sulfur content of no more than 0.5% wt in compliance with the s Multi-Pollutant Regulation.

### 4.2.1 Dry Sorbent Injection and Fuel Oil Sulfur Content

To comply with the Multi-Pollutant Regulation, dry sorbent injection (DSI) will be installed to control SO<sub>2</sub> emissions from Unit 4. DSI requires less capital equipment, less physical space, and less modification to existing ductwork than do spray dryer absorbers or wet scrubbers. However, reagent costs are much higher and, depending on the absorbent and amount of sorbent injected, control efficiency is lower than for a spray dryer absorber. Lime, soda ash, and sodium based sorbents (such as Trona, or sodium sesquicarbonate) are possible reagents. Lime and soda ash are the least reactive reagents, resulting in low efficiencies even at high injection rates. Trona is a very reactive reagent that can be used to achieve a range of efficiencies depending on the amount of sorbent injected.

The sorbent particles need to be ground extremely fine (milled) to maximize the surface area of the particles. The finer the particles, the faster and more complete the reaction for a given injection rate. The neutralization reaction between the SO<sub>2</sub> (mild acid) and the sorbent (strong base) takes place on the surface area of the sorbent particles. After finely ground sorbent is pulverized, it is blown into the hot flue gas stream using a high pressure blower. The sorbent reacts with the acid gases in the flue gas stream, and the reacted particles are removed with the ash in the particulate control device.

The chemical reaction of the acid components of the flue gas with the alkaline reagent takes place in the ductwork ahead of the particulate collection device and continues in the device itself. The main chemical reaction is as follows:



Plant operating conditions will ultimately affect the performance of the sodium sesquicarbonate in acid gas removal. The most important variables for high removal efficiency are injection temperature,  $\text{SO}_2$  concentration, retention time, and fine particle size (~10 microns).

As designed, DSI will be capable of limiting  $\text{SO}_2$  emissions from Unit 4 to the standards established in the Multi-Pollutant Regulation, that is, 0.37 lb/MMBtu by May 1, 2009 and 0.26 lb/MMBtu by January 1, 2012. In addition, DSI will remove an equivalent percentage of the  $\text{SO}_3$  and sulfates in the gas stream, thus reducing the inorganic condensable  $\text{PM}_{10}$  from Unit 4 by 50% over baseline conditions. Similar reductions in visibility-affecting emissions from Unit 3, which is not a BART-eligible source, will also occur due to Trona injection for that unit.

#### 4.2.2 Low Sulfur Fuel Oil

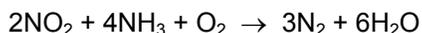
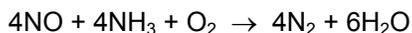
To comply with the Multi-Pollutant Regulation, the maximum sulfur content of the residual fuel oil fired in Unit 5 will be reduced to 0.5%, resulting in almost a 20% reduction in  $\text{SO}_2$  emissions over baseline conditions. In addition, lower sulfur fuel oil should remove an equivalent percentage of the  $\text{SO}_3$  and sulfates in the gas stream.

### 4.3 Nitrogen Oxides Controls

Currently, Edge Moor Unit 4 consists of a tangentially-fired boiler equipped with low- $\text{NO}_x$  coal burners (LNB) and overfire air (OFA) for the control of  $\text{NO}_x$  emissions. To comply with DNREC's Multi-Pollutant Regulation, Unit 4 will enhance and optimize the LNB and OFA, and install selective non-catalytic reduction (SNCR). Likewise, Edge Moor Unit 5 is equipped with LNB and OFA for the control of  $\text{NO}_x$  emissions. To comply with Multi-Pollutant Regulation, Unit 5 will enhance and optimize the LNB and OFA, and install a new boosted overfire air system, enhanced SNCR system, and flue gas recirculation (FGR) system.

#### 4.3.1 Selective Non-Catalytic Reduction

To comply with the Multi-Pollutant Regulation, selective non-catalytic reduction (SNCR) will be installed to control  $\text{NO}_x$  emissions from both Units 4 and 5. SNCR has been applied to a number of different types of combustion sources, including utility and industrial boilers fired with natural gas, oil, and coal. The SNCR process is based on a gas-phase homogeneous reaction, within a specified temperature range, between  $\text{NO}_x$  in the flue gas and injected ammonia to produce gaseous nitrogen and water vapor. The SNCR process converts  $\text{NO}_x$  to nitrogen and water by the following general reactions:



In an SNCR system,  $\text{NO}_x$  reduction does not take place in the presence of a catalyst, but rather is driven by the thermal decomposition of ammonia or urea and the subsequent reduction of  $\text{NO}_x$ . Consequently, the SNCR process operates at higher temperatures than the SCR process. Critical to the successful reduction of  $\text{NO}_x$  with SNCR is the temperature of the flue gas at the point where the reagent is injected. For the ammonia injection process, the necessary temperature range is 1,700 to 1,900 °F. The factors affecting SNCR performance are gas mixing, residence time at temperature, and ammonia slip.

Theoretically, one mole of ammonia will react with one mole of  $\text{NO}_x$ , forming elemental nitrogen and water. In reality, not all the injected reagent will react, due to imperfect mixing, uneven temperature distribution, and insufficient residence time. These physical limitations may be compensated for by injecting excess ammonia and essentially achieving low  $\text{NO}_x$  emissions at the expense of ammonia slip. Thus, for a given boiler

configuration, there is a limit on the degree of NO<sub>x</sub> reduction that can be achieved with SNCR while maintaining acceptable levels of ammonia slip.

In combination with enhanced staged combustion techniques, the SNCR will be capable of limiting NO<sub>x</sub> emissions from Units 4 and 5 to the standards established in the Multi-Pollutant Regulation, that is, 0.15 lb/MMBtu by May 1, 2009 and 0.125 lb/MMBtu by January 1, 2012. By minimizing ammonia slip, the SNCR will not result in an appreciable change in PM<sub>10</sub> emissions. This is in contrast with selective catalytic reduction (SCR), which would remove more NO<sub>x</sub> emissions, but would increase the primary emissions of H<sub>2</sub>SO<sub>4</sub> by causing increased oxidation of the SO<sub>2</sub> emissions. During warm-weather months when NO<sub>x</sub> emissions create very low amounts of particulate (ammonium nitrate) due to the chemistry equilibrium between ammonium nitrate and gaseous nitric acid, the operation of SCR equipment can actually lead to no visibility improvement or, in certain cases, even increased visibility impairment due to the increased H<sub>2</sub>SO<sub>4</sub> emissions that result.

#### **4.3.2 Staged Combustion**

A number of techniques have been employed to reduce the formation of NO<sub>x</sub> by reducing peak flame temperature and/or starving the hottest parts of the flame for oxygen. By staging the combustion process, a longer, cooler flame results, which forms less NO<sub>x</sub>. Staged combustion techniques include low-NO<sub>x</sub> burners (LNB), over-fire air (OFA), and flue gas recirculation (FGR). To further reduce NO<sub>x</sub> emissions, Unit 5 will be retrofitted with enhanced LNB and supplemental OFA, and will also be retrofitted with FGR.

#### **4.4 Technical Feasibility of PM Control Options**

Fabric filters and ESPs have been applied to large-scale, coal-fired utility boilers for many years. These devices have been demonstrated to achieve high PM collection efficiencies with minimal problems, maintenance, or downtime. Because of the particle size distribution of the PM emission from the existing unit, however, another ESP in series with the existing control device would provide little to no additional PM control and hence is not considered further in this analysis. The COHPAC Collector, on the other hand, has very limited experience on utility boiler applications, having been applied to only four coal-fired boilers and two refuse-fired combustors over the past ten years. Likewise, the Max-9 Hybrid has yet to be demonstrated on combustion installations comparable to the size of Edge Moor Unit 4. Despite physical site constraints, the BART analysis therefore focuses on the effectiveness and economic impacts associated with the retrofit of a fabric filter on Edge Moor Unit 4.

To date, ESPs and cyclones are the only PM control devices that have been applied to large-scale, residual oil-fired utility boilers. Because of severe physical site constraints, however, the retrofit of an ESP downstream of the existing multiclone is not considered technically feasible and hence is not considered further in this analysis. Because of the sticky and hygroscopic nature of residual oil fly ash, fabric filters have never been applied to oil-fired units, unless the bags are first pre-conditioned by means of dry sorbent injection upstream of the baghouse for SO<sub>2</sub> control. Likewise, the COHPAC Collector and Max-9 Hybrid have never been applied to oil-fired boilers. The use of lower sulfur No. 4 or No. 2 fuel oils to further reduce PM emissions is not considered technically feasible, because there is insufficient space onsite for the required fuel oil storage tanks and handling system. Likewise, the use of natural gas to further reduce PM emissions is not technically feasible because a non-interruptible supply of natural gas is not available to the site. Therefore, there are no control technologies considered technically feasible to further reduce PM emissions from Unit 5.

#### **4.5 Effectiveness of Feasible PM Control Options**

As previously addressed, the SO<sub>2</sub> control technologies to be implemented in response to the MPR will also have effects on the PM emissions from Units 4 and 5. These control technologies, therefore constitute BART Control Option 1. The retrofit of a fabric filter on Unit 4 then will further reduce PM emissions from Unit 4. Based on recent permit approvals for new installations, the manufacturers of these control devices will guarantee filterable PM emissions on the order of 0.015 lb/MMBtu. The retrofit of a fabric filter on Unit 4 then constitutes BART Control Options 2. Tables 4-1 and 4-2 provide the PM emission rates and speciation used as input to CALPUFF for BART Control Options 1 and 2, respectively.

## 4.6 Impacts of Technically Feasible Options

To determine the cost effectiveness of the PM control options, the capital and annual operating costs for the technically feasible PM<sub>10</sub> control technologies were estimated using CUECOST3, as revised on February 9, 2000. Because these costs are order of magnitude estimates, they are accurate only to about ±30%. The capital costs were annualized over a 30-year period and then added to the annual operating costs to obtain the total annual costs for each technology. Table 4-4 shows the costs of the BART Control Options applied to Edge Moor Units 4 and 5.

**Table 4-3: Cost Effectiveness of BART Control Options**

Control Option	Capital Cost (\$)	Annual Fixed Charges (\$/yr)	Annual O&M Costs (\$/yr)	Total Annual Costs (\$/yr)
1	\$0	\$0	\$0	\$0
2	\$23,843,834	\$2,789,729	\$1,541,721	\$4,331,450

This BART analysis does not identify any substantive energy impacts associated with the alternative PM control technologies considered for Edge Moor Units 4 and 5. Likewise, there are no significant non-air quality environmental impacts associated with these control technologies.

## 4.7 Conclusions

The EPA established procedures for determining BART in its Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determinations updated on July 24, 2005. The BART Guidelines recommend the following five steps for a case-by-case BART determination:

- Step 1– Identify all available control technologies for the unit including improvements to existing control equipment or installation of new add-on control equipment.
- Step 2– Eliminate technically infeasible options considering the commercial availability of the technology, space constraints, operating problems and reliability, and adverse side effects on the rest of the facility.
- Step 3– Evaluate the control effectiveness of the remaining technologies based on current pollutant concentrations, flue gas properties and composition, control technology performance, and other factors.
- Step 4– Evaluate the annual and incremental costs of each feasible option in accordance with approved EPA methods, as well as the associated energy and non-air quality environmental impacts.
- Step 5- Determine the visibility impairment associated with baseline emissions and the visibility improvements provided by the control technologies considered in the engineering analysis.

To minimize filterable PM<sub>10</sub> emissions from Edge Moor Power Plant, Units 4 and 5 are equipped with an ESP and multiclone, respectively. These particulate collection devices have been shown to achieve performance levels comparable to those being specified as BACT for new coal- and oil-fired boilers. The existing control devices, therefore, are considered representative of BART for filterable PM<sub>10</sub>. In selecting the SO<sub>2</sub> and NO<sub>x</sub> control technologies designed to comply with CAIR and the Multi-Pollutant Regulations, Conectiv essentially completed the first four steps in the case-by-case BART determination established by the EPA. The selected SO<sub>2</sub> control systems are also effective in reducing primary sulfate emissions, a constituent of condensable PM<sub>10</sub>.

The fifth step in the case-by-case BART determination is satisfied in the visibility analysis documented in the next section of this report.

**Table 4-1 Emissions for BART Control Option 1**

Facility	Unit	Description	Nominal Maximum Heat Input	Higher Heating Value	Higher Heating Value	Ash Content	Fuel Sulfur Content	Maximum Filterable PM Emissions			Filterable PM10					Condensable PM10			Total PM10
											total	coarse	Fine			total	SO4	organic	
													fine total	fine soil	EC				
			MMBtu/hr (a)	Btu/gal (b)	Btu/lb (b)	% wt. (c)	% wt. (c)	lb/MMBtu	lb/hr	Basis	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	
Edge Moor Power Plant	4	Unit 4, Coal, 175 MW, PC Tangential, Dry Bottom, DSI, ESP	1,793	N.A.	12,567	9.12	0.75	0.0290 (d)	52.05	AP-42	35.13 (e)	19.52	15.61 (e)	15.04	0.58 (f)	19.28	3.14 (g)	16.14 (h)	54.41
Edge Moor Power Plant	5	Unit 5, #6 Oil, 445 MW, Multiple Cyclone	4,551	150,000	N.A.	0.00	0.50	0.0515 (i)	234.19	AP-42	166.48 (j)	45.15	121.33 (j)	112.35	8.98 (k)	45.51 (l)	38.68 (l)	6.83 (l)	211.99

(a) Nominal maximum heat input is based on information received from Conectiv on April 5, 2007.

(b) Higher heating values are based on the average values for calendar years 2001 through 2006.

(c) Ash content is based on the values cited in the latest complete emission statement submitted to DNREC in 2004 and sulfur content reflect maximum allowable under the Multi-Pollutant Regulations.

(d) Total filterable PM is determined from the relationship "0.08A lb/ton" (where A is the ash content in % wt.) based on AP-42, Table 1.1-4.

(e) Total filterable PM10 is 67% of filterable PM and fine filterable PM10 is 29% of filterable PM based on AP-42, Table 1.1-6.

(f) Elemental carbon is 3.7% of fine PM based on the best estimate for electric utility coal combustion in Table 6 of "Catalog of Global Emissions Inventories and Emission Inventory Tools for Black Carbon", William Battye and Kathy Boyer, EPA Contract No. 68-D-98-046, January 2002.

(g) H2SO4 emissions are based on "Estimating Total Sulfuric Acid Emissions from Coal Fired Power Plants," Keith Harrison, Larry Monroe and J. Edward Cichanowicz, Southern Company Services and Southern Research Institute, Revision 3, October 2005. Before control, H2SO4 is determined from the relationship "0.008(%S/100)(10\*6/HHV)(HIR)(98.06/32.07)" (where S is the sulfur content in % wt., HHV, the higher heating value in Btu/lb, and HIR, the heat input rate in MMBtu/hr). H2SO4 control is 0.49 for an air preheater, 0.49 for a cold-side ESP, and 0.50 for DSI.

(h) Condensable organic PM10 is determined from the relationship, "0.20(0.1S-0.03 lb/MMBtu)" (where S is the sulfur content in % wt.) based on AP-42, Table 1.1-5.

(i) Total filterable PM is determined from the relationship "0.83(1.12S+0.37) lb/Mgal" (where S is the sulfur content in % wt.) based on AP-42, Table 1.3-4.

(j) Total filterable PM10 and fine filterable PM10 is 71% of filterable PM fine PM10 is 52% of filterable PM based on AP-42, Table 1.3-4.

(k) Elemental carbon is 7.4% of fine PM based on the best estimate for electric utility petroleum combustion in Table 6 of "Catalog of Global Emissions Inventories and Emission Inventory Tools for Black Carbon", William Battye and Kathy Boyer, EPA Contract No. 68-D-98-046, January 2002.

(l) Total condensable PM10 is 1.5 lb/Mgal based on AP-42, Table 1.3-2. Inorganic and inorganic fractions are 85% and 15% of total condensable PM10, respectively.

**Table 4-2 Emissions for BART Control Option 2**

Facility	Unit	Description	Nominal Maximum Heat Input	Higher Heating Value	Higher Heating Value	Ash Content	Fuel Sulfur Content	Maximum Filterable PM Emissions			Filterable PM10					Condensable PM10			Total PM10
											total	coarse	Fine			total	SO4	organic	
													fine total	fine soil	EC				
MMBtu/hr (a)	Btu/gal (b)	Btu/lb (b)	% wt. (c)	% wt. (c)	lb/MMBtu	lb/hr	Basis	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr			
Edge Moor Power Plant	4	Unit 4, Coal, 175 MW, PC Tangential, Dry Bottom, DSI, ESP, FF	1,793	N.A.	12,567	9.12	0.75	0.0150 (d)	26.90	AP-42	18.15 (e)	10.09	8.07 (e)	7.77	0.30 (f)	16.45	0.31 (g)	16.14 (h)	34.61
Edge Moor Power Plant	5	Unit 5, #6 Oil, 445 MW, Multiple Cyclone	4,551	150,000	N.A.	0.00	0.50	0.0515 (i)	234.19	AP-42	166.48 (j)	45.15	121.33 (j)	112.35	8.98 (k)	45.51 (l)	38.68 (l)	6.83 (l)	211.99

(a) Nominal maximum heat input is based on information received from Conectiv on April 5, 2007.

(b) Higher heating values are based on the average values for calendar years 2001 through 2006.

(c) Ash content is based on the values cited in the latest complete emission statement submitted to DNREC in 2004 and sulfur content is based on maximum allowable under the Multi-Pollutant Regulations.

(d) Total filterable PM is determined from the relationship "0.08A lb/ton" (where A is the ash content in % wt.) based on AP-42, Table 1.1-4.

(e) Total filterable PM10 is 67% of filterable PM and fine filterable PM10 is 29% of filterable PM based on AP-42, Table 1.1-6.

(f) Elemental carbon is 3.7% of fine PM based on the best estimate for electric utility coal combustion in Table 6 of "Catalog of Global Emissions Inventories and Emission Inventory Tools for Black Carbon", William Battye and Kathy Boyer, EPA Contract No. 68-D-98-046, January 2002.

(g) H2SO4 emissions are based on "Estimating Total Sulfuric Acid Emissions from Coal Fired Power Plants," Keith Harrison, Larry Monroe and J. Edward Cichanowicz, Southern Company Services and Southern Research Institute, Revision 3, October 2005. Before control, H2SO4 is determined from the relationship "0.008(%S/100)(10\*6/HHV)(HIR)(98.06/32.07)" (where S is the sulfur content in % wt., HHV, the higher heating value in Btu/lb, and HIR, the heat input rate in MMBtu/hr). H2SO4 control is 49% for an air preheater, 49% for a cold-side ESP, 0.50 for DSI, and 0.10 for FF.

(h) Condensable organic PM10 is determined from the relationship, "0.20(0.1S-0.03 lb/MMBtu)" (where S is the sulfur content in % wt.) based on AP-42, Table 1.1-5.

(i) Total filterable PM is determined from the relationship "0.83(1.12S+0.37) lb/Mgal" (where S is the sulfur content in % wt.) based on AP-42, Table 1.3-4.

(j) Total filterable PM10 and fine filterable PM10 is 71% of filterable PM fine PM10 is 52% of filterable PM based on AP-42, Table 1.3-4.

(k) Elemental carbon is 7.4% of fine PM based on the best estimate for electric utility petroleum combustion in Table 6 of "Catalog of Global Emissions Inventories and Emission Inventory Tools for Black Carbon", William Battye and Kathy Boyer, EPA Contract No. 68-D-98-046, January 2002.

(l) Total condensable PM10 is 1.5 lb/Mgal based on AP-42, Table 1.3-2. Inorganic and inorganic fractions are 85% and 15% of total condensable PM10, respectively.

## 5.0 CALPUFF Modeling Results

### 5.1 Baseline CALPUFF Modeling Results

CALPUFF modeling results of the baseline emissions at two Class I areas are presented in Table 5-1. Modeling was conducted for all three years of CALMET meteorological data (2001-2003). Emission rates that were used in modeling the baseline emissions are listed in Table 2-2.

The results of the visibility analysis for the baseline emissions demonstrate that visibility impacts from Edge Moor Units 4 and 5 are clearly imperceptible, being well below the BART perceptibility threshold value of 0.5 delta-dv for all Class I areas. The baseline visibility impacts are slightly above the MANE-VU “significance” threshold of 0.1 delta-dv when sulfates are included in the analysis. The analysis determined that more than half of the PM<sub>10</sub>-caused visibility impacts can be attributed to inorganic condensable PM emissions, which result from the conversion of a small fraction of SO<sub>2</sub> in the gas stream into SO<sub>3</sub> and H<sub>2</sub>SO<sub>4</sub>. Consequently, it is anticipated that the implementation of CAIR and the Delaware Multi-Pollutant Regulation will not only result in a significant reduction in SO<sub>2</sub> and NO<sub>x</sub> emissions from Units 4 and 5, but also the emissions of sulfates and other inorganic condensable PM emissions (Control Option Case 1). This implementation of the additional SO<sub>2</sub> control systems, therefore, will result in further improvements in the visibility impacts associated with Edge Moor Units 4 and 5.

The results in Table 5-1 indicate that the 8th highest day’s impacts for each year and each Class I area are well below 0.5 delta-dv, and are comparable to the low MANE-VU contribution threshold of 0.1 delta-dv.

### 5.2 CALPUFF Modeling Results for Feasible Control Options

Two feasible BART control options were modeled for each meteorological year (2001-2003) and for two Class I areas to determine the effects of controlling PM<sub>10</sub> emissions from Units 4 and 5. Emission rates that were used in modeling the BART control options are listed in Tables 4-1 and 4-2. These control scenarios are more fully discussed in Section 4.

The results of the BART control options modeling are presented in Table 5-1. Results for each feasible candidate BART control case are discussed in more detail below.

**Control Option 1:** This control option would result in 50% reduction of inorganic condensable PM<sub>10</sub> emissions due to SO<sub>2</sub> emission controls with DSI. Modeling results for direct PM<sub>10</sub> emissions show that the visibility may improve by about 0.01 delta-dv (relative to the baseline case) at Shenandoah National Park and Brigantine Wilderness. The improvement in visibility is minor, but additional visibility benefits would be obtained from the SO<sub>2</sub> and NO<sub>x</sub> emission MPR reductions that are accommodated into the CAIR implementation. As discussed below, ENSR and Conectiv conclude that this control option is the Best Available Retrofit Technology alternative for the Edge Moor Generating Station based on the expected incremental visibility improvement, the cost of compliance, energy impacts, and other non-air quality environmental impacts

**Control Option 2:** This option involves adding fabric filter to Unit 4 to control PM<sub>10</sub> emissions. This option would reduce total PM<sub>10</sub> emissions by about 40%, but would result in a very minor visibility improvement at high cost. The incremental visibility improvement at Brigantine Wilderness is only 0.02 delta-dv and 0.01 delta-dv at Shenandoah National Park.

**Table 5-1 Summary of Results – Edge Moor BART Modeling**

Class I Area	Case	2001				2002				2003			
		Days > than		MAX dv Δ B <sub>ext</sub>	8 <sup>th</sup> Highest dv Δ B <sub>ext</sub>	Days > than		MAX dv Δ B <sub>ext</sub>	8 <sup>th</sup> Highest dv Δ B <sub>ext</sub>	Days > than		MAX dv Δ B <sub>ext</sub>	8 <sup>th</sup> Highest dv Δ B <sub>ext</sub>
		0.1 dv Δ B <sub>ext</sub>	0.5 dv Δ B <sub>ext</sub>			0.1 dv Δ B <sub>ext</sub>	0.5 dv Δ B <sub>ext</sub>			0.1 dv Δ B <sub>ext</sub>	0.5 dv Δ B <sub>ext</sub>		
Brigantine W	Baseline	13	0	0.20	0.13	6	0	0.15	0.10	8	0	0.16	0.10
	BART Case 1	12	0	0.19	0.12	6	0	0.14	0.09	7	0	0.15	0.09
	BART Case 2	10	0	0.18	0.11	6	0	0.13	0.08	6	0	0.14	0.09
Shenandoah NP	Baseline	0	0	0.05	0.02	0	0	0.06	0.03	1	0	0.12	0.04
	BART Case 1	0	0	0.04	0.02	0	0	0.06	0.03	1	0	0.11	0.04
	BART Case 2	0	0	0.04	0.02	0	0	0.05	0.02	1	0	0.10	0.04

### 5.3 Cost of BART Control Options

**Table 5-2 Cost of BART Control Options**

	Baseline	BART Option 1	BART Option 2
Capital Costs	n/a	n/a	\$23,843,834
Fixed Capital Costs	n/a	n/a	\$2,789,729
Annual O&M Costs	n/a	n/a	\$1,541,721
Total Annual Costs	n/a	n/a	\$4,331,450
Incremental Direct PM <sub>10</sub> Emissions Removed (tons) relative to previous control option	n/a	38.31 <sup>(1)</sup>	78.67 <sup>(1)</sup>
Incremental PM <sub>10</sub> Emissions Removal Cost (\$/ton)	n/a	n/a	\$55,060
8 <sup>th</sup> Highest Ave over 3-Years in Brigantine (dv)	0.110	0.100	0.093
8 <sup>th</sup> Highest Ave over 3-Years in Shenandoah (dv)	0.030	0.030	0.027
Incremental Visibility Improvement Cost in Brigantine (\$/dv)	n/a	n/a	\$8,259,037
Incremental Visibility Improvement Cost in Shenandoah (\$/dv)	n/a	n/a	\$16,518,074
(1) Unit 4 2001-2006 average utilization factor is 91%, and Unit 5 2001-2006 average utilization factor is 30%.			

## 6.0 Conclusions and BART Recommendations

Edge Moor has been identified by DNREC as a source that is eligible for consideration of BART controls for PM<sub>10</sub> (CAIR serves as BART for SO<sub>2</sub> and NO<sub>x</sub>). A BART modeling and engineering analysis has been completed in accordance with an approved BART modeling protocol, and in conjunction with a conference call with the DNREC in which the proposed procedures were discussed and approved for use. Additional BART determination analyses have been performed to respond to DNREC comments received earlier this year.

The results of the modeling study using peak daily baseline PM<sub>10</sub> emissions demonstrate that visibility impacts from Edge Moor Units 4 and 5 are clearly imperceptible, being well below the EPA-prescribed BART threshold value of 0.5 delta-dv (8<sup>th</sup> highest or 98<sup>th</sup> percentile day in each of the three modeled years) for both Class I areas. In addition, the visibility impacts are comparable to the lower MANE-VU “significance” threshold of 0.1 delta-dv (8<sup>th</sup> highest or 98<sup>th</sup> percentile day in each of the three modeled years).

The DNREC has indicated that an engineering review and Class I modeling of anticipated emission reductions from the BART-eligible sources should be provided even if the baseline modeling results show very low visibility impacts. ENSR conducted engineering review and Class I modeling of available PM<sub>10</sub> control options for Units 4 and 5. The modeling results for two feasible options indicate that the visibility improvements for the proposed PM<sub>10</sub> alternative control technologies are very minor relative to the baseline.

ENSR and Conectiv recommend that Control Option 1 (DSI on Unit 4 and 0.5% sulfur oil for Unit 5) as the Best Available Retrofit Technology alternative for the Edge Moor Generating Station. The controls associated with this option will be implemented as a result of Delaware’s Multi-Pollutant Regulation. The emission reductions from non-BART Unit 3 will also provide beneficial visibility improvements that are in addition to those from the Edge Moor BART-eligible units.

Control Option 2 with a fabric filter on Unit 4 was rejected as BART due to the very small incremental improvement in visibility at high cost. A summary of the BART analysis is presented in Table 6-1.

Table 6-1 Summary of BART Analysis

	<i>Step 1</i>	<i>Step 2</i>	<i>Step 3</i>	<i>Step 4a</i>	<i>Step 4b</i>	<i>Step 5</i>	
	Identify Control Technologies	Feasible Control Technology?	Evaluate Control Effectiveness for Potentially Technically Feasible Control Technologies	Calculated Cost Effectiveness for Control Technologies	Determine Energy, Other Non-Air Quality Environmental Impacts, and Remaining Useful Life	Evaluate Visibility Impacts of Control Technologies	Identify BART Control
<b>Control Option 1</b>	<b>Unit 4:</b> Dry-sorbent injection (reduces inorganic condensable PM <sub>10</sub> )	Yes	50% reduction of inorganic condensable PM <sub>10</sub>	Cost is not calculated since this control option will be implemented as a result of Delaware's Multi-Pollutant Regulation.	No significant non-air quality or energy impacts	8 <sup>th</sup> Highest impact improvement of 0.01 delta-dv in Brigantine and Shenandoah for PM <sub>10</sub> emission reductions relative to baseline emissions.	This set of emission controls will occur as a result of Delaware's Multi-Pollutant Regulation.
	<b>Unit 5:</b> Sulfur content capped at 0.5%		8.6% reduction of total PM <sub>10</sub>				
<b>Control Option 2</b>	<b>Unit 4:</b> Dry-sorbent injection and fabric filter	Yes	40% reduction of total PM <sub>10</sub>	Capital cost of \$23,843,834; annual operating cost of \$4,331,450	No significant non-air quality or energy impacts	8 <sup>th</sup> Highest impact improvement of 0.02 delta-dv in Brigantine and 0.01 delta-dv in Shenandoah relative to Control Option 1.	BART not justified due to visibility improvement of only 0.02 delta-dv at high cost.
	<b>Unit 5:</b> Sulfur content capped at 0.5%		8.6% reduction of total PM <sub>10</sub>				

## 7.0 References

Battye, W. and K. Boyer, 2002, Catalog of Global Emissions Inventories and Emission Inventory Tools for Black Carbon, Table 6, EPA Contract No. 68-D-98-046, available at [http://www.cleanairnet.org/asia/1412/articles-37073\\_resource\\_1.pdf](http://www.cleanairnet.org/asia/1412/articles-37073_resource_1.pdf)

Environmental Protection Agency (EPA), AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, January, 1995

Environmental Protection Agency (EPA), Guidance for Tracking Progress Under the Regional Haze Rule, EPA-454/B-03-003, Appendix A, Table A-3, September, 2003

Environmental Protection Agency (EPA), Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Program, EPA 454/B-03-005, September 2003

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Environmental Protection Agency (EPA), 40 CFR Part 51, FRL -7925-9, RIN: 2060-AJ31, Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determinations (Appendix Y), updated June 24, 2005

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Visibility Improvement State and Tribal Association of the Southeast (VISTAS), Revision 3, Protocol for the Application of the CALPUFF Model for Analyses of Best Available Retrofit Technology (BART), updated July 18, 2006.

## **Appendix A**

### **Relevant Excerpts from EPA’s “Additional Regional Haze Questions”**

(available at [http://www.tceq.state.tx.us/assets/public/implementation/air/sip/bart/EPA\\_QA-Haze.pdf](http://www.tceq.state.tx.us/assets/public/implementation/air/sip/bart/EPA_QA-Haze.pdf))

- Q. If the unit is already controlled (e.g., under MACT or BACT) and it is the best, the latest control technology, does the source still need to conduct a full blown BART analysis and control technology evaluation including the installed control device? Or, can the source just describe the control device on their BART-eligible source unit and make the case that it qualifies as BART, without having to evaluate other technologies?
- A. If the unit has “best, latest...”, then the source can just describe the control device on their BART-eligible source unit and make the case that it qualifies as BART, without having to evaluate other technologies. The streamlining of BART analyses in this situation is addressed in Section IV.C of the BART Guidelines, “How does a BART review relate to [MACT] Standards under CAA section 112, or to other emission limitations required under the CAA?”
- Q. How does the CAIR substitute for BART?
- A. States subject to and participating in the CAIR cap and trade program for SO<sub>2</sub> and NO<sub>x</sub> may treat the CAIR requirements for EGUs as a substitute for the application of BART controls for these pollutants. States do not need to require BART-eligible EGUs subject to the CAIR to install, maintain, and operate BART per 40 CFR 51.308(e)(4).
- Q. If a CAIR facility is found to be exempt from BART for SO<sub>2</sub> and NO<sub>x</sub>, and the State does exemption modeling on PM<sub>10</sub> and concludes there is no impact on a Class I area, can the State totally exempt the utility from BART?
- A. States subject to and participating in the CAIR cap and trade program for SO<sub>2</sub> and NO<sub>x</sub> are allowed to treat the CAIR requirements for EGUs as a substitute for the application of BART controls per 40 CFR 51.308(e)(4). This does not mean EGUs are exempt for SO<sub>2</sub> and NO<sub>x</sub>, only that CAIR satisfies the BART requirement for those pollutants. The remaining visibility pollutants to consider for determining BART-eligible sources are PM, and, using judgment, VOCs, and ammonia. For PM, the July 6, 2005, final BART rule at 70 FR 39160 notes PM<sub>10</sub> may be used as an indicator for PM in this step of the determination and thus, PM<sub>10</sub> can be used for the exemption modeling.

## **Appendix B**

### **Re-Calculating CALPOST Visibility Outputs with the New IMPROVE Algorithm**

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## **Recalculating CALPOST Visibility Outputs with the New IMPROVE Algorithm**

**15 August 2006**

### **Introduction**

CALPOST processes outputs from CALPUFF modeling of a source's emissions to calculate the incremental visibility impairments caused by the modeled source. Those increments are presented in two tables, both labeled "Ranked Daily Visibility Change", in the CALPOST output (.LST) file. The table of interest to us has the subtitle "Modeled Extinction by Species" and lists the dates and locations of such incremental impacts in light extinction ( $b_{\text{ext}}$ ) in ranked order, starting with the one that represents the largest percentage change in light extinction.<sup>1</sup>

Visibility effects are calculated in CALPOST from CALPUFF-modeled particulate matter component concentrations using effectively the "traditional" IMPROVE algorithm. CALPOST allows for choice of the humidity scattering enhancement function ( $f(\text{RH})$ ) to be used with the IMPROVE algorithm; for modeling in connection with the US EPA's Regional Haze Regulations (RHR), the appropriate form of  $f(\text{RH})$  is the one described and tabulated in the EPA's 2003 guidance for tracking progress under the RHR.

Recently, the IMPROVE Steering Committee developed a new algorithm for estimating light extinction from particulate matter component concentrations. This algorithm (the "new IMPROVE algorithm") provides a better correspondence between the measured visibility and that calculated from particulate matter component concentrations. The new algorithm differs in several substantive ways from the traditional one:

- The extinction efficiencies of sulfates, nitrates, and organics have been changed and are now functions of their concentrations. The extinction efficiencies of

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<sup>1</sup> The other table in the CALPOST output file, with the subtitle "% of Modeled Extinction by Species", provides equivalent results in terms of changes in the haze index, in deciviews. The two tables represent the same results, with identical ranking of events, while just using different (but mathematically related) metrics.

sulfate and nitrate are no longer identical, although the new hygroscopic scattering enhancement factors applied to them are the same.

- The concentration of particulate organic matter (POM; variously also labeled OCM or OMC, and sometimes just called “organics”) is now taken to be 1.8 times that of the measured organic carbon (OC) concentration. (Confusingly, CALPOST labels the organics concentration as OC.)
- The contribution of fine sea salt to light extinction has been added, and is accompanied by its own hygroscopic scattering enhancement factor,  $f_{ss}(RH)$ .
- The light scattering by air itself (Rayleigh scattering) now varies with site elevation and mean temperature. It is to be rounded off to the nearest one  $Mm^{-1}$  when used with the new algorithm.
- The light absorption by  $NO_2$  gas has been added.

The new IMPROVE algorithm is represented by the following formula:<sup>2</sup>

$$\begin{aligned}
 b_{ext} = & 2.2 \cdot f_s(RH) \cdot [small\ sulfate] + 4.8 \cdot f_l(RH) \cdot [large\ sulfate] \\
 & + 2.4 \cdot f_s(RH) \cdot [small\ nitrate] + 5.1 \cdot f_l(RH) \cdot [large\ nitrate] \\
 & + 2.8 \cdot [small\ organics] + 6.1 \cdot [large\ organics] \\
 & + 10 \cdot [elemental\ carbon] \\
 & + 1 \cdot [fine\ soil] \\
 & + 1.7 \cdot f_{ss}(RH) \cdot [sea\ salt] \\
 & + 0.6 \cdot [coarse\ matter] \\
 & + Rayleigh\ scattering\ (site\ specific) \\
 & + 0.33 \cdot [NO_2(ppb)]
 \end{aligned}
 \tag{Eq. 1}$$

The concentrations of “large” and “small” sulfate particles are calculated as follows:

$$\begin{aligned}
 [large\ sulfate] &= \{[total\ sulfate]/20\} \cdot [total\ sulfate] \text{ if } [total\ sulfate] < 20\ \mu g^3 \\
 [large\ sulfate] &= [total\ sulfate] \text{ if } [total\ sulfate] \geq 20\ \mu g/m^3 \\
 [small\ sulfate] &= [total\ sulfate] - [large\ sulfate].
 \end{aligned}
 \tag{Eqs. 2}$$

Identical formulas, with changes in component names, are used for nitrate and organics. In effect, these formulas conclude that low concentrations of these components are mainly in the form of “small” particles with their own extinction efficiency and  $f_s(RH)$ , while high concentrations (approaching  $20\ \mu g/m^3$ ) are mainly in the form of “large” particles with a different extinction efficiency and  $f_l(RH)$ . The scaling factor  $[total\ sulfate]/20$  sets the fraction of total sulfate that is small.

<sup>2</sup> Square brackets denote concentrations.

The sea salt concentration is taken to be  $1.7 \cdot [\text{Cl}^-]$  or, if chloride ion measurements are not available, the chlorine concentration can be used in its place. Site specific Rayleigh scattering values have been calculated for all IMPROVE sites.<sup>3</sup> Nitrogen dioxide concentrations are not measured at IMPROVE sites and the concentrations are sufficiently low that the  $\text{NO}_2$  term is very small and can typically be ignored in rural areas.

In order for CALPOST to calculate CALPUFF-modeled source impacts on visibility using the new IMPROVE algorithm, CALPOST would have to be extensively reprogrammed. As an alternative, such a calculation could be done “off line” by adding another layer of post processing after CALPOST. To this end, I have developed a processor, in the form of an Excel workbook, that takes the CALPOST “Ranked Daily Visibility Change: Modeled Extinction by Species” output table based on default annual average natural conditions concentrations and creates an equivalent table of results based on the new algorithm.

The following describes the science behind the processor (which we’ll call the CALPOST-IMPROVE Processor) and provides instructions for using it.

### Concepts

In addition to the mechanical changes imposed by all the new terms in the new IMPROVE formula, applying the new algorithm also requires some conceptual changes. The biggest of these is that the extinction efficiencies of sulfates, nitrates, and organics now depend on the concentrations of those species. The practical implication of this is that extinction is no longer linearly additive. You cannot take a background level of extinction and add to it CALPOST’s calculation of extinction caused by the particulate matter coming from a source, because when the two aerosols mix in the atmosphere their combined mass concentration results in increases in the extinction efficiencies of both the background and the source contribution. This means that combining background particulate matter with the particulate matter from a source gives an extinction result that is greater than the sum of the two separated extinctions.

With the nonlinear behavior resulting from applying the new IMPROVE algorithm, the extinction impact of the source (i.e., the increase in extinction resulting from introducing source emissions into the atmosphere) is the sum of three parts:

(Part A) The source impact calculated by the new IMPROVE algorithm using the CALPOST outputs for a plume in isolation;

(Part B) An increase in that source impact because the extinction efficiency increases when the source’s aerosol combines with the background aerosol; and correspondingly,

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<sup>3</sup> *Revised IMPROVE Algorithm for estimating Light Extinction from Particle Speciation Data.* Report to IMPROVE Steering Committee, November 2005.

(Part C) An increase in the extinction of the background aerosol because of that same mixing.

The total new extinction is the sum of the above three components plus the original background extinction. The original background extinction is just that calculated by the new IMPROVE algorithm from background concentrations of the various components, without any consideration of the effects of the plume.

For example, assume that the sulfate concentration attributed to a source is  $[S_S]$  and the sulfate in the natural background is  $[S_N]$ , for a total ambient sulfate concentration of  $[S_T]$ . According to Equations 1 and 2, the total extinction due to sulfate for this combination is

$$b_{ext}(sulfate) = 2.2 \cdot f_S(RH) \cdot [small\ sulfate] + 4.8 \cdot f_L(RH) \cdot [large\ sulfate], \quad (\text{Eq. 3})$$

where

$$\begin{aligned} [large\ sulfate_T] &= \{[S_T]/20\} \cdot [S_T] \text{ if } [S_T] < 20 \mu g^3 \\ [large\ sulfate_T] &= [S_T] \text{ if } [S_T] \geq 20 \mu g/m^3 \\ [small\ sulfate_T] &= [S_T] - [large\ sulfate_T], \end{aligned} \quad (\text{Eqs. 4})$$

and the subscript T denotes total sulfate

For the portion of the extinction due directly to the source emissions (Parts A and B, above), we have, however

$$\begin{aligned} [large\ sulfate_S] &= \{[S_T]/20\} \cdot [S_S] \text{ if } [S_T] < 20 \mu g^3 \\ [large\ sulfate_S] &= [S_S] \text{ if } [S_T] \geq 20 \mu g/m^3 \\ [small\ sulfate_S] &= [S_S] - [large\ sulfate_S], \end{aligned} \quad (\text{Eqs. 5})$$

because we are now partitioning  $[S_S]$  into large and small sulfate, where the size of the fraction depends on the concentration of all of the sulfate,  $[S_T]$ .

Similarly, for the portion of the extinction due to the background (the original background  $S_N$  plus the enhancement described under Part C, above), we have

$$\begin{aligned} [large\ sulfate_N] &= \{[S_T]/20\} \cdot [S_N] \text{ if } [S_T] < 20 \mu g^3 \\ [large\ sulfate_N] &= [S_N] \text{ if } [S_T] \geq 20 \mu g/m^3 \\ [small\ sulfate_N] &= [S_N] - [large\ sulfate_N], \end{aligned} \quad (\text{Eqs. 6})$$

As a check, we see that adding the corresponding formulas in Equations 5 and 6 gives the results in Equations 4.

Finally, for the original background, where there is no source impact, the corresponding formulas are

$$\begin{aligned} [large\ sulfate_N] &= \{[S_N]/20\} \cdot [S_N] \text{ if } [S_N] < 20 \mu g^3 \\ [large\ sulfate_N] &= [S_N] \text{ if } [S_N] \geq 20 \mu g/m^3 \\ [small\ sulfate_N] &= [S_N] - [large\ sulfate_N], \end{aligned} \quad (\text{Eqs. 7})$$

As usual, the fractional change in extinction is then calculated as

$$(b_{ext,T} - b_{ext,N})/b_{ext,N} \quad (\text{Eq. 8})$$

which can also be expressed in deciviews.

These formulas are used in the CALPOST-IMPROVE Processor. Similar formulas apply for nitrates and organics. There is no nonlinearity in the remaining terms in Equation 1.

### Description of Processor

The CALPOST-IMPROVE Processor is a Microsoft Excel workbook that consists of four worksheets:

1. Input/Output – The output table from CALPOST is imported to here and user entries are made for the Rayleigh scattering coefficient and, if desired, for a sea salt concentration at the Class I area of interest. A revised table, with extinction based on the new IMPROVE algorithm is then presented on the same page. This is the only page on which user input takes place, and the results of the calculations appear on this page.
2. Calculations -- The calculations themselves are all done on this worksheet. There is no user input to this page. The variables are explained on the worksheet itself, so the user can find intermediate values if so inclined. Since NO<sub>2</sub> concentrations are not measured at IMPROVE sites and the NO<sub>2</sub> absorption in rural areas is expected to be small, NO<sub>2</sub> has been omitted from these calculations.
3. F(RH) – This worksheet tabulates the traditional IMPROVE f(RH) against RH, and then also lists values for the three new humidity growth functions, f<sub>S</sub>(RH), f<sub>L</sub>(RH), and f<sub>SS</sub>(RH). It serves as a lookup table for the “Calculations” worksheet .
4. Rayleigh & Sea Salt – This page tabulates the IMPROVE-recommended Rayleigh scattering coefficients for all VISTAS Class I areas and for Class I areas in adjacent states. It also lists the average sea salt concentrations for the same

locations, based on chloride or chlorine measurements by IMPROVE monitors between 2000 and 2004. This sheet just provides information for the user; it is not linked to the rest of the workbook. The user can obtain Rayleigh and sea salt numbers for the Class I area of interest from this table and then manually enter them in the designated spaces in worksheet 1.

### Instructions for Using the CALPOST-IMPROVE Processor

Step 1. Begin by opening the output (.LST) file from CALPOST in a text editor or word processing program.<sup>4</sup> In the second half of the file, locate the table “Ranked Daily Visibility Change” with the subheading “Modeled Extinction by Species”.<sup>5</sup>

Step 2. Copy this table and paste it onto a new page. Save it as a text (.txt) file, not as a formatted (e.g., MS Word .doc or .rtf) file. The final table should contain only the column headings and the data. Delete all other captions, any additional data summaries at the end, and blank lines before or after the table. The processor can handle a maximum of 22 lines of data (i.e., the highest rank in the last, unlabeled, column should be 22) plus a row of column captions. Delete any data that exceed this limit. The result should look like the example in Figure 1.

Step 3. Open the CALPOST-IMPROVE Processor with Microsoft Excel. Save the open file under a new name so that the original empty processor will remain available for future use. The front worksheet, labeled “Input/Output” looks like Figure 2. There is a large empty box, surrounded by double lines, into which the table created above will be imported, as described below.<sup>6</sup> Two smaller boxes provide for user input of the Rayleigh scattering coefficient and, optionally, sea salt concentration for the Class I area, as described below. Results of the new IMPROVE algorithm calculations appear in blue in the lower half of the worksheet and some additional results, that are also useful for quality control, appear in green to the right of the large box. At the moment, many results cells will display nonsensical numbers and error messages, such as shown in Figure 2.

Step 4. Select the upper left cell (A7) in the large box. On the Excel menu bar, go to *Data>Get External Data* and click on *Import Text File*. (If the large box is not empty, click on *Edit Text Import* instead.) Select the file that contains the table created in Step 2 and click on the *Get Data* button. Go through the Text Import Wizard steps, checking that all values appear correctly in separate columns. (The label “COORDINATES (km)” will be split over two columns; this is OK.) When everything appears in order, click *Finish*.

<sup>4</sup> The background concentrations that were entered into CALPOST must be the EPA-prescribed default annual average natural conditions concentrations for the East. The processor will not give correct answers if other concentrations were used in CALPOST.

<sup>5</sup> For future reference, this may also be a good time to locate the table with the same title but with the subtitle “% of Modeled Extinction by Species”, which appears later in the output file.

<sup>6</sup> If the workbook has already been used, the boxes may not be empty. This does not matter.

YEAR	DAY	HR	RECEPTOR	COORDINATES (km)			TYPE	BEXT(Model)			BEXT(BKG)	
BEXT(Total)	%CHANGE	F(RH)	bxSO4	bxNO3	bxOC	bxEC	bxPMC	bxPMF				
2002	175	0	1027	1479.069	24.683	D	5.495	21.650		27.145		
25.38	3.500	5.401	0.045	0.042	0.002	0.001	0.004	1				
2002	172	0	1021	1479.244	23.778	D	4.923	21.650		26.573		
22.74	3.500	4.475	0.404	0.038	0.001	0.001	0.004	2				
2002	284	0	1045	1484.348	27.580	D	3.150	21.470		24.620		
14.67	3.300	2.684	0.428	0.033	0.001	0.001	0.003	3				
2002	353	0	1026	1482.762	24.457	D	2.594	21.290		23.884		
12.18	3.100	2.017	0.557	0.018	0.001	0.000	0.002	4				
2002	283	0	1026	1482.762	24.457	D	2.502	21.470		23.972		
11.65	3.300	2.269	0.201	0.028	0.001	0.001	0.003	5				
2002	195	0	1045	1484.348	27.580	D	2.011	21.830		23.841		
9.21	3.700	1.963	0.031	0.015	0.001	0.000	0.001	6				
2002	20	0	1117	1486.636	34.592	D	1.872	21.200		23.072		
8.83	3.000	1.542	0.320	0.009	0.000	0.000	0.001	7				
2002	173	0	1128	1479.259	35.042	D	1.649	21.650		23.299		
7.62	3.500	1.625	0.012	0.010	0.000	0.000	0.001	8				
2002	234	0	1021	1479.244	23.778	D	1.524	22.190		23.714		
6.87	4.100	1.482	0.029	0.011	0.000	0.000	0.001	9				
2002	298	0	1021	1479.244	23.778	D	1.459	21.470		22.929		
6.80	3.300	1.284	0.160	0.014	0.001	0.000	0.001	10				
2002	299	0	1021	1479.244	23.778	D	1.436	21.470		22.906		
6.69	3.300	1.281	0.140	0.013	0.000	0.000	0.001	11				
2002	275	0	1026	1482.762	24.457	D	1.270	21.470		22.740		
5.92	3.300	1.202	0.058	0.009	0.000	0.000	0.001	12				
2002	263	0	1045	1484.348	27.580	D	1.237	22.100		23.337		
5.60	4.000	1.223	0.008	0.005	0.000	0.000	0.001	13				
2002	252	0	1026	1482.762	24.457	D	1.189	22.100		23.289		
5.38	4.000	1.166	0.013	0.009	0.000	0.000	0.001	14				
2002	285	0	1021	1479.244	23.778	D	0.992	21.470		22.462		
4.62	3.300	0.813	0.179	0.001	0.000	0.000	0.000	15				
2002	161	0	1026	1482.762	24.457	D	0.873	21.650		22.523		
4.03	3.500	0.842	0.020	0.009	0.000	0.000	0.001	16				
2002	150	0	1026	1482.762	24.457	D	0.857	21.380		22.237		
4.01	3.200	0.822	0.026	0.007	0.000	0.000	0.001	17				
2002	340	0	1140	1481.017	37.258	D	0.817	21.290		22.107		
3.84	3.100	0.663	0.153	0.001	0.000	0.000	0.000	18				
2002	151	0	1117	1486.636	34.592	D	0.745	21.380		22.125		
3.49	3.200	0.704	0.033	0.007	0.000	0.000	0.001	19				
2002	160	0	1021	1479.244	23.778	D	0.735	21.650		22.385		
3.40	3.500	0.710	0.014	0.010	0.000	0.000	0.001	20				
2002	346	0	1021	1479.244	23.778	D	0.703	21.290		21.993		
3.30	3.100	0.620	0.080	0.002	0.000	0.000	0.000	21				
2002	247	0	1021	1479.244	23.778	D	0.661	22.100		22.761		
2.99	4.000	0.654	0.004	0.002	0.000	0.000	0.000	22				

**Figure 1. Example of CALPOST Output Table, in Proper Format for Importing into the CALPOST-IMPROVE Processor.**

Step 5.<sup>7</sup> The “Import Data” window will appear, with cell A7 indicated as the location at which data will be entered. Click on the *Properties* button. In the window that appears, select “Overwrite existing cells with new data, clear unused cells” and uncheck “Adjust column width”, then click on *OK*. Now click on the *OK* button in the “Import Data” window.

Step 6. Assuming that your Excel application is set up to automatically recalculate whenever any entries are changed, you should now have filled the cells in the large box

<sup>7</sup> If the processor already had data in it and *Edit Text Import* was clicked in Step 4, then the “Import Data” window will not appear and Step 5 can be skipped.



on the first worksheet, numbers should have appeared in the green columns to the right, and some numbers will have appeared in the output table in blue on the lower half of the worksheet. If the data import worked properly, none of the imported data should have spilled out of the large box. Check that all the column captions in bold outside the large box are now duplicated on the first line in the box. (There won't be a caption for Rank.)

Step 7. As a further check on whether everything is correct so far, the dv information in the three columns to the right of the large box should be the same as that in the second CALPOST table "Ranked Daily Visibility Change: % of Modeled Extinction by Species", which was mentioned in Footnote 1.

Step 8. Fill in the small box after red instruction 3 with the Rayleigh scattering coefficient for the Class I area of interest. Also, if you wish, fill in the other small box, the one after red instruction 4, with the annual average sea salt concentration. (The sea salt box may be left blank, but the Rayleigh scattering coefficient box must be filled in.) To help with filling in these two boxes, the fourth worksheet, "Rayleigh & Sea Salt", provides IMPROVE-calculated values of the Rayleigh coefficients for Class I areas in the VISTAS region and in adjacent states. Also, average sea salt concentrations for 2000-2004, calculated in accordance with the new IMPROVE procedures, can be found there. At this point the "Input/Output" worksheet should look something like Figure 3, with all columns filled with meaningful data.

Step 9. The new IMPROVE algorithm output table at the bottom of the page can be compared with the original CALPOST table at the top of the page. All of the columns in both tables show exactly the same variables, except that the F(RH) column in the top table is replaced by just the RH in the lower table (since the new procedure has three different f(RH) functions). Although the events are in the same order in both tables, note that their rankings may have changed, as in New Ranks 12 vs. 13 and 19 vs. 20 in Figure 3.

For those who are interested in more detail, values of the three f(RH) functions appear in columns L through N on the second, "Calculations" spreadsheet. The extinction impact of the source, including enhancement of the extinction efficiencies for sulfates, nitrates, and organics due to the Part B that was described above, appears in columns U through AA. Extinction due to the annual average natural background appears in Columns AH through AL; natural background extinctions for those components that are enhanced by greater total mass concentrations (Part C) appear in columns AS through AV.

CALPOST Recalculation with New IMPROVE Algorithm																					
----- INPUT from CALPOST (based on old IMPROVE algorithm) -----																					
1. At cell A7, import "Ranked Daily Visibility Change" (bext) table, including column headings, from CALPOST (22 days, max)																	2. Check calculated values below against CALPOST's "Ranked Daily Visibility Change" (dv) table				
YEAR DAY	HR	RECEPTOR	COORDINATES (km)		TYPE	BEXT(Model)	BEXT(BKG)	BEXT(Total)	%CHANGE	F(RH)	bsSO4	bsNO3	bsOC	bsEC	bsPMC	bsPMF	Rank	dv(total)	dv(bkg)	Δdv	
2002	175	0	1027	1479.069	24.683	D	5.495	21.65	27.145	25.38	3.5	5.401	0.045	0.042	0.002	0.001	0.004	1	9.99	7.72	2.26
2002	172	0	1021	1479.244	23.778	D	4.923	21.65	26.573	22.74	3.5	4.475	0.404	0.038	0.001	0.001	0.004	2	9.77	7.72	2.05
2002	284	0	1045	1484.348	27.58	D	3.15	21.47	24.62	14.67	3.3	2.684	0.428	0.033	0.001	0.001	0.003	3	9.01	7.64	1.37
2002	353	0	1026	1482.762	24.457	D	2.594	21.29	23.884	12.18	3.1	2.017	0.557	0.018	0.001	0	0.002	4	8.71	7.56	1.15
2002	283	0	1026	1482.762	24.457	D	2.502	21.47	23.972	11.65	3.3	2.269	0.201	0.028	0.001	0.001	0.003	5	8.74	7.64	1.10
2002	195	0	1045	1484.348	27.58	D	2.011	21.93	23.941	9.21	3.7	1.963	0.031	0.015	0.001	0	0.001	6	8.69	7.81	0.88
2002	20	0	1117	1486.636	34.592	D	1.872	21.2	23.072	8.83	3	1.542	0.32	0.009	0	0	0.001	7	8.36	7.51	0.85
2002	173	0	1128	1479.259	35.042	D	1.649	21.65	23.299	7.62	3.5	1.625	0.012	0.01	0	0	0.001	8	8.46	7.72	0.73
2002	234	0	1021	1479.244	23.778	D	1.524	22.19	23.714	6.87	4.1	1.482	0.029	0.011	0	0	0.001	9	8.63	7.97	0.66
2002	298	0	1021	1479.244	23.778	D	1.459	21.47	22.929	6.8	3.3	1.284	0.16	0.014	0.001	0	0.001	10	8.30	7.64	0.66
2002	299	0	1021	1479.244	23.778	D	1.436	21.47	22.906	6.59	3.3	1.281	0.14	0.013	0	0	0.001	11	8.29	7.64	0.65
2002	275	0	1026	1482.762	24.457	D	1.27	21.47	22.74	5.92	3.3	1.202	0.058	0.009	0	0	0.001	12	8.22	7.64	0.57
2002	263	0	1045	1484.348	27.58	D	1.237	22.1	23.337	5.6	4	1.223	0.008	0.005	0	0	0.001	13	8.47	7.93	0.54
2002	252	0	1026	1482.762	24.457	D	1.189	22.1	23.289	5.38	4	1.166	0.013	0.009	0	0	0.001	14	8.45	7.93	0.52
2002	285	0	1021	1479.244	23.778	D	0.992	21.47	22.462	4.62	3.3	0.813	0.179	0.001	0	0	0	15	8.09	7.64	0.45
2002	161	0	1026	1482.762	24.457	D	0.873	21.65	22.523	4.03	3.5	0.842	0.02	0.009	0	0	0.001	16	8.12	7.72	0.40
2002	150	0	1026	1482.762	24.457	D	0.857	21.38	22.237	4.01	3.2	0.822	0.026	0.007	0	0	0.001	17	7.99	7.60	0.39
2002	340	0	1140	1481.017	37.258	D	0.817	21.29	22.107	3.84	3.1	0.663	0.153	0.001	0	0	0	18	7.93	7.56	0.38
2002	151	0	1117	1486.636	34.592	D	0.745	21.38	22.125	3.49	3.2	0.704	0.033	0.007	0	0	0.001	19	7.94	7.60	0.34
2002	160	0	1021	1479.244	23.778	D	0.735	21.65	22.385	3.4	3.5	0.71	0.014	0.01	0	0	0.001	20	8.06	7.72	0.33
2002	346	0	1021	1479.244	23.778	D	0.703	21.29	21.993	3.3	3.1	0.62	0.08	0.002	0	0	0	21	7.88	7.56	0.32
2002	247	0	1021	1479.244	23.778	D	0.661	22.1	22.761	2.99	4	0.654	0.004	0.002	0	0	0	22	8.22	7.93	0.29

3. Enter value of site-specific Rayleigh scattering coefficient, from "Rayleigh & Sea Salt" worksheet	11
4. (Optional) Insert annual average sea salt concentration, from "Rayleigh & Sea Salt" worksheet. Leave blank if not used.	0.02

----- OUTPUT (based on new IMPROVE algorithm) -----																					
YEAR DAY	HR	RECEPTOR	COORDINATES (km)		TYPE	BEXT(Source)	BEXT(BKG)	BEXT(Total)	%CHANGE	RH(%)	bsSO4	bsNO3	bsOC	bsEC	bsPMC	bsPMF	New Rank	dv(total)	dv(bkg)	Δdv	
2002	175	0	1027	1479.069	24.683	D	4.441	22.04	26.521	20.32	86	4.363	0.039	0.033	0.002	0.001	0.004	1	9.75	7.90	1.85
2002	172	0	1021	1479.244	23.778	D	3.989	22.04	26.063	18.24	86	3.604	0.349	0.029	0.001	0.001	0.004	2	9.58	7.90	1.68
2002	284	0	1045	1484.348	27.58	D	2.464	21.78	24.264	11.40	84	2.076	0.357	0.026	0.001	0.001	0.003	3	8.86	7.78	1.08
2002	353	0	1026	1482.762	24.457	D	2.000	21.57	23.586	9.35	82	1.528	0.455	0.014	0.001	0	0.002	4	8.58	7.69	0.89
2002	283	0	1026	1482.762	24.457	D	1.947	21.78	23.744	9.02	84	1.753	0.167	0.022	0.001	0.001	0.003	5	8.65	7.78	0.86
2002	195	0	1045	1484.348	27.58	D	1.609	22.21	23.837	7.30	87	1.569	0.027	0.012	0.001	0	0.001	6	8.69	7.98	0.70
2002	20	0	1117	1486.636	34.592	D	1.427	21.48	22.916	6.70	81	1.16	0.26	0.007	0	0	0.001	7	8.29	7.64	0.65
2002	173	0	1128	1479.259	35.042	D	1.316	22.04	23.370	6.02	86	1.297	0.01	0.008	0	0	0.001	8	8.49	7.90	0.58
2002	234	0	1021	1479.244	23.778	D	1.249	22.64	23.896	5.56	89	1.213	0.026	0.009	0	0	0.001	9	8.71	8.17	0.54
2002	298	0	1021	1479.244	23.778	D	1.134	21.78	22.924	5.25	84	0.989	0.133	0.011	0.001	0	0.001	10	8.30	7.78	0.51
2002	299	0	1021	1479.244	23.778	D	1.114	21.78	22.903	5.16	84	0.986	0.117	0.01	0	0	0.001	11	8.29	7.78	0.50
2002	275	0	1026	1482.762	24.457	D	0.981	21.78	22.770	4.54	84	0.925	0.048	0.007	0	0	0.001	13	8.23	7.78	0.44
2002	263	0	1045	1484.348	27.58	D	1.038	22.64	23.684	4.62	89	1.026	0.007	0.004	0	0	0.001	12	8.62	8.17	0.45
2002	252	0	1026	1482.762	24.457	D	0.998	22.64	23.643	4.44	89	0.978	0.012	0.007	0	0	0.001	14	8.60	8.17	0.43
2002	285	0	1021	1479.244	23.778	D	0.775	21.78	22.561	3.58	84	0.625	0.149	0E-04	0	0	0	15	8.14	7.78	0.35
2002	161	0	1026	1482.762	24.457	D	0.696	22.04	22.744	3.18	86	0.67	0.017	0.007	0	0	0.001	16	8.22	7.90	0.31
2002	150	0	1026	1482.762	24.457	D	0.651	21.67	22.322	3.03	83	0.623	0.021	0.005	0	0	0.001	17	8.03	7.73	0.30
2002	340	0	1140	1481.017	37.258	D	0.625	21.57	22.200	2.92	82	0.5	0.125	0E-04	0	0	0	18	7.98	7.69	0.29
2002	151	0	1117	1486.636	34.592	D	0.567	21.67	22.237	2.64	83	0.533	0.027	0.005	0	0	0.001	20	7.99	7.73	0.26
2002	160	0	1021	1479.244	23.778	D	0.586	22.04	22.634	2.68	86	0.565	0.012	0.008	0	0	0.001	19	8.17	7.90	0.26
2002	346	0	1021	1479.244	23.778	D	0.534	21.57	22.109	2.50	82	0.467	0.065	0.002	0	0	0	21	7.93	7.69	0.25
2002	247	0	1021	1479.244	23.778	D	0.553	22.64	23.195	2.46	89	0.548	0.004	0.002	0	0	0	22	8.41	8.17	0.24

Figure 3. Example of Appearance of Finished Input/Output Worksheet.

## Appendix Details of Calculation Approach

As an example of the calculation steps, assume that the sulfate concentration resulting from emissions from a source is  $[S_E]$  and the sulfate in the undisturbed natural background is  $[S_N]$ , for a total ambient sulfate concentration of  $[S_T]$ . According to Equations 1 and 2 in the main body of this document, the total extinction due to sulfate for this combination is

$$b_{ext}(sulfate) = 2.2 \cdot f_s(RH) \cdot [small\ sulfate] + 4.8 \cdot f_L(RH) \cdot [large\ sulfate], \quad (\text{Eq. A-1})$$

where

$$\begin{aligned} [large\ sulfate_T] &= \{[S_T]/20\} \cdot [S_T] \text{ if } [S_T] < 20 \mu\text{g}^3 \\ [large\ sulfate_T] &= [S_T] \text{ if } [S_T] \geq 20 \mu\text{g}/\text{m}^3 \\ [small\ sulfate_T] &= [S_T] - [large\ sulfate_T], \end{aligned} \quad (\text{Eqs. A-2})$$

and the subscript T denotes total sulfate

For the original background, where there is no source impact, the corresponding formulas for the terms in Equations A-2 are

$$\begin{aligned} [large\ sulfate_N] &= \{[S_N]/20\} \cdot [S_N] \text{ if } [S_N] < 20 \mu\text{g}^3 \\ [large\ sulfate_N] &= [S_N] \text{ if } [S_N] \geq 20 \mu\text{g}/\text{m}^3 \\ [small\ sulfate_N] &= [S_N] - [large\ sulfate_N], \end{aligned} \quad (\text{Eqs. A-3})$$

where the subscript N denotes natural sulfate.

Similar calculations need to be carried out for nitrates. Contributions of the other particulate components are linear and can just be calculated according to Equation 1.

If the impact due to  $\text{NO}_2$  is also to be considered, then the source impact due to this component is, according to Equation 1,

$$b_{ext}(\text{NO}_2) = 0.33 \cdot [\text{NO}_2], \quad (\text{Eq. A-4})$$

where  $[\text{NO}_2]$  is in ppb. It is reasonable to assume that the ambient  $\text{NO}_2$  concentrations under natural conditions would be so small as to cause negligible light absorption, so the corresponding term is not needed in the natural conditions calculation.

The contributions due to the various components are summed together as in Equation 1 to obtain the total extinction  $b_{ext,T}$  and the natural background extinction  $b_{ext,N}$ . The

fractional change in extinction is then calculated as the difference, normalized by the natural background extinction

$$(b_{ext,T} - b_{ext,N})/b_{ext,N} \quad (\text{Eq. A-5})$$

a result that can also be expressed in deciviews.

These formulas are used in the CALPOST-IMPROVE Processor. Similar formulas apply for nitrates and organics. There is no nonlinearity in the remaining terms in Equation 1.

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