

BEST AVAILABLE RETROFIT TECHNOLOGY DETERMINATION
DOMTAR INDUSTRIES INC. ■ ASHDOWN MILL (AFIN 41-00002)

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Domtar Industries Inc. (Domtar) owns and operates a kraft paper mill located at 285 Highway 71 South in Ashdown, Arkansas (the Ashdown Mill). The Ashdown Mill is a major source as defined in Arkansas Pollution Control and Ecology Commission (ADP&E) Regulation 26, *Regulations of the Arkansas Operating Air Permit Program*, and currently operates under the authority of Arkansas Department of Environmental Quality (ADEQ) Operating Air Permit 0287-AOP-R6, which was issued on July 12, 2006.

The ADEQ has determined that the Ashdown Mill operates two emission units – No. 1 and No. 2 Power Boilers – that are eligible to be regulated under the Best Available Retrofit Technology (BART) provisions of the U.S. Environmental Protection Agency’s (EPA) Regional Haze Rule in Title 40 of the Code of Federal Regulations (40 CFR) Part 51. BART is the primary mechanism identified for regulating haze-forming pollutants from stationary sources for the first implementation period under the Regional Haze Rule. The ADEQ has also determined, based on air dispersion modeling, that emissions from the Ashdown Mill BART-eligible source contributes to visibility impairment at a federally protected Class I area. Therefore, Domtar has prepared this report to document its BART determination in accordance with *Appendix Y to Part 51 – Guidelines for BART Determinations Under the Regional Haze Rule* (the BART Guidelines).

An overview of the Regional Haze Rule and BART Guidelines is provided in Section 1.1. Descriptions of the Ashdown Mill’s BART-eligible emission units are included in Section 2. Section 3 describes the BART applicability analysis completed by the ADEQ for the Ashdown Mill BART-eligible source. Domtar’s BART determination analysis is included in Section 4.

1.1 OVERVIEW OF REGIONAL HAZE RULE AND BART GUIDELINES

The Regional Haze Rule requires that major sources of visibility-affecting pollutants belonging to one or more of 26 specific industrial source categories evaluate BART if the source was in existence before August 7, 1977 and began operation after August 7, 1962. “Major sources of visibility-affecting pollutants” are sources that have the potential to emit 250 tons per year (tpy) or more of any of the following: oxides of nitrogen (NO_x), sulfur dioxide (SO₂), or particulate matter (PM).¹ The “BART-eligible source” is the collection of sources at a facility meeting the applicability criteria.

1.1.1 BART APPLICABILITY

In the BART applicability analysis, a BART-eligible source is determined to be subject to BART if it causes or contributes to visibility impairment at one or more of the 156 federally protected Class I areas. Per the U.S. EPA’s BART Modeling Guidance, “an individual source will be considered to ‘cause visibility impairment’ if the emissions

¹ As allowed in the BART Guidelines, the ADEQ has determined that volatile organic compounds (VOC) and ammonia are not visibility-affecting pollutants for the purposes of BART analyses.

results in a change (delta Δ) in deciviews (dv)² that is greater than or equal to 1.0 deciview on the visibility in a Class I area...if the emissions from a source results in a change in visibility that is greater than or equal to 0.5 dv in a Class I area the source will be considered to ‘contribute to visibility impairment.’” To determine whether a BART-eligible facility causes or contributes to visibility impairment, the U.S. EPA guidance requires the use of an air quality model, specifically recommending the CALPUFF modeling system, to quantify the impacts attributable to a single BART-eligible source. Because contribution to visibility impairment is sufficient cause to require a BART determination, 0.5 dv is the critical threshold for assessment of BART applicability.

Regional haze is quantified using the light extinction coefficient (b_{ext}), which is expressed in terms of the haze index (HI) expressed in dv. The HI is calculated as shown in the following equation.

$$HI = 10 \ln \left(\frac{b_{ext}}{10} \right)$$

The impact of a BART-eligible source is determined by comparing the HI attributable to a source to estimated natural background conditions. That is, a single-source visibility impact is measured as the change in light extinction versus background, and is referred to as Δdv . The background extinction coefficient is affected by various chemical species and the Rayleigh scattering phenomenon and can be calculated as shown in the following equation.

$$b_{ext,background} (Mm^{-1}) = b_{SO_4} + b_{NO_3} + b_{OC} + b_{Soil} + b_{Coarse} + b_{EC} + b_{Ray}$$

where:

$$b_{SO_4} = 3[(NH_4)_2SO_4]f(RH)$$

$$b_{NO_3} = 3[NH_4NO_3]f(RH)$$

$$b_{OC} = 4[OC]$$

$$b_{Soil} = 1[Soil]$$

$$b_{Coarse} = 0.6[Coarse\ Mass]$$

$$b_{EC} = 10[EC]$$

$$b_{Ray} = \text{Rayleigh Scattering (10 Mm}^{-1} \text{ by default)}$$

$$f(RH) = \text{Relative Humidity Function}$$

$$[] = \text{Concentration in } \mu\text{g}/\text{m}^3$$

$[(NH_4)_2SO_4]$ denotes the ammonium sulfate concentration

$[NH_4NO_3]$ denotes the ammonium nitrate concentration

$[OC]$ denotes the concentration of organic carbon

$[Soil]$ denotes the concentration of fine soils

$[Coarse\ Mass]$ denotes the concentration of coarse dusts

$[EC]$ denotes the concentration of elemental carbon

Rayleigh Scattering is scattering due to air molecules

Values for the parameters listed above specific to the natural background conditions at each Class I area are provided on an annual-average basis in the U.S. EPA’s *Guidance for Estimating Natural Visibility Conditions under the Regional Haze Rule*.³

² The deciview (dv) is a metric used to represent normalized light extinction attributable to visibility-affecting pollutants.

³ U.S. EPA, *Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule*, Table 2-1, Attachment A, September 2003, EPA-454/B-03-005.

Particulate species that affect visibility are emitted from anthropogenic (human-caused) sources and include coarse particulate matter (PMC), fine particulate matter (PMF), and elemental carbon (EC) as well as precursors to secondary organic aerosols (SOA) and fine particulate matter such as SO₂ and NO_x. The extinction coefficient due to emissions of visibility-affecting pollutants from a single BART-eligible source is calculated according to the following equation.

$$b_{ext,source}(\text{Mm}^{-1}) = b_{SO_4} + b_{NO_3} + b_{SOA} + b_{PMF} + b_{PMC} + b_{EC}$$

where:

$$b_{SO_4} = 3[(\text{NH}_4)_2\text{SO}_4]f(RH)$$

$$b_{NO_3} = 3[\text{NH}_4\text{NO}_3]f(RH)$$

$$b_{SOA} = 4[\text{SOA}]$$

$$b_{PMF} = 1[\text{PMF}]$$

$$b_{PMC} = 0.6[\text{PMC}]$$

$$b_{EC} = 10[\text{EC}]$$

$$f(RH) = \text{Relative Humidity Function}$$

$$[] = \text{Concentration in } \mu\text{g}/\text{m}^3$$

$[(\text{NH}_4)_2\text{SO}_4]$ denotes the ammonium sulfate concentration

$[\text{NH}_4\text{NO}_3]$ denotes the ammonium nitrate concentration

$[\text{SOA}]$ denotes the concentration of secondary organic aerosols

$[\text{PMF}]$ denotes the concentration of fine PM

$[\text{PMC}]$ denotes the concentration of coarse PM

$[\text{EC}]$ denotes the concentration of elemental carbon

1.1.1.1 CALPUFF MODELING ANALYSES

As stated above, the BART Guidelines recommend using the CALPUFF modeling system to compute the 24-hour average visibility impairment attributable to a BART-eligible source to assess whether the 0.5 Δ dv contribution threshold is exceeded, and if so, the frequency, duration, and magnitude of any exceedance events. CALPUFF is a refined air quality modeling system that is capable of simulating the dispersion, chemical transformation, and long-range transport of multiple visibility-affecting pollutant emissions and is therefore preferred for BART applicability and determination analyses.

1.1.2 BART DETERMINATION

BART-eligible sources that are found to cause or contribute to visibility impairment at a Class I area are required to make a BART determination. The BART Guidelines define BART as follows:

BART means an emission limitation based on the degree of reduction achievable through the application of the best system of continuous emission reduction for each pollutant which is emitted by...[a BART-eligible source]. The emission limitation must be established, on a case-by-case basis, taking into consideration the technology available, the costs of compliance, the energy and non-air quality environmental impacts of compliance, any pollution control equipment in use or in existence at the source, the remaining useful life

of the source, and the degree of improvement in visibility which may reasonably be anticipated to result from the use of such technology. The BART analysis identifies the best system of continuous emission reduction taking into account:

- (1) The available retrofit control options,*
- (2) Any pollution control equipment in use at the source (which affects the availability of options and their impacts),*
- (3) The costs of compliance with control options,*
- (4) The remaining useful life of the facility,*
- (5) The energy and non-air quality environmental impacts of control options[, and]*
- (6) The visibility impacts analysis.*

2. BART-ELIGIBLE EMISSION UNITS

The BART Guidelines define the following three steps for determining which emission units at a facility are BART-eligible:

1. Identify the emission units in the BART source categories,
2. Identify the start-up dates of those units, and
3. Compare potential emissions to the 250 ton/yr cutoff.

“Fossil-fuel boilers of more than 250 million BTUs per hour heat input” are one of the listed BART source categories. The Ashdown Mill’s No. 1 and No. 2 Power Boilers are each greater than 250 million British thermal units per hour (MMBtu/hr), were in existence on August 7, 1977, began operation after August 7, 1962, and each have potential emissions greater than 250 tpy of PM, NO_x, or SO₂; therefore, these units make up the Ashdown Mill’s BART-eligible source. A summary of the BART eligibility criteria for each emission unit is provided in Table 2-1.

TABLE 2-1. SUMMARY OF BART-ELIGIBLE EMISSION UNITS

Emission Unit	Source Number	BART Source Category	Year of Completion of Construction or Reconstruction	Potential SO ₂ Emissions (tpy)	Potential NO _x Emissions (tpy)	Potential PM/PM ₁₀ Emissions (tpy)
No. 1 Power Boiler	SN-03	Boiler ^a	1968	214.0	1,084.1	1,502.3
No. 2 Power Boiler	SN-05	Boiler ^a	1976	4,305.5	2,514.1	359.2

^a Fossil-fuel boilers of more than 250 million BTUs per hour heat input.

Detailed descriptions of each unit are provided in the sub-sections below.

2.1 NO. 1 POWER BOILER

The No. 1 Power Boiler (SN-03), also known as the Bark Boiler, was installed in 1968. It has a heat input rating of 580 MMBtu/hr and an average steam generation rate of approximately 120,000 pounds per hour (lb/hr). It combusts primarily bark (approximately 75 percent of the heat input is supplied by bark), but is also permitted to burn bark and wood chips used to absorb oil spills, wood waste, recycled sanitary products composed of cellulose and polypropylene, pelletized paper fuel (PPF), tire-derived fuel (TDF), municipal yard waste, No. 6 fuel oil, reprocessed fuel oil, used oil generated on site, and natural gas. Natural gas is only used to supplement other fuels during high steam demand periods. Fuel oil usage is limited to 2,700,000 gallons per year, and the sulfur content of the fuel oil used is limited to 3.0 percent by weight. TDF usage (total for No.1, No. 2, and No. 3 Power Boilers) is limited to 220 tons per day.

The No. 1 Power Boiler is equipped with a traveling grate, a combustion air system, and

multiclones.

The No. 1 Power Boiler is not subject to any New Source Performance Standards (NSPS) in 40 CFR Part 60. It is subject to 40 CFR Part 63, Subpart DDDDD, *National Emissions Standard for Hazardous Air Pollutants* (NESHAP) *for Industrial, Commercial, and Institutional Boilers and Process Heaters*. NESHAP DDDDD establishes Maximum Achievable Control Technology (MACT) limits and is commonly referred to as “the Boiler MACT.”

To meet the applicable Boiler MACT PM emission standard of 0.07 lb/Mmbtu, Domtar is preparing to install a wet electrostatic precipitator (WESP) on the No. 1 Power Boiler.

2.2 No. 2 POWER BOILER

The No. 2 Power Boiler (SN-05) started operations in February 1976. It has a heat input rating of 820 MMBtu/hr and an average steam generation rate of approximately 600,000 lb/hr. It combusts primarily bituminous coal (over 80 percent of the heat input is supplied by coal), but is also permitted to burn bark, bark and wood chips used to absorb oil spills, wood waste, petroleum coke (pet coke), recycled sanitary products based on cellulose and polypropylene, PPF, TDF, municipal yard waste, No. 6 fuel oil, reprocessed fuel oil, used oil generated on site, natural gas, and non-condensable gases (NCGs). The NCGs are produced in the pulp area (from the cooking of chips) and evaporator area (where weak black liquor is concentrated) and consist of nitrogen, total reduced sulfur (TRS) compounds, methanol, acetone, SO₂, and minor quantities of other compounds such as methyl ethyl ketone (MEK). Under normal operating conditions, natural gas is not combusted.

The No. 2 Power Boiler is equipped with a traveling grate, combustion air system including overfire air, multiclones, and two parallel venturi scrubbers. The SO₂ loading to the boiler is significant since the boiler burns coal and NCGs. Therefore, the scrubbing fluid includes water and a source of alkali, such as sodium hydroxide (i.e., caustic) and/or pulp mill extraction stage filtrate.

The No. 2 Power Boiler is subject to 40 CFR 60, Subpart D, *Standards of Performance for Fossil-Fuel-Fired Steam Generators for Which Construction is Commenced After August 17, 1971*, 40 CFR 60, Subpart BB, *Standards of Performance for Kraft Pulp and Paper Mills* (since it combusts NCGs), and 40 CFR Part 63, Subpart DDDDD, *National Emissions Standard for Hazardous Air Pollutants for Industrial, Commercial, and Institutional Boilers and Process Heaters*.

The No. 2 Power Boiler is equipped with Continuous Emissions Monitoring Systems (CEMS) for NO_x, SO₂, and carbon monoxide (CO). In accordance with 40 CFR 60, Subpart BB, the No. 2 Power Boiler also has a continuous flame pyrometer to measure the temperature at the point of NCG injection (the temperature at the injection point must remain at or above 1200 °F for at least 0.5 seconds at all times that NCGs are being burned).

3. BART APPLICABILITY ANALYSIS

This section summarizes the source-specific inputs and results of the BART applicability analysis conducted by the ADEQ for Domtar's Ashdown Mill BART-eligible source. The screening modeling methodologies and data resources used by the ADEQ in executing the CALPUFF modeling system are described in technical detail in the ADEQ's *Draft BART Modeling Protocol* (the Protocol), dated June 7, 2006, and in the Central Regional Air Planning Association (CENRAP) *BART Modeling Guidelines* (issued on December 22, 2005, and re-issued on February 3, 2006). A copy of the Protocol is included in Appendix A.

3.1 MODELED ASHDOWN MILL EMISSIONS

Whereas the BART eligibility determination relies on current potential emissions of visibility-affecting pollutants, the BART applicability modeling analysis is based on maximum 24-hour average actual emission rates of NO_x, SO₂, and PM₁₀ for the modeled three-year period (i.e., 2001, 2002, & 2003).⁴ At the ADEQ's request, Domtar estimated the 24-hour average maximum actual emission rates of visibility-affecting pollutants from the No. 1 and No. 2 Power Boilers using a combination of CEMS data, source-specific stack testing results, and emission factors from U.S. EPA's AP-42. These emission rates are summarized in Table 3-1.

TABLE 3-1. SUMMARY OF 24-HOUR AVERAGE MAXIMUM ACTUAL EMISSION RATES

	NO _x	SO ₂	PM ₁₀ /PMF
Emission Unit	Emissions (lb/hr)	Emissions (lb/hr)	Emissions (lb/hr)
No. 1 Power Boiler	179.6	442.5	169.5
No. 2 Power Boiler	526.8	788.2	81.6

3.2 MODELED ASHDOWN MILL STACK PARAMETERS

Actual stack parameters were input to the CALPUFF model to represent each emissions point. The location of each point was represented using the Lambert Conformal Coordinate (LCC) system. According to the Protocol, because the BART modeling focuses on mesoscale transport to Class I areas, effects of building downwash were not considered in the ADEQ's analysis. Table 3-2 summarizes the stack parameters modeled for the BART-eligible emission units at Domtar's Ashdown Mill.

⁴ The ADEQ assumed all PM₁₀ emissions were PMF for modeling purposes.

TABLE 3-2. STACK PARAMETERS

Emission Unit	LCC East (km)	LCC North (km)	Base Elevation (m)	Stack Height (m)	Stack Diameter (m)	Exhaust Temperature (K)	Exhaust Velocity (m/s)
No. 1 Power Boiler	267.47491	-698.66686	97.5	66.1	1.890	522	26.76
No. 2 Power Boiler	267.48245	-698.74355	97.5	71.6	3.659	325	11.92

3.3 POTENTIALLY AFFECTED CLASS I AREAS

Regardless of distance from the BART-eligible source, the ADEQ evaluated all Class I areas within 300 km of the Arkansas state boundary in all analyses. Figure 3-1 illustrates the location of the Ashdown Mill relative to each of the modeled Class I areas.

FIGURE 3-1. LOCATION OF ASHDOWN MILL RELATIVE TO MODELED CLASS I AREAS

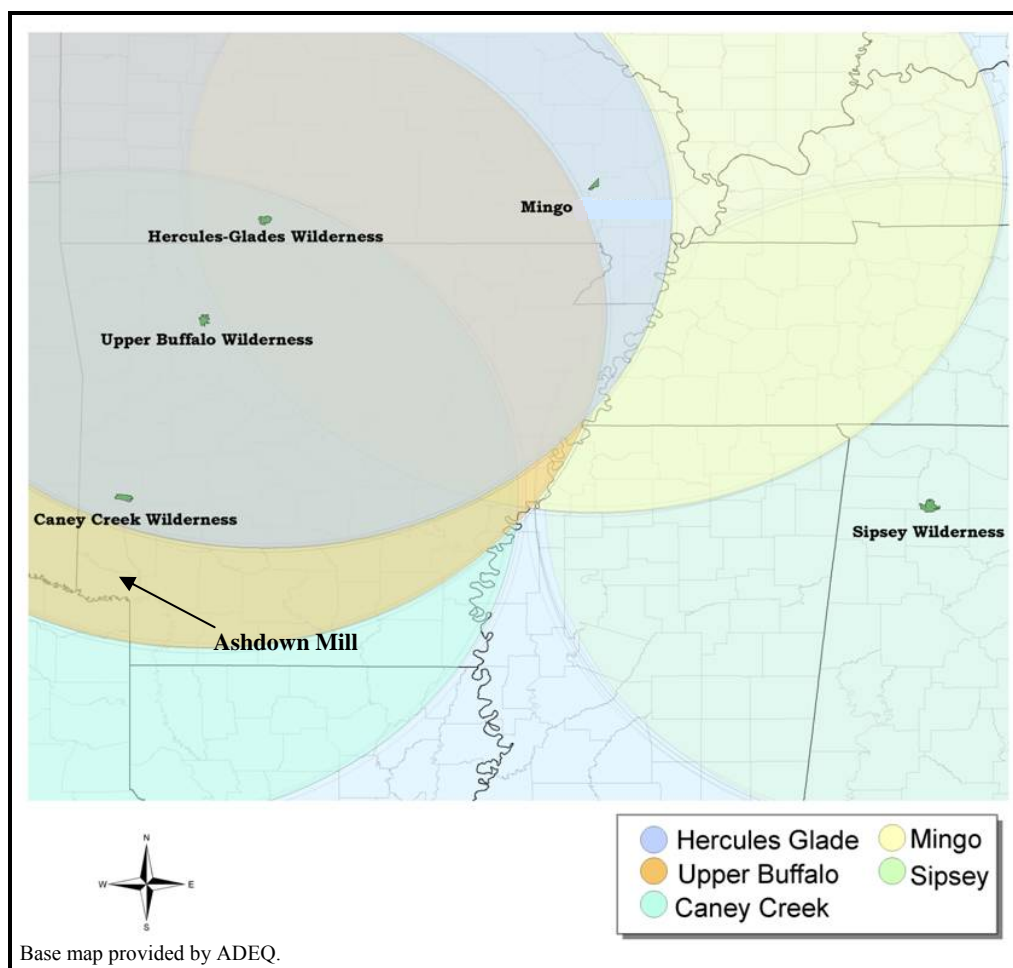


Table 3-3 presents the Class I areas (and responsible Federal Land Manager [FLM]) included in ADEQ's analyses and the approximate distance from each area to the Ashdown Mill.

TABLE 3-3. MODELED CLASS I AREAS

Class I Area	FLM ^a	Approximate Distance from Ashdown Mill (km)
Caney Creek Wilderness	FS	85
Upper Buffalo Wilderness	FS	250
Hercules-Glades Wilderness	FS	350
Mingo Refuge	FWS	510
Sipsey Wilderness	FS	620

^a FS = Forest Service (Department of Agriculture), FWS = Fish and Wildlife Service (Department of Interior).

3.4 BART APPLICABILITY ANALYSIS RESULTS

The ADEQ's BART applicability analysis showed that Domtar's Ashdown Mill contributes to visibility impairment, since the maximum modeled 24-hour average impacts were greater than 0.5 Δdv , in the Caney Creek, Upper Buffalo, Hercules-Glades, and Mingo Class I areas. The results of the ADEQ's BART applicability analysis for Domtar's Ashdown Mill are summarized in Table 3-4.

TABLE 3-4. SUMMARY OF BART APPLICABILITY ANALYSIS RESULTS

Class I Area	Maximum 24-hour Impact (Δdv) ^a	Number of Days > 0.5 Δdv ^a	Number of Days > 1.0 Δdv ^a
Caney Creek	2.262	159	50
Upper Buffalo	1.181	18	1
Hercules-Glades	0.701	3	0
Mingo	0.923	2	0
Sipsey	0.341	0	0

^a For total modeled period: years 2001, 2002, and 2003.

Since the ADEQ's BART applicability analysis shows that Domtar's Ashdown Mill BART-eligible source contributes to visibility impairment in at least one Class I area, Domtar must conduct a BART determination analysis for the No. 1 and No. 2 Power Boilers.

4. BART DETERMINATION ANALYSIS

In general, BART is determined for each eligible emissions unit using the following five (5) steps from Section IV.D of the BART Guidelines:

- Step 1 – Identify all available retrofit control technologies,
- Step 2 – Eliminate technically infeasible options,
- Step 3 – Evaluate control effectiveness of remaining control technologies,
- Step 4 – Evaluate impacts and document the results, and
- Step 5 – Evaluate visibility impacts.

However, in the preamble to the BART Guidelines, the U.S. EPA clearly encourages the use of streamlined approaches for BART determinations so that states and industry can focus their resources on the main contributors to visibility impairment.⁵ Domtar asserts that streamlined BART determinations are appropriate for emissions of PM and SO₂ from the Ashdown Mill's No. 1 and No. 2 Power Boilers. The streamlined BART determinations for PM and SO₂ are presented in Sections 4.1, 4.2, and 4.3. Steps 1 through 4 of the BART determination analysis for NO_x emissions from the No. 1 and No. 2 Power Boilers are presented in Section 4.3. Section 4.5 presents the visibility impacts evaluation for all pollutants.

4.1 BART DETERMINATION FOR PM

Section IV.C of the BART Guidelines describes a streamlined approach for evaluating BART for certain sources that are subject to MACT standards (i.e., NESHAP in 40 CFR 63). The Ashdown Mill's No. 1 and No. 2 Power Boilers are affected sources (in the existing, large, solid fuel subcategory) under the Boiler MACT, and are subject to a PM emissions standard of 0.07 lb/MMBtu. Since the Boiler MACT standard was established recently the technology analysis is up-to-date. The No. 1 and No. 2 Power Boilers must be in compliance with the Boiler MACT standards by September 13, 2007, in advance of the anticipated 2013 BART compliance deadline. Domtar is planning to equip the No. 1 Power Boiler with a WESP to meet the PM standard. The No. 2 Power Boiler is equipped with a wet scrubber and can meet the Boiler MACT PM emission standard. Domtar has not identified any feasible upgrades to the No. 2 Power Boiler's wet scrubber. At ADEQ's request, Domtar evaluated the costs for installing a WESP on the No. 2 Power Boiler. The estimated cost effectiveness, based on the estimates given in the proposal for the WESP on the No. 1 Power Boiler, is at a minimum \$30,000/ton – clearly infeasible. Table 4-1 presents the maximum PM emission rates from each power boiler based on heat input capacity and the Boiler MACT standard.

⁵ Federal Register, Vol. 70, No. 128, July 6, 2005, pp 39107 and 39116.

TABLE 4-1. BART / BOILER MACT-BASED PM EMISSION RATES

Emission Unit	PM Emissions (lb/hr)	PM Emissions (tpy)
No. 1 (Bark) Power Boiler	40.6	177.9
No. 2 (Coal) Power Boiler	57.4	251.5

The recent Boiler MACT PM emission standard is presumptively relied upon to meet BART requirements. Accordingly, a comprehensive BART determination analysis is not necessary to determine BART for PM emissions from the Ashdown Mill's No. 1 and No. 2 Power Boilers. The ADEQ agreed to allow this streamlined MACT-equals-BART option in a September 8, 2006, letter, but required that Domtar "consult with the ADEQ Air Division regarding whether the wet electrostatic precipitator (MACT Control) is the best available and cost effective control technology for PM_{2.5}."⁶ Domtar provides the following evidence that a WESP is the best choice for control of the No. 1 Power Bark Boiler.

Particulate emissions from wood-fired boilers are typically controlled by one of four technologies: baghouse (fabric filter), ESP (wet or dry), wet scrubber, or cyclone. Cyclones provide for the lowest control efficiencies of the options at up to 65 percent, and particulate collection efficiencies of 85 percent or greater have been reported for venturi [wet] scrubbers operating on wood-fired boilers.⁷ To achieve control efficiencies of 90 percent or greater, a baghouse or ESP is used. The normal PM control efficiency range for a fabric filter is 95 to 99+ percent, and the normal PM control efficiency range for a WESP is 98 to 99+ percent.⁸ Fabric filters are rarely used on wood-fired boilers due to concerns about bag flammability.⁹ The principal drawback is a fire danger arising from the collection of combustible carbonaceous fly ash.¹⁰ Both types (i.e., wet and dry) of ESPs are capable of greater than 99 percent removal of particle sizes above 1 micron.¹¹ An additional benefit of WESPs is that the wash used in WESPs can also have some control effect on other pollutant gases via absorption and can help condense other emissions due to the cooling of the stream.¹² Based on the comparison of control efficiencies and the applicability of each control device, Domtar asserts that the WESP is the best control technology (i.e., BART) for the No. 1 Power Boiler.

⁶ Mike Bates (ADEQ), letter to Kelley Crouch (Domtar), September 8, 2006.

⁷ U.S. EPA, *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Source* (AP-42), Fifth Edition, Section 1.6 – Wood Residue Combustion in Boilers, September 2003.

⁸ MACTEC, *Midwest RPO Boiler BART Engineering Analysis*, March 30, 2005.

⁹ NCASI, *Information on Retrofit Control Measures for Kraft Pulp Mill Sources and Boilers for NO_x, SO₂ and PM Emissions*, Corporate Correspondence Memo 06-014.

¹⁰ U.S. EPA, *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Source* (AP-42), Fifth Edition, Section 1.6 – Wood Residue Combustion in Boilers, September 2003.

¹¹ Northeast States for Coordinated Air Use Management (NESCAUM) and Mid-Atlantic/Northeast Visibility Union (MANE-VU), *Assessment of Control Technology Options for BART-Eligible Sources – Steam Electric Boilers, Industrial Boilers, Cement Plant and Paper and Pulp Facilities*, March 2005.

¹² MACTEC, *Midwest RPO Boiler BART Engineering Analysis*, March 30, 2005.

4.2 BART DETERMINATION FOR SO₂ – No. 1 POWER BOILER

Generally, pre-combustion SO₂ control strategies involve fuel switching/blending or fuel cleaning so that less fuel-bound sulfur enters the process. However, because wood already contains very little sulfur, pre-combustion SO₂ controls are ineffective.

Post-combustion SO₂ control is accomplished by reacting the SO₂ in the gas with a reagent (usually calcium-based [e.g., lime or limestone] or sodium-based [e.g., caustic]) and removing the resulting product (a sulfate/sulfite) for disposal or commercial use. SO₂ reduction technologies are commonly referred to as flue gas desulfurization (FGD) and/or scrubbers and are usually described in terms of the process conditions (wet versus dry), byproduct utilization (throwaway versus saleable) and reagent utilization (once-through versus regenerable).¹³ Post-combustion SO₂ controls have not been installed on wood-fired boilers because of the relatively low SO₂ emissions from wood-combustion (due to the low sulfur content of wood).

Due to the low fuel sulfur input, emissions from wood combustion are inherently low and have a negligible impact on visibility impairment. Therefore, Domtar proposes no additional add-on control, i.e., only the existing fuel restrictions (fuel oil sulfur content and usage limitations) and no additional SO₂ removal as BART for SO₂ emissions from the No. 1 Power Boiler.

4.3 BART DETERMINATION FOR SO₂ – No. 2 POWER BOILER

Section IV.D.1.9 of the BART Guidelines provides an option to skip the comprehensive BART determination analysis for BART-eligible emission units that are already equipped with the most stringent controls available (including any possible improvements to the control device) “as long as these most stringent controls available are made federally enforceable for the purpose of implementing BART for that source.” The Ashdown Mill’s No. 2 Power Boiler is equipped with a wet scrubber for control of SO₂ (and particulate) emissions. The existing wet scrubber achieves an SO₂ control efficiency of approximately 90 percent, which is within the normal range for the highest efficiency SO₂ control strategies and is the BART-based control efficiency presumed by the Central Regional Air Planning Association (CENRAP) and the Midwest Regional Planning Organization (MRPO) for pulp and paper industry power boilers.^{14,15}

The No. 2 Power Boiler is equipped with a CEMS for SO₂. Thus, Domtar is able to immediately identify needs for both ongoing operational adjustments and periodic maintenance and/or scrubber improvements to maintain high levels of SO₂ control. Domtar has not identified any feasible upgrades to the existing wet scrubber. It should be noted that the No. 2 Power Boiler is operated such that SO₂ emissions are well below any applicable limits/standards. Since wet scrubbing is the most effective method of controlling SO₂ emissions, no additional analysis is needed for SO₂ emissions from the No. 2 Power Boiler. Domtar proposes no additional SO₂ removal as BART for the No. 2 Power Boiler.

¹³ NESCAUM and MANE-VU, *Assessment of Control Technology Options for BART-Eligible Sources – Steam Electric Boilers, Industrial Boilers, Cement Plant and Paper and Pulp Facilities*, March 2005.

¹⁴ CENRAP’s Control Estimates Spreadsheet dated January 10, 2006.

¹⁵ MRPO, *Interim White Paper – Midwest RPO Candidate Control Measures*, March 29, 2005.

4.4 BART DETERMINATION ANALYSIS FOR NO_x

Each required step of the BART determination analysis for emissions of NO_x from the No. 1 and No. 2 Power Boilers is presented below.

4.4.1 STEP 1 - IDENTIFY ALL AVAILABLE RETROFIT CONTROL TECHNOLOGIES

The BART Guidelines require the consideration of all “control technologies with a practical potential for application to the emissions unit and the regulated pollutant under evaluation.” The list of available control options should include “the most stringent option and a reasonable set of options for analysis...[, but] it is not necessary to list all permutations of available control levels that exist for a given technology – the list is complete if it includes the maximum level of control each technology is capable of achieving.”

Per the BART Guidelines, the BART determination analysis must “take into account technology transfer of controls that have been applied to similar source categories and gas streams [in addition to] existing controls for the source category in question.” However, “technologies which have not yet been applied to (or permitted for) full scale operations need not be considered as available; [the U.S. EPA does] not expect the source owner to purchase or construct a process or control device that has not already been demonstrated in practice.” The BART Guidelines provides the following additional considerations for preparing the list of potential control options:

- One of the control options should reflect the level of control equivalent to any applicable NSPS,
- Source redesign should not be considered,
- Fuel switching should not be considered, and
- For emission units with existing control measures or devices, one of the control options should involve improvements to the existing controls.

Potential NO_x control technologies and resulting emission control quantities for the Ashdown Mill’s No. 1 and No. 2 Power Boilers were identified from the exhaustive review of the U.S. EPA’s Clean Air Technology Center, including the RACT/BACT/LAER Clearinghouse (RBLC), control equipment vendor information, publicly-available air permits and applications, and technical literature published by the U.S. EPA, the Regional Planning Organizations (RPOs), and industry groups such as the National Council for Air and Stream Improvement, Inc. (NCASI).¹⁶ In fact, Domtar has largely relied upon the extensive research conducted by NCASI regarding the applicability and effectiveness of each control option for coal- and wood-fired pulp and paper mill power boilers. Each NO_x

¹⁶ NCASI is an independent, non-profit research institute that focuses on environmental topics of interest to the forest products industry. NCASI was established in 1943...In the years since, NCASI has developed technical expertise spanning the spectrum of environmental challenges facing the forest products industry, and is today recognized as the leading source of reliable data on environmental issues affecting this industry. (<http://www.ncasi.org/about/default.aspx>)

control option identified as potentially applicable to either power boiler is listed below and explained in detail in the following subsections.

- Selective Non-Catalytic Reduction (SNCR) / NO_xOUT
- Selective Catalytic Reduction (SCR)
- Low NO_x Burners (LNB) and Ultra Low NO_x Burners (ULNB)
- Over-fire Air (OFA)
- Reburning / Methane de-NO_x (MdN)
- Flue Gas Recirculation (FGR) (Internal and External)
- Fuel Blending / Boiler Operational Modifications / Tuning / Optimization

For this analysis, utility boiler control technology determinations were generally not considered since utility boilers and pulp and paper mill power boilers are considered too dissimilar.

The greatest difference in utility and power boiler operations is the fluctuating steam demand characteristic of pulp and paper mill operations which requires that power boilers continuously adjust fuel firing rates and excess air levels. Even with the most sophisticated combustion controls, it is not practical or safe to maintain excess air continuously at minimum levels. Consequently, power boilers have characteristically and inherently higher NO_x emissions.

...NO_x reduction measures are particularly difficult to implement in small, low capacity facilities because a) residence time is limited and often inadequate for applying OFA without excessive loss of thermal efficiency or induced smoking; b) relatively small furnace dimensions limit combustion modifications that increase flame length and tend to cause the flame to impinge on tube wall; c) peak boiler efficiency and minimized NO_x emissions occur close to minimum flue-gas O₂ content, which is at the threshold of smoke or combustible-emissions formation; d) steam is used far more effectively in industrial applications than in conventional electric utility plants and, consequently, emission limits based on boiler heat input or volume of flue gas do not recognize such efficiency.¹⁷

Combustion-related NO_x emissions are formed by two mechanisms. NO_x formed from oxidation of molecular nitrogen (N₂) in combustion air is referred to as “thermal NO_x” and is dependent on high temperatures (approximately 2,800 °F) and an excess of combustion air. NO_x formed by oxidation of nitrogen compounds in fuel is referred to as “fuel NO_x.” The NO_x formed from coal combustion is primarily fuel NO_x.¹⁸ Fuel NO_x is also the dominant NO_x formation mechanism operative during wood combustion because wood combustion in boilers seldom reaches high enough temperatures.^{19,20}

¹⁷ NCASI, *NO_x Control in Forest Products Industry Boilers: A Review of Technologies, Costs and Industry Experience*, Special Report 03-04.

¹⁸ MACTEC, *Midwest RPO Boiler BART Engineering Analysis*, March 30, 2005.

¹⁹ NCASI, *Information on Retrofit Control Measures for Kraft Pulp Mill Sources and Boilers for NO_x, SO₂ and PM Emissions*, Corporate Correspondence Memo 06-014.

The possible NO_x emissions control technologies generally fit into one of two categories: combustion modifications, which are often associated with improving boiler performance, or flue gas treatment (i.e., post-combustion controls). Pre-combustion techniques to reduce fuel NO_x have shown little promise.²¹ Combustion modifications are the most common, commercially available means of controlling NO_x emissions from fossil fuel-fired boilers.²² However, since wood-fired boilers normally burn at lower temperatures (around 1,500 °F), the units have inherently lower NO_x emissions, and, as a result, NO_x combustion control technologies are not applicable to wood-fired boilers.²³ During the past decade, LNB with FGR and LNB alone were the most commonly recommended NO_x control technologies for oil/gas and coal-fired boilers, respectively, while good combustion control was typically the only recommendation for wood waste-fired boilers.²⁴

COMBUSTION MODIFICATIONS

4.4.1.1 FLUE GAS RECIRCULATION

Generally, FGR involves extracting a portion (15 to 30 percent) of the flue gas and readmitting it to the furnace through the burner window. When the flue gas is extracted from the economizer or air heater outlet, a separate fan/blower is needed to withdraw the flue gas. This setup is referred to as external or forced FGR. Internal or induced FGR refers to the setup where the flue gas is extracted from upstream of the stack using the forced draft (FD) fan instead of a separate FGR fan. In either setup, the recirculated flue gas acts as a thermal diluent (i.e., heat sink) to reduce combustion temperatures. It also dilutes the combustion reactants and reduces the excess air requirements thereby reducing the concentration of oxygen in the combustion zone. Thus, thermal NO_x formation is inhibited.²⁵ The onset of thermal NO_x occurs around 2,800 °F, and NO_x generation increases exponentially with temperatures beyond 2,800 °F. As only thermal NO_x can be controlled by this technique, it is especially effective only in oil and gas-fired units.²⁶

4.4.1.2 LOW NO_x BURNERS / ULTRA LOW NO_x BURNERS

LNB technology utilizes advanced burner design to reduce NO_x formation through the restriction of oxygen, flame temperature, and/or residence time. A

²⁰ NCASI, *NO_x Control in Forest Products Industry Boilers: A Review of Technologies, Costs and Industry Experience*, Special Report 03-04.

²¹ Ibid.

²² Ibid.

²³ STAPPA and ALAPCO, *Controlling Fine Particulate Matter Under the Clean Air Act: A Menu of Options*, March 2006.

²⁴ NCASI, *NO_x Control in Forest Products Industry Boilers: A Review of Technologies, Costs and Industry Experience*, Special Report 03-04.

²⁵ U.S. EPA, Clean Air Technology Center, *Nitrogen Oxides (NO_x), Why and How They Are Controlled*. Research Triangle Park, North Carolina, EPA-456/F-99-006R, November 1999.

²⁶ NCASI, *NO_x Control in Forest Products Industry Boilers: A Review of Technologies, Costs and Industry Experience*, Special Report 03-04.

LNB is a staged combustion process that is designed to split fuel combustion into two zones, primary combustion and secondary combustion. Two general types of LNB exist: staged fuel and staged air. Lower emission rates can be achieved with a staged fuel burner than with a staged air burner. Staged fuel LNB separate the combustion zone into two regions. The first region is a lean primary combustion region where the total quantity of combustion air is supplied with a fraction of the fuel. Combustion in the primary region (first stage) takes place in the presence of a large excess of oxygen at substantially lower temperatures than a standard burner. In the second region, the remaining fuel is injected and combusted with any oxygen left over from the primary region. The remaining fuel is introduced in the second stage outside of the primary combustion zone so that the fuel/oxygen are mixed diffusively (rather than turbulently), which maximizes the reducing conditions. This technique inhibits the formation of thermal NO_x , but has little effect on fuel NO_x . By increasing residence times staged air LNB provide reducing conditions, which have a greater impact on fuel NO_x than staged fuel burners. The estimated NO_x control efficiency for LNB in high temperature applications is 25 percent.²⁷

The application of LNB is often limited by the longer flames produced as a consequence of improved air distribution control. While there is generally ample room for LNB flames in utility furnaces, their use on smaller power boilers can result in flame impingement on furnace walls, leading to tube wall overheating and mechanical failure. Flame impingement can also result in premature flame quenching and increased soot and CO emissions.²⁸

ULNB combine LNB and FGR technologies and may incorporate other techniques such steam injection. The FGR design within ULNB recirculates flue gas from the flame or firebox back into the combustion zone in an effort to reduce oxygen concentrations without significantly reducing flame temperature. Reduced oxygen concentrations in the flame have a strong impact on fuel NO_x .²⁹ ULNB also tend to have large diameters, but shorter flame lengths and may be easier to retrofit.³⁰

Combustion modification with LNB is used in both gas/oil-fired and coal-fired units.³¹ LNB are not used for wood-fired boilers. The No. 1 Power Boiler burns only a small amount of fuel for which LNB technology exists. Therefore, LNB is not considered further for the No. 1 Power Boiler.

²⁷ MACTEC, *Midwest RPO Boiler BART Engineering Analysis*, March 30, 2005.

²⁸ NCASI, *NO_x Control in Forest Products Industry Boilers: A Review of Technologies, Costs and Industry Experience*, Special Report 03-04.

²⁹ MACTEC, *Midwest RPO Boiler BART Engineering Analysis*, March 30, 2005.

³⁰ NCASI, *NO_x Control in Forest Products Industry Boilers: A Review of Technologies, Costs and Industry Experience*, Special Report 03-04.

³¹ Ibid.

4.4.1.3 OVERFIRE AIR

In OFA, about 10 to 20 percent of the combustion air flow is directed to separate air ports located downstream of the burners. OFA works by reducing the excess air in the burner zone, thereby enhancing the combustion staging effect and theoretically reducing NO_x emissions. Residual unburned material, such as CO and unburned carbon, which inevitably escapes the main burner zone, is oxidized as the OFA is admixed later.³²

OFA vendors (e.g., Jansen Combustion and Boiler Technologies, Inc.) have informed Domtar that while OFA often results in decreased NO_x emissions, the primary purpose is combustion optimization, and implementation of OFA can actually increase NO_x emissions in certain circumstances. Domtar has experienced this potential adverse effect. A recent OFA upgrade to the Ashdown Mill's No. 3 Power Boiler (not a BART-eligible unit) is still in startup mode, but so far Domtar has measured a noteworthy increase in NO_x emissions.

Domtar does not consider OFA to be a potential NO_x control technology, and OFA is not considered further in this analysis.

4.4.1.4 REBURNING / METHANE DE-NO_x

In reburning, also known as “off-stoichiometric combustion” or “fuel staging,” a fraction (5 to 25 percent) of the total fuel heat input is diverted to a second combustion zone downstream of the primary zone. The fuel in the fuel-rich secondary zone acts as a reducing agent, reducing NO, which is formed in the primary zone, to N₂. Low nitrogen-containing fuels such as natural gas and distillate oil are typically used for reburning to minimize further NO_x formation. Generally, it is more economical for a facility to use the same fuel for reburning as it does for primary combustion, although there are exceptions. In order to use coal as a reburning fuel, it must be finely ground, which requires additional pulverizing equipment.³³

MdN utilizes the injection of natural gas together with recirculated flue gases (for enhanced mixing) to create an oxygen-rich zone above the combustion grate. Air is then injected at a higher furnace elevation to burn out the combustibles. This process is claimed to yield between 50 and 70 percent NO_x reduction and to be suitable for all solid fuel-fired stoker boilers. However, as of 2002, MdN had only been demonstrated for a short duration in one pulp mill wood-fired stoker boiler that also burned small amounts of waste treatment plant residuals, with NO_x reductions of 40 to 50 percent reported.³⁴

³² Ibid.

³³ STAPPA and ALAPCO, *Controlling Fine Particulate Matter Under the Clean Air Act: A Menu of Options*, March 2006.

³⁴ NCASI, *NO_x Control in Forest Products Industry Boilers: A Review of Technologies, Costs and Industry Experience*, Special Report 03-04.

More recently, MdN is being applied to kraft pulp mill stoker boilers by utilizing the VOC content of NCGs to partially replace the natural gas (by up to 25 percent). This technology has been tested for over a year at one pulp mill boiler, and is being tested at several boilers within one forest products industry (FPI) company.³⁵

4.4.1.5 FUEL BLENDING

Since wood is inherently low in nitrogen content, fuel blending is not feasible for wood-fired boilers. Therefore, this control strategy is not considered for the Ashdown Mill's No. 1 Power Boiler.

Coal-fired boilers could experience a decrease in NO_x emissions from fuel blending. Preliminary results show that the co-firing of up to 7 percent biomass, on a heat-input basis, with crushed or pulverized coal can lower NO_x emissions by as much as 15 percent.³⁶ However, fuel biasing on an industrial boiler subject to rapid and excessive load swings could result in too rich or too lean firing conditions, which can lead to flame stability problems and explosive conditions.³⁷ In addition, unlike utilities, which can specify the nitrogen content of their large oil purchases, most industrial mills cannot.³⁸

Domtar historically mixes 10 to 15 percent (heat input basis) wood with coal in the No. 2 Power Boiler. Therefore, fuel blending is considered part of the base case for the No. 2 Power Boiler.

4.4.1.6 BOILER OPERATIONAL MODIFICATIONS / TUNING / OPTIMIZATION

Combustion optimization efforts can lead to improvements in NO_x emissions of 5 to 15 percent. Recent developments of intelligent controls – software-based systems that "learn" to operate a unit and then maintain its performance during normal operation – are expected help in keeping plants well tuned.³⁹ Domtar has employed, and will continue to employ, the latest boiler optimization and tuning techniques. This control strategy is considered part of the base case for the Ashdown Mill's No. 1 and No. 2 Power Boilers.

³⁵ Ibid.

³⁶ Ibid.

³⁷ Ibid.

³⁸ Ibid.

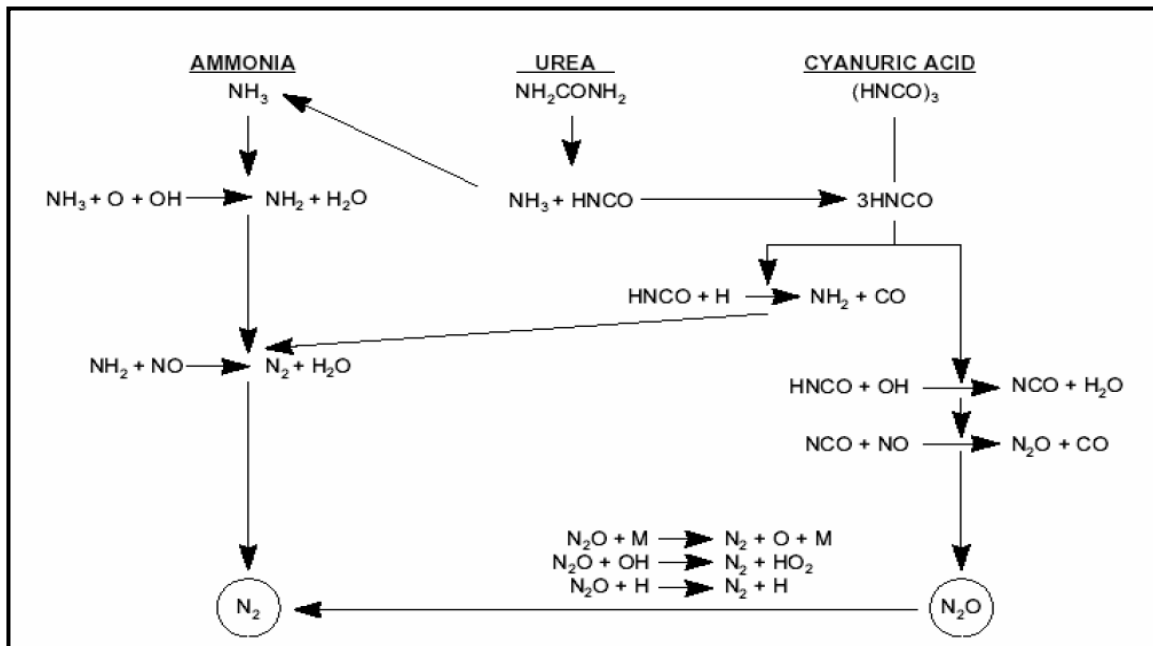
³⁹ NESCAUM and MANE-VU, *Assessment of Control Technology Options for BART-Eligible Sources – Steam Electric Boilers, Industrial Boilers, Cement Plant and Paper and Pulp Facilities*, March 2005.

POST-COMBUSTION CONTROLS

4.4.1.7 SELECTIVE NON-CATALYTIC REDUCTION

SNCR is a post-combustion NO_x control technology based on the reaction of urea or ammonia (NH_3) and NO_x . In the SNCR chemical reaction, urea or ammonia-based chemicals are injected into the combustion gas path to reduce the NO_x to nitrogen and water. The primary SNCR reaction sequences are shown in Figure 4-1.⁴⁰

FIGURE 4-1. PRIMARY SNCR REACTION SEQUENCES



Typical NO_x removal efficiency for SNCR is 30 to 65 percent. For industrial coal-fired boilers, SNCR can achieve approximately 40 percent NO_x control.⁴¹ An important consideration for implementing SNCR is the operating temperature range. The optimum temperature range is approximately 1,600 to 2,000 °F.⁴² Operation at temperatures below this range results in ammonia slip. Operation above this range results in oxidation of ammonia, forming additional NO_x . In addition, the urea must have sufficient residence time, about 3 to 5 seconds, at the optimum operating temperatures for efficient NO_x reduction. Therefore, the injection point is typically prior to convective heat recovery.⁴³

⁴⁰ ABB Power Plant Laboratories, *Engineering development of coal-fired high performance power systems – Phase II topical report*, Selective Non-Catalytic Reduction System Development Subcontract to United Technologies Research Center, Contract No. DE-AC22-95PC95144, February 24, 1997 (reprinted in NCASI's Special Report No. 03-04).

⁴¹ MRPO, *Interim White Paper – Midwest RPO Candidate Control Measures*, March 29, 2005.

⁴² U.S. EPA, Clean Air Technology Center, *Nitrogen Oxides (NO_x), Why and How They Are Controlled*. Research Triangle Park, North Carolina, EPA-456/F-99-006R, November 1999.

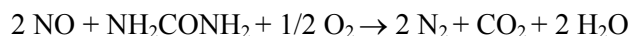
⁴³ U.S. EPA. *Summary of NO_x Control Technologies and their Availability and Extent of Application*. Research Triangle Park, North Carolina. EPA-450/3-92-004, February 1992.

According to the U.S. EPA, the performance of an SNCR system is affected by six factors.

These are a) inlet NO_x level, b) temperature, c) mixing, d) residence time, e) reagent-to- NO_x ratio, and f) fuel sulfur content. Lower inlet NO_x concentrations reduce the reaction kinetics and hence the achievable NO_x emissions reductions. As mentioned above, temperatures below the desired window result in ammonia emissions (slip), and temperatures above the desired window result in NH₃ being oxidized to NO_x. Mixing becomes an important consideration in regions distant from an injection nozzle where the level of turbulence is reduced and stratification of the reagent and flue gas will probably be a greater problem, especially at low boiler loads. Residence time becomes important to allow the desired reactions to go to completion. Small, packaged, water tube boilers and boilers with varying steam loads are therefore difficult applications for SNCR. As higher than the theoretical NH₃ to NO_x ratios are generally required to achieve desired NO_x emission reductions, a trade-off exists between NO_x control and the presence of NH₃ in the flue gas. The main disadvantage of SNCR is the low NO_x reduction that is experienced when the allowable ammonia slip is low. Finally, in the case of high sulfur fuels, excess NH₃ can react with sulfur trioxide to form ammonium sulfate salt compounds that deposit on downstream equipment leading to plugging and reduced heat transfer efficiencies.⁴⁴

One concern about the SNCR process is its ability to perform adequately under changing load and fuel conditions.⁴⁵ Based on its research regarding this concern, NCASI concludes that SNCR is most widely used for base-loaded boilers, and is not suited for power boilers that experience wide temperature variances, i.e., high load swings. NCASI also points out that the use of SNCR systems on coal-fired boilers is still in the development stage.⁴⁶

The NO_xOUT process is an SNCR hybrid based on the following chemical reaction that ideally occurs in the temperature range of 1700 to 2000 °F:



⁴⁴ U.S. EPA, *New source performance standards, subpart Db – technical support for proposed revisions to NO_x*, EPA-453-R-95-012 (republished in NCASI's Special Report 03-04).

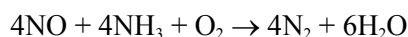
⁴⁵ NCASI, *NO_x Control in Forest Products Industry Boilers: A Review of Technologies, Costs and Industry Experience*, Special Report 03-04.

⁴⁶ Ibid.

The problems with typical SNCR systems (e.g., ammonia slippage and heat transfer surface fouling with byproduct formation) also exist with the NO_xOUT process.

4.4.1.8 SELECTIVE CATALYTIC REDUCTION

SCR is a post-combustion gas treatment process in which NH₃ is injected into the exhaust gas in the presence of a catalyst bed usually located between the boiler and air preheater. The catalyst lowers the activation energy required for NO_x decomposition.⁴⁷ On the catalyst surface, NH₃ and nitric oxide (NO) react to form diatomic nitrogen and water. The overall chemical reaction can be expressed as:



When operated within the optimum temperature range of approximately 575 to 750 °F, the reaction can result in removal efficiencies between 70 and 90 percent. For coal-fired industrial boilers, SCR can achieve approximately 80 percent NO_x control.⁴⁸ The specific temperature ranges are 600 to 750 °F for conventional (vanadium or titanium) catalysts, 470 to 510 °F for platinum catalysts, and 600 to 1000 °F for high-temperature zeolite catalysts.⁴⁹ SCR units have the ability to function effectively under fluctuating temperature conditions (usually ± 50 °F), although fluctuation in exhaust gas temperature reduces removal efficiency by disturbing the chemical kinetics (speed) of the NO_x-removal reaction.

According to the U.S. EPA, the performance of an SCR system is affected by six factors.

These are a) NO_x level at SCR inlet, b) flue gas temperature, c) NH₃-to-NO_x ratio, d) fuel sulfur content, e) gas flow rate, and f) catalyst condition. For SCR, when inlet NO_x concentrations fall below 150 ppm, the reduction efficiencies decrease with decreasing NO_x concentrations. Each type of catalyst has an optimum operating temperature range. Temperatures below this range result in ammonia emissions (slip), and temperatures above the desired range result in NH₃ being oxidized to NO_x. For up to about 80 percent NO_x reduction efficiencies, a 1:1 NH₃:NO_x ratio is sufficient. For higher efficiencies, higher reagent to NO_x ratios are required which may result in higher NH₃ slip. In the case of high sulfur fuels, excess NH₃ can react with sulfur trioxide to form ammonium sulfate salt compounds that deposit and foul downstream equipment. SCR application experience in the case of

⁴⁷ MACTEC, *Midwest RPO Boiler BART Engineering Analysis*, March 30, 2005.

⁴⁸ MRPO, *Interim White Paper – Midwest RPO Candidate Control Measures*, March 29, 2005.

⁴⁹ MACTEC, *Midwest RPO Boiler BART Engineering Analysis*, March 30, 2005.

medium-to-high sulfur fuels is limited. For a given flue gas flow rate, the catalyst structural design should be chosen so that the residence time needed for the reduction reactions to take place on the catalyst surface is achievable.⁵⁰

4.4.2 STEP 2 – ELIMINATE TECHNICALLY INFEASIBLE OPTIONS

Per the BART Guidelines, documentation of infeasibility should “explain, based on physical, chemical, or engineering principles, why technical difficulties would preclude the successful use of the control option under review.” The BART Guidelines use the two key concepts of “availability” and “applicability” to determine if a control option is technically feasible. These concepts are defined in Section IV.D.2:

...a technology is considered "available" if the source owner may obtain it through commercial channels, or it is otherwise available within the common sense meaning of the term. An available technology is "applicable" if it can reasonably be installed and operated on the source type under consideration.

The typical stages for bringing a control technology concept to reality as a commercial product are:

- *concept stage;*
- *research and patenting;*
- *bench scale or laboratory testing;*
- *pilot scale testing;*
- *licensing and commercial demonstration; and*
- *commercial sales.*

A control technique is considered available, within the context presented above, if it has reached the stage of licensing and commercial availability. Similarly, we do not expect a source owner to conduct extended trials to learn how to apply a technology on a totally new and dissimilar source type. Consequently, you would not consider technologies in the pilot scale testing stages of development as “available” for purposes of BART review.

In general, a commercially available control option will be presumed applicable if it has been used on the same or a similar source type. Absent a showing of this type, you evaluate technical feasibility by examining the physical and chemical characteristics of the pollutant-bearing gas stream, and comparing them to the gas stream characteristics of the source types to which the technology had been applied previously.

COMBUSTION MODIFICATIONS

⁵⁰ U.S. EPA, *New source performance standards, subpart Db – technical support for proposed revisions to NO_x*, EPA-453-/R-95-012 (republished in NCASI’s Special Report 03-04).

4.4.2.1 FLUE GAS RECIRCULATION

FGR is used to reduce thermal NO_x formation. Emissions due to fuel-bound NO_x, which are significant for coal-fired boilers, are not meaningfully affected by FGR. Therefore, FGR is not technically feasible to control NO_x emissions from coal-fired boilers.⁵¹ Similarly, FGR would not be effective in wood combustion since most of the NO_x generated during wood combustion is also from the fuel NO_x pathway.⁵² Recent refusals by vendors (e.g., Entropy Technology & Environmental Consultants LP⁵³) to provide budgetary estimates for installing FGR are further evidence that FGR is not applicable for the Ashdown Mill's No. 1 and No. 2 Power Boilers.

4.4.2.2 REBURNING / METHANE DE-NO_x

Generally, Domtar considers MdN not feasible because (1) it is not fully demonstrated and (2) it incorporates FGR, which is clearly technically infeasible (see Section 4.4.2.1). However, Domtar was able to obtain equipment cost estimates from vendors of MdN. Therefore, MdN is considered further in this analysis.

POST-COMBUSTION MODIFICATIONS

NCASI points out the following issues of concern for post-combustion NO_x controls (i.e., SNCR and SCR) for pulp and paper mill power boilers:⁵⁴

Load Swings - Pulp mill combination and power boilers frequently exhibit wide and rapid load swings that are not consistent with the steady conditions required for effective use of either SNCR or SCR NO_x control technologies. The load swings produce variable temperature conditions in the boiler, causing the temperature zone for NO_x reduction to fluctuate, making it more difficult to know where to inject the reactants.

Temperature Incompatibility - Combination and power boilers are affected by temperature profile incompatibility. To obtain the required temperature window, the only location to install this technology is upstream of the particulate matter control device, yet this is where flue gases are dirty and can foul the catalyst rapidly.

⁵¹ U.S. EPA. *Alternative Control Technologies Document: NO_x Emissions from Utility Boilers*. (EPA-453/R-94-023).

⁵² NCASI, *NO_x Control in Forest Products Industry Boilers: A Review of Technologies, Costs and Industry Experience*, Special Report 03-04.

⁵³ Steve Wood (ETEC), e-mail to Joel Martin (Domtar), September 20, 2006: "Based on the design and operational data provided regarding #2 Coal Boiler, ETEC would decline to bid the application Induced Flue Gas Recirculation for Boiler #2 NO_x control. Flue gas recirculation technology is very effective in reducing natural gas and light oil fuel NO_x emissions, but is not for No.6 fuel oil, coal, bark and other solid fuels. To the best of our knowledge, flue gas recirculation for NO_x control has never been installed on a coal fired boiler."

⁵⁴ Ibid.

Downstream of the PM control device, the temperature is too low for the catalyst to be effective.

Unproven – SCR or SNCR controls, technologies which, for the most part, are untested and infeasible for pulp and paper mill boilers. These technologies must be operated on a continuous basis within a specified temperature range in order to be effective. The type of fuel burned influences the design of the technology, and FPI facilities' frequent fuel changes and co-firing of multiple fuels would result in design and operational problems.

Lack of Guarantee for FPI Boilers – Boiler owners are finding that vendors of SCR and SNCR technologies are unwilling to provide performance guarantees that the controls will meet the level of reduction called for in [NSPS Subpart Db (promulgated on September 16, 1998)].

4.4.2.3 SELECTIVE NON-CATALYTIC REDUCTION

Most boilers in the pulp and paper industry operate in the swing load mode, a consequence of supplying steam as required to the various components of the process. The problem with control of the required flue gas temperature window is an inherent difficulty with use of SNCR for load-following boilers, whether wood or fossil fuel.⁵⁵

Controlling flue gas temperatures over the entire range of operating loads that the boiler is expected to experience will be very difficult to achieve. Boilers in the pulp and paper industry rarely operate under base loaded conditions. Consequently, the location of the desired temperature window is expected to change constantly. Accurate, instantaneous temperature measurement, as well as the ability to accurately adjust the location of the injection nozzle, would be necessary. Ammonia slip would be a recurring problem associated with the application of the SNCR process to industrial boilers with fluctuating loads.⁵⁶

Inadequate reagent dispersion in the region of reagent injection in wood-fired boilers is also a factor mitigating against the use of SNCR technology.⁵⁷ Good dispersion of the reagent in the flue gas is needed to get good utilization of the reagent and to avoid excessive ammonia slip from the process. The need for a

⁵⁵ NCASI, *Information on Retrofit Control Measures for Kraft Pulp Mill Sources and Boilers for NO_x, SO₂ and PM Emissions*, Corporate Correspondence Memo 06-014.

⁵⁶ NCASI, *NO_x Control in Forest Products Industry Boilers: A Review of Technologies, Costs and Industry Experience*, Special Report 03-04.

⁵⁷ NCASI, *Information on Retrofit Control Measures for Kraft Pulp Mill Sources and Boilers for NO_x, SO₂ and PM Emissions*, Corporate Correspondence Memo 06-014.

sufficient volume in the boiler at the right temperature window precludes the application of SNCR in all types of industrial boilers.⁵⁸

Additional issues with SNCR include the potential for formation of ammonium sulfate salts (if sulfur oxides are present in the gas stream where they can react with excess ammonia from the SNCR process to form ammonium salts), which cause plugging problems. Ammonia also poses potential water quality issues - ammonia slip released to the atmosphere could contaminate surface waters by deposition.

SNCR has been applied to a few base-loaded wood and combination wood-fired boilers, mainly in the electric generating industry. However, its efficacy on wood-fired boilers with changing loads has not been demonstrated, except when used as a polishing step. Early use of ammonia injection in the case of one pulp mill wood-fired boiler met with significant problems and had to be abandoned (significant ammonia slip, caused by inefficient dispersion of the reagent within the boiler, was to blame). The boiler was unable to meet the manufacturer guarantee unless operated at less than half load. Even then, reducing NO_x to near permitted limits consumed considerably more ammonia than anticipated, leading to the formation of a visible ammonium chloride plume. A similar problem was encountered at a second FPI mill where nearly half the urea (on a molar basis) injected was being emitted as ammonia.⁵⁹

The use of SNCR on stoker type wood-fired boilers that have significant load swings has not been demonstrated. Excessive ammonia slip is a primary concern when adequate dispersion of the SNCR chemical is not achieved in the boiler ductwork within the range of residence times available and temperatures needed for the NO_x reduction reactions to go to completion. Additional concerns include the impact of interference from higher CO levels present in many wood-fired boilers, the possibility of appreciable SNCR chemical being absorbed onto the ash matrix in a wood-fired boiler, and the extent and fate of ammonia in scrubber purge streams.⁶⁰

The MRPO concludes, “if combustion zone temperatures within the boiler do not fall into [the ideal temperature range], then SNCR would be infeasible.”⁶¹

4.4.2.4 SELECTIVE CATALYTIC REDUCTION

The use of SCR on boilers operating in the FPI has also never been successfully demonstrated for wood boilers, and would face the same inherent problem of requiring it to be post PM-control to protect the catalyst, and

⁵⁸ NESCAUM and MANE-VU, *Assessment of Control Technology Options for BART-Eligible Sources – Steam Electric Boilers, Industrial Boilers, Cement Plant and Paper and Pulp Facilities*, March 2005.

⁵⁹ NCASI, *NO_x Control in Forest Products Industry Boilers: A Review of Technologies, Costs and Industry Experience*, Special Report 03-04.

⁶⁰ Ibid.

⁶¹ MACTEC, *Midwest RPO Boiler BART Engineering Analysis*, March 30, 2005.

achieving and maintaining the required temperature window for effective NO_x control.⁶² There are numerous other issues with using SCR including catalyst plugging and soluble alkali poisoning as well as increased energy consumption.⁶³

The use of SCR technology would be considered technically infeasible based upon the fact that post-particulate removal flue gas temperatures are typically significantly lower than those desired for this application. Many boilers are equipped with wet scrubbers for particulate emission (PM) control. Reheating the scrubbed flue gases from these boilers to bring them within the desired temperature window would involve a significant energy penalty. For pre-particulate removal flue gas application, catalyst deactivation from high particulate loading would be a serious concern, in addition to the impact of fluctuating loads on flue gas temperatures. Deactivation and/or poisoning could result from the size and density of fly ash particulate, and from their unique chemical and physical nature. Water-soluble alkali (such as Mg or Na) in particulate-laden gas streams has been known to poison SCR catalysts. Space considerations for installing a catalyst section in an existing boiler's ductwork are also important. Also note the use of solid fuels can result in catalyst contamination even with efficient PM control system and high moisture levels in exhaust air would result in inefficient SCR operation.⁶⁴

Most boilers feature a flue gas temperature at the economizer exit that is below the ammonium sulfate/bisulfate dew point. Air heater surfaces must withstand corrosion from ammonium sulfates and bisulfates, be easily cleaned with conventional soot blowing, and survive corrosion-inducing water washing. SO₃ produced by the catalyst may condense on cooler surfaces, depending on the temperature, during both steady-state and non-steady-state operation. Higher levels of SO₂ to SO₃ conversion could cause accelerated corrosion or higher SO₃-induced plume opacity. Minimizing ammonia levels in the stack (typically <2 to 3 ppm) is required to avoid problems with disposal of scrubber byproduct contaminated by ammonia. The use of a particular catalyst puts restrictions on the fuel flexibility for a boiler. For example, purchasing coal with fly ash containing calcium oxide and arsenic outside the defined range absolves the catalyst supplier from responsibility for arsenic poisoning.⁶⁵

The only "wood-fired" boiler SCR application in service in the U.S. was located at a woodworking facility in Ohio. This SCR was located downstream of a mechanical collector and electrostatic precipitator, operating in flue gas temperatures ranging from 550 to 650 °F. The only problem reported at this

⁶² NCASI, *Information on Retrofit Control Measures for Kraft Pulp Mill Sources and Boilers for NO_x, SO₂ and PM Emissions*, Corporate Correspondence Memo 06-014.

⁶³ NCASI, *NO_x Control in Forest Products Industry Boilers: A Review of Technologies, Costs and Industry Experience*, Special Report 03-04.

⁶⁴ Ibid.

⁶⁵ Ibid.

installation was minor catalyst blinding due to the deposition of fine particulate that escaped the PM collection devices. It was learned the operating temperature for this SCR system allowed the use of conventional catalysts designed to accommodate high dust applications. For these catalysts, the catalyst openings through which the flue gas flows are sized to provide proper surface area contact and sufficient flue gas velocity to minimize fouling. Low temperature catalyst designs are considerably different and would not be recommended for use on any high dust application. Based on this description of the air pollution control system configuration and the operating conditions for this particular wood-fired boiler, it is important to identify several specific differences between this installation and those that operate in the FPI. First, due to the requirement to provide hot air to burn all but the driest of wood fuels, wood-fired boilers are usually equipped with air preheaters. Thus, even when dry particulate control devices like an ESP are utilized, the installation of an SCR catalyst section after a PM control device is not amenable for adaptation to such boilers without, of course, incurring a severe energy penalty. Second, a significant portion of the FPI's wood-fired boilers is controlled for PM emissions by multiclones and wet scrubbers. Therefore the PM emissions from these would be higher than the example situation. Third, it is unclear how the Ohio facility's SCR system would have worked under the fluctuating boiler load characteristics common to many FPI boilers. Finally, sawdust, which was the fuel fired in the Ohio facility's boiler, is a low moisture fuel and the particulate matter present in the flue gases from its combustion is likely to be of different composition than when bark or hog fuel (typically much higher moisture) is burned.⁶⁶

Hence the use of SCR technology has clearly not been demonstrated for industrial wood, biomass or combination fuel-fired boilers in the FPI.⁶⁷

4.4.3 STEP 3 – EVALUATE CONTROL EFFECTIVENESS OF REMAINING CONTROL TECHNOLOGIES

Table 4-2 presents a ranking of the technically feasible control strategies in order of their effectiveness (i.e., potential control efficiency). For controls with a range of performance levels, the BART Guidelines note:

It is not [the U.S. EPA's] intent to require analysis of each possible level of efficiency for a control technique as such an analysis would result in a large number of options. It is important, however, that in analyzing the technology you take into account the most stringent emission control level that the technology is capable of achieving.

⁶⁶ Ibid.

⁶⁷ Ibid.

TABLE 4-2. RANKING OF CONTROL STRATEGIES

Control Strategy	Applicability	Potential Control Efficiency (%)
MdN	No. 1 & No. 2 Boilers	50 ^a
LNB	No. 2 Boiler Only	30 ^{b,c}
Original OFA + Boiler Tuning/Optimization	No. 1 Boiler	Base Case
Original OFA + NO _x Air + Fuel Blending + Boiler Tuning/Optimization	No. 2 Boiler	Base Case

^a Based on estimate from Energy System Associates.

^b NCASI, *NO_x Control in Forest Products Industry Boilers: A Review of Technologies, Costs and Industry Experience*, Special Report 03-04.

^c Based on estimate from B&W.

Note that MdN is included in Table 4-2 despite its questionable technical feasibility.

4.4.4 STEP 4 – EVALUATE IMPACTS AND DOCUMENT RESULTS

The technically feasible control technologies are evaluated on the basis of (1) costs of compliance, including consideration of the remaining useful life, (2) energy impacts, and (3) non-air quality environmental impacts.

For the purposes of this analysis, energy and non-air quality environmental impacts are considered minimal for all the technically feasible control options listed in Table 4-2. Per the BART Guidelines, the costs of compliance analysis for each control option consists of comparisons of the average cost effectiveness and the incremental cost effectiveness, which are defined in Section IV.D.4 as follows:

Average cost effectiveness means the total annualized costs of control divided by the annual emissions reduction (the difference between baseline annual emissions and the estimate of emissions after controls), using the following formula:

Average cost effectiveness (dollars per ton removed) = Control option annualized cost ÷ (Baseline annual emissions – Annual emissions with Control option)

...the incremental cost effectiveness calculation compares the costs of performance level of a control option to those of the next most stringent option, as shown in the following formula (with respect to cost per emissions reduction):

Incremental Cost Effectiveness (dollars per incremental ton removed) = (Total annualized costs of control option) – (Total annualized costs of next control

option) ÷ (Control option annual emissions) – (Next control option annual emissions)

The average and incremental (where applicable) cost effectiveness for each feasible control option for the Ashdown Mill's No. 1 and No. 2 Power Boilers are summarized in Table 4-3. Detailed control costs calculations are presented in Appendix B.

TABLE 4-3. CONTROLS COSTS SUMMARY

Emission Unit	Control Strategy	Total Annualized Cost (MM\$)	NO _x Removed (tpy)	Cost Effectiveness	
				Average (\$/ton)	Incremental (\$/ton)
No. 1 Power Boiler	MdN	3.94	542	7,262	17,354
No. 2 Power Boiler	MdN	5.35	1,257	4,259	9,571
	LNB	1.10	754	1,465 ^b	N/A

^b This estimate is consistent with NCASI's Special Report 03-04, which states, "for pulverized coal boilers, a 30 percent NO_x reduction could be achieved with LNB at a cost of <\$2,000/ton."

Based on Domtar's analysis, MdN is considered cost prohibitive for both the No. 1 and No. 2 Power Boilers and is ruled out as a BART option. Based on steps 1 through 4 of the BART determination analysis, no retrofit controls are available for the No. 1 Power Boiler and LNB is the best available retrofit control technology for the No. 2 Power Boiler.

PROPOSED BART DETERMINATIONS FOR NO_x

For the No. 1 and No. 2 Power Boilers, Domtar proposes NO_x BART limits of 179.6 lb/hr and 368.7 lb/hr, respectively.

A summary of all proposed BART determinations is provided in Table 4-4. Please note that while example control technologies theoretically capable of achieving the proposed BART limits are listed, Domtar reserves the right to implement other equivalent control strategies between now and the BART effective date (~2013) to meet the same emission limits.

TABLE 4-4. SUMMARY OF PROPOSED BART DETERMINATIONS

Emission Unit	Pollutant	BART Limit	<i>Example Control Technology</i>
No. 1 Power Boiler	PM	0.07 lb/MMBtu (Boiler MACT)	<i>WESP</i>
	SO ₂	442.5 lb/hr	<i>No additional add-on controls (existing fuel restrictions)</i>
	NO _x	179.6 lb/hr	<i>No add-on controls</i>
No. 2 Power Boiler	PM	0.07 lb/MMBtu (Boiler MACT)	<i>Wet Scrubber</i>
	SO ₂	788.2 lb/hr	<i>Wet Scrubber</i>
	NO _x	368.7 lb/hr (30 Percent Control)	<i>LNB</i>

4.5 STEP 5 – EVALUATE VISIBILITY IMPACTS

The degree of visibility improvement is assessed based on the change in modeled impacts for the pre-control (i.e., the BART applicability analysis) and post-control (i.e., the predicted maximum 24-hour emission rate after implementation of BART) emission scenarios. Per the BART Guidelines, this assessment “may consider the frequency, magnitude, and duration components of [visibility] impairment.”

The post-control modeling for the visibility improvement analysis was conducted using the CALPUFF modeling system in the same manner as the ADEQ’s BART applicability analysis, which is described in Section 3 of this report and in the Protocol (see Appendix A). In fact, the post-control modeling was conducted using the same CALPUFF, POSTUTIL, and CALPOST input files generated by the ADEQ for the applicability analysis. The only changes made to these files for the post-control modeling was to the emissions rates and stack parameter changes associated with implementing the chosen BART controls. Table 4-5 and Table 4-6 summarize the maximum 24-hour average emission rates and the stack parameters, respectively, that were modeled in the post-control analysis.

TABLE 4-5. SUMMARY OF 24-HOUR AVERAGE MAXIMUM POST-CONTROL EMISSION RATES

Emission Unit	NO_x Emissions (lb/hr)	SO₂ Emissions (lb/hr)	Total PM Emissions (lb/hr)
No. 1 Power Boiler	179.6	442.5	40.6
No. 2 Power Boiler	368.7	788.2	57.4

TABLE 4-6. POST-CONTROL STACK PARAMETERS

Emission Unit	LCC East (km)	LCC North (km)	Elevation (m)	Stack Height (m)	Stack Diameter (m)	Exhaust Temperature (K)	Exhaust Velocity (m/s)
No. 1 Power Boiler	267.47491	-698.66686	97.5	66.1	1.890	522	26.76
No. 2 Power Boiler	267.48245	-698.74355	97.5	71.6	3.659	325	11.92

Visibility improvement is quantified and judged in a cumulative matter. That is, to compare to the pre-control modeling analysis executed by the ADEQ, Domtar’s post-control modeling analysis simulated all emissions reductions from both emission units. Note that since maximum applicability analysis impacts were less than 0.5 Δ dv for the Sipsey Class I area, this area was not evaluated in the post-control scenario. Table 4-7 summarizes the results of the visibility improvement analysis.

TABLE 4-7. SUMMARY OF VISIBILITY IMPROVEMENT ANALYSIS RESULTS

Class I Area	Maximum 24-hour Impact (Δdv)^a	Number of Days > 0.5 Δdv^a	Number of Days > 1.0 Δdv^a
Caney Creek	2.039	118	29
Upper Buffalo	1.029	14	1
Mingo	0.836	2	0
Hercules-Glades	0.631	2	0

^a For total modeled period: years 2001, 2002, and 2003.

As shown in Table 4-7, the application of BART on the Ashdown Mill's No. 1 and No. 2 Power Boilers results in significant visibility impacts improvement in the affected Class I areas. Visibility impairment at Upper Buffalo was reduced by 29 percent while impairment at Caney Creek was reduced by 32 percent (based on total impact and excluding any days with impacts less than 0.50 Δdv). The number of days within the modeled three-year period with impacts greater than 0.50 Δdv decreased from 159 to 118 for the Caney Creek Class I area and from 18 to 14 for the Upper Buffalo Class I area.

In addition to the cumulative analysis, the ADEQ requested emission unit specific and pollutant specific modeling. Since cumulative analysis impacts in the Upper Buffalo and Mingo Class I areas are minimal, the emission unit and pollutant specific modeling was only conducted for the Caney Creek Class I area. The results of these pre- and post-control analyses (each conducted for the entire modeling period: year 2001, 2002, and 2003) are presented in Table 4-8.

TABLE 4-8. EMISSION UNIT & POLLUTANT SPECIFIC MODELING RESULTS

Emission Unit	Pollutant	Pre-Control Scenario		Post-Control Scenario	
		Max. 24-hour Impact (Δdv)	Number of Days > 0.5 Δdv	Max. 24-hour Impact (Δdv)	Number of Days > 0.5 Δdv
No. 1 Power Boiler	PM	0.252	0	0.065	0
	SO ₂	0.575	2	0.575	2
	NO _x	0.398	0	0.398	0
No. 2 Power Boiler	PM	0.135	0	0.095	0
	SO ₂	1.036	5	1.036	5
	NO _x	1.072	35	0.762	14
No. 1 & 2 Power Boilers	PM	0.391	0	0.156	0
	SO ₂	1.542	30	1.542	30
	NO _x	1.427	54	1.129	36

Additionally, as requested by the ADEQ in its September 8, 2006, letter, Domtar's post-control (and pre-control, where different from the ADEQ's applicability modeling files) CALPUFF, POSTUTIL, and CALPOST input files and CALPOST output files are included with this report on electronic media. The file naming convention is explained below. Note that all filenames contain the "doas" root (characters 4 through 7) to denote Domtar – Ashdown. Note also that path names will need to be modified to represent the user's directory structure when replicating these analyses.

File Naming Convention:

CALPUFF & POSTUTIL		<i>xx_d o a s y y (v *) . f f f</i>	
<i>xx</i> = Model:	<i>cp</i> = CALPUFF		
	<i>pu</i> = POSTUTIL		
<i>yy</i> = Year:	01 = 2001		
	02 = 2002		
	03 = 2003		
<i>v*</i> = Pollutant Run Identifier	A = PM Pre-controls		
	B = PM Post-controls		
	C = SO ₂ Pre- and Post-controls		
	D = NO _x Pre-controls		
	E = NO _x Post-controls		
<i>fff</i> = File type:	<i>inp</i> = Input		

CALPOST		<i>xx_d o a s y y z (v *) . f f f</i>	
<i>xx</i> = Model:	<i>ct</i> = CALPOST		
<i>yy</i> = Year:	01 = 2001		
	02 = 2002		
	03 = 2003		
<i>z</i> = Class I area:	<i>c</i> = Caney Creek		
	<i>m</i> = Mingo		
	<i>u</i> = Upper Buffalo		
	<i>h</i> = Hercules-Glades		
	<i>s</i> = Sipseey		
<i>v*</i> = Pollutant Run Identifier	A = PM Pre-controls		
	B = PM Post-controls		
	C = SO ₂ Pre- and Post-controls		
	D = NO _x Pre-controls		
	E = NO _x Post-controls		
<i>fff</i> = File type:	<i>inp</i> = Input		
	<i>lst</i> = Output		

The "v" designator is used only for the unit and source specific model runs requested by ADEQ.

APPENDIX A – ADEQ’S DRAFT BART MODELING PROTOCOL

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**Draft
BEST AVAILABLE RETROFIT
TECHNOLOGY (BART)
MODELING PROTOCOL**

June 7, 2006

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I. Introduction

On 6 July 2005, the U.S. Environmental Protection Agency (EPA) published final amendments to its 1999 Regional Haze Rule in the Federal Register, including Appendix Y, the final guidance for Best Available Retrofit Technology (BART) determinations (70 FR 39104-39172). The BART rule requires the installation of BART on emission sources that fit specific criteria and “may reasonably be anticipated to cause or contribute” to visibility impairment in any Class I area. Air quality modeling is the preferred method for establishing which emission sources cause or contribute to visibility impairment. Arkansas’ BART modeling protocol is provided herein.

According to the Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determination; Final Rule (40 CFR Part 51, p 39125), each state is required to develop a BART Modeling Protocol that describes the required methodology to assess the levels of controls needed on sources subject to BART. The aforementioned regulation also requires states to work in partnership with all stakeholders including Tribes, EPA, Federal Land Managers (FLMs), Regional Planning Organizations (RPOs) and the various source operators. Although states are required to work in concert with the previously mentioned stakeholders, EPA has the ultimate authority to approve or disapprove a state’s State Implementation Plan (SIP).

The main objective of this protocol is compliance with the RHR visibility improvement goals. To accomplish this goal, the Arkansas Department of Environmental Quality (ADEQ) has set forth three functions of this protocol. First, ADEQ will use the protocol to determine which BART-eligible units are subject-to-BART and must perform a BART-analysis. Second, facilities that ADEQ notifies that are subject-to-BART will use this protocol to conduct post-control modeling required for their BART-analysis. Third, the results from this protocol will be used to conduct cumulative modeling to show the change in visibility impact on Class I areas based on ADEQ’s BART determination and the BART emission limits for facilities based on their BART-analysis. The subject-to-BART and final modeling will be submitted to the EPA as part of the BART section of the Arkansas State Implementation Plan (SIP) for Regional Haze.

The AR RH SIP submittal deadline to EPA as set forth in the Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determination; Final Rule (40 CFR Part 51, p 39156) is December 17, 2007. To meet this deadline, ADEQ has developed a schedule for completing BART determinations and implementing the BART strategy in order to meet the mandatory SIP submittal deadline (Appendix A). As shown in Appendix A, the modeling results must be completed no later than March 1, 2007.

The Central States Regional Planning Association (CENRAP) contracted with Alpine Geophysics, LLC to develop a modeling protocol for the states within CENRAP’s region of which the state of Arkansas is a member. On December 22, 2005, Alpine Geophysics, LLC delivered the final version of the CENRAP BART Modeling Guidelines (Tesche, et

al, 2005). However, comments from EPA Regions VI and VII and the Federal Land Managers (FLMs) were not incorporated into the guidelines; thus, Alpine Geophysics, LLC rewrote the guidelines to reflect the comments from Regions VI and VII and FLMs. These guidelines were re-issued February 3, 2006. Hence, CENRAP's BART Modeling Guidelines (Teschke, et al, 2005) have been approved by Regions VI and VII and the FLMs. Therefore, the Planning and Air Quality Analysis Branch, Air Division, Arkansas Department of Environmental Quality has chosen to adopt the CENRAP BART Modeling Guidelines as ADEQ's BART Modeling Protocol. Additionally, in preparing this draft protocol, ADEQ also consulted the following draft BART modeling protocols:

1. Best Available Retrofit Technology (BART) Modeling Protocol to Determine Sources Subject to BART in the State of Kansas draft version February 24, 2006
2. Best Available Retrofit Technology (BART) Modeling Protocol to Determine Sources Subject to BART in the State of Minnesota draft version February 24, 2006

This draft protocol is most similar to the CENRAP BART Modeling Guidelines. These guidelines were developed to ensure "consistency between states in the development of BART modeling protocols and to harmonize the approaches between adjacent RPOs" (Teschke, et al, 2005).

Soon after the finalization of this modeling protocol, ADEQ will notify sources subject-to-BART. For those facilities subject-to-BART, ADEQ will provide guidance for conducting their BART-analyses.

II. Background

The Clean Air Act Amendments (CAAA) of 1977 established 156 Class I areas where visibility was determined to be an important value (Figure 1). Areas designated as Class I areas are those national parks exceeding 6000 acres, wilderness areas and national memorial parks exceeding 5000 areas, and all international parks that were in existence on August 7, 1977. While Rainbow Lake Wilderness Area, Wisconsin has been designated as a Class I area, the FLMs have indicated that visibility is not a valuable characteristic and therefore, is not included in BART or other RH analyses.

The state of Arkansas has within her boundary two mandatory Class I federal areas (Class I area), Upper Buffalo Wilderness Area and Caney Creek Wilderness Area which are managed by the United States Forest Service (Figure 2). However, there are two Class I areas in southern Missouri that are located downwind of facilities operating in Arkansas. The Missouri Class I areas are Hercules-Glade Wilderness Area (US Forest Service) and Mingo National Wildlife Refuge (US Fish and Wildlife). While EPA has not listed the maximum distance from a Class I area to model, this criteria has been set by CENRAP as 300 km. As shown in Figure 3, the eastern portion of Arkansas is within the 300 km radius of Sipsey Wilderness Area (US Forest Service), Alabama. Therefore, there are

five Class I areas Arkansas will be performing BART determination/exemption modeling (Table 1).



Figure 1 Mandatory Class I federal areas in the United States of America

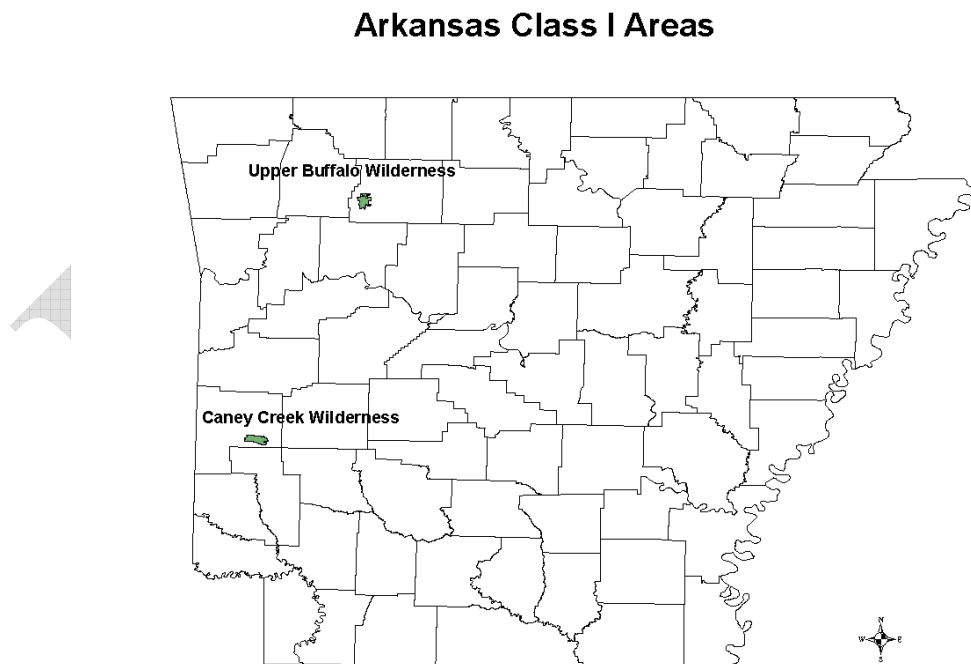


Figure 2 Arkansas's Class I areas

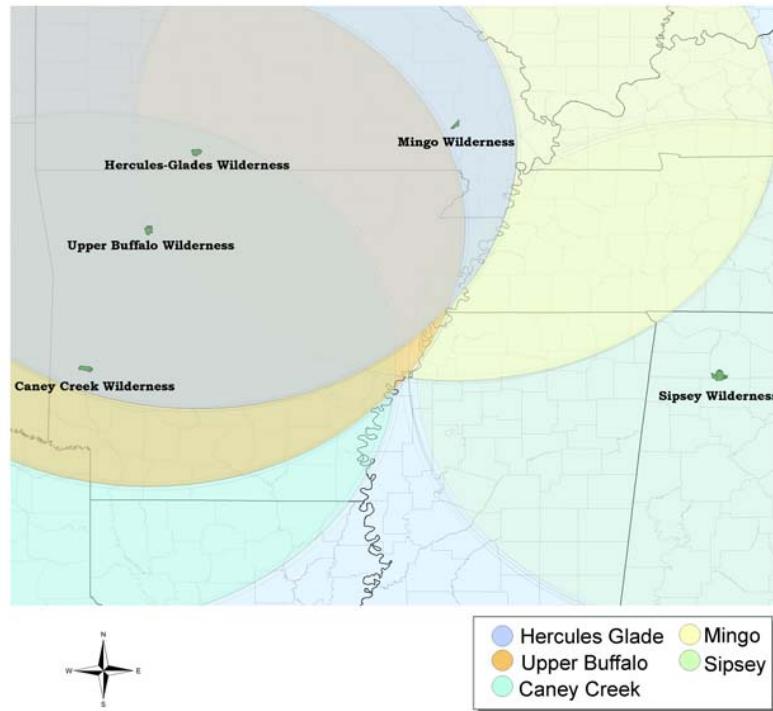


Figure 3 Map showing the 300 km radius buffer zones around five separate receptors (north, south, east, west, and center) located in the following Class I areas: Upper Buffalo, Caney Creek, Hercules Glade, Mingo, and Sipsy. This map was developed to determine which Class I areas will be assessed during the BART determination modeling

Table 1 Class I areas and the State they are located in as well as the supervising agencies ADEQ will evaluate during the BART determination/exemption modeling

Class I Area	State	Supervising Agency
Upper Buffalo Wilderness Area	AR	U.S. Forest Service
Caney Creek Wilderness	AR	U.S. Forest Service
Hercules Glade Wilderness Area	MO	U.S. Forest Service
Mingo NWS	MO	U.S. Fish and Wildlife
Sipsy Wilderness Area	AL	U.S. Forest Service

III. BART-Eligible Sources

The BART requirements in the RHR are intended to reduce emissions specifically from large emission units that, due to age, were exempted from other control requirements of the CAAA. For an emissions unit to be considered eligible for BART, it must fall into one of 26 specified categories, must have the potential to emit at least 250 tons per year of certain haze-forming pollutants, and must have been in existence on August 7, 1977, but not in operation before August 7, 1962.

ADEQ staff determined Arkansas' BART-eligible sources by first identifying which of Arkansas' stationary sources fit the first criteria of being listed in the BART 26 specific categories. After identifying the sources which fit the first criteria, a database search of

these facilities was performed to determine whether or not these emitting units' potential to emit were at least 250 tons per year of sulfur dioxide (SO₂), nitrogen oxides (NO_x), and particulate matter (PM). The next stage of determining BART-eligibility was to research the permit applications for the year the point source was placed into operation. The final step in the process was to contact facilities for the exact date of operation especially for sources that were placed into operation in the years 1977 and 1962. Tables 2 and 3 contain the list of BART-eligible facilities (18) by BART source category and the number of BART-eligible emitting units (27) within each facility. Figure 4 is a map of Arkansas which shows the location of the 18 BART-eligible facilities located in Arkansas. Figure 5 depicts the five Class I areas Arkansas will be assessing and the BART-eligible sources in Arkansas. Appendix B contains maps showing the receptors at each Class I area ADEQ will be assessing.

Table 2 Fossil fuel-fired steam electric plants > 250 MMBtu/hr and Kraft pulp mills facilities with BART-eligible emission units

BART Source Category Number and Name	Facility Name/Location	Facility ID	AFIN	Unit ID	Unit Description
1. Fossil fuel-fired Electric Plants > 250 MMBtu/hour – Electric Generating Units (EGUs)	American Electric Power (SWEPCO)/Gentry	05-007-00107	04-0017	SN-01	Boiler
	AR Electric Cooperative/Augusta	05-147-00024	74-00024	SN-01	Boiler 1350mm
	AR Electric Cooperative/Camden	05-103-00055	52-00055	SN-01	Boiler
	Entergy – Lake Catherine/Jones Mill	05-059-00011	30-00011	SN-03	Unit 4 Boiler
	Entergy – Ritchie Plant/Helena	05-107-00017	54-00017	SN-02	Unit 2
	Entergy – White Bluff/Redfield	05-069-00110	35-00110	SN-01	Unit 1
	Entergy – White Bluff/Redfield	05-069-00110	35-00110	SN-02	Unit 2
	Entergy – White Bluff/Redfield	05-069-00110	35-00110	SN-05	Auxiliary Boiler
3. Kraft Pulp Mills	Domtar, Inc./Ashdown	05-081-00002	41-00002	SN-03	#1 Power Boiler
	Domtar, Inc./Ashdown	05-081-00002	41-00002	SN-05	#2 Power Boiler
	Delta Natural Kraft/Pine Bluff	05-069-00017	35-00017	SN-02	Recovery Boiler
	Georgia – Pacific Paper/Crossett	05-003-00013	02-00013	SN-22	9A Boiler
	Green Bay Packing/Morrilton	05-029-00001	15-00001	SN-05A	Recover Boiler
	Potlatch/McGehee	05-041-00036	21-00036	SN-04	Power Boiler

Table 3 Petroleum refineries, sintering plants and chemical processing plant facilities with BART-eligible emissions units

BART Source Category Number and Name	Facility Name/Location	Facility ID	AFIN	Unit ID	Unit Description
11. Petroleum Refineries	Lion Oil/El Dorado	05-139-00016	70-00016	SN-809	#7 Catalyst Regenerator
19. Sintering Plants	Big River Industries /West Memphis	05-035-00082	198-00082	SN-01	Kiln A
21. Chemical Processing Plants	Albermarle – South Plant/Magnolia	05-027-00028	14-00028	SR-01	Tail Gas Incinerator
	Albermarle – South Plant/Magnolia	05-027-00028	14-00028	BH-01	Boiler #1
	Albermarle – South Plant/Magnolia	05-027-00028	14-00028	BH-02	Boiler #2
	Eastman Chemical/Batesville	05-063-00036	32-00036	6M01-01	3 Coal Boilers
	El Dorado Chemical/El Dorado	05-139-00040	70-00040	SN-08	West Nitric Acid Plant
	El Dorado Chemical/El Dorado	05-139-00040	70-00040	SN-09	East Nitric Acid Plant
	El Dorado Chemical/El Dorado	05-139-00040	70-00040	SN-10	Nitric Acid Concentrator

Arkansas Class I Areas and BART-Eligible Facilities

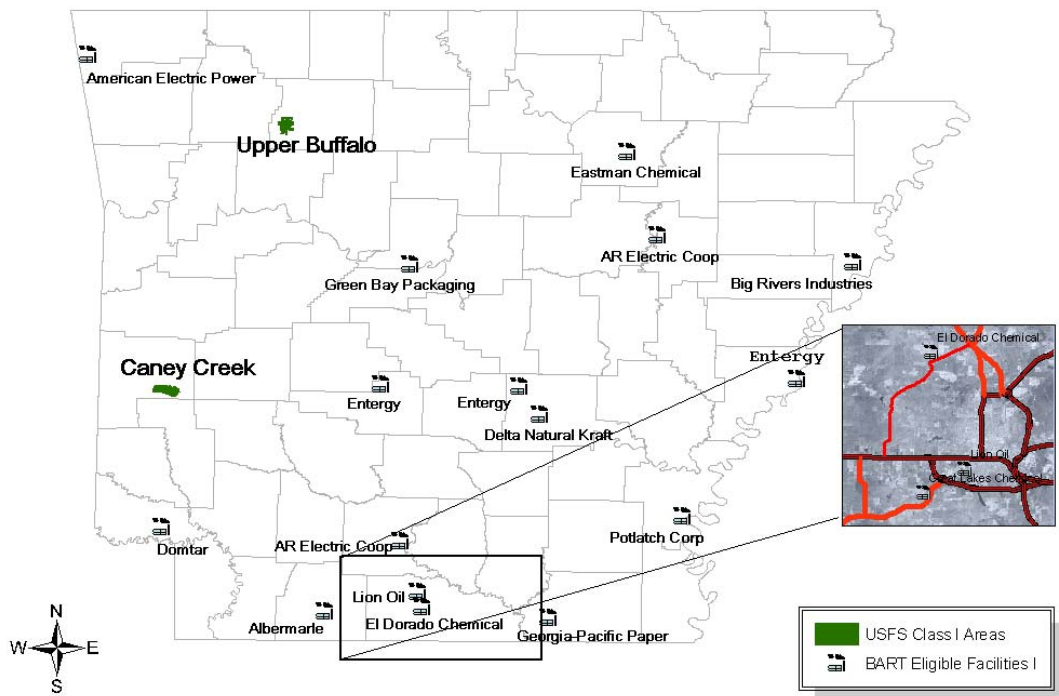


Figure 4 Map indicating the locations of Upper Buffalo, Caney Creek and the eighteen BART-eligible facilities located in Arkansas

Class I Areas Assessed

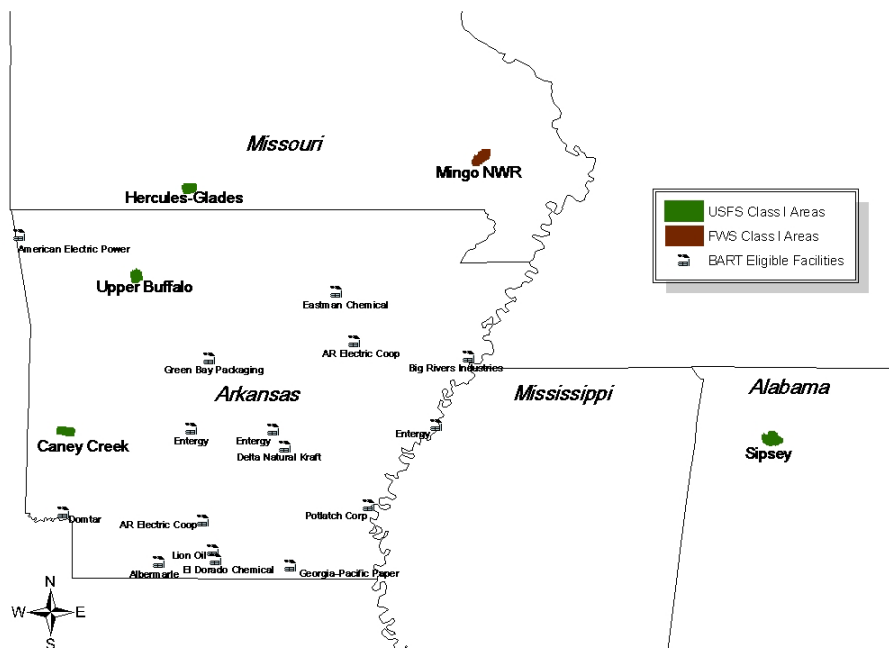


Figure 5 Map indicating the locations of Upper Buffalo, Caney Creek, Hercules Glade, Mingo and the eighteen BART-eligible facilities located in Arkansas

IV. CAIR and Arkansas

The Clean Air Interstate Rule was finalized in May 2005 by EPA and applies to states in the eastern U.S. Reconsiderations were finalized March 2006. This rule address air pollution transport across state borders. EPA determined which states must reduce which pollutants based on modeling which showed how the travel of pollution affects non-attainment in other states. CAIR requires states to reduce NO_x and/or SO₂ emissions. Of the three programs in CAIR, Arkansas is required to participate in only the Ozone-Season NO_x reductions program. Although EPA's BART Modeling Guidance allows CAIR states to participate in the CAIR cap and trade program, the state of Arkansas is not eligible for the aforementioned trading program because Arkansas is in CAIR only for NO_x during the ozone season. Therefore, in Arkansas CAIR is **not better** than BART. Thus BART-eligible EGUs will be modeled for BART determination/exemption by ADEQ.

V. BART Air Quality Modeling Approach

According to EPA's BART Modeling Guidance, "CALPUFF is the best regulatory modeling application currently available ... and is currently the only EPA-approved model..." (p 45); therefore, ADEQ and CENRAP have chosen to use CALPUFF in the

BART determination process as well as in the post-control analysis. One of the air quality modeling approaches suggested by EPA in the BART guidance is an individual source attribution approach. This is the approach ADEQ proposes to take. Specifically, this entails modeling source-specific units and comparing modeled impacts to a particular deciview threshold (described below). ADEQ has decided to conduct the subject-to-BART modeling, rather than have each BART-eligible facility either conduct the modeling or hire a contractor. This plan will eliminate the need for ADEQ to quickly review many air quality modeling analyses conducted using varying approaches. This plan will also satisfy the need to use a consistent approach among the modeling analyses. Once the subject-to-BART modeling is complete, all the modeling inputs will be available to facilities subject to BART for them or their consultants to conduct modeling for making BART analyses.

ADEQ will follow EPA's BART Modeling Guidance (p 42) in setting a threshold limit in determining whether a BART-eligible source is either subject-to-BART or exempt. According to the aforementioned modeling guidance, an individual source will be considered to "cause visibility impairment" if the emissions results in a change (Δ) in deciviews (dv) that is greater than or equal to 1.0 deciview on the visibility in a Class I area. Additionally, if the emissions from a source results in a change in visibility that is greater than or equal to 0.5 dv in a Class I area the source will be considered to "contribute to visibility impairment" (BART Final Rule, 40 CFR 51 p 39113). Thus, ADEQ has set the threshold limit at **0.5 dv**.

The modeling approach discussed here is specifically designed for conducting the subject-to-BART screening analyses. There may be differences between modeling for conducting BART analyses and that for conducting a visibility analysis for a New Source Review permit, which may involve similar emission sources and the same air dispersion model used here.

To **ensure** that no sources pass the screening test when they should fail, the simple approach, by its nature, must be the most conservative of all the conditions likely to be examined for the source in question. For example, many factors influence the contribution of a source to the Class I area other than distance. The frequency of winds transporting the pollutants toward the Class I area may often be important to include for a reliable screening analysis. Also, a more distant Class I area downwind in the predominant wind direction from a source may receive a higher visibility impact than a closer Class I area that is infrequently downwind of the source. Another example of conservatism in the screening process is the use of the latest beta version of the CALMET/CALPUFF modeling system using the no-observation (no-obs) mode (the prognostic meteorological model MM5). Thus, the **maximum** impact instead of the 98th percentile will be used to determine if a source has an impact on visibility in a Class I.

Additionally, the BART analysis process includes several other steps in addition to the modeling described in this protocol (EPA, 2005). These steps, none of which are addressed in this document, include detailed analysis of:

- Costs of compliance among the various retrofit control options
- Energy and non-air quality impacts
- Existing pollution control technologies in use at the BART-eligible unit particularly with respect to their affecting the choice of retrofit options
- Remaining useful life of the units and/or facility
- Improvements in visibility expected from the use of BART controls.

VI. BART-Eligible Units Physical Parameters

The physical characteristics of the BART-eligible point sources to be used for the screening stage one analysis will be provided by ADEQ staff. For the stage two screening analysis, ADEQ staff will work with the BART-eligible facilities in the development of actual emissions.

A. Stack Parameters

Stack parameters required for modeling BART-eligible units were extracted from the permit applications. Stack parameters include height of the stack opening from ground in meters, inside diameter in meters, exit velocity in meters per second, exit gas temperature in Kelvin, ground elevation of the stack base in meters, and location coordinates of the stack in Lambert Conformal Conical (LCC). The stack coordinates were taken (in Universal Transverse Mercator, UTM, and then converted to LCC) by ADEQ staff and then verified using ArcMap. Because the BART modeling focuses on mesoscale transport to Class I areas, other source term parameters (needed to calculate localized impacts) such as building heights and widths for calculating downwash will not be used. Appendix C contains tables indicating the stack parameters and coordinates for each BART-eligible emitting unit.

B. Emission rates

ADEQ notified by email the BART-eligible facilities to provide the 24-hour average **actual** emission rate with normal operations from the highest emitting day of the year. Excluded from consideration are days where start-up, shutdown or malfunctions occurred unless these activities are regular, frequently occurring components of the source's operation cycle.

ADEQ does not intend to use emissions of VOCs and ammonia from facilities for subject-to-BART analysis. Only specific VOC compounds form secondary organic aerosols that affect visibility. These compounds are a fraction of the total VOCs reported in the emissions inventory, and ADEQ does not have the breakdown of VOC emissions necessary to model those that only impair visibility. Further, the prescribed screening model (CALPUFF) cannot simulate formation of particles from anthropogenic VOCs, nor their visibility impacts. Ammonia from specific sources will not be evaluated in this process, although ammonia is included in the modeling as a background concentration—this will be discussed later in this modeling protocol. The appropriate VOCs and

ammonia emission data can, and will be, included in regional scale modeling used for the Regional Haze SIP.

VII. Air Quality Model and Inputs

As stated in the previous section, CALPUFF is the preferred regulatory air dispersion model for long distance and therefore is the model ADEQ will be using in the BART determination process. ADEQ recognizes that CALPUFF has limited ability to simulate the complex atmospheric chemistry involved in the estimation of secondary particulate formation. However, for purposes of the subject-to-BART analysis, ADEQ intends to use CALPUFF for the following reasons:

1. The increased level of effort required for conducting particulate apportionment in the regional scale, full-chemistry Eulerian model (CAMx) to acquire individual source contributions to Class I areas, relative to the simplicity of the CALPUFF model
2. The lack of a plume-in-grid feature with the particulate apportionment technique currently available in CAMx
3. The desire to be consistent with other CENRAP states, which all (except Texas and Iowa) appear to be using CALPUFF
4. The limited scope of what this modeling is to determine
5. The additional modeling of BART controls that will be conducted as part of the Regional Haze SIP with the CAMx or CMAQ model(s). EPA's BART guidance states that States should follow the EPA's Interagency Workgroup on Air Quality Modeling (IWAQM) guidance, Phase 2 recommendations for long-range transport. The IWAQM guidance was developed to address air quality impacts as assessed through the Prevention of Significant Deterioration (PSD) program at Class I areas, where the source generally is located beyond 50 km of the Class I area. The IWAQM guidance does not specifically address the type of assessment that will occur with the BART analysis.

EPA recommends in their BART modeling guidelines (2005) that States follow the Interagency Workgroup on Air Quality Modeling (IWAQM) Phase II (1998) for long-range transport. The IWAQM guidance was developed to address air quality impact – as assessed through the Prevention of Significant Deterioration (PSD) program – at Class I areas, where the source generally is located beyond 50 km of the Class I area. The IWAQM guidance does not specifically address the type of assessment that will occur with the BART modeling.

A. CALPUFF Screening Modeling:

CALPUFF modeling will be performed on all Arkansas BART-eligible sources. ADEQ intends to closely follow the CENRAP BART modeling protocol for most of the settings and inputs. Kansas attempted puff splitting and found this method to be computationally prohibitive on the current domain (State of Kansas, 2006). Also, according to Tesche, et al (2005),

“There is no quantitative evidence that the horizontal and vertical puff-splitting algorithms in CALPUFF yield improved accuracy and precision in model estimates of inert or linearly reactive pollutants although conceptually the methods have appeal in that they attempt to mimic lateral and vertical wind speed and direction shears.” (p 6-6)

Therefore, ADEQ will not invoke puff splitting in the no-obs screening analysis nor in the refined screening analysis. However, if a potentially subject-to-BART facility wishes to invoke the puff splitting mode, they will be required to notify ADEQ in writing of their intent and provide a protocol for approval prior to performing the analysis.

1. Modeling domain

The CALPUFF modeling will be conducted on the CENRAP central 6 km grid. The extent of the proposed CALPUFF domain is shown in Figure 2.

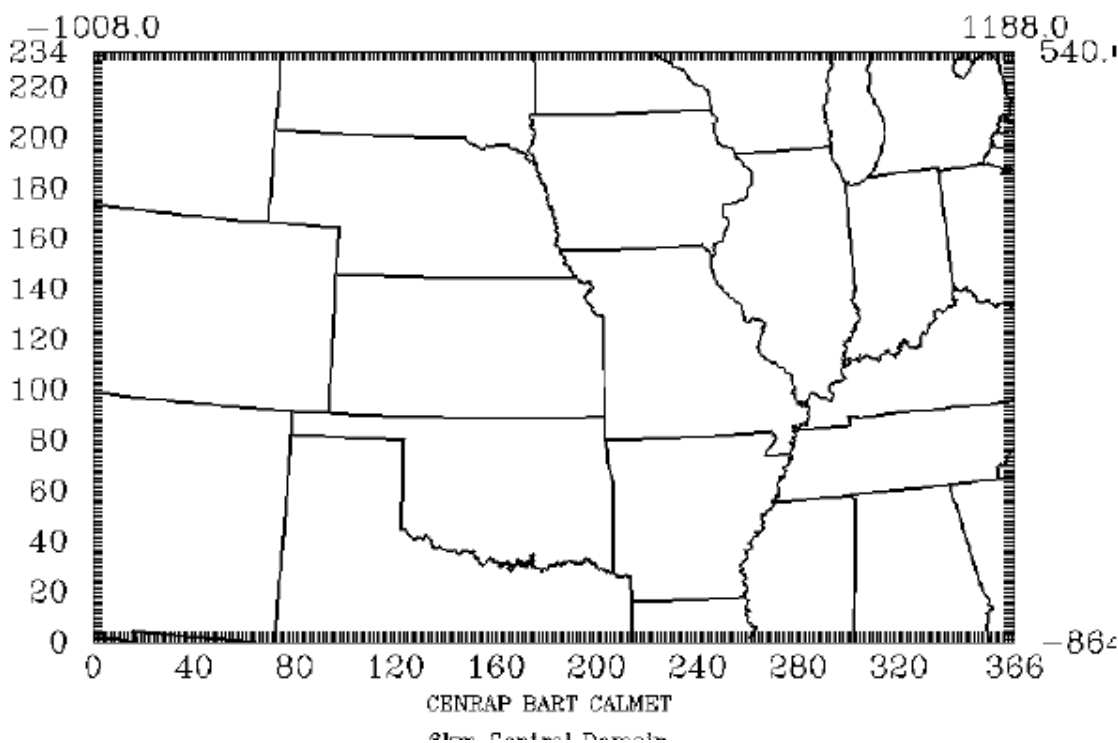


Figure 6 6 km CENRAP Central CALPUFF domain (Tesche, et al, 2005)

CALPUFF will be applied to each source for three annual simulations spanning the years 2001 through 2003. The IWAQM Phase II guidance allows the use of fewer than 5 years of meteorological data if a meteorological model using four-dimensional data assimilation is used to supply data. This is the case in this modeling analysis. See the section on meteorology for more information.

2. CALPUFF system implementation

There are three main components to the CALPUFF model:

1. Meteorological Data Modeling (CALMET);
2. Dispersion Modeling (CALPUFF); and
3. Post-processing (CALPOST)

Versions of the modeling components to use in this BART analysis are shown in Table 4.
Table 4 CALPUFF Modeling Components

Processor	Version	Level
TERREL	3.311	030709
CTGCOMP	2.42	030709
CTGPROC	2.42	030709
MAKEGEO	2.22	030709
CALMM5	2.4	050413
CALMET	5.53a	040716
CALPUFF	5.753	051130
POSTUTIL	1.4	040818
CALPOST	5.6392	051130

The specific use of each of these components in the BART analysis is described in more detail below.

For screening applications, ADEQ will use the VISTAS version which is the latest ‘beta’ versions of the CALMET/CALPUFF modeling system. Note that these are **not** the EPA guideline codes but rather an updated version containing recent (as of this writing) science improvements and bug fixes. The current guideline CALPUFF code is version 5.7, level 030402. This substitution results from EPA phasing out the use of the legacy Pasquill-Gifford (P-G) dispersion parameters with the introduction of AERMOD as a new guideline model. CALPUFF employs the AERMOD turbulence-based dispersion coefficients and probability density function (pdf) dispersion methods scheme instead of P-G.

The appropriate model codes may be downloaded from www.src.com or purchased with the latest graphical user interface (GUI) from the model developer. The sequence of model processors listed in Table 4 corresponds to the order in which the programs are typically run.

3. Meteorological data modeling (CALMET)

ADEQ will use the 2001-2003 CENRAP developed no-obs CALMET dataset for the screening analysis.* This decision was based on EPA Regions VI and VII written comments on the CENRAP BART Modeling Guidelines (Teschke, et al, 2005) which state,

“Normally, in accordance with Section 8.3.1.2 (d) of the Guideline on Air Quality Models, the EPA would require that observations be incorporated in conjunction with prognostic meteorological data. While the idea of use of prognostic data alone holds promise, it is our opinion that this option requires further evaluation to insure that this approach does not bias CALPUFF towards underestimation (Guideline on Air Quality Models, Section 3.2.2 (d)(iv)). While we have significant concern regarding the use of the CALMET fields as they have been developed under the procedures documented in this protocol, we would consider the use of the CALMET meteorological fields provided the screening methodology described in Section 6.1 of the protocol is strictly adhered to. In this case, we feel that the use of the maximum visibility impact rather than the 98th percentile value is conservative in its application, and would overcome concerns of a potential bias towards underprediction [sic] of the “no-observation” mode. Under these circumstances, we would consider the use of the CALMET fields acceptable for the CALPUFF screening procedure.” (EPA, 2005)

As stated in Section V. BART Air Quality Modeling Approach, ADEQ will use the **maximum** impact instead of the 98th percentile to determine if a source has an impact on visibility in a Class I.

However, subject-to-BART facilities have the option of using the CENRAP CALMET processed data or incorporating observational meteorological data into the aforementioned CALMET data. If a subject-to-BART facility opts to use the CENRAP CALMET processed data, then the facility will be required to use the maximum impact instead of the 98th percentile (8th day). If a subject-to-BART facility decides they would rather use the 98th percentile, then the facility will be required to incorporate observational data and provide a protocol as well as a performance evaluation which will need to be approved by ADEQ, EPA, and the FLMs.

Appendix F contains the detailed information on all CALMET setting that was used to develop the post-processed no-obs data fields.

4. Dispersion modeling (CALPUFF)

The CALMET output is used as input to the CALPUFF model, which simulates the effects of the meteorological conditions on the transport and dispersion of pollutants from an individual source. In general, ADEQ proposes to use the recommended default options in the CALPUFF model. There are some deviations, which are discussed below. Table 5 indicates the species that will be modeled and/or emitted in the no-obs and refined BART analyses.

Table 5 Species modeled in BART screening analyses

Species	Modeled	Emitted	Dry Deposited
SO ₂	Yes	Yes	Computed-gas
SO ₄ ⁻²	Yes	No	Computed-particle
NO _x	Yes	Yes	Computed-gas
HNO ₃	Yes	No	Computed-gas
NO ₃ ⁻	Yes	No	Computed-particle
PM-fine*	Yes	Yes	Computed-particle
PM ₁₀ *	Yes	Yes	Computed-particle

*Please refer to Section VI subsection B for a detailed discussion on PM-fine and PM₁₀.

Emissions Speciation: ADEQ does not intend to model sulfate (SO₄⁻²), nitrate (NO₃⁻), elemental carbon (EC), and secondary organic aerosols (SOA) during the screening analyses. However, ADEQ recognizes the impact EC and SOA have on visibility. For instance, the light extinction (β_{ext}) coefficient for EC is 10 and for SOA it is 4. Currently, data are quite limited on appropriate speciation of organic/inorganic and filterable/condensable emissions by source category. Although there are speciation profiles available for gas- and oil-fired combustion turbines and coal combustion processes, currently there are no detailed profiles for the full range of BART-eligible sources. Thus, in the case of a subject-to-BART source where the PM profile for SO₄⁻², EC, and SOA are known, ADEQ recommends the aforementioned species be modeled as separate species in CALPUFF in the post-control modeling analysis.

Condensable Emissions: According to Tesche, et al (p 6-5 2005), “condensable emissions are considered primary fine particulate.” ADEQ is aware of the inability to measure PM_{2.5} emissions. Thus, BART-eligible facilities will be most likely use AP-42 emission factors to develop the “actual” highest average 24-hr emission rate for this pollutant. In the development of this emission rate, ADEQ will require these facilities to use the AP-42 emission factors for condensable PM_{2.5}. For sources where AP-42 factors are not available, assumptions for partitioning need to be resolved with ADEQ.

Size Classification of Primary PM Emissions: Particle size parameters are entered in the CALPUFF input file for dry deposition of particles. There are default values for “aerosol” species (i.e., SO₄⁻², NO₃⁻, and PM_{2.5}). The default value for each of these species is 0.48 μ m geometric mass mean diameter and 2.0 μ m geometric standard deviation. The main sources of these particles are fuel combustion. A way to account for this, without including EC and SOA in the modeling, is to use particle speciation in the post-processing step. This is discussed below in the CALPOST section.

As stated in a previous section, all PM₁₀ emissions will be modeled as PM_{2.5} for the no-obs model simulations (Tesche, et al, 2005).

Background Ozone concentrations: Ozone (O₃) can be input to CALPUFF as hourly or monthly background values. Hourly values of ozone concentrations were obtained from two rural monitoring sites in Arkansas: Deer, Newton County monitoring site and Eagle Mountain, Montgomery County monitoring site. The hourly ozone concentrations were adjusted for the time differences between the post-processed prognostic meteorological

file (0 GMT) and the collection time of the ozone (LST). Also, the concentrations were adjusted from parts per million (ppm) to parts per billion (ppb). These hourly ozone values will be used in this modeling.

Background Ammonia concentrations: Background ammonia concentration is assumed to be temporally and spatially invariant and will be fixed at 3 ppb across the entire domain for all months. It may be possible to derive NH₃ concentrations from regional modeling outputs that CENRAP is currently developing. At this time these NH₃ values are not available in a model ready form.

Receptors: Receptors are locations where model results are calculated and provided in the CALPUFF output files. Receptor locations were derived from the National Park Service's Class I area receptor database at <http://www2.nature.nps.gov/air/maps/receptors/index.cfm>. Only these discrete NPS receptors will be modeled in CALPUFF. The discrete receptors are necessary for calculating visibility impacts in the nine selected Class I areas that will be evaluated by ADEQ. All the discrete receptors will be placed with enough density that the highest visibility impacts should be evident. The NPS provides receptors in all the Class I areas on a 1 km basis. These receptors will be kept at the 1 km spacing for the BART modeling, and all receptors will be retained. NPS also provides a conversion program to convert the coordinates of the receptors from latitude/longitude (lat/long) to Lambert Conformal Conical (LCC). ADEQ used this conversion program to convert the receptors located in the five Class I areas it is assessing from lat/long to LCC.

Outputs: The CALPUFF modeling results will be displayed in units of micrograms per cubic meter ($\mu\text{g}/\text{m}^3$). In order to determine visibility impacts, the CALPUFF outputs must be post-processed.

Detailed information on all CALPUFF setting to be used in this screening analysis is located in Appendix G.

5. Post-processing (POSTUTIL/CALPOST)

Hourly concentration outputs from CALPUFF are processed through POSTUTIL and CALPOST to determine visibility conditions. Specifically, POSTUTIL takes the concentration file output from CALPUFF and recalculates the nitric acid and nitrate partition based on total available sulfate and ammonia. The ammonia-limiting method (ALM) in CALPUFF repartitions nitric acid and nitrate on a receptor-by-receptor and hour-by-hour basis to account for the models systematic over-prediction due to overlapping puffs. For both screening applications, the parameter MNIRATE=1 is set in POSTUTIL to implement this approximate correction in its simplest form. The background ammonia concentration that was obtained from CENRAP's regional modeling effort will be used to maintain regional consistency in the CENRAP region. CALPOST uses the concentration file processed through POSTUTIL, along with relative humidity (RH) data, to perform visibility calculations. For the BART analysis, the only modeling results out of the CALPUFF modeling system of interest are the visibility impacts.

Please see Appendix H and I for detailed settings for POSTUTIL and CALPOST.

Light extinction: Light extinction must be computed in order to calculate visibility. CALPOST has seven methods for computing light extinction. This BART screening analysis will use Method 6, which computes extinction from speciated particulate matter with monthly Class I area-specific relative humidity adjustment factors, and is implied by the BART guidance. Relative humidity (RH) is an important factor in determining light extinction (and therefore visibility) because SO_4^{-2} and NO_3^{-} aerosols, which absorb moisture from the air, have greater extinction efficiencies with greater RH. All BART analyses will apply relative humidity correction factors (f_{RH} s) to SO_4^{-2} and NO_3^{-} concentrations outputs from CALPUFF, which were obtained from EPA's "Guidance for Estimating Natural Visibility Conditions under the Regional Haze Rule (EPA, 2003). The f_{RH} values for the Class I areas that will be assessed are provided in Table 5.

Table 6 EPA recommended monthly averaged f_{RH} for the five Class I areas ADEQ is assessing (EPA, 2003)

Class I Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Caney Creek	3.4	3.1	2.9	3.0	3.6	3.6	3.4	3.4	3.6	3.5	3.4	3.5
Hercules-Glades	3.2	2.9	2.7	2.7	3.3	3.3	3.3	3.3	3.4	3.1	3.1	3.3
Mingo	3.3	3.0	2.8	2.6	3.0	3.2	3.3	3.5	3.5	3.1	3.1	3.3
Sipsey	3.3	3.0	2.8	2.7	3.1	3.4	3.5	3.5	3.5	3.3	3.1	3.3
Upper Buffalo	3.3	3.0	2.7	2.8	3.4	3.4	3.4	3.4	3.6	3.3	3.2	3.3

The $\text{PM}_{2.5}$ concentrations are considered part of the dry light extinction equation and do not have a humidity adjustment factor. The light extinction equation is the sum of the wet SO_4^{-2} and NO_3^{-} and dry components $\text{PM}_{2.5}$ plus Rayleigh scattering (β_{Ray}), which is 10 inverse megameters (Mm^{-1}).

To account for sources modeled with a known PM speciation profile for EC, SOA, and SO_4 , an adjustment to the extinction coefficient for the PM components will be made in CALPOST. ADEQ intends to follow the method outlined in the FLM CALPUFF Reviewer's Guide (Gebhart, 2005) which is located in Appendix K.

6. Measuring visibility impacts

The recommended procedure for quantifying visibility impacts can be found in Chapter 3 of the CENRAP BART Modeling Guidelines (Teschke, et al, 2005) which is located in Appendix J. The key point is that the light extinction coefficient (β_{ext}) can be calculated from the IMPROVE equation as:

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

The monthly site-specific $f_{(RH)}$ values were obtained for the five Class I Area ADEQ is assessing from Table A-3 in the EPA (2003) guidance document. Then, the haze index (HI), in dv , is calculated in terms of the extinction coefficient via:

$$HI = 10 \ln (\beta_{ext}/10)$$

The change in visibility (measured in terms of Δdv) is then compared against background conditions. The Δdv value is calculated from the source's contribution to extinction, β_{source} , and background extinction, $\beta_{background}$, as follows:

$$\Delta dv = 10 \ln (\{ \beta_{background} + \beta_{source} \} / \beta_{background})$$

If the Δdv value is greater than or equal to 0.5 dv , the source is said to contribute to visibility impairment and is thus subject-to-BART controls. If not, it is BART-exempt.

The annual average natural levels of aerosol components at each Class I area being evaluated by ADEQ are shown in Table 7. Natural conditions by component in Table 6 are based on whether the Class I area is in the eastern or the western part of the United States. In this BART analysis, all Class I areas are located in the East. The source of this data is from EPA's Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule (EPA, 2003).

Table 7 Average annual natural levels of aerosol components ($\mu g/m^3$) (EPA, 2003)

Class I Area	Region	SO ₄	NO ₃	OC	EC	Soil	Coarse Mass
Caney Creek	East	0.23	0.10	1.40	0.02	0.50	3.00
Hercules-Glades	East	0.23	0.10	1.40	0.02	0.50	3.00
Mingo	East	0.23	0.10	1.40	0.02	0.50	3.00
Sipsey	East	0.12	0.10	0.47	0.02	0.50	3.00
Upper Buffalo	East	0.23	0.10	1.40	0.02	0.50	3.00

As stated in section V, in a cooperative agreement with EPA Regions VI and VII and FLMS, CENRAP guidance deviates from use of the 98th percentile impact. The CALMET datasets as described in this protocol were processed with the no-obs options (i.e., surface observations were not used in the CALMET wind field interpolation). Aware that exercising CALMET with no-obs may lead in some applications to potentially less conservatism in the CALPUFF visibility results compared with the use of CALMET with observations, CENRAP has agreed to EPA's recommendation that the **maximum** visibility impact, rather than the 98th percentile value, should be used for the no-obs screening analysis using the CENRAP-developed CALMET datasets.

If the no-obs screening analysis results indicate a BART-eligible facility's maximum Δdv on a Class I area is less than 0.5 dv , then they will be considered exempt from BART and will be notified by ADEQ of their status. However, if the maximum Δdv is equal to or greater than 0.5 dv , the source will be considered to be subject-to-BART. ADEQ will notify these subject-to-BART facilities.

VIII. Change in Visibility Due to BART Controls

Once a facility is determined to be subject-to-BART, this facility must perform an engineering analysis and a post-control modeling analysis using CALPUFF. This modeling analysis must be compared to the pre-control modeling results. Please note that this will be a source specific (i.e. emitting unit specific) and pollutant specific modeling analysis using CALPUFF. If a subject-to-BART facility opts to use the 98th percentile rather than the maximum impact, the subject-to-BART facility will be required to be incorporate observational data with the post processed CALMET prognostic meteorological data. Also these facilities will be required to submit their meteorological modeling protocol, model performance evaluation, and CALPUFF modeling protocol to ADEQ, EPA Region VI, and FLMs for approval. However, if the subject-to-BART facility opts to use the maximum impact rather than the 98th percentile, these facilities may use the post-processed CALMET MM5 data.

Additionally, one control measure that a source may opt to use is to revise their Title V permit to provide for synthetic minor limits so that it falls under the BART emission cap. That permit modification must be done prior to the State going to public hearing on its RH SIP. The limits must be in place for as long as the RH SIP is applicable or for as long as the source is operational. However, the source will still need to do a post-control CALPUFF modeling analysis to determine the amount of emissions it needs to reduce for visibility improvement. (Note: ADEQ **strongly** recommends that all subject-to-BART facilities work closely with ADEQ in their engineering analyses.) Also, after all of the post-control results are submitted to and approved by ADEQ, these results will then be inputted into either CAMx or CMAQ for a cumulative model run. If the control measures proposed by the BART facilities still impact a Class I area, the BART facilities will need to implement additional control. Please note that all post-modeling results are due to ADEQ no later than October 23, 2006.

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Appendix A. Proposed Time-line

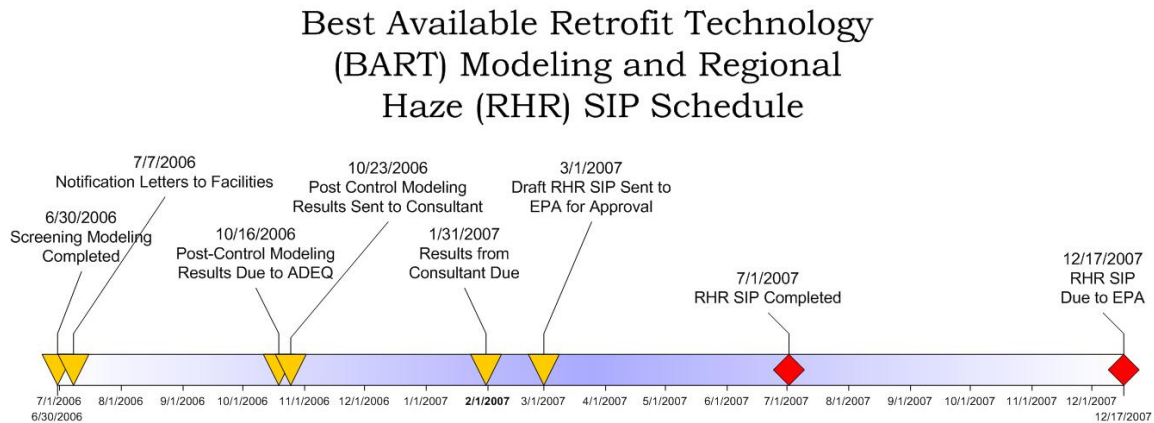


Figure A-1 ADEQ's proposed time-line to meet the RH SIP deadline of December 17, 2007 as set forth by EPA in its Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART) Determination (40 CFR Part 51, p 39156)

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Appendix B. Map of receptors

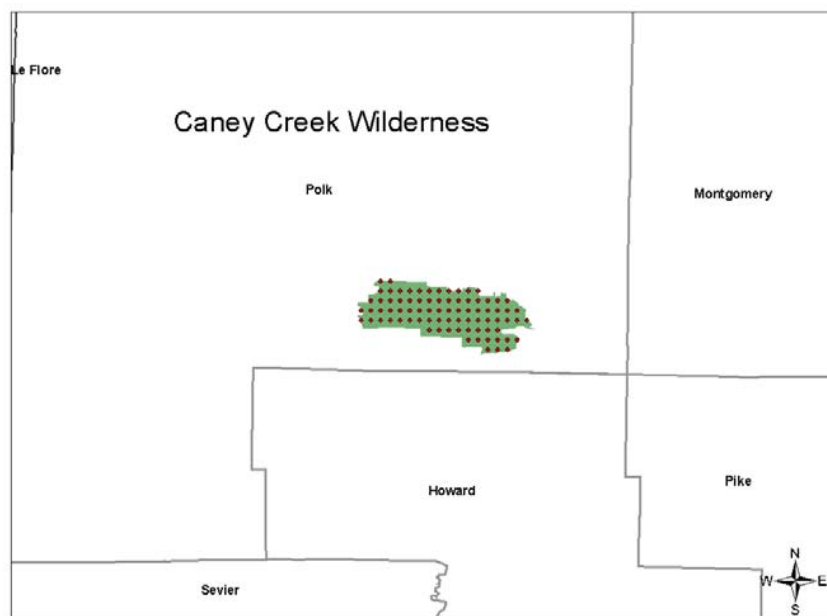


Figure B-1 Receptors located in Caney Creek Wilderness Area, Arkansas

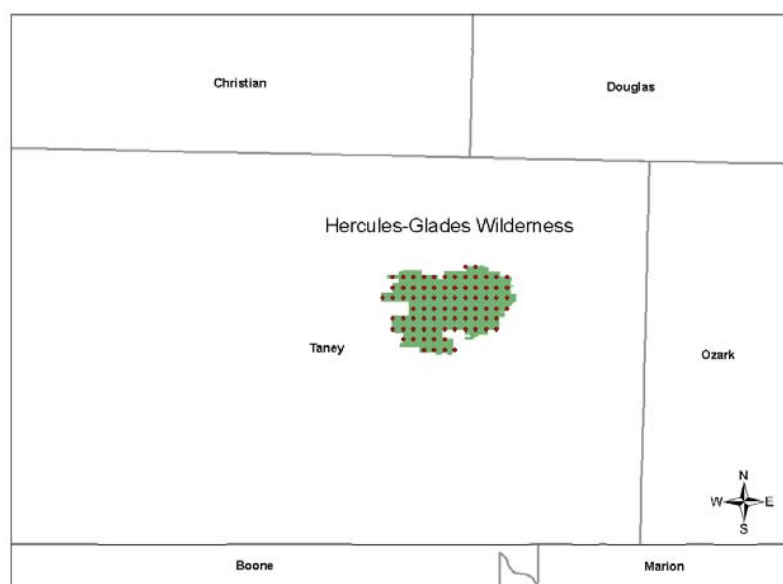


Figure B-2 Receptors located in Hercules-Glade Wilderness Area, Missouri

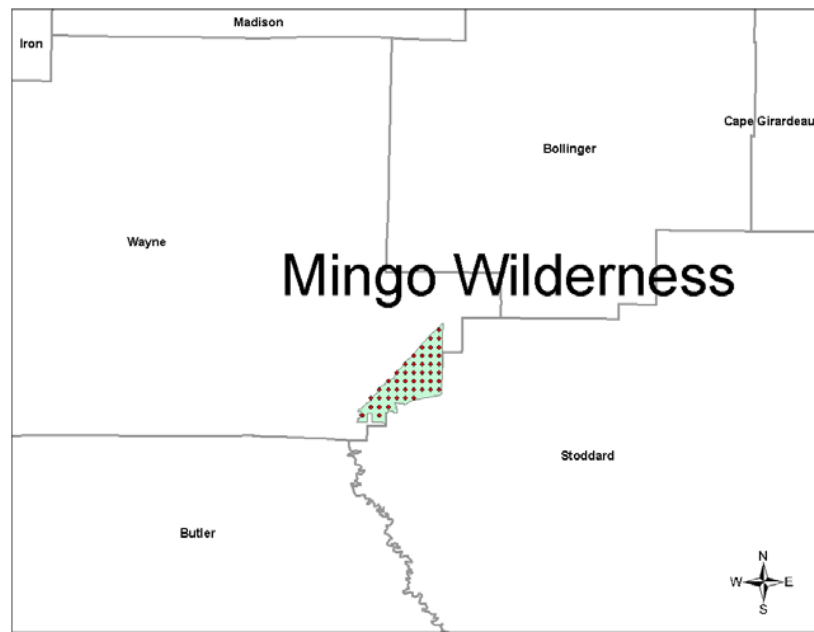


Figure B-3 Receptors located in Mingo Wilderness Area, Missouri



Figure B-4 Receptors located in Sipsey Wilderness, Alabama

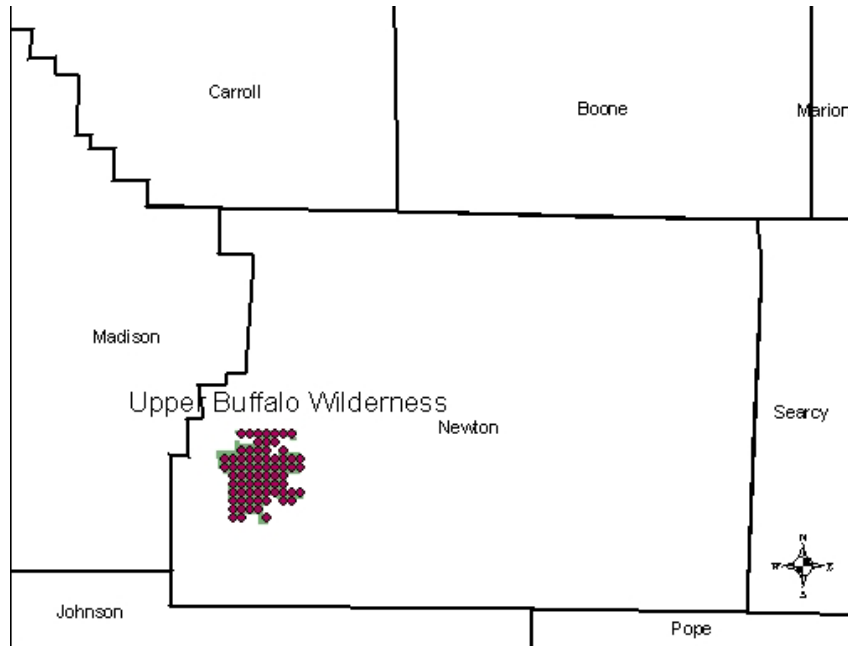


Figure B-4 Receptors located in Upper Buffalo Wilderness Area, Arkansas

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Appendix C. BART-Eligible Sources' Stack Parameters, Base Elevation at Ground Level, and Stack Coordinates

Table C-1 BART-eligible sources' stack parameters

STATIONARY SOURCE NAME/LOCATION	Emission Unit ID	Stack Height Meters	Stack Diameter Meters	Exit Velocity m/sec	Temperature °K
Albermarle-South Plant / Magnolia	SR-01	57.9	0.814	15.24	922
Albermarle-South Plant / Magnolia	BH-01	6.4	2.591	9.14	505
Albermarle-South Plant / Magnolia	BH-02	6.4	2.591	9.14	505
American Elect. Power (SWEPCO) / Gentry	SN-01	164.6	6.096	34.14	408
AR Elect. Coop - Bailey Plant / Augusta	SN-01	50.9	3.000	28.04	444
AR Elect. Coop - McClellan Plant / Camden	SN-01	48.8	3.301	28.04	444
Big River Industries / W. Memphis	SN-01	30.5	1.524	21.88	330
Delta Natural Kraft / Pine Bluff	SN-02	50.3	2.134	13.29	348
Domtar, Inc. / Ashdown	SN-03	66.1	1.890	26.76	522
Domtar, Inc. / Ashdown	SN-05	71.6	3.659	11.92	325
Eastman Chemical / Batesville	6M01-01	61.0	2.743	9.45	422
El Dorado Chemical / El Dorado	SN-08	22.9	1.219	33.53	505
El Dorado Chemical / El Dorado	SN-09	22.9	1.219	32.00	500
El Dorado Chemical / El Dorado	SN-10	23.8	0.152	23.77	313
Entergy - Lake Catherine / Jones Mill	SN-03	59.4	5.182	3.08	396
Entergy - Ritchie Plant / Helena	SN-02	71.9	3.658	28.62	390
Entergy - White Bluff / Redfield	SN-01	304.8	7.833	27.43	434
Entergy - White Bluff / Redfield	SN-02	304.8	7.833	27.43	434
Entergy - White Bluff / Redfield	SN-05	4.6	0.914	19.81	519
Georgia-Pacific Paper / Crossett	SN-22	53.3	3.658	10.45	341
Great Lakes Chemical / El Dorado	SN-302A	9.1	0.762	40.54	555
Green Bay Packaging / Morrilton	SN-05A	30.8	1.798	25.60	456
Lion Oil / El Dorado	SN-809	61.0	1.753	9.75	533
Potlatch Corp. / McGehee	SN-04	89.6	2.743	14.78	444

Table C-2 BART-Eligible Emission Units' Base Elevation and Lambert Conformal Conical (LCC) Coordinates

STATIONARY SOURCE NAME/LOCATION (BART File Name)	Emission UNIT ID	Base Elevation, meters (m)	X Easting LCC x	Y Northing LCC y
Albermarle-South Plant / Magnolia	SR-01	86.9	352.81836	-747.03381
Albermarle-South Plant / Magnolia	BH-01	88.4	352.67618	-746.98114
Albermarle-South Plant / Magnolia	BH-02	88.4	352.65801	-746.98190
American Elect. Power (SWEPCO) / Gentry	SN-01	349.9	221.58128	-410.39077
Ark. Elect. Coop - Bailey Plant / Augusta	SN-01	61.3	510.86643	-507.71488
Ark. Elect. Coop - McClellan Plant / Camden	SN-01	33.5	390.21870	-702.15534
Big River Industries (General Shale)/ W. Memphis	SN-01	60.0	609.12652	-517.70639
Delta Natural Kraft / Pine Bluff	SN-02	66.4	457.00824	-621.20692
Domtar, Inc. / Ashdown	SN-03	97.5	267.47491	-698.66686
Domtar, Inc. / Ashdown	SN-05	97.5	267.48245	-698.74355
Eastman Chemical / Batesville	6M01-01	82.3	493.14724	-458.02938
El Dorado Chemical / El Dorado	SN-08	63.1	401.11728	-734.65321
El Dorado Chemical / El Dorado	SN-09	63.1	401.13533	-734.65236
El Dorado Chemical / El Dorado	SN-10	62.2	401.19594	-734.67412
Entergy - Lake Catherine / Jones Mill	SN-03	100.0	375.45658	-606.40861
Entergy - Ritchie Plant / Helena	SN-02	54.9	586.25363	-591.07129
Entergy - White Bluff / Redfield	SN-01	94.2	446.73457	-625.11197
Entergy - White Bluff / Redfield	SN-02	94.2	445.61252	-604.15523
Entergy - White Bluff / Redfield	SN-05	94.2	445.61539	-604.25671
Georgia-Pacific Paper / Crossett	SN-22	46.0	469.03486	-745.02133
Green Bay Packaging / Morrilton	SN-05A	98.5	387.29077	-532.44265
Lion Oil / El Dorado	SN-809	75.6	403.01817	-741.82948
Potlatch Corp. / McGehee	SN-04	43.9	533.13136	-678.59798

Appendix D. BART-Eligible Emission Rates used for the No-Obs Modeling Run

Table D-1 BART-eligible units' highest 24-hour actual emission rates for SO₂, NO_x, PM₁₀* and PM_{2.5} in grams per second (g/sec)

BART-Eligible Facilities/ Locations	Emission Unit ID Number	Highest 24-Hour Actual Emission Rates (g/sec)			
		SO ₂	NO _x	PM ₁₀	PM _{2.5}
Albermarle-South Plant / Magnolia	SR-01	48.126	0.076	0.000	0.009
Albermarle-South Plant / Magnolia	BH-01	0.353	2.075	0.000	0.136
Albermarle-South Plant / Magnolia	BH-02	0.535	2.578	0.000	0.128
American Elect. Power (SWEPCO) / Gentry	SN-01	595.781	245.066	21.725	5.531
AR Elect. Coop - Bailey Plant / Augusta	SN-01	299.344	36.933	21.729	21.729
AR Elect. Coop - McClellan Plant / Camden	SN-01	346.189	47.124	28.764	28.764
Big River Industries/ W. Memphis	SN-01	0.000	8.589	0.000	7.076
Delta Natural Kraft / Pine Bluff	SN-02	0.239	1.701	1.058	0.529
Domtar, Inc. / Ashdown	SN-03	0.774	22.632	0.000	21.354
Domtar, Inc. / Ashdown	SN-05	70.175	52.008	0.000	7.881
Eastman Chemical / Batesville	6M01-01	54.046	11.045	0.290	0.217
El Dorado Chemical / El Dorado	SN-08	0.000	20.060	0.000	0.000
El Dorado Chemical / El Dorado	SN-09	0.000	15.645	0.000	0.000
El Dorado Chemical / El Dorado	SN-10	0.000	0.415	0.000	0.000
Entergy - Lake Catherine / Jones Mill	SN-03	0.420	309.535	0.365	0.246
Entergy - Ritchie Plant / Helena	SN-02	0.105	17.640	0.997	0.997
Entergy - White Bluff / Redfield	SN-01	978.164	550.821	15.592	11.802
Entergy - White Bluff / Redfield	SN-02	985.933	596.075	16.653	12.915
Entergy - White Bluff / Redfield	SN-05	4.095	3.811	0.365	0.246
Georgia-Pacific Paper / Crossett	SN-22	77.275	182.677	0.000	9.310
Green Bay Packaging / Morrilton	SN-05A	4.934	8.771	0.000	1.165
Lion Oil / El Dorado	SN-809	23.142	5.980	0.000	7.696
Potlatch Corp. / McGehee	SN-04	6.942	10.533	2.752	2.752

Appendix E. Chapter 5 of the CENRAP BART Modeling Guidelines (Tesché, et al, 2005)

5.0 DATA BASES FOR CALPUFF MODELING

To support BART modeling by the states and source operators, both meteorological and aerometric data sets are required. Regional meteorological data sets generated by the CALMET model suitable for direct input to the CALPUFF modeling system have been developed and archived. These data sets cover calendar years 2001, 2002, and 2003 for three sub-regional grid domains shown in Figures 5-1 through 5-4. The procedures used in developing the CALMET data sets generally follow the IWAQM recommendations (EPA, 1998), except for a few notable refinements. *The processed CALMET files, in CALPUFF-ready input format, are available from CENRAP on hard disk drives to interested states and stakeholders.*

This chapter describes how these meteorological modeling sets were developed and evaluated. The basic CALMET model configuration used to generate the three years of CALPUFF-ready meteorology is described in detail so that users of this information have a clear understanding of the data sets and their applicability. In addition, for those states or source operators who elect to conduct more source-specific CALMET/CALPUFF modeling, the information in this chapter may be helpful in guiding specification of revised CALMET model inputs and generation of revised CALMET data sets.

Also included in Section 5.2 is a discussion of routinely available air quality monitoring data sets available to the states and source operators in support of screening and source-specific BART modeling exercises.

5.1 Development of CALMET Meteorological Files

5.1.1 MM5 Data Sets

Alpine Geophysics developed a consistent set of CALMET regional meteorological modeling data sets for use by the CENRAP States, BART eligible sources within the region and others. These meteorological modeling data sets were constructed through the joint use of the CALMET processor and results from existing annual three-dimensional MM5 meteorological simulations. The specific annual prognostic model simulations available for CENRAP BART modeling included:

- > 2001 MM5 data set at 36/12 km resolution developed for EPA by Alpine Geophysics (McNally and Tesché, 2002; McNally 2003);
- > 2002 MM5 data set at 36 km resolution developed for CENRAP by Iowa DNR (Johnson, 2003a,b),

- > 2003 MM5 data set at 36 km resolution developed for the Midwest RPO (Baker, 2005; Baker et al., 2004; Kembell-Cook et al., 2005)

Each of these studies included a performance evaluation of the MM5 generated data sets against surface meteorological observations and the results of these evaluations are contained in the reports or presentations cited above. While there exists a set of annual 12 km MM5 meteorology for 2002, this data set was developed by four independent CENRAP modeling centers and these data sets have not been concatenated into one master data base. More importantly, there has been no systematic, rigorous model performance evaluation performed on the CENRAP 2002 12 km MM5 data yet. Accordingly, until such time as the 2002 12 km data set has been evaluated and shown to be of comparable reliability as the aforementioned MM5 data sets, its use is contraindicated.

5.1.2 CALMET Model Configuration

The CALMET modeling procedures used to construct meteorological inputs to CALPUFF for visibility screening of BART eligible sources generally follows the IWAQM recommendations (EPA, 1998), except as noted below.

CALMET Model Options. The CALMET model has a number of user-selected options, parameter settings, and ‘switches’ that must be defined prior to exercising the processing system. These options and settings are well-described in the CALMET User’s Guide (Scire et al., 2000a) and in the CALMET input file to the executable code. Appendix A of this protocol summarizes the CALMET configurations used in developing the processed 6 km meteorological fields over the three CENRAP BART modeling domains. Also included in the tables in Appendix A are the default CALMET options and parameter settings recommended in the IWAQM Phase 2 Report (EPA, 1998).

CALMET Domain. Three slightly overlapping modeling domains were defined by CENRAP to support BART modeling. These domains are shown in Figures 5-1 through 5-4 and Table 5-1. The processors used to generate the domain, land use, and elevation data for the CALMET/CALPUFF system include TERREL, CTGPROC, and MAKEGEO, as described below.

- > TERREL is the terrain pre-processor that averages terrain features to the modeling grid resolution; TERREL constructs the basic properties of the gridded domain and defines the coordinates upon which meteorological data are stored. Key parameters include specification of grid type, location, resolution and terrain elevation.
- > CTGPROC computes the fractional land use for the modeling grid resolution. Land use characteristics for each grid cell are assigned using CTGPROC. The primary variable adjustment associated with CTGPROC is selection of an appropriate land use database. Version 2.0 of the North American Land Cover Characteristics database is used.
- > MAKEGEO is the final pre-processor that combines the terrain and land use data for input to CALMET. Generating the appropriate MAKEGEO.INP control file requires only minimal alteration of the default assignments. Key modifications include specifying domain attributes and ensuring input files are correctly referenced.

Terrain. CALMET requires both terrain height and land use/land cover for the application region. These are generated using the CALMET CTGPROC, TERREL and MAKEGEO processors. The terrain data were created using the TERREL (version 3.311, level 030709) processor and the Shuttle Radar Topography Mission (SRTM)-GTOPO 30 second (~1 km) resolution dataset.

Land Use. The landuse data set was created using the Composite Theme Grid CTGROC processor (version 2.42, level 030709) and the United States Geological Survey (USGS) Global Land Cover Characterization (GLCC) version 2.0 database. The GLCC database is available at 30 second (~1km) resolution. References for these and other modeling datasets can be found at www.src.com.

Vertical Layer Structure. The vertical layer structure for the CALMET/CALPUFF screening applications is more refined than the general suggestions of IWAQM. The CENRAP vertical structure was designed to reduce the need for vertical interpolation while simultaneously improving vertical resolution within the planetary boundary layer (PBL). Table 5-2 identifies the 11 layer interfaces required to define the 10 layer vertical CALMET grid structure. The top interface in the CALMET simulation is 4000 meters.

Use of Observations. Based on considerable discussions with State and Federal managers and agency personnel, CENRAP has elected to use the No-Obs mode in CALMET for constructing the 6 km meteorological fields for CALPUFF screening exercises. The three annual MM5 simulations (2001, 2002, and 2003) will be used as the sole source for meteorological data within CALMET. Blending observational data with the MM5 data within CALMET (i.e., use of the “OBS” option is essentially a redundant use of the same data. Substantial improvement in the MM5 initialization data and in the use of four dimensional data assimilation (FDDA) has been achieved in recent years using observational data. The ETA analysis data used in initial and boundary conditions estimates as well as within the FDDA fields derive from 3-hourly, 40 km objective

analysis fields computed using an extensive supply of observational data (National Weather Service surface and upper air data, GOES satellite precipitable water; VAD wind profiles from NEXRAD; ACARS aircraft temperature data; SSM/I oceanic surface winds; daily NESDIS snow cover and sea-ice analysis data; RAOB balloon drift; GOES and TOVS-1B radiance data; 2D-VAR SST from NCEP Ocean Modeling Branch; radar estimated rainfall; and surface rainfall). The complexity, resolution, and accuracy of the ETA data that is used to initialize and ‘nudge’ the MM5 forecasts is extensive indeed. Particularly at the 12-36 km horizontal grid scales over the flat to modestly rolling topography of the CENRAP domain, there is no need to introduce local meteorological observations in order to retrieve local terrain effects, for example. Thus, mesoscale wind patterns are likely to be adequately characterized by the MM5 simulations.

Many observations, especially surface observations, reflect local conditions on a scale smaller than the 6 km CENRAP CALMET fields. The introduction of the local observations into the regional modeling domain may extend the influence of the observational data beyond its true representativeness and result in internally inconsistent flow features. In particular the time interpolation of the 12-hourly upper air sounding data may wash out structure in the MM5 fields that are appropriate to retain. Given that the CENRAP domain as a whole includes areas of moderately rolling terrain, coastal regions and relatively flat terrain, a single set of representative weights¹ that allows significant influence of the observations where appropriate, will involve a considerable effort and substantial testing. The internally consistent MM5 fields are considered likely to be appropriate for the regional simulations, and the incremental benefit of adding the observational data into the regional CALMET simulations is not considered worthwhile.

However, on the smaller domains likely to be considered in source-specific modeling (e.g., 1-4 km in scale) with the higher CALMET grid resolution and the smaller domain size, more control over the region of influence of the meteorological observations can be achieved. It is easier for the diagnostic model to allow the local flow observations to have appropriate influence in the vicinity of the observation, but allow terrain-adjusted flow to dominate away from the observations. Given that the fine scale source-specific domains will be used especially in irregular and/or meteorologically complex settings, the relatively coarser-scale MM5 simulations are less likely to be fully adequate, and the introduction observational data into CALMET is more likely to achieve improvements in the resulting meteorological fields.

Diagnostic Model Settings

A number of diagnostic model settings must be selected for CALMET to properly process representative diagnostic meteorological data sets. These are summarized in Appendix A, compared to the default CALMET settings, and discussed in the following:

¹ Weights are assigned in CALMET to control the ‘blending’ of observations and MM5 predictions.

- > CALMET options dealing with radius of influence parameters (R1, R2, RMAX1, RMAX2, RMAX3), BIAS, ICALM parameters are not used in No-Observations mode;
- > Gridded cloud data were inferred from the MM5 relative humidity fields (ICLOUD=3);
- > Given that all state variables are MM5-derived (IPROG=14; ITPROG=2), surface layer winds were not extrapolated to the upper layers (IEXTRP = -1);
- > The IWAQM recommendation for disabling the computation of kinematic effects in the wind field options and parameters was selected. This was selected in light of the very modest elevated terrain in the CENRAP domain, relative to the mountainous regions in the U.S. and Alps where the kinematic parameterizations were originally developed. Thus, the option for computing kinematic effects was disabled (IKINE = 0).
- > The BIAS array was set to 0. in the CALMET control file because surface and upper air data were not used (NOOBS = 2);
- > Because the MM5 wind fields supply CALMET with the initial guess fields to the diagnostic wind model (IWFCOD =1, IPROG = 14) and observational data are not reintroduced, the following variables were set to nominal values:
 - The minimum distance for which extrapolation of surface winds should occur was set to -1 (RMIN2 = -1.).
 - RMIN was left at the IWAQM recommendation of 0.1 km.
 - RMAX1 and RMAX2 were each assigned a value of 30 km. RMAX3 was assigned a value of 50 km.
 - R1 and R2 were each assigned the value of 1.0.
 - ISURFT and IUPT were assigned placeholder values of 4 and 2, respectively.
- > The radius of influence regarding terrain features is comparable to the resolution of the processed terrain data: 12 km.
- > The radius of influence for temperature interpolation is set to 36 km (TRADKM), a value considered appropriate given the 6 km CALMET domain and 36/12 km MM5 domain.
- > The beginning/ending land use categories for temperature interpolation over water are assigned category 55: (JWAT1 = JWAT2 = 55).

- > SIGMAP was set to 50 km, while the IWAQM recommendation is 100 km, but with no supporting documentation. Because precipitation rates are explicitly incorporated from the MM5 data, a lower radius of influence was deemed appropriate.
- > Diagnostic options: IWAQM default values were used (see Appendix A);
- > TERRAD (terrain scale) is required for runs with diagnostic terrain adjustments (i.e., the 2003 simulations). Values of ~10-20 km were tested, and an appropriate value determined.
- > Land use defining water: JWAT1 = 55, JWAT2 = 55 (large bodies of water). This feature allows the temperature field over large bodies of water such as the Gulf of Mexico and the Great lakes to be properly characterized by buoy observations.
- > Mixing height averaging parameter (MNMDAV) were determined sensitivity tests. The purpose of the testing is to optimize the variable to allow spatial variability in the mixing height field, but without excessive noise.

Obviously, there are some instances where more advanced and/or recently developed procedures for constructing the CALMET fields have been used compared with the IWAQM (1998) guidance. For example, one agency expressed concern about the choice to employ prognostic model-derived gridded cloud cover data in CALMET (ICLOUD = 3). While this is admittedly a ‘non-guideline’ option, in our view it represents the best science option currently available. In particular, the EPA CAIR and CAMR rulemaking modeling and the CAMx/CMAQ modeling being performed by the RPOs for regional haze all utilize the gridded moisture fields in the MM5 model as a basis for estimating cloud. Presumably, if the method is suitable for such advanced visibility modeling, it is adequate for CALPUFF modeling. Of course, in the protocol negotiation, the States, source operators, and regulatory agencies have an opportunity to re-examine the CALMET diagnostic model settings used in creating the CENRAP gridded fields and modify them if warranted.

In summary, the development of the regional CALMET meteorological fields from MM5 data was conducted in No-Observations (“No-Obs”) mode. CALMET’s boundary layer modules were used to compute mixing heights, turbulence coefficients and other meteorological parameters required as input to CALPUFF.

5.1.3 MM5/CALMET Processing

Construction of the CALPUFF-ready meteorological fields entails a two-step process. First, the MM5 prognostic model output fields are extracted and processed for input to CALMET. This step entails running various extraction software routines

followed by the CALMM5 code. Then, CALMET is exercised for the full three year period over each sub-regional CENRAP domain.

CALMM5. Previous applications of the prognostic Mesoscale Meteorological model version 5 (MM5) served as the source of the gridded meteorological fields for calendar years 2001, 2002, and 2003. The actual CALMM5 configuration entailed modification of a few user-specified variables. However, two settings are of primary importance:

- > All vertical layers from MM5 were extracted, providing CALMET configuration flexibility, and
- > Vertical velocity, relative humidity, cloud/rain fields, and ice/snow fields were extracted. (Graupel was extracted for 2001, the only year where the data were available in the MM5 datasets.)

CALMET. CALMET (v5.53a, lev 040716) was applied consistent with CENRAP's recommendation that the 6 km be generated using the 'No-Obs' option. The specific options used have been discussed above and are summarized in Appendix A.

5.1.4 Evaluation of the CALPUFF-Ready Meteorological Data Sets

In typical applications the adequacy of the CALMET fields is seldom evaluated using independent measurements. Often, only cursory visual examination of wind vector plots or time series is considered. This evaluation is important because the CALMET performance analysis gives direct insight into the adequacy of the model-processed fields on a subregional basis. It also serves as an independent quality assurance tool. Alpine's MAPS evaluation software to perform an independent evaluation of the processed CALMET data bases. MAPS was used in conjunction with the NCAR DS472 TDL data sets to evaluate the surface winds and temperatures for 2001-2003 across all three domains. Since only a small portion of the meteorological content of these data were ingested in the MM5 data assimilation routines (see Johnson, 2003a), these data sets are essentially an independent, quantitative means for evaluating the adequacy of the meteorological fields input to CALPUFF.

CALMET Evaluation Methodology

Several statistical measures were calculated as part of the CALMET meteorological evaluation using established procedures (e.g., Tesche et al., 1990; Emery et al., 2001). Additional plots and graphs are used to present these statistics on both hourly and daily time frames over the full annual cycle. For this study, evaluation measures were calculated for wind, temperature, and relative humidity because these parameters are the principal meteorological inputs to CALPUFF. The full set of CALMET evaluation statistics and graphical displays generated with the AG-MAPS

software (McNally and Tesche,1994) are contained on a DVD available from CENRAP.

The statistics used to evaluate the meteorological fields for 2001-2003 are generated in both absolute terms (e.g., wind speed error in m/s), and relative terms (percent error) as is commonly done for air quality assessments. Obviously, a very different significance is associated with a given relative error for different meteorological parameters. For example, a 10% error for wind speed measured at 10 m/s is an absolute error of 1 m/s, a minor error. Yet a 10% error for temperature at 300 K is an absolute error of 30 K, a ridiculously large error. On the other hand, pollutant concentration errors of 10% at 1 ppb or 10 ppm carry practically the same significance.

Three key meteorological metrics include the bias, error, and index of agreement (IOA) for wind speed, temperature and relative humidity. These measures are defined as follows:

Bias (B): Calculated as the mean difference in prediction-observation pairings with valid data within a given analysis region and for a given time period (hourly or daily):

$$B = \frac{1}{IJ} \sum_{j=1}^J \sum_{i=1}^I (P_j^i - O_j^i)$$

Error (E): Calculated as the mean *absolute* difference in prediction-observation pairings with valid data within a given analysis region and for a given time period

$$E = \frac{1}{IJ} \sum_{j=1}^J \sum_{i=1}^I |P_j^i - O_j^i|$$

(hourly or daily).

Note that the bias and gross error for winds are calculated from the predicted-observed residuals in speed and direction (not from vector components u and v). The direction error for a given prediction-observation pairing is limited to range from 0 to $\pm 180^\circ$.

Index of Agreement (IOA): calculated following the approach of Willmont (1981). This metric condenses all the differences between model estimates and observations within a given analysis region and for a given time period (hourly and daily) into one statistical quantity. It is the ratio of the total RMSE to the sum of two differences – between each prediction and the observed mean, and each observation and the observed mean:

$$IOA = 1 - \left[\frac{IJ \cdot RMSE^2}{\sum_{j=1}^J \sum_{i=1}^I |P_j^i - M_o| + |O_j^i - M_o|} \right]$$

Viewed from another perspective, the index of agreement is a measure of the match between the departure of each prediction from the observed mean and the departure of each observation from the observed mean. Thus, the correspondence between predicted and observed values across the domain at a given time may be quantified in a single metric and displayed as a time series. The index of agreement has a theoretical range of 0 to 1, the latter score suggesting perfect agreement.

CALMET Evaluation Results

Table 5-5 summarizes the statistical measures, averaged over the month, for temperature, wind speed, and relative humidity for all three years. The CALMET evaluation DVD contains a full compilation of the statistical and graphical results. Figures 5-7 through 5-31 present a variety of graphical displays of processed and observed surface temperature, relative humidity, and wind across the three CENRAP subdomains for the three-year period 2001-2003. Figures 5-28 through 5-31 provide convenient summaries of the bias and error in the relative humidity, temperature, and wind speed fields across the continuous 36 month period by subdomain.

Thorough discussion of the performance findings is beyond the scope of these guidelines. However, a few key findings of the evaluation are worth noting here. From Table 5-5, the wind speed index of agreement, a general measure of correlation between measured and observed winds, is systematically greater than a value of 0.8 for virtually every month. These values are typically better than those generally achieved in urban- and regional-scale model applications for ozone SIPs. For example, the statistical benchmark for IOA suggested by Emery et al., (2001) is $IOA > 0.6$. Thus, the wind speed agreement for all three domains and all three years appears quite good relative to other MM5/RAMS model applications. From Figure 5-11, the wind speed root mean square error for the Central domain for 2002 is generally below 2.0 m/s, the performance goal for this parameter. From Figure 5-29 (as well as in Table 5-5), the temperature bias results for the 36 month are generally quite close to the ± 0.5 deg C performance goal. As shown in Figure 5-30 the temperature error results are slightly poorer than the 2 deg C performance goal for 2001 and 2003, but are below the 2.0 deg C threshold for 2002. Note that the benchmarks were developed not to provide a pass/fail standard to which all modeling results should be held, but rather to put the results into an historical context.

In summary, we find that:

- Relative Humidity
 - Bias over three-year period near zero all domains
 - For some months over- and under-prediction (up to 10% or more) is evident – no discernable trend
 - Errors typically diminish from 2001 through 2003, and are generally < 12% after 1st quarter of 2001.
- Surface Temperatures

- Monthly averaged temperatures are systematically biased low (cooler) by 0.25 to 1.25 deg C.
- The errors in monthly averaged temperatures typically range between 1.8 and 2.6 deg C
- Average error over all months is about 2.2 deg C.
- Surface Wind Speeds
 - IOA typically between 0.8 0-0.9
 - Seasonally variable
 - Central subdomain gives best correlation
- Results from MM5/CALMET evaluation provide potentially useful information for diagnosing BART visibility modeling analyses
- MM5/CALMET fields exhibit good statistical agreement with observations, in part because observations figure prominently in the construction of the interpolated CALMET fields.
- MM5/CALMET fields for the three CENRAP subdomains are quite sufficient for use in CALPUFF modeling.

5.1.5 Meteorological Data Archive and Distribution

All models, scripts and CALMET data (excepting MM5 outputs) are available from CENRAP on appropriate external combination Firewire/USB drives.

5.2 Aerometric Monitoring Networks

Data from ambient monitoring networks for both gas-phase and aerosol species are available for use in CENRAP BART modeling analyses. Table 5-4 summarizes ambient monitoring networks. Data for 2002 have been compiled for all networks covering the CENRAP domain with the exception of the PAMS and PM Supersites. These data sets may be obtained from CENRAP. Figures 5-5 and 5-6 display the locations of monitoring sites in and near the CENRAP States.

Table 5-1. CENRAP Lambert Conic Conformal Modeling Domain Specifications (40.97 degree projection origin; 33 and 45 degree matching parallels).

Domain	Southwest Coordinate (km)	Number of X grid cells	Number of Y grid cells	Horizontal Resolution
CALMET				
South	-1008, -1620	306	246	6 km
Central	-1008, -864	388	234	6 km
North	-1008, 0	300	193	6 km

Table 5-2. Vertical Layer Structure in CALMET Fields. (Heights are in meters.)

LAYER NUMBER	LAYER HEIGHT	LAYER NUMBER	LAYER HEIGHT
0	0.	6	640.
1	20.	7	1200.
2	40.	8	2000.
3	80.	9	3000.
4	160.	10	4000.
5	320.		

Table 5-3. Meteorological Model File Sizes for CENRAP BART Modeling.

CALMET 6 km File Sizes, (Gbytes)				MM5 File Sizes, (Gbytes)		
Domain	Monthly	Annual	3 Years	Domain	Grid	3 years
North	4.6	55.2	165.6	2001	12 km	1370
Central	6.6	79.2	237.6	2002	36 km	430
South	6.0	72.0	216.0	2003	36 km	430
total	17.2	206.4	619.2	total		2230

Table 5-4. Statistical Evaluation of the CALMET Meteorological Fields for 2001-2003.

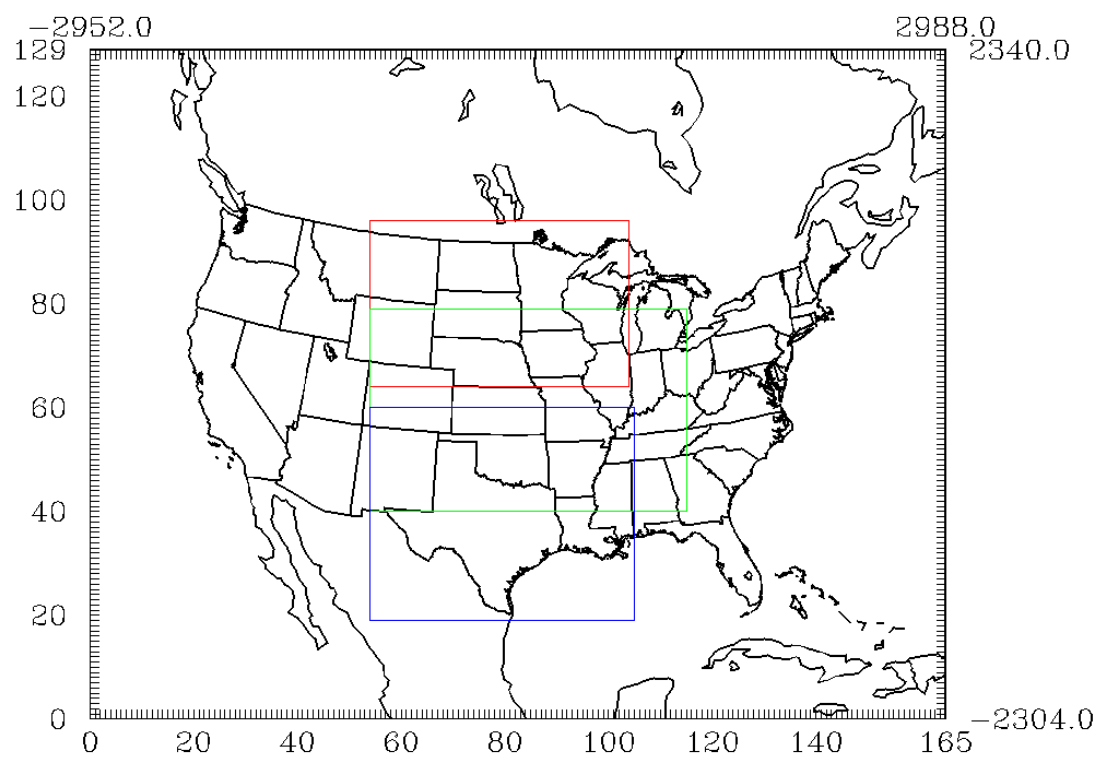
CALMET Model Evaluation Statistics for 2001.													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
RH Bias (%)													
North	4.54	3.19	0.17	-14.55	-12.09	-4.35	-0.62	1.17	-2.07	-7.98	-6.62	-4.22	-3.62
Central	-2.60	-7.28	-11.38	-10.69	-8.62	-2.90	0.66	1.07	-1.44	-5.46	-6.16	-7.78	-5.21
South	-10.23	-11.53	-13.78	-4.24	-2.08	0.99	4.12	3.16	-0.12	-2.12	-3.44	-9.76	-4.09
RH Error (%)													
North	10.06	10.31	14.03	18.77	16.28	12.39	11.82	11.76	13.26	15.54	13.53	12.89	13.39
Central	13.32	15.86	17.45	17.05	14.50	11.67	11.52	11.32	12.26	15.52	14.79	14.95	14.18
South	16.22	18.37	18.17	13.26	12.15	11.51	12.09	12.40	11.82	14.85	14.73	16.19	14.31
Temp Bias (°C)													
North	-1.63	-1.23	-1.23	-0.24	0.08	-0.29	-0.23	-0.54	-0.55	-0.09	-0.40	-1.27	-0.64
Central	-0.99	-0.65	-0.54	-0.16	0.13	-0.23	-0.43	-0.54	-0.36	-0.34	-0.30	-0.74	-0.43
South	-0.47	-0.42	0.03	-0.31	-0.33	-0.63	-0.99	-0.85	-0.52	-0.36	-0.19	-0.21	-0.44
Temp Error (°C)													
North	3.10	2.88	2.54	2.49	2.44	2.43	2.42	2.49	2.58	2.48	2.89	2.55	2.61
Central	2.38	2.25	1.99	2.18	1.99	2.01	2.07	2.11	2.21	2.52	2.61	2.42	2.23
South	2.31	2.28	1.92	2.13	2.01	2.17	2.19	2.21	2.19	2.70	2.49	2.50	2.26
Wind Speed IOA													
North	0.79	0.83	0.83	0.87	0.86	0.85	0.81	0.84	0.84	0.82	0.81	0.79	0.83
Central	0.85	0.87	0.88	0.88	0.89	0.86	0.84	0.86	0.87	0.86	0.85	0.84	0.86
South	0.81	0.80	0.85	0.79	0.83	0.83	0.78	0.80	0.82	0.82	0.80	0.82	0.81

CALMET Model Evaluation Statistics for 2002.													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
RH Bias (%)													
North	8.33	9.52	6.63	0.95	-2.42	1.25	2.43	1.60	0.57	0.47	4.47	7.73	3.46
Central	7.43	5.13	4.60	1.65	-1.02	1.52	2.50	1.88	-0.27	-1.40	-0.01	4.35	2.20
South	3.08	-1.19	2.53	2.32	1.26	1.98	2.51	2.62	-0.80	-2.42	-4.45	-1.03	0.53
RH Error (%)													
North	11.85	13.18	11.61	11.13	11.90	10.04	9.54	9.08	10.26	10.26	11.55	11.61	11.00
Central	12.21	12.43	11.26	10.58	10.72	9.89	9.55	9.54	10.22	10.25	11.42	11.26	10.78
South	11.24	11.76	10.34	8.95	9.30	9.49	9.46	9.61	9.68	9.33	11.63	10.95	10.14
Temp Bias (°C)													
North	-0.70	-0.82	-0.96	-0.52	-0.25	-0.36	-0.53	-0.49	-0.44	-0.67	-0.76	-0.69	-0.60
Central	-0.57	-0.65	-0.79	-0.62	-0.41	-0.68	-0.81	-0.74	-0.49	-0.54	-0.55	-0.52	-0.61
South	-0.23	-0.13	-0.52	-0.61	-0.61	-0.94	-0.94	-1.07	-0.65	-0.47	0.04	-0.13	-0.52
Temp Error (°C)													
North	2.15	2.07	2.04	1.89	1.86	1.83	1.86	1.80	1.95	1.78	1.99	2.15	1.95
Central	2.12	2.05	2.14	1.95	1.91	1.93	1.93	1.92	2.02	1.77	2.00	2.00	1.98
South	2.18	2.05	2.17	1.83	1.89	1.91	1.88	2.00	1.92	1.68	2.06	1.93	1.96
Wind Speed IOA													
North	0.82	0.84	0.86	0.88	0.86	0.85	0.85	0.83	0.85	0.85	0.81	0.78	0.84
Central	0.87	0.88	0.90	0.90	0.88	0.87	0.84	0.84	0.87	0.88	0.85	0.85	0.87
South	0.86	0.86	0.85	0.85	0.84	0.82	0.79	0.80	0.83	0.83	0.83	0.82	0.83

CALMET Model Evaluation Statistics for 2003.													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
RH Bias (%)													
North	10.15	7.40	6.01	0.93	-3.76	-0.38	1.38	2.04	-1.66	-1.99	2.96	7.68	2.56
Central	6.94	4.76	4.15	0.42	-2.18	0.17	2.08	2.13	-2.05	-4.13	0.00	5.47	1.48
South	0.00	0.00	0.47	-1.10	-0.37	0.54	1.77	2.89	-3.31	-6.01	-3.66	-0.33	-0.76
RH Error (%)													
North	13.30	11.21	12.32	11.70	11.65	10.03	9.70	9.57	11.13	12.68	11.53	11.85	11.39
Central	12.77	10.95	11.61	11.18	10.33	9.91	9.49	9.50	10.70	12.69	12.10	12.43	11.14
South	11.18	10.00	9.85	10.17	9.20	9.54	8.90	9.91	10.21	12.12	12.15	12.39	10.47
Temp Bias (°C)													
North	-1.24	-0.99	-0.63	-0.29	-0.11	-0.10	-0.22	-0.49	-0.34	0.29	-0.85	-1.34	-0.53
Central	-0.84	-0.80	-0.64	-0.47	-0.27	-0.36	-0.60	-0.66	-0.32	0.30	-0.54	-0.89	-0.51
South	-0.17	-0.27	-0.36	-0.43	-0.46	-0.62	-0.91	-0.98	-0.28	0.53	0.00	-0.03	-0.33
Temp Error (°C)													
North	2.31	2.15	2.14	2.02	1.81	1.77	1.91	1.98	2.25	2.57	2.30	2.67	2.16
Central	2.14	2.03	2.15	2.13	1.80	1.81	1.96	1.99	2.16	2.54	2.31	2.45	2.12
South	2.10	1.90	2.00	2.08	1.84	1.81	1.88	2.06	1.94	2.40	2.28	2.48	2.06
Wind Speed IOA													
North	0.79	0.81	0.83	0.86	0.87	0.85	0.86	0.87	0.84	0.82	0.80	0.82	0.83
Central	0.85	0.88	0.87	0.89	0.90	0.87	0.87	0.86	0.87	0.87	0.86	0.86	0.87
South	0.83	0.83	0.85	0.83	0.85	0.81	0.83	0.82	0.85	0.84	0.82	0.82	0.83

Table 5-5. Overview of Ambient Data Monitoring Networks Covering the CENRAP Domain.

Monitoring Network	Chemical Species Measured	Sampling Period	Data Availability/Source
The Interagency Monitoring of Protected Visual Environments (IMPROVE)	Speciated PM25 and PM10 (see species mappings)	1 in 3 days; 24 hr average	http://vista.cira.colostate.edu/improve/Data/IMPROVE/improve_data.htm
Clean Air Status and Trends Network (CASTNET)	Speciated PM25, Ozone (see species mappings)	Approximately 1-week average	http://www.epa.gov/castnet/data.html
National Atmospheric Deposition Program (NADP)	Wet deposition (hydrogen (acidity as pH), sulfate, nitrate, ammonium, chloride, and base cations (such as calcium, magnesium, potassium and sodium)), Mercury	1-week average	http://nadp.sws.uiuc.edu/
Air Quality System (AQS) Aka Aerometric Information Retrieval System (AIRS)	CO, NO2, O3, SO2, PM25, PM10, Pb	Typically hourly average	http://www.epa.gov/air/data/
Speciation Trends Network (STN)	Speciated PM	24-hour average	http://www.epa.gov/ttn/amtic/amticpm.html
Southeastern Aerosol Research and Characterization (SEARCH) (Southeastern US only)	24-hr PM25 (FRM Mass, OC, BC, SO4, NO3, NH4, Elem.); 24-hr PM coarse (SO4, NO3, NH4, elements); Hourly PM2.5 (Mass, SO4, NO3, NH4, EC, TC); Hourly gases (O3, NO, NO2, NOy, HNO3, SO2, CO)	Hourly or 24-hour average, depending on parameter.	Electric Power Research Institute (EPRI), Southern Company, and other companies. http://www.atmospheric-research.com
EPA Particulate Matter Supersites (Includes St. Louis in the CENRAP region)	Speciated PM25		http://www.epa.gov/ttn/amtic/supersites.html
Photochemical Assessment Monitoring Stations (PAMS)	Varies for each of 4 station types.		http://www.epa.gov/ttn/amtic/pamsmain.html
National Park Service Gaseous Pollutant Monitoring Network	Acid deposition (Dry; SO4, NO3, HNO3, NH4, SO2), O3, meteorological data	Hourly	http://www2.nature.nps.gov/ard/gas/netdata1.htm



CENRAP CALMM5 Extraction Regions

Figure 5-1. CENRAP North, Central, and South 6 km Meteorological Domains.

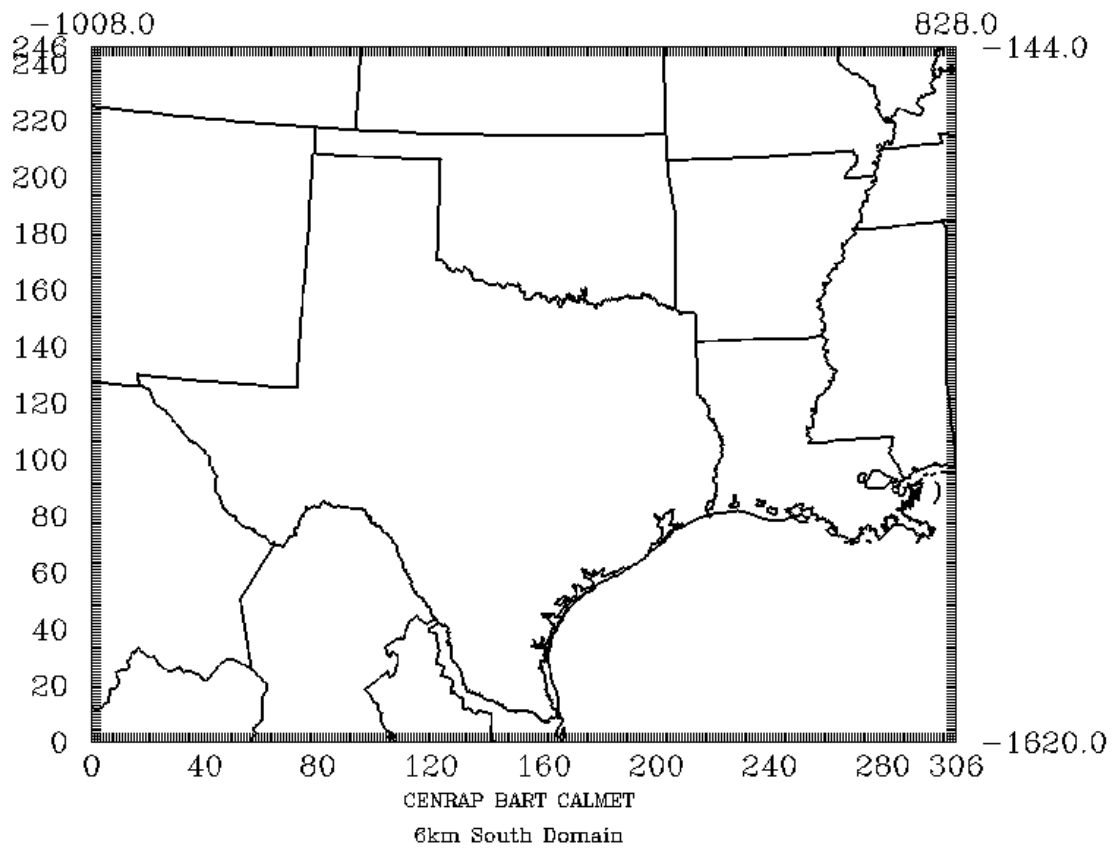


Figure 5-2. CENRAP South Domain.

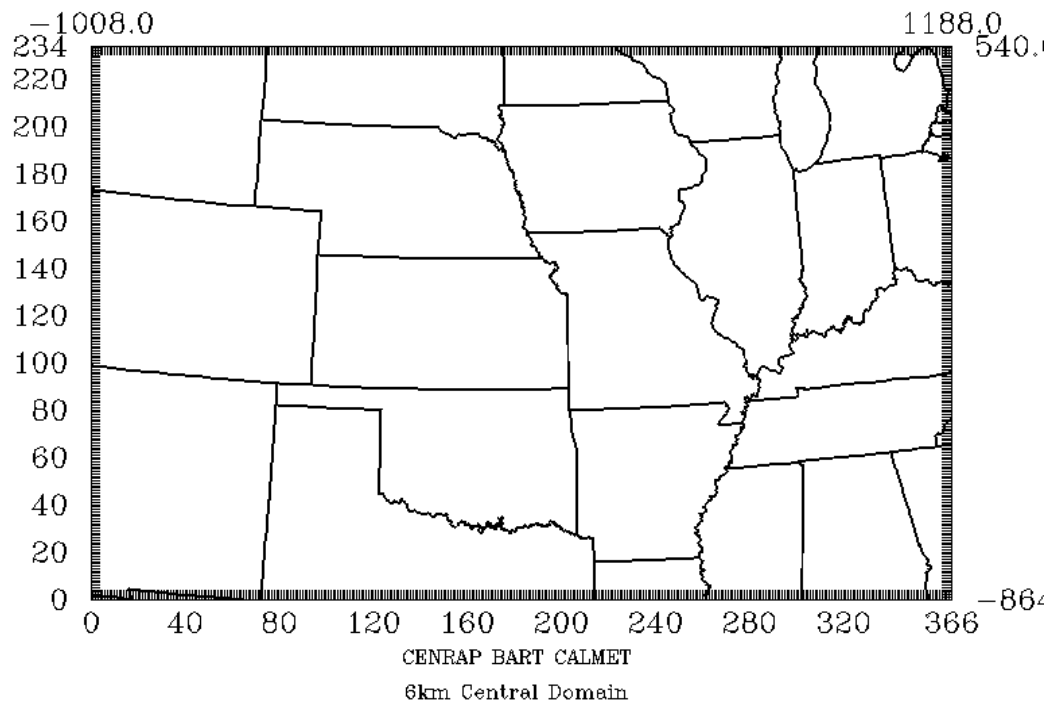


Figure 5-3. CENRAP Central Domain.

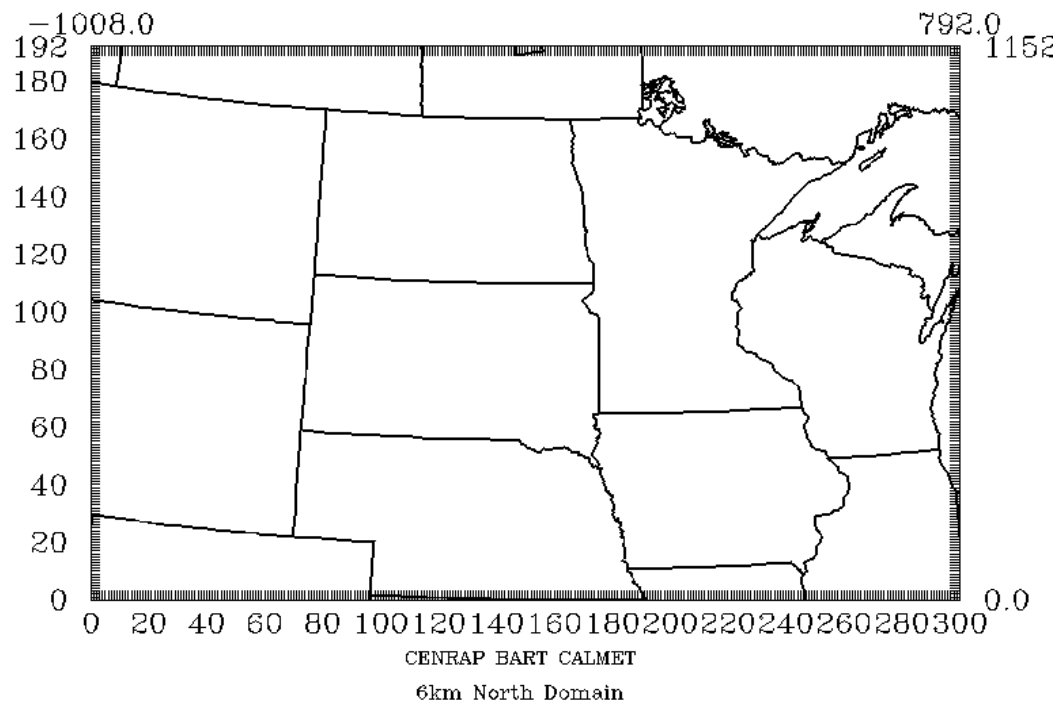


Figure 5-4. CENRAP North Domain.

DRAFT

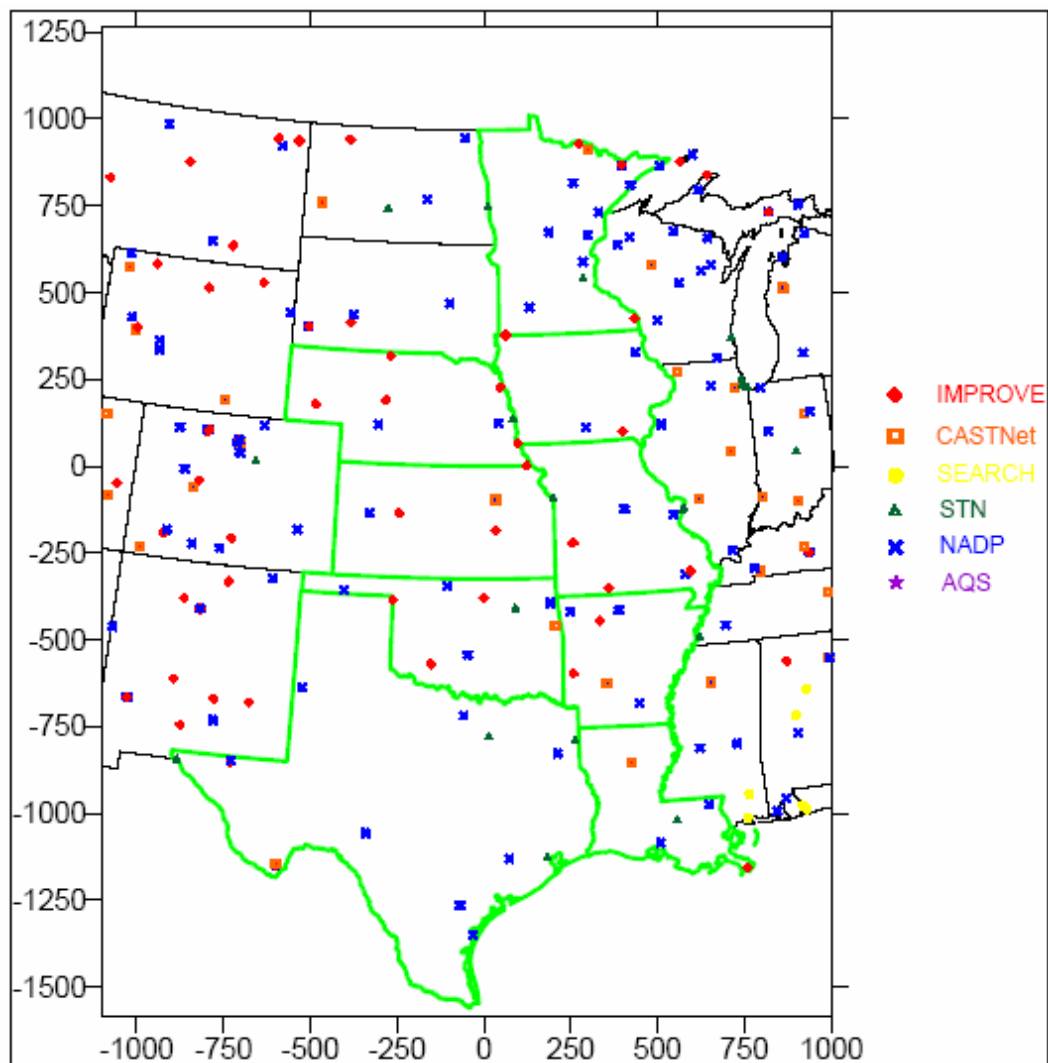


Figure 5-5. Locations of IMPROVE, CASTNet, SEARCH, STN and NADP Monitoring Sites in and Near the CENRAP States.

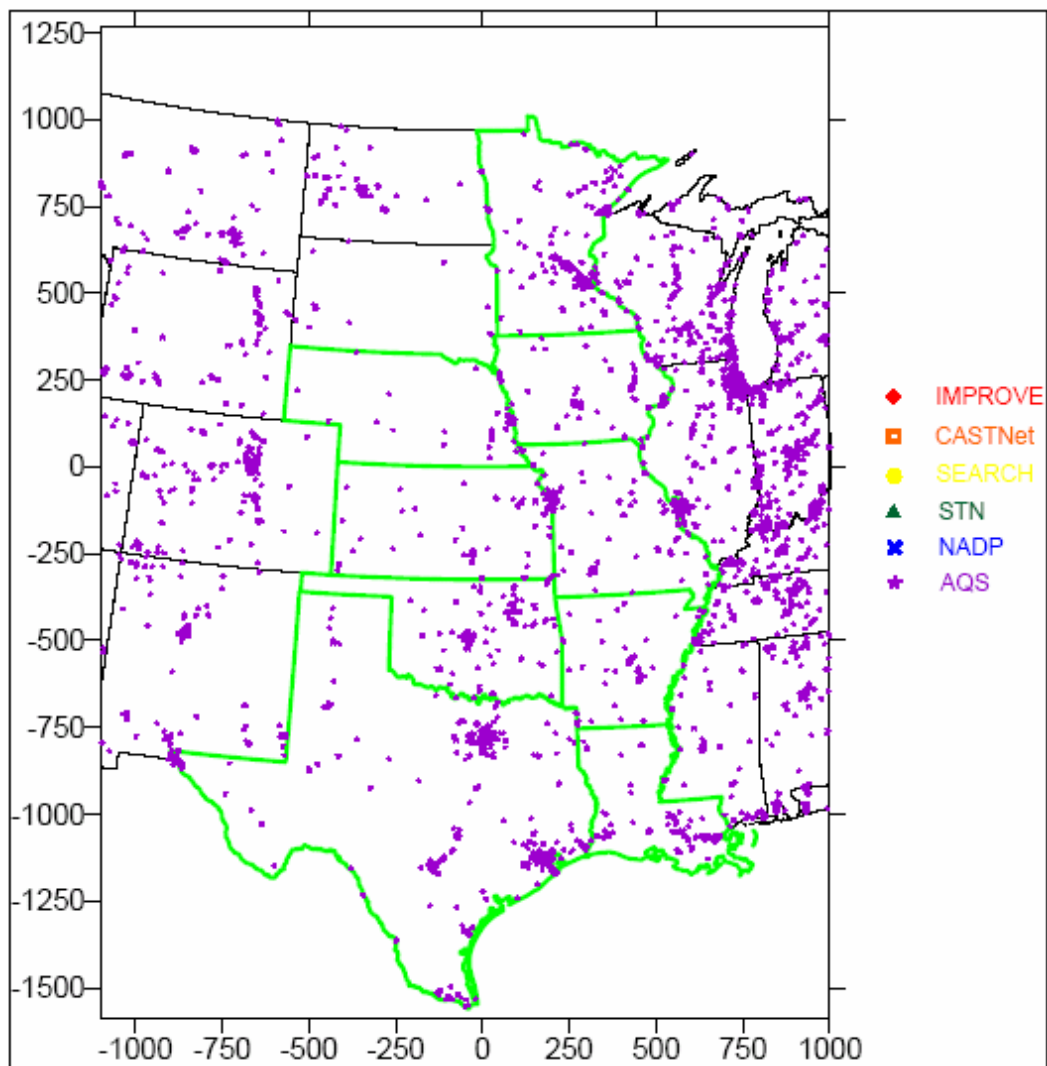


Figure 5-6. Locations of AQS Monitoring Sites in and Near the CENRAP States.

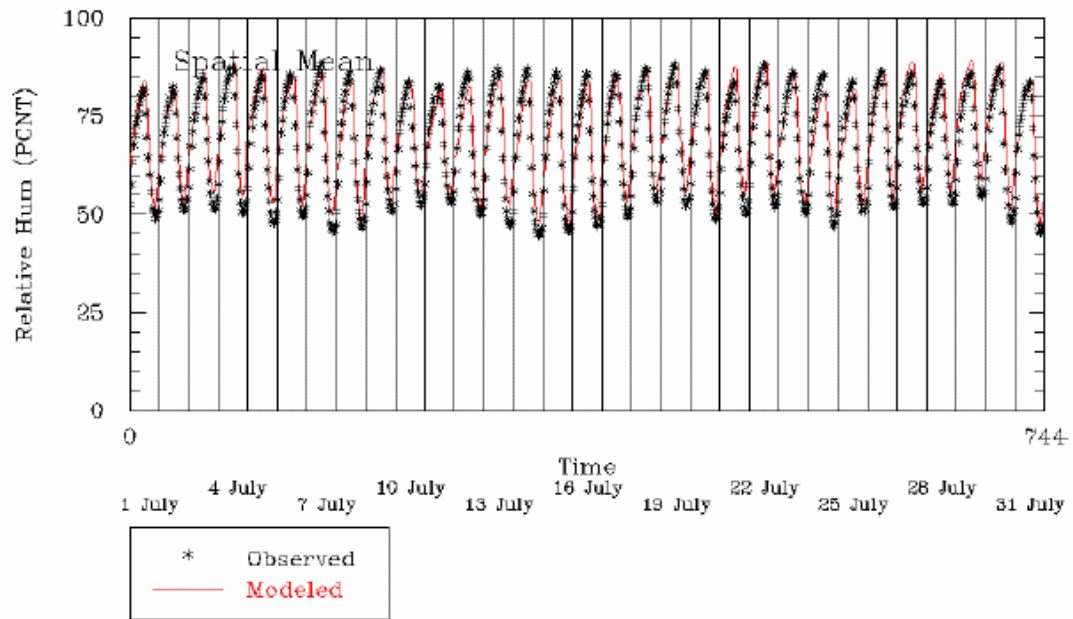


Figure 5-7. Spatial Mean Relative Humidity (%) over the Central Domain: July 2002.

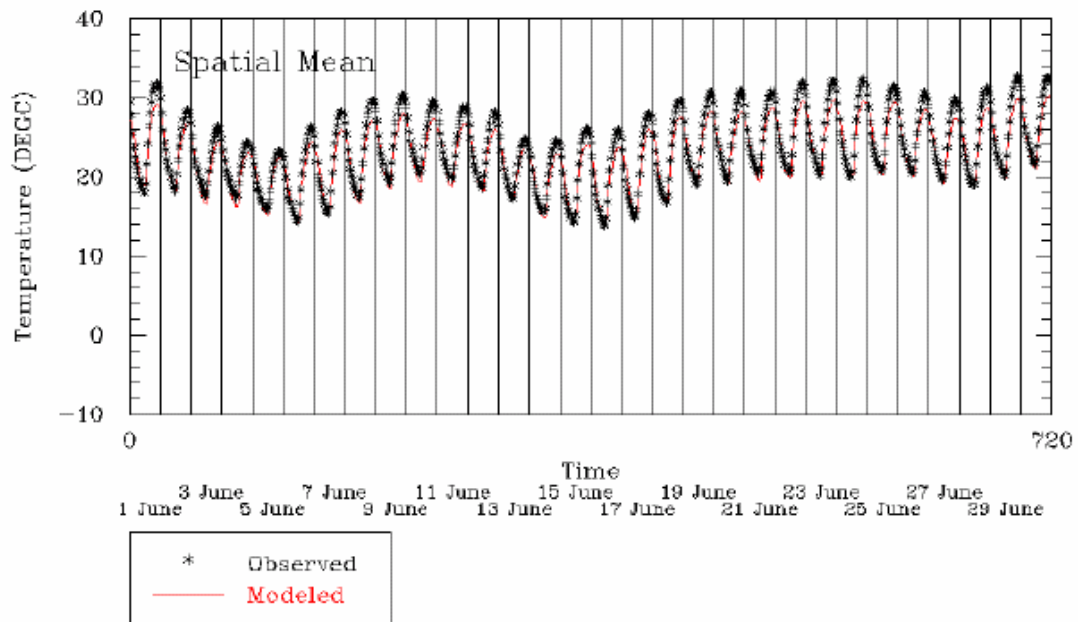


Figure 5-8. Spatial Mean Surface Temperature (deg C) over the Central Domain: July 2002.

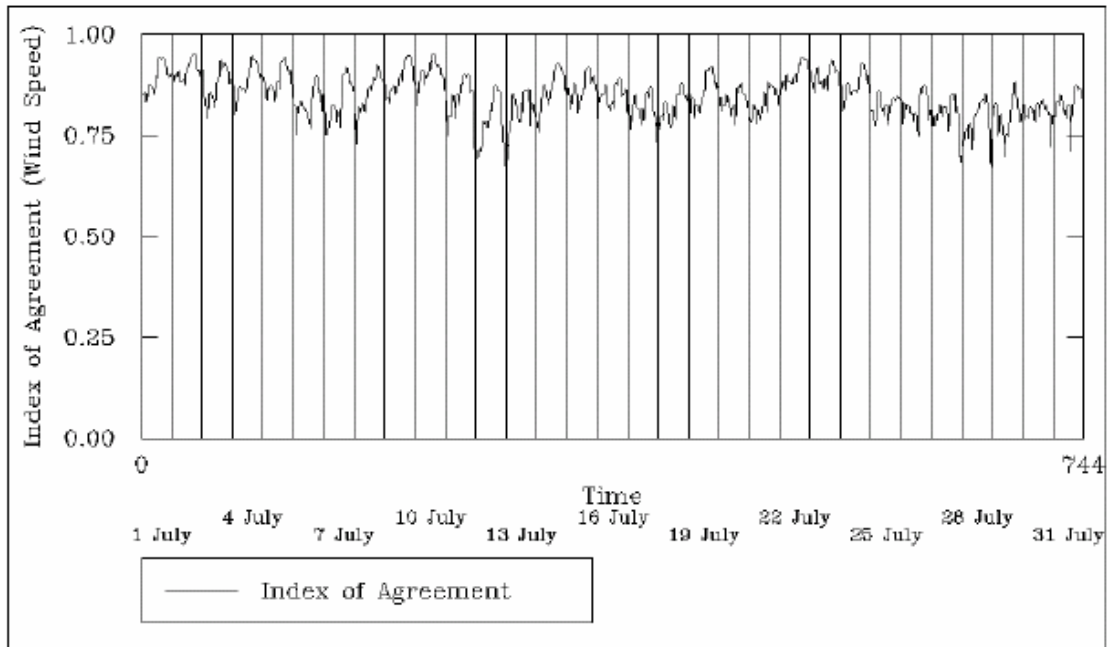


Figure 5-9. Wind Speed Index of Agreement over the Central Domain: July 2002.

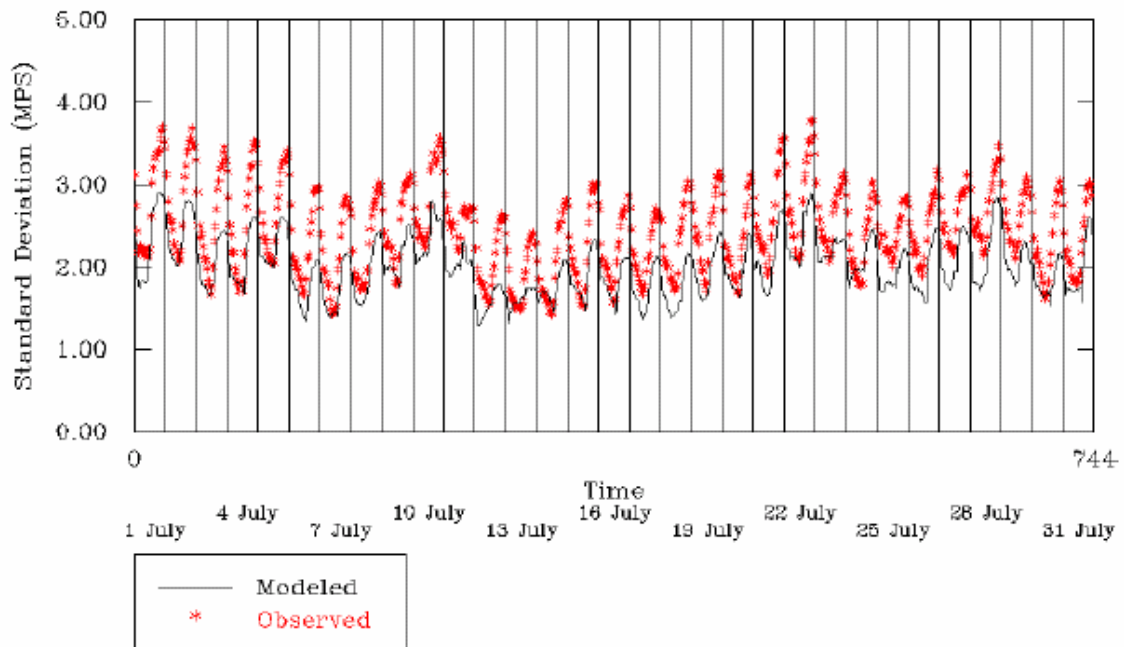


Figure 5-10. Standard Deviation in Wind Speed (m/s) over the Central Domain: July 2002.

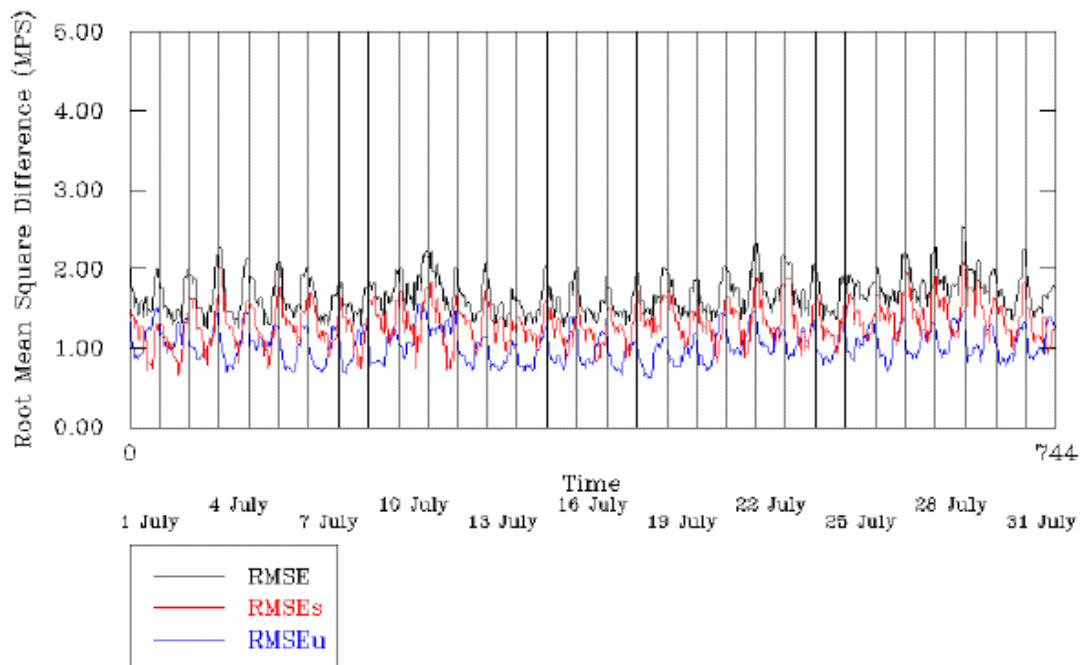


Figure 5-11. Root Mean Square Error in Wind Speed (m/s) over the Central Domain: July 2002.

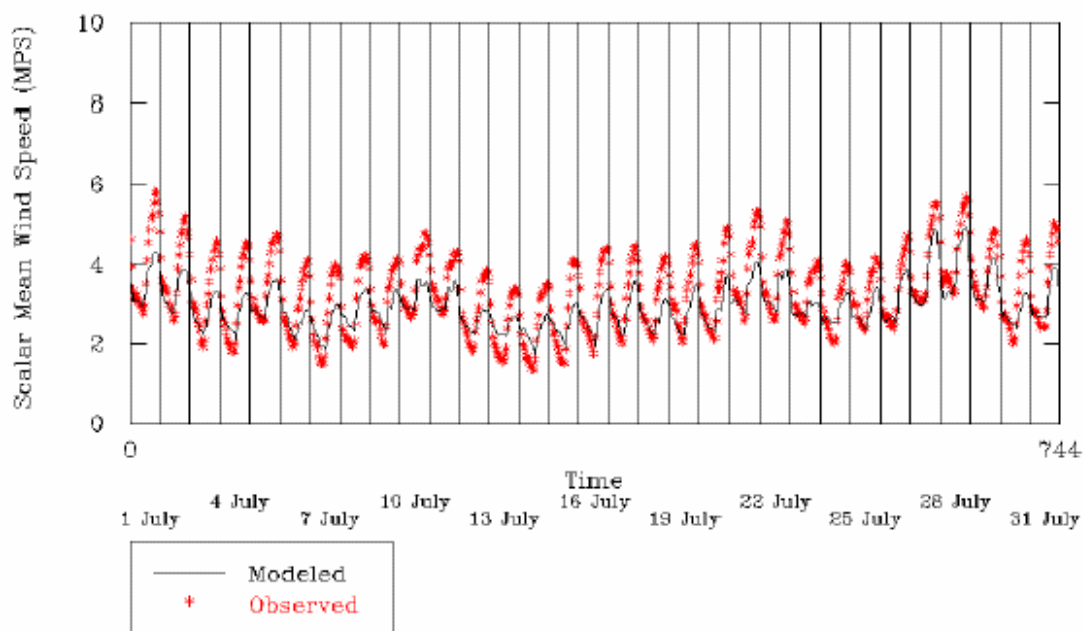


Figure 5-12. Scalar Mean Wind Speed (m/s) over the Central Domain: July 2002.

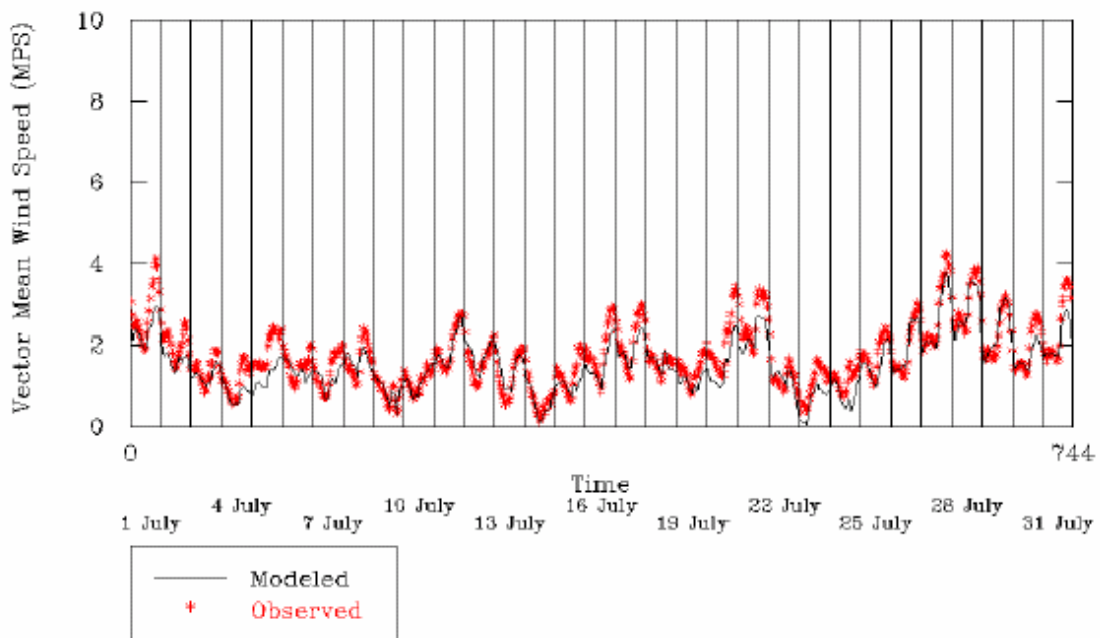


Figure 5-13. Vector Mean Wind Speed (m/s) over the Central Domain: July 2002.

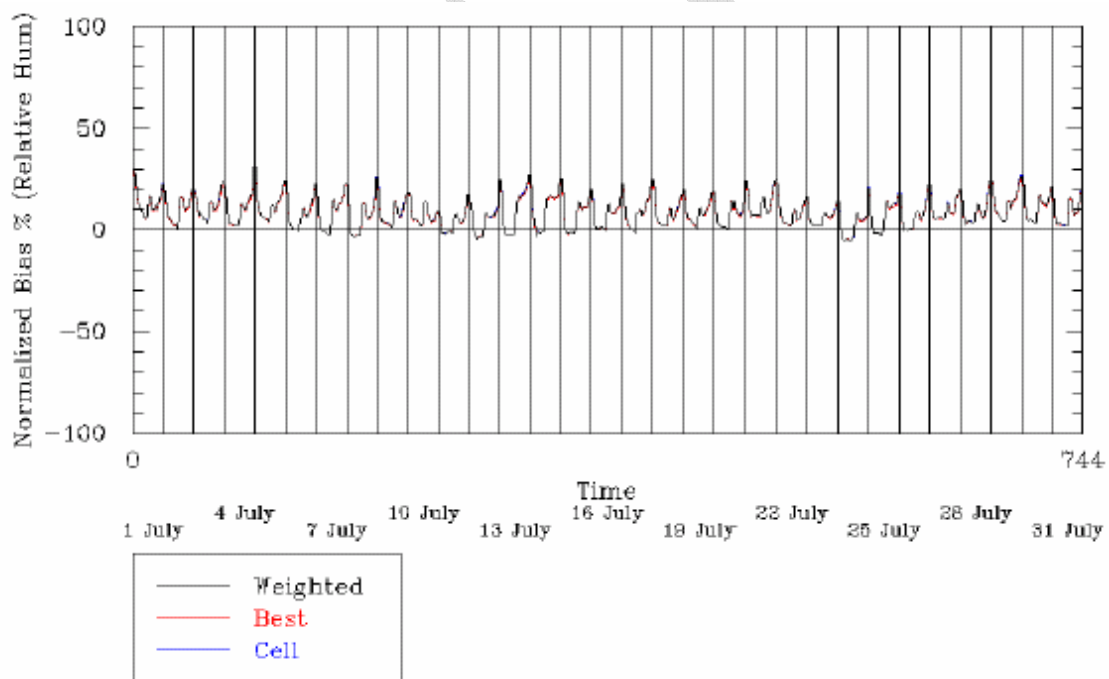


Figure 5-14. Normalized Bias in Relative Humidity (%) over the Central Domain: July 2002.

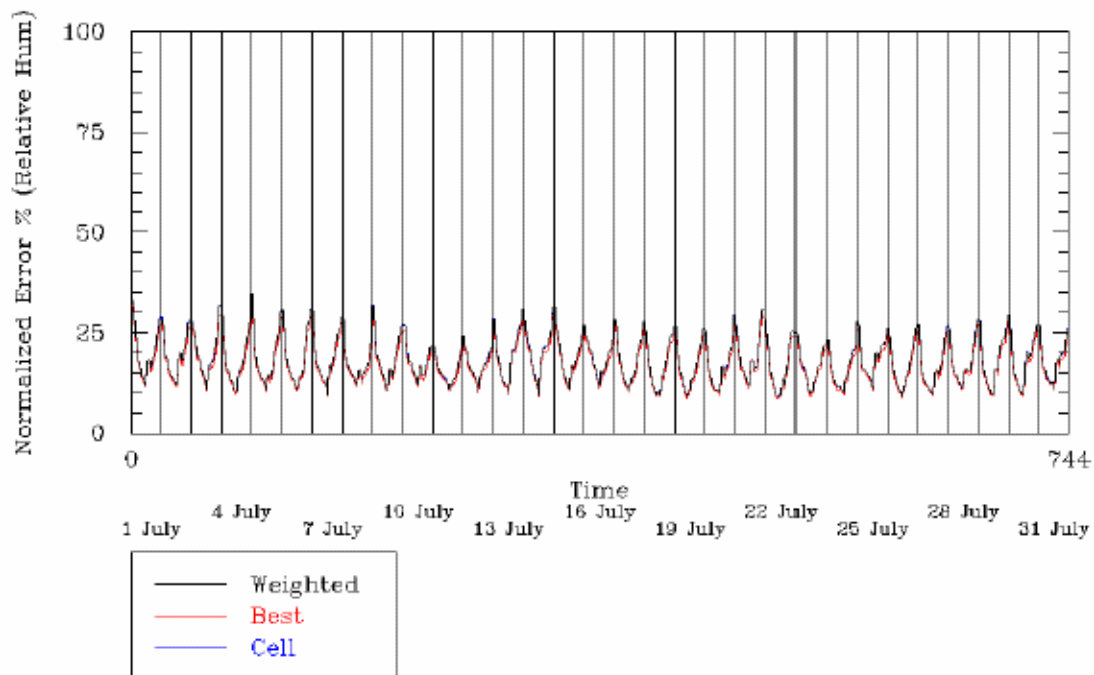


Figure 5-15. Normalized Error in Relative Humidity (%) over the Central Domain: July 2002.

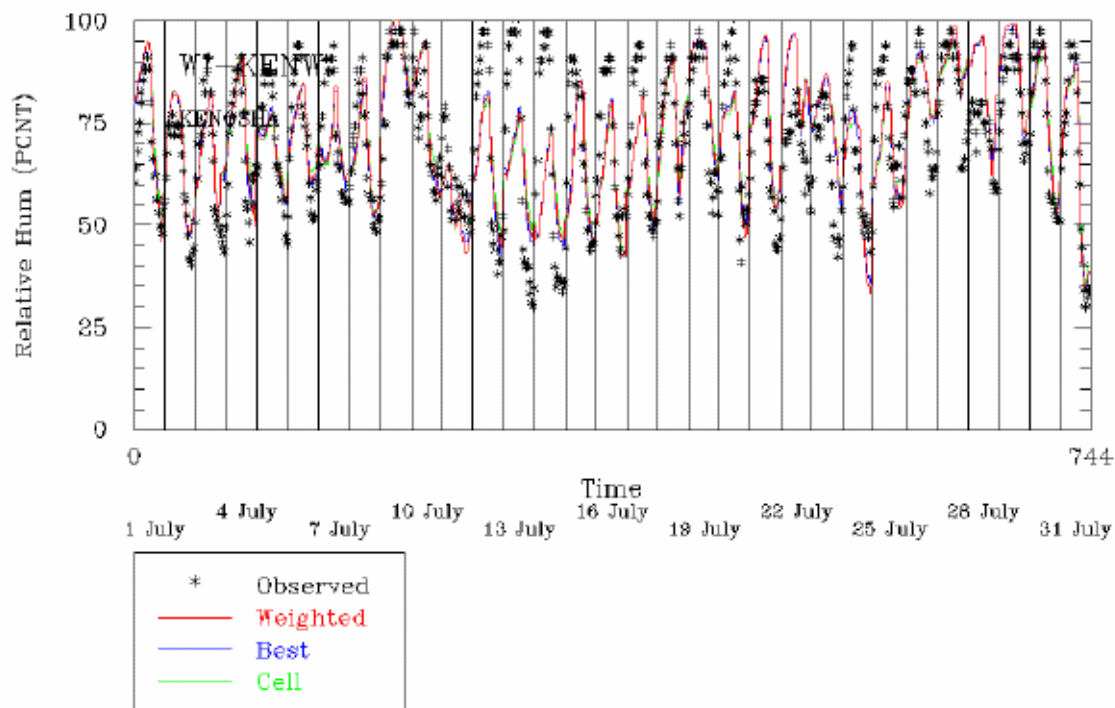


Figure 5-16. Relative Humidity (%) at Kenosha, WI: July 2002.

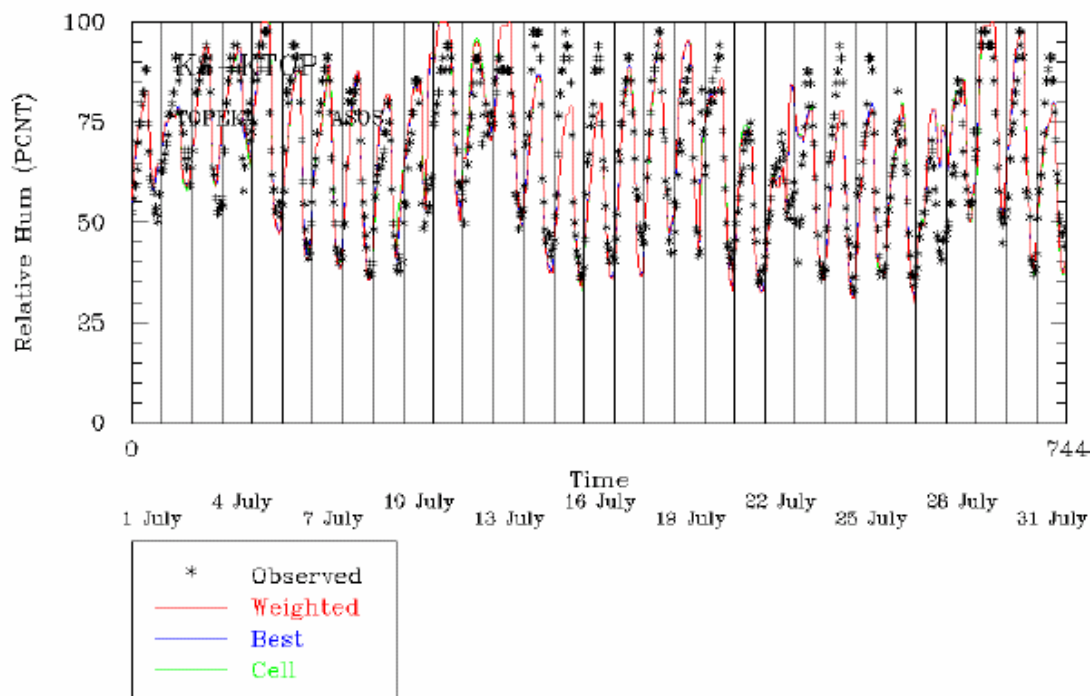


Figure 5-17. Relative Humidity (%) at Topeka, KS: July 2002.

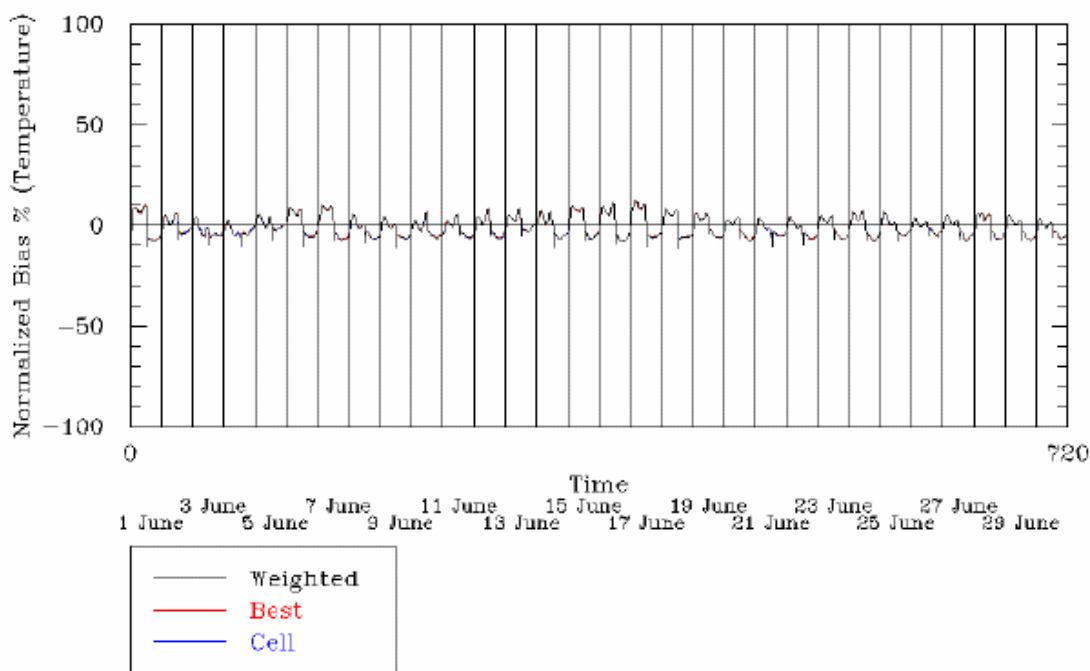


Figure 5-18. Normalized Bias in Surface Temperature (%) over the Central Domain: July 2002.

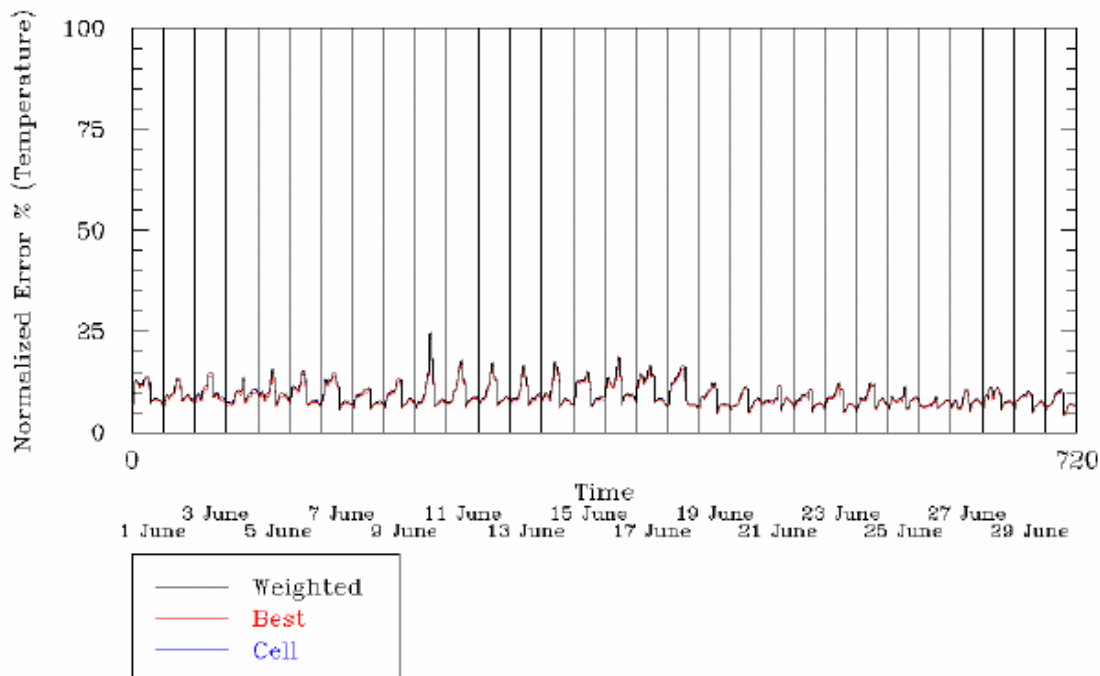


Figure 5-19. Normalized Error in Surface Temperature over the Central Domain: July 2002.

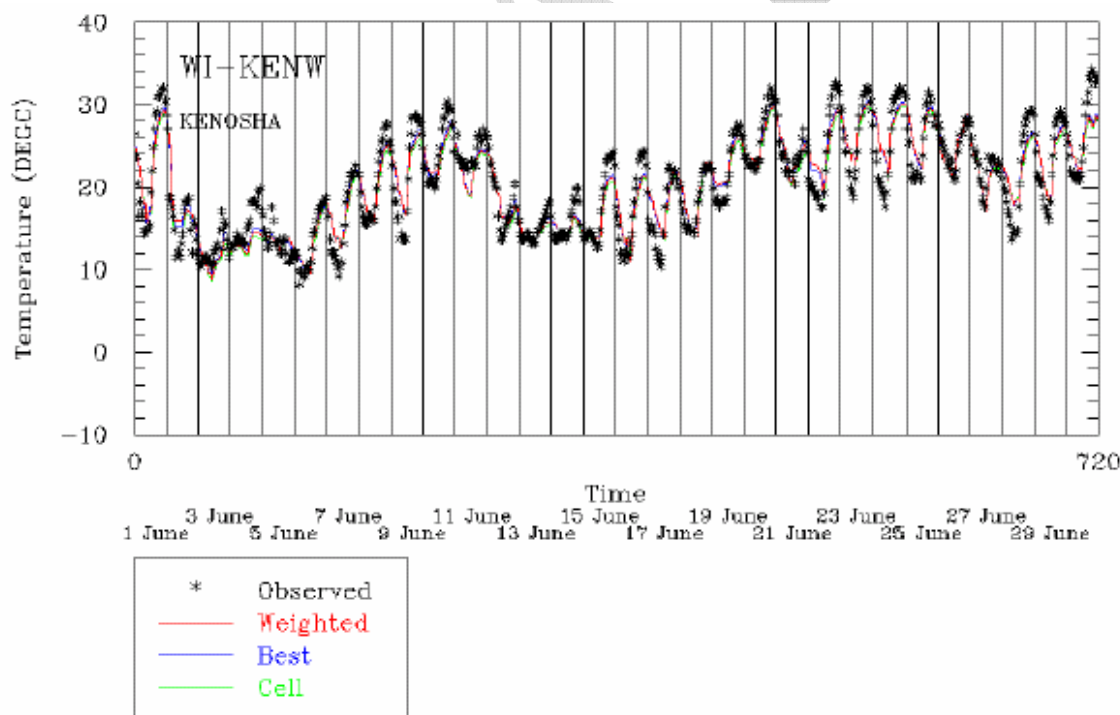


Figure 5-20. Surface Temperature (deg C) at Kenosha, WI: July 2002.

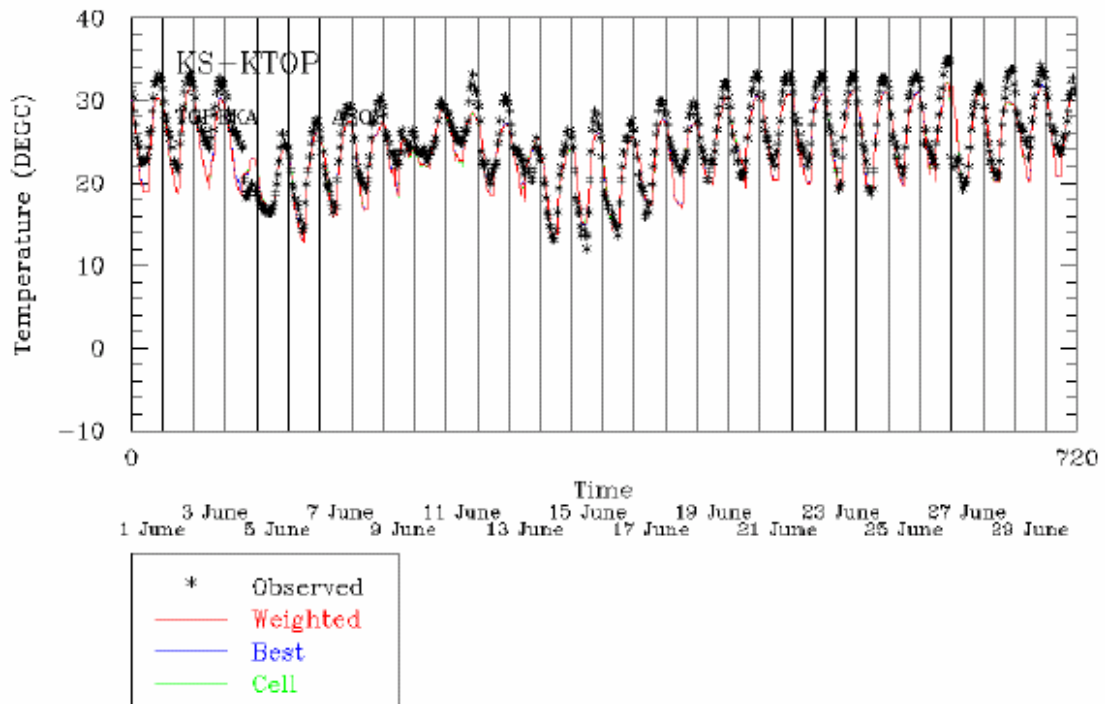


Figure 5-21. Surface Temperature at Topeka, KS: July 2002.

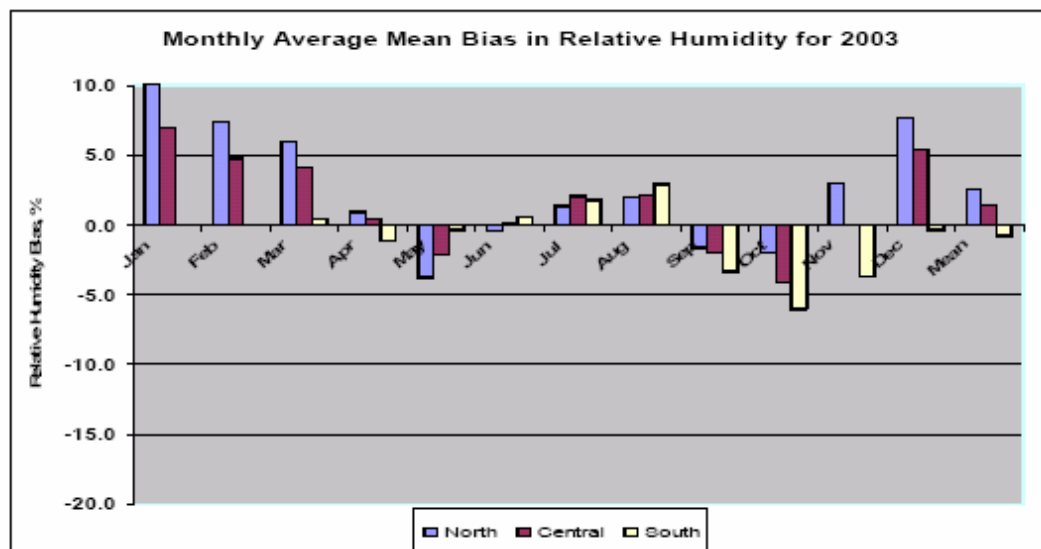
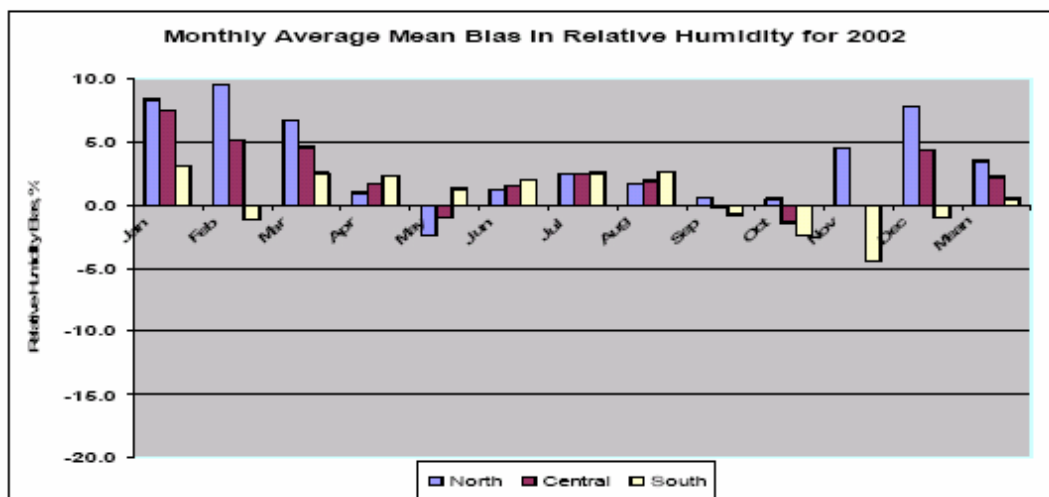
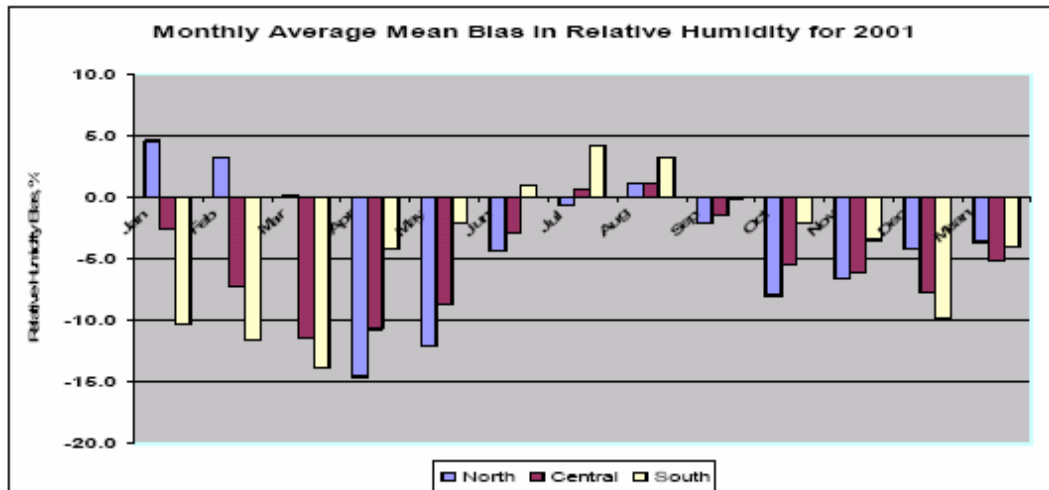


Figure 5-22. MM5/CALMET Relative Humidity Bias (%) by Month for Three BART Modeling Years (2001, 2003, and 2003).

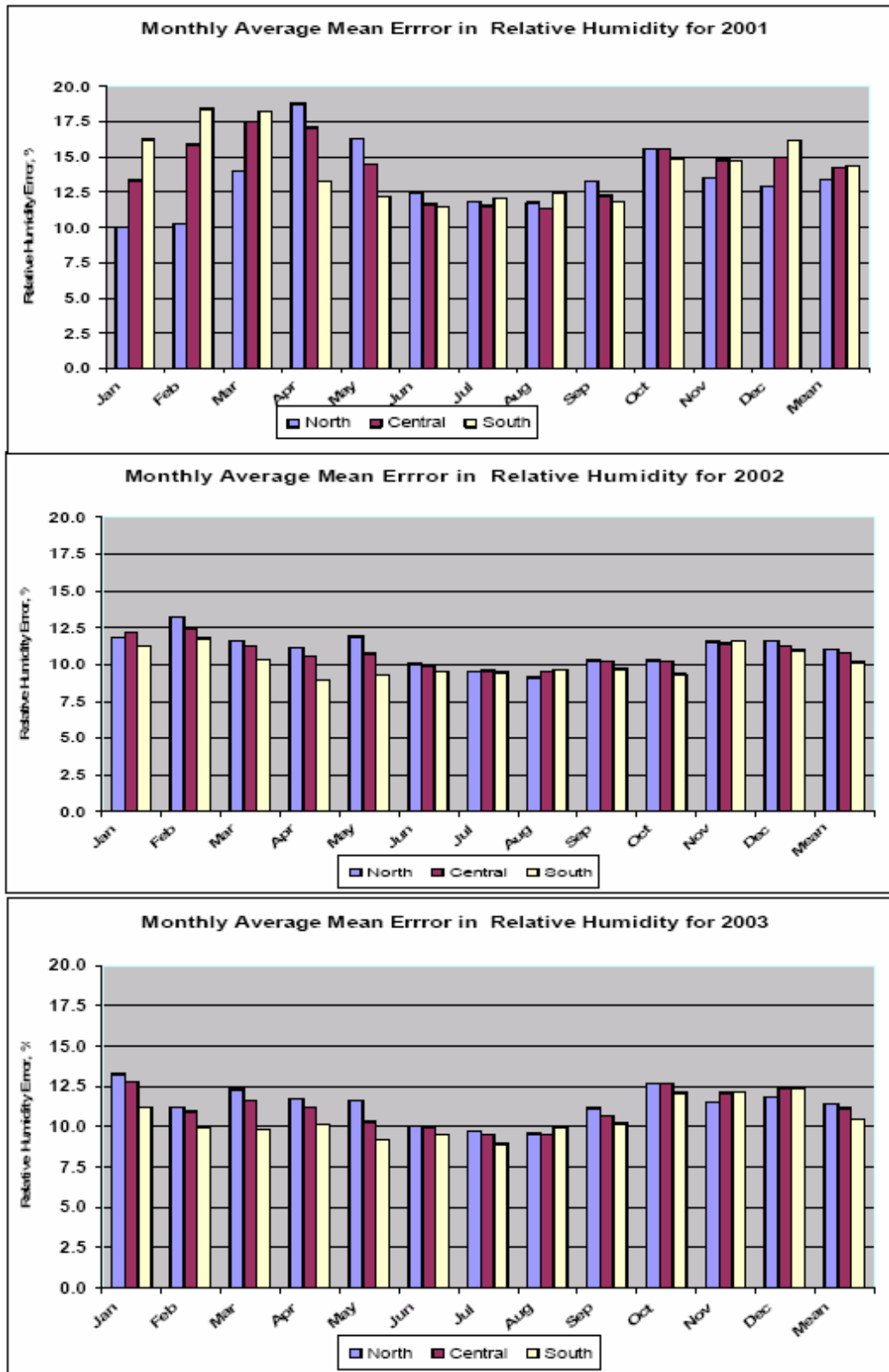


Figure 5-23. MM5/CALMET Relative Humidity Error (%) by Month for Three BART Modeling Years (2001, 2003, and 2003).

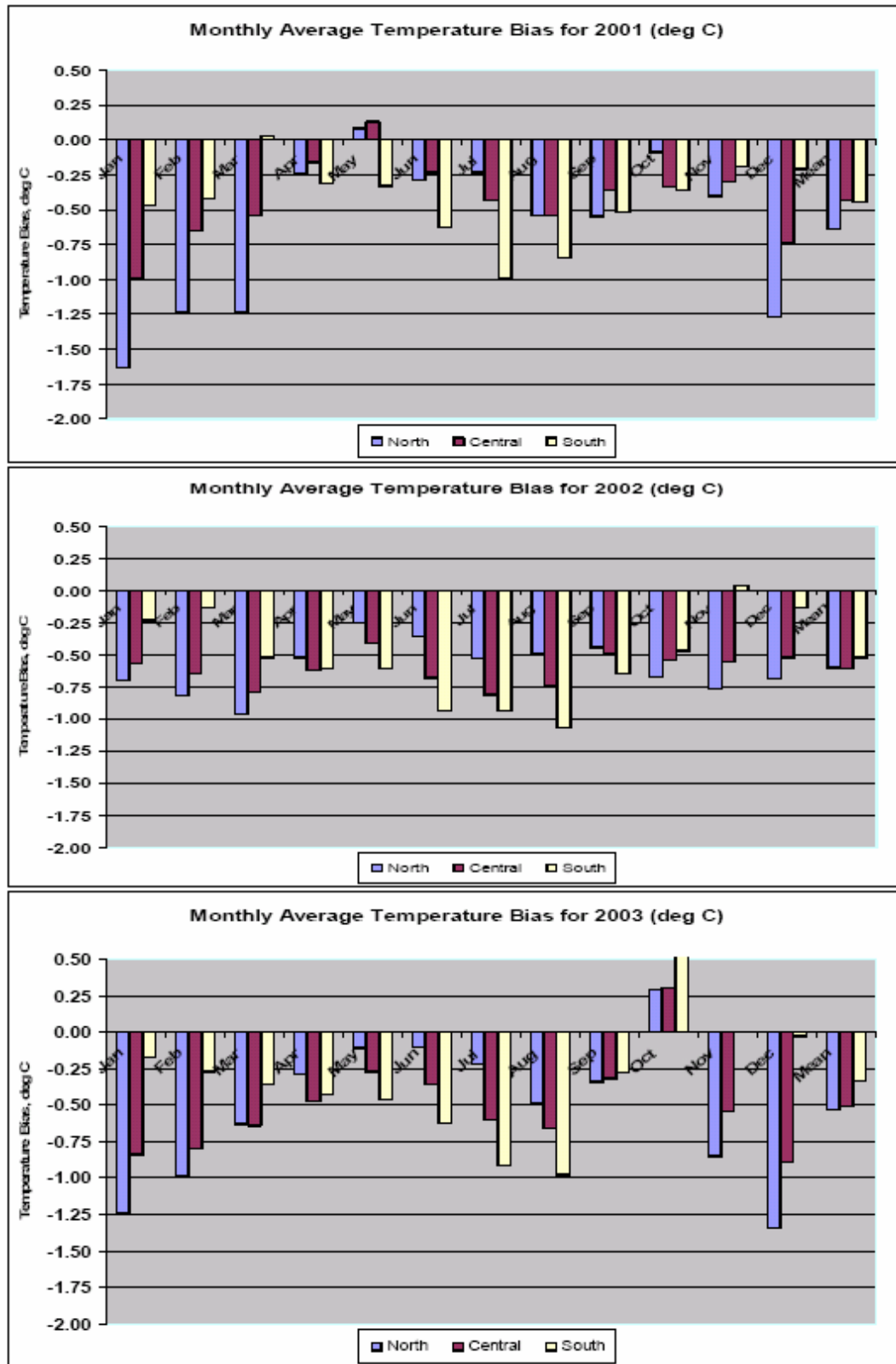


Figure 5-24. MM5/CALMET Temperature Bias (deg C) by Month for Three BART Modeling Years (2001, 2003, and 2003).

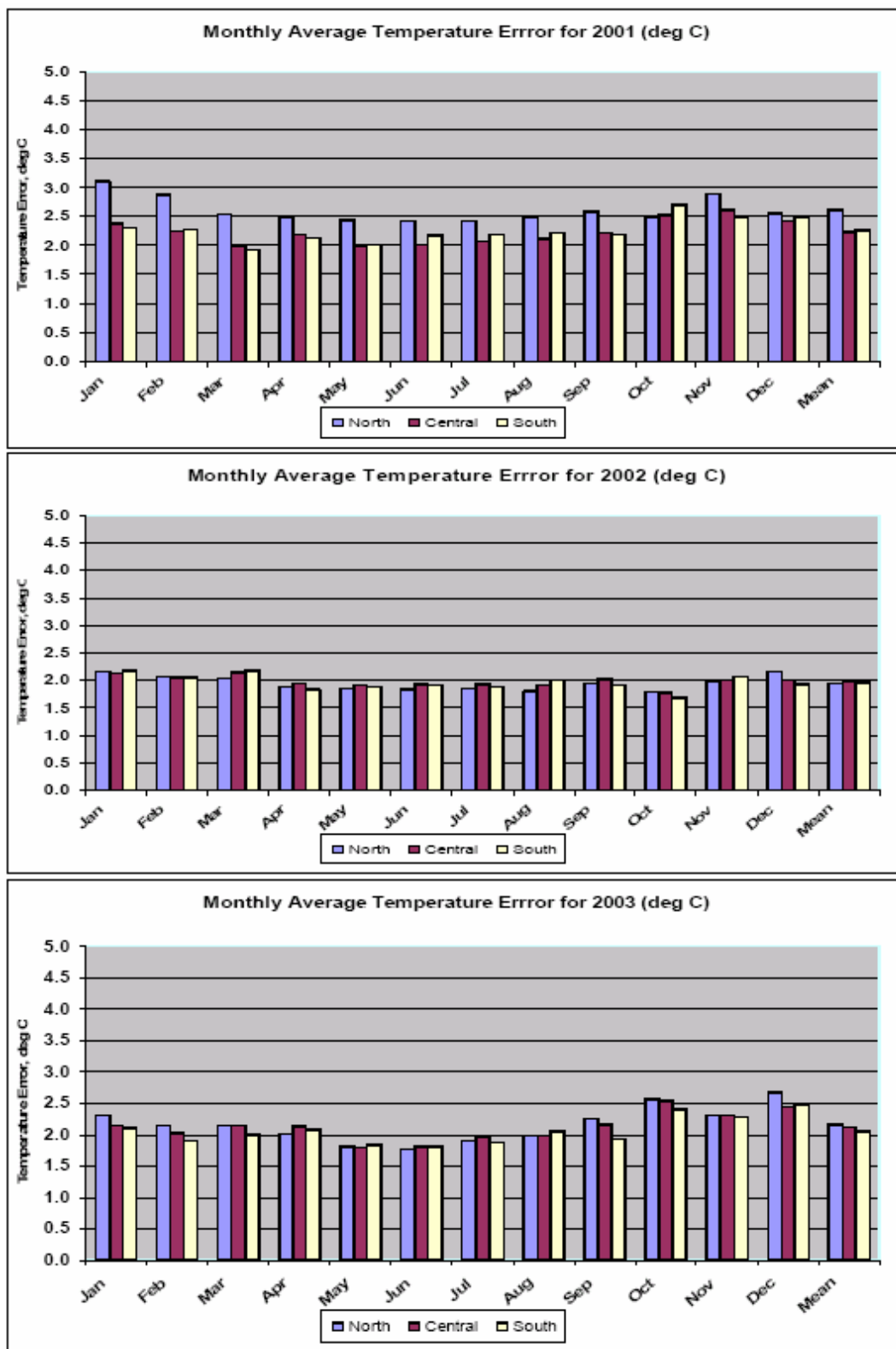


Figure 5-25. MM5/CALMET Temperature Error (deg C) by Month for Three BART Modeling Years (2001, 2003, and 2003).

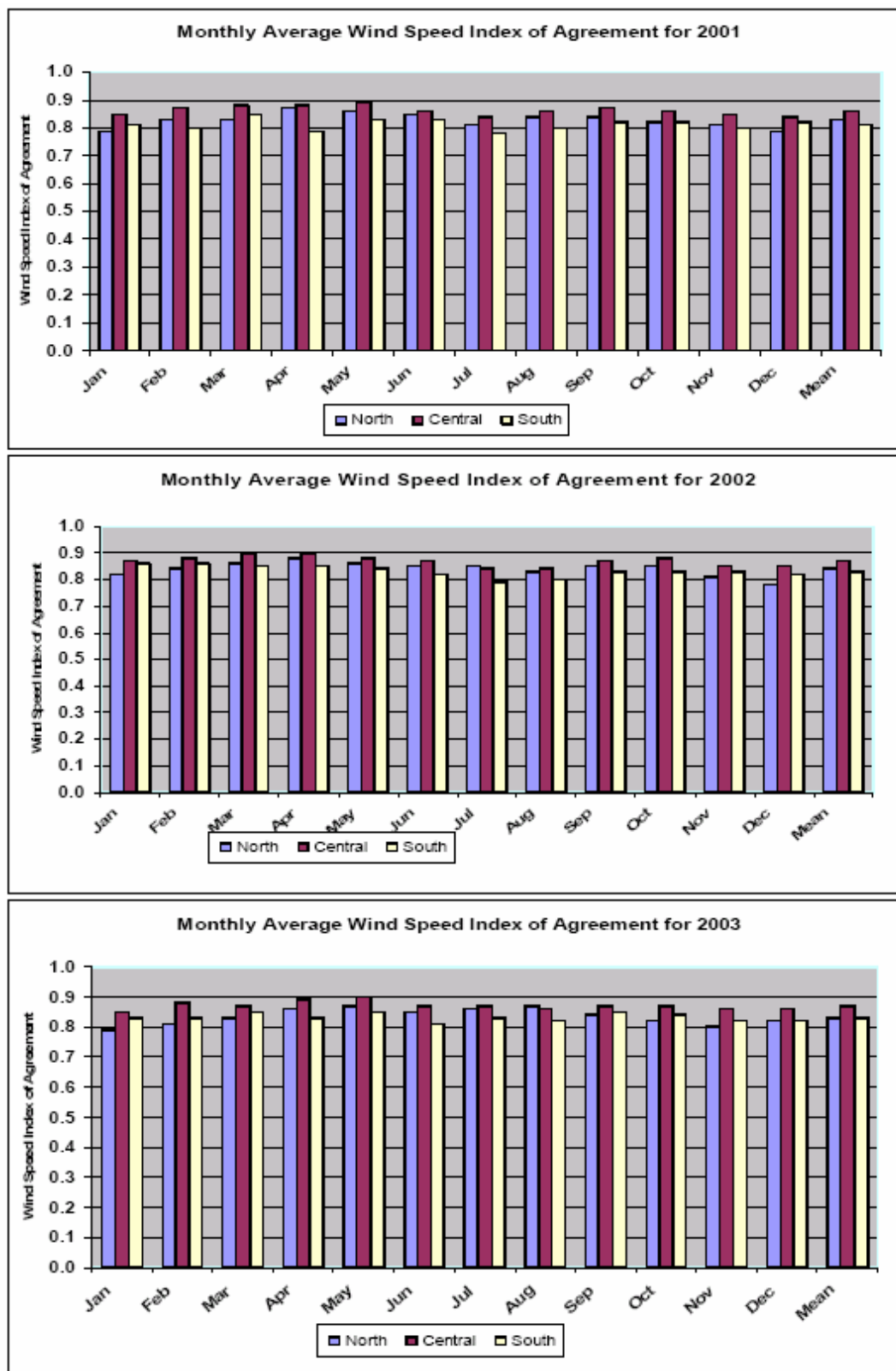


Figure 5-26. MM5/CALMET Wind Speed Index of Agreement by Month for Three BART Modeling Years (2001, 2003, and 2003).

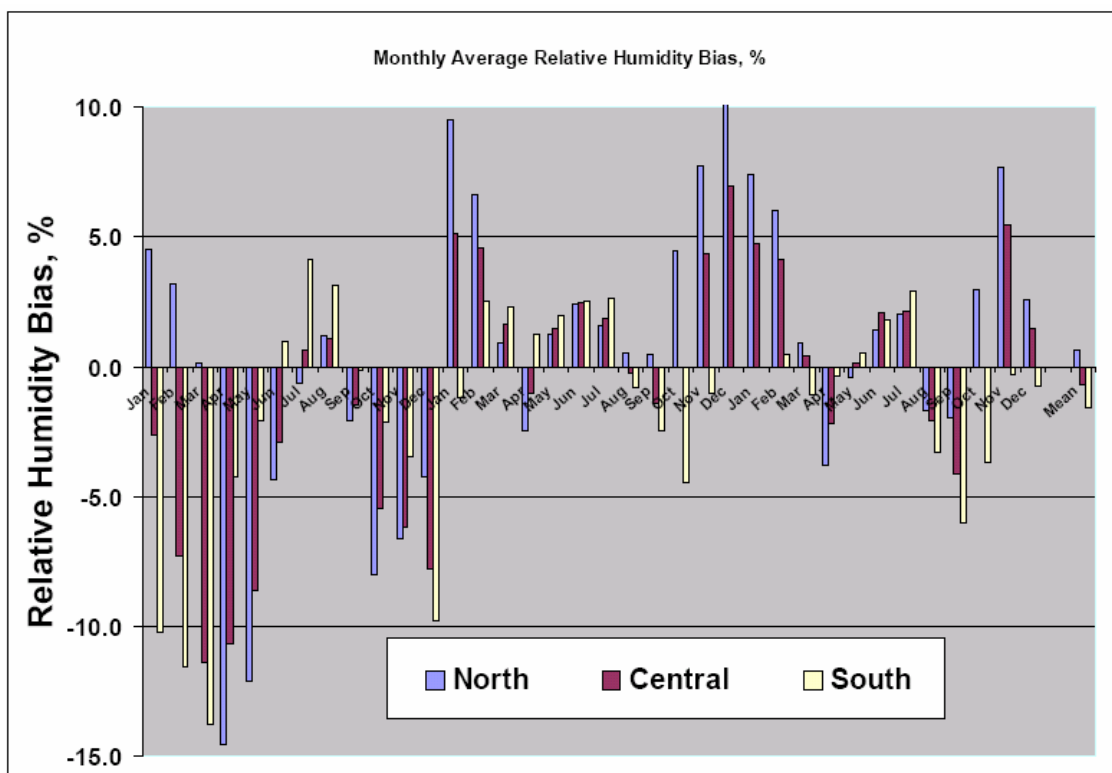


Figure 5-27. MM5/CALMET Relative Humidity Bias (%) over Three Years in All CENRAP Domains.

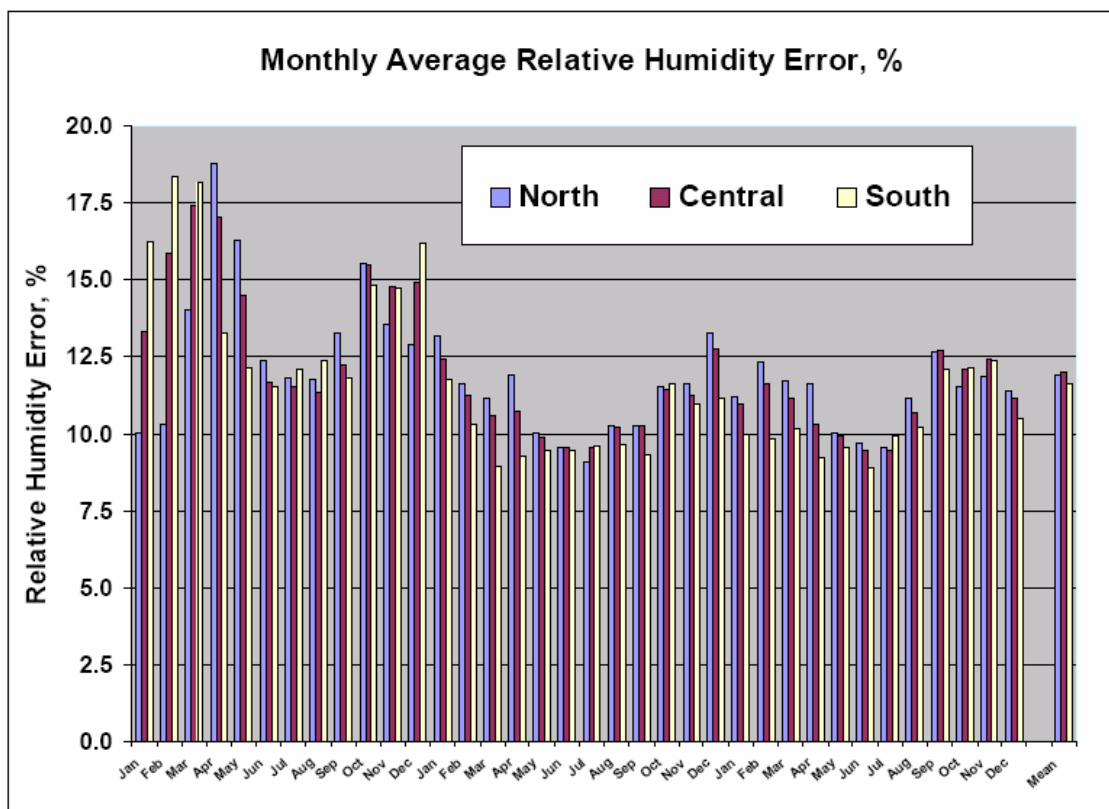


Figure 5-28. MM5/CALMET Relative Humidity Error (%) over Three Years in All CENRAP Domains.

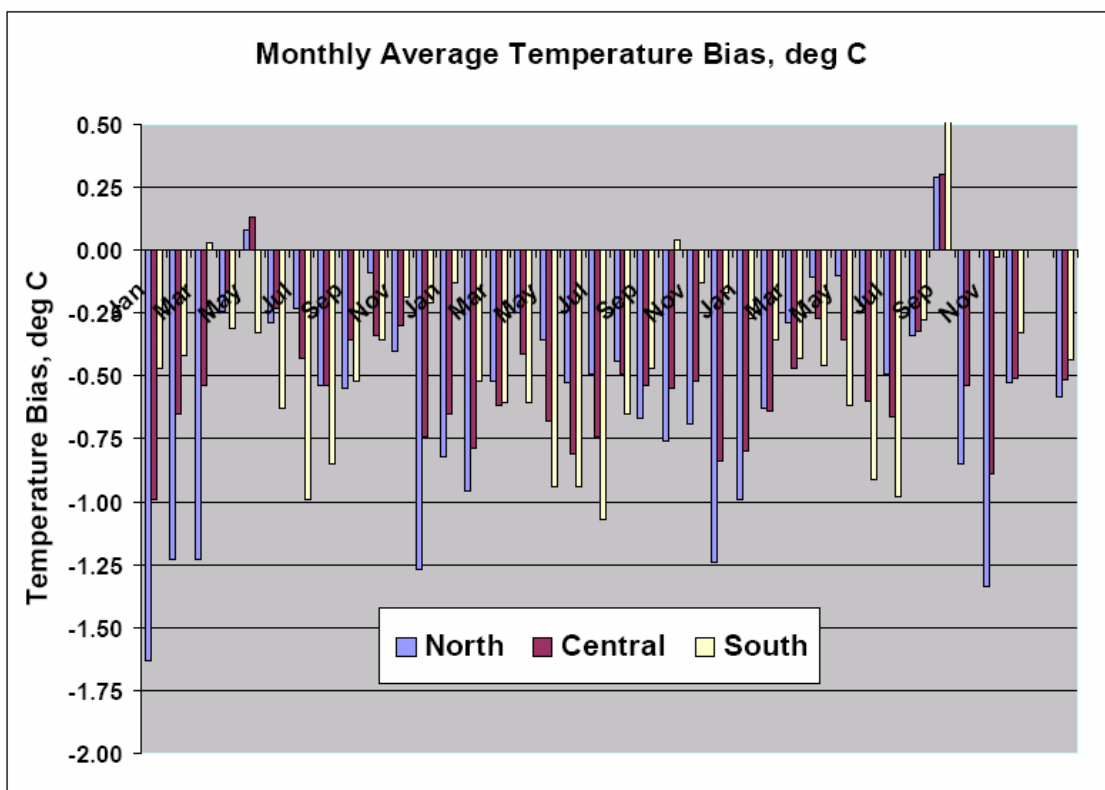


Figure 5-29. MM5/CALMET Surface Temperature Bias (deg C) over Three Years in All CENRAP Domains.

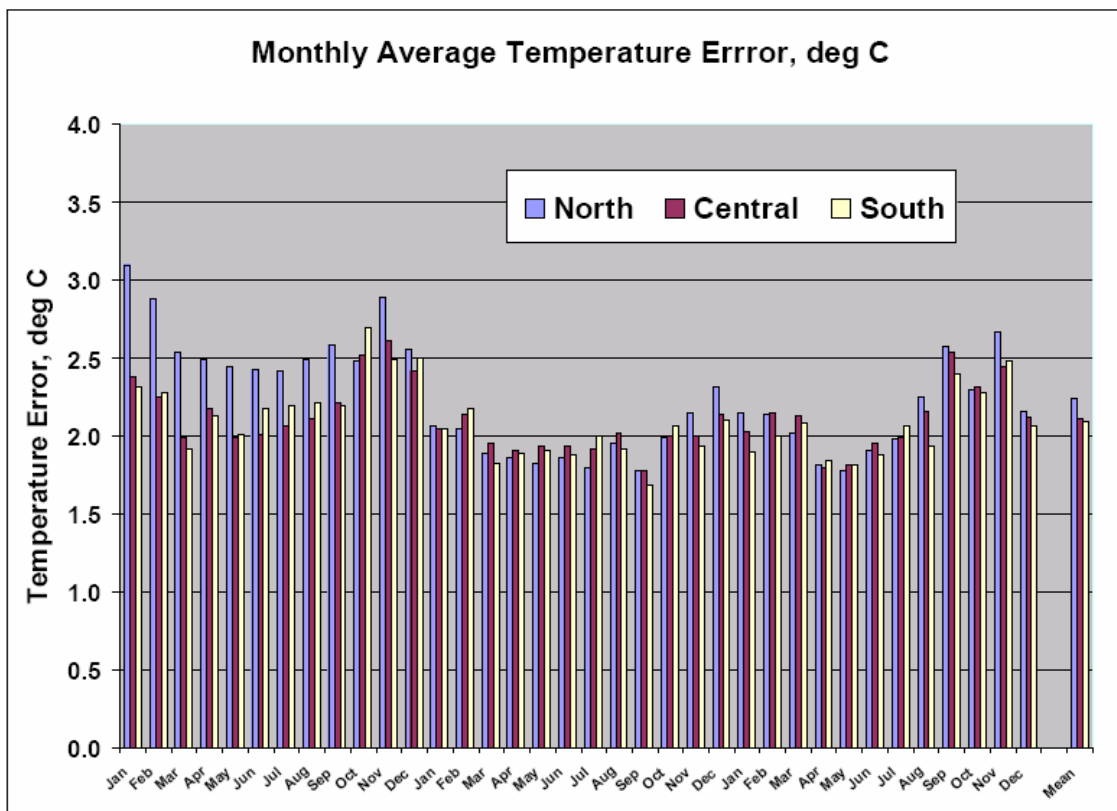


Figure 5-30. MM5/CALMET Surface Temperature Error (deg C) over Three Years in All CENRAP Domains.

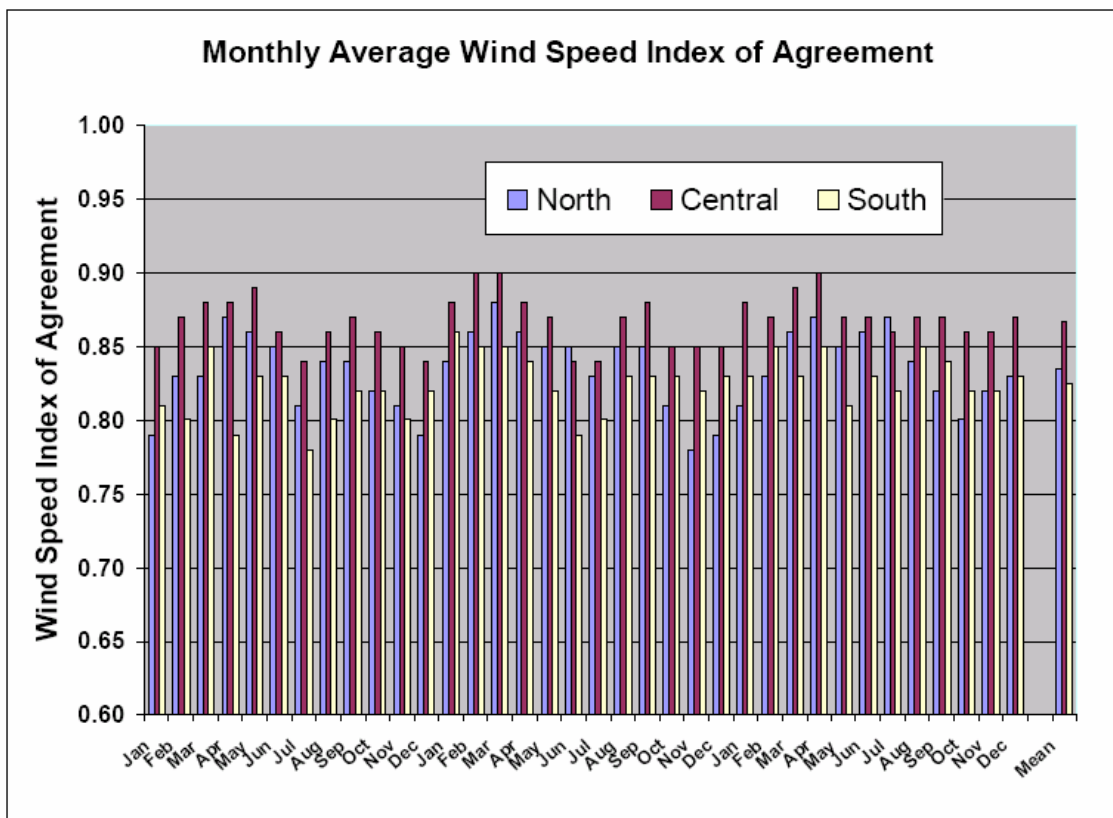


Figure 5-31. MM5/CALMET Wind Speed Index of Agreement over Three Years in All CENRAP Domains.

Appendix F. CALMET Input Control Parameters

Table F-1 Input Groups in the CALMET Control File.

Input Group	Description	Applicable
0	Input and output file names	Yes
1	General run control parameters	Yes
2	Map Projection and Grid Control Parameters	Yes
3	Output Options	Yes
4	Meteorological Data Options	Yes
5	Wind field Options and Parameters	Yes
6	Mixing Height, Temperature and Precipitation Parameters	Yes
7	Surface Meteorological Station Parameters	Yes
8	Upper Air Meteorological Station Parameters	Yes
9	Precipitation Station Parameters	Yes

Table F-2 CALMET Model Input Group 0: Input and Output File Names

Parameter	Default	Value	Comments
Input	GEO.DAT	GEO.DAT	
Input	SURF.DAT	SURF.DAT	
Input	CLOUD.DAT	CLOUD.DAT	
Input	PRECIP.DAT	PRECIP.DAT	
Input	MM4.DAT	MM4.DAT	
Input	WT.DAT	WT.DAT	
Output	CALMET.LST	CALMET.LST	
Output	CALMET.DAT	CALMET.DAT	
Output	PACOUT.DAT	PACOUT.DAT	
NUSTA	--	0	Number of upper air stations
NOWSTA	--	0	Number of over water stations
Input	UP1.DAT	UP1.DAT	
Input	UP2.DAT	UP2.DAT	
Input	UP3.DAT	UP3.DAT	
Input	SEA1.DAT	SEA1.DAT	
Input	DIAG.DAT	DIAG.DAT	
Input	PROG.DAT	PROG.DAT	
Output	TEST.PRT	TEST.PRT	
Output	TEST.OUT	TEST.OUT	
Output	TEST.KIN	TEST.KIN	
Output	TEST.FRD	TEST.FRD	
Output	TEST.SLP	TEST.SLP	

Table F-3 CALMET Model Input Group 1: General Run Control Parameters

Parameter	Default	Value	Comments
IBYR	-	2001	Starting year
IBMO	-	1	Starting month
IBDY	-	1	Starting day
IBHR	-	1	Starting hour
IBTZ	-	6	Base time zone
IRLG	-	8760	Length of run
IRTYPE	1	1	Run type (must = 1 to run CALPUFF)
LCALGRD	T	F	Compute CALGRID data fields
ITEST	2	2	Stop run after SETUP to do input QA

Table F-4 CALMET Model Input Group 2: Map Projection and Grid Control Parameters

Parameter	Default	Value	Comments
PMAP	UTM	LCC	Map Projection
RLATO	--	40N	Latitude (dec. degrees) of projection origin
RLONO	--	97W	Longitude (dec. degrees) of projection origin
XLAT1	--	33N	Matching parallel(s) of latitude for projection
XLAT2	--	45N	Matching parallel(s) of latitude for projection
DATUM	WGS-G	WGS-G	
NX	--	300	Number of X grid cells in meteorological grid
NY	--	192	Number of Y grid cells in meteorological grid
DGRIDKM	--	6.0	Grid spacing, km
XORIGKM	--	-1008.	Ref. Coordinate of SW corner of grid cell (1,1)
YORIGKM	--	0.0	Ref. Coordinate of SW corner of grid cell (1,1)
NZ	--	10	No. of vertical layers
ZFACE	--	0, 20 40, 80, 160, 320, 640, 1200, 2000, 3000, 4000	Cell face heights in arbitrary vertical grid, m

Table F-5 CALMET Model Input Group 3: Output Options

Parameter	Default	Value	Comments
LSAVE	T	T	Disk output option
IFORMO	1	1	Type of unformatted output file
LPRINT	F	F	Print met fields
IPRINF	1	1	Print intervals
IUVOUT(NZ)	NZ*0	NZ*0	Specify layers of u,v wind components to print
IWOUT(NZ)	NZ*0	NZ*0	Specify layers of w wind component to print
ITOUT(NZ)	NZ*0	NZ*0	Specify levels of 3-D temperature field to print
LDB	F	F	Print input met data and variables
NN1	1	1	First time step for debug data to be printed
NN2	1	1	Last time step for debug data to be printed
IOUTD	0	0	Control variable for writing test/debug wind fields
NZPRN2	1	0	Number of levels starting at surface to print
IPR0	0	0	Print interpolated wind components
IPR1	0	0	Print terrain adjusted surface wind components
IPR2	0	0	Print initial divergence fields
IPR3	0	0	Print final wind speed and direction
IPR4	0	0	Print final divergence fields
IPR5	0	0	Print winds after kinematic effects
IPR6	0	0	Print winds after Froude number adjustment
IPR7	0	0	Print winds after slope flows are added
IPR8	0	0	Print final wind field components

Table F-6 CALMET Model Input Group 4: Meteorological Data Options

Parameter	Default	Value	Comments
NOOBS	0	2	2 = No surface, over water, or upper air observations; use MM5 for surface, over water, and upper air data
NSSTA	--	0	Number of meteorological surface stations
NPSTA	--	0	Number of precipitation stations
ICLOUD	--	3	Gridded cloud fields
IFORMS	2	2	Formatted surface meteorological data file
IFORMP	2	2	Formatted surface precipitation data file
IFORMC	2	2	Formatted cloud data file

Table F-7 CALMET Model Input Group 5: Wind field Options and Parameters

Parameter	Default	CENRAP	Comments
IWFCOD	1	1	Model selection variable
IFRADJ	1	1	Compute Froude number adjustment effects?
IKINE	0	0	Compute kinematic effects?
IOBR	0	0	Use O'Brien (1970) vertical velocity adjustment?
ISLSOPE	1	1	Compute slope flow effects?
IEXTRP	-4	-1	Extrapolate surface wind obs to upper levels?
ICALM	0	0	Extrapolate surface winds even if calm?
BIAS	NZ*0	0, 0, 0, 0, 0, 0, 0, 0, 0, 0	Layer-dependent biases weighting aloft measurements
RMIN2	4.	-1.0	Minimum vertical extrapolation distance
IPROG	0	14	14 = Yes, use winds from MM5.DAT file as initial guess field [IWFCOD = 1]
ISTEPPG	1	1	MM5 output time step
LVARY	F	T	Use varying radius of influence
RMAX1	--	30.	Maximum radius of influence over land in sfc layer
RMAX2	--	30.	Maximum radius of influence over land aloft
RMAX3	--	50.	Maximum radius of influence over water
RMIN	0.1	0.1	Minimum radius of influence used anywhere
TERRAD	--	12.	Terrain features radius of influence
R1	--	1.	Weighting of first guess surface field
R2	--	1.	Weighting of first guess aloft field
RPROG	--	0.	MM5 windfield weighting parameter
DIVLIM	5.E-6	5.E-6	Minimum divergence criterion
NITER	50	50	Number of divergence minimization iterations
NSMMTH	2, 4, 4, 4, 4, 4, 4	2, 4, 4, 4, 4, 4, 4	Number of passes through smoothing filter in each layer of CALMET
NITR2	99.	5, 5, 5, 5, 5, 5, 5, 5, 5, 5	Maximum number of stations used in each layer for the interpolation of data to a grid point
CRITFN	1.0	1.0	Critical Froude number
ALPHA	0.1	0.1	Kinematic effects parameter
FEXTR2	NZ*0.0	NZ*0.0	Scaling factor for extrapolating sfc winds aloft
NBAR	0	0	Number of terrain barriers
IDIOTP1	0	0	Surface temperature computation switch
ISURFT	--	4	Number of sfc met stations to use for temp calcs
IDIOPT2	0	0	Domain-averaged lapse rate switch
IUPT	0	2	Upper air stations to use for lapse rate calculation
ZUPT	200.	200.	Depth through which lapse rate is calculated
IDIOPT3	0	0	Domain-averaged wind component switch

IUPWND	-1	-1	Number of aloft stations to use for wind calc
ZUPWND	1., 1000.	1., 1000.	Bottom and top of layer through which the domain-scale winds are computed
IDIOPT4	0	0	Observed surface wind component switch
IDIOPT5	0	0	Observed aloft wind component switch
LLBREZE	F	F	Use Lake Breeze Module
NBOX	0	0	Number of lake breeze regions
NLB	--	0	Number of stations in the region
METBXID(NLB)	--	0	Station ID's in the region

Table F-8 CALMET Model Input Group 6: Mixing Height, Temperature and Precipitation

Parameter	Default	Value	Comments
CONSTB	1.41	1.41	Neutral stability mixing height coefficient
CONSTE	0.15	0.15	Convective stability mixing height coefficient
CONSTN	2400.	2400.	Stable stability maxing height coefficient
CONSTW	0.16	0.16	Over water mixing height coefficient
FCORIOL	1.E-4	1.E-4	Absolute value of Coriolis parameter
IAVEZI	1	1	Conduct spatial averaging? Yes = 1
MNMDAV	1	10	Maximum search radius in averaging process
HAFANG	30.	30.	Half-angle of upwind looking cone for averaging
ILEVZI	1	1	Layers of wind use in upwind averaging
DPTMIN	0.001	0.001	Minimum potential temperature lapse rate in the stable layer above the current convective mixing ht
DZZI	200.	200.	Depth of layer above current conv. mixing height through which lapse rate is computed
ZIMIN	50.	50.	Minimum overland mixing height
ZIMAX	3000.	3000.	Maximum overland mixing height
ZIMINW	50.	50.	Minimum over water mixing height
ZIMAXW	3000.	3000.	Maximum over water mixing height
ITPROG	0	2	3D temperature from observations or from MM5?
IRAD	1	1	Type of interpolation; 1 = 1/R
TRADKM	500.	36.	Temperature interpolation radius of influence
NUMTS	5	5	Max number of stations for temp interpolation
IAVET	1	1	Spatially average temperatures? 1 = yes
TGDEFB	-.0098	-.0098	Temp gradient below mixing height over water
TGDEFA	-.0045	-.0045	Temp gradient above mixing height over water
JWAT1	--	55	Beginning land use categories over water
JWAT2	--	55	Ending land use categories for water
NFLAGP	2	2	Precipitation interpolation flag; 2 = 1/R-squared
SIGMAP	100.	50.	Radius of influence for precipitation interpolation
CUTP	0.01	0.01	Minimum precipitation rate cutoff (mm/hr)

Appendix G. CALPUFF Input Control Parameters

Table G-1 Input Groups in the CALPUFF Control File

Input Group	Description	Applicable
0	Input and output file names	Yes
1	General run control parameters	Yes
2	Technical options	Yes
3	Species list	Yes
4	Grid control parameters	Yes
5	Output options	Yes
6	Sub grid scale complex terrain inputs	Yes
7	Dry deposition parameters for gases	Yes
8	Dry deposition parameters for particles	Yes
9	Miscellaneous dry deposition for parameters	Yes
10	Wet deposition parameters	Yes
11	Chemistry parameters	Yes
12	Diffusion and computational parameters	Yes
13	Point source parameters	Yes
14	Area source parameters	No
15	Line source parameters	No
16	Volume source parameters	No
17	Discrete receptor information	Yes

Table G-2 CALPUFF Model Input Group 0: Input and Output File Names

Parameter	Default	Value	Comments
METDAT	CALMET.DAT	Not used	Input file name
PUFLST	CALPUFF.LST	Varies with facility	CALPUFF output file name
CONDAT	CONC.DAT	Varies with facility	Concentration output file name
DFDAT	DFLX.DAT	Varies with facility	Dry flux output file name
WFDAT	WFLX.DAT	Varies with facility	Wet flux output file name
VISDAT	VISB.DAT	Varies with facility	Visibility output file name
OZDAT	OZONE.DAT	Varies with year	Ozone input file name
LCFILES	-	T	File names converted to lower case
NMETDAT	1	12	Number of CALMET.DAT files for run
CALMET.DAT	-	METDAT=/location of CALMET.DAT files	12 entries one for each month

Table G-3 CALPUFF Model Input Group 1: General Run Control Parameters

Parameter	Default	Value	Comments
METRUN	0	0	All model periods in met file(s) will be run
IBYR	-	See note 1 below	Starting year
IBMO	-	1	Starting month
IBDY	-	1	Starting day
IBHR	-	1	Starting hour
XBTZ	-	0	Time zone for met files (0 = GMT)
IRLG	-	See note 2 below	Length of run
NSPEC	5	10	Number of MESOPUFF II chemical species
NSE	3	See note 3 below	Number of chemical species to be emitted
ITEST	2	2	Program is executed after SETUP phase
MRESTART	0	0	Do not read or write a restart file during run
NRESPD	0	0	File written only at last period
METFM	1	1	CALMET binary file (CALMET.MET)
AVET	60	60	Averaging time in minutes
PGTIME	60	60	PG Averaging time in minutes

Note 1: Enter the year being modeled (i.e. 2001, 2002, or 2003)

Note 2: Enter 8760 for the years 2001 and 2002 but enter 8748 for the year 2003

Note 3: Enter 6 for the no-obs run and 7 for the refined run

Table G-4 CALPUFF Model Input Group 2: Technical Options

Parameter	Default	Value	Comments
MGAUSS	1	1	Gaussian distribution used in near field
MCTADJ	3	3	Partial plume path terrain adjustment
MCTSG	0	0	Sub-grid-scale complex terrain not modeled
MSLUG	0	0	Near-field puffs not modeled as elongated
MTRANS	1	1	Transitional plume rise modeled
MTIP	1	1	Stack tip downwash used
MSHEAR	0	0	(0, 1) Vertical wind shear (not modeled, modeled)
MSPLIT	0	0	Puffs are not split
MCHEM	1	1	MESOPUFF II chemical parameterization scheme
MAQCHEM	0	0	Aqueous phase transformation not modeled
MWET	1	1	Wet removal modeled
MDRY	1	1	Dry deposition modeled
MDISP	3	2	AERMOD dispersion coefficients
MTURBVW	3	3	Use both σ_v and σ_w from PROFILE.DAT to compute σ_v and σ_z (n/a)
MDISP2	3	2	AERMOD dispersion coefficients
MROUGH	0	0	PG σ_v and σ_z not adjusted for roughness
MPARTL	1	1	No partial plume penetration of elevated inversion

MTINV	0	0	Strength of temperature inversion computed from default gradients
MPDF	0	0	PDF not used for dispersion under convective conditions
MSGTIBL	0	0	Sub-grid TIBL module not used for shoreline
MBCON	0	0	Boundary concentration conditions not modeled
MFOG	0	0	Do not configure for FOG model output
MREG	1	1	Technical options must conform to USEPA Long Range Transport (LRT) guidance

Table G-5 CALPUFF Model Input Group 3: Species List-Chemistry Options

CSPEC	Modeled ¹	Emitted ²	Dry Deposition ³	Output Group Number
SO ₂	1	1	1	0
SO ₄ ⁻²	1	0	2	0
NO _x	1	1	1	0
HNO ₃	1	0	1	0
NO ₃ ⁻	1	0	2	0
NH ₃	0	0	1	0
PM ₁₀ ⁴	1	1	2	0
PMF ⁴	1	1	2	0
EC ⁵	1	1	2	0
SOA ⁵	1	1	2	0

Note 1: 0 = No, 1 = Yes

Note 2: 0 = No, 1 = Yes (Depends on if species is being modeled or not)

Note 3: 0 = none, 1 = computed gas, 2 = computed particle, 3 = user specified

Note 4: Only PMF will be modeled and emitted in the no-obs run; however, both PM₁₀ and PMF will be modeled and emitted in the refined analysis

Note 5: EC and SOA will not be modeled nor will it be emitted during the no-obs and the refined runs

Table G-6 CALPUFF Model Input Group 4: Map Projection and Grid Control Parameters

Parameter	Default	Value	Comments
PMAP	UTM	LCC	Map Projection
FEAST	0.0	0.000	False Easting
FNORTH	0.0	0.000	False Northing
RLATO	None	40N	Latitude and Longitude of projection origin
RLONO	None	97W	Latitude and Longitude of projection origin
XLAT1	None	33N	Matching parallel of latitude for map projection
XLAT2	None	45N	Matching parallel of latitude for map projection
DATUM	WGS-84	WGS-G	Datum region for output coordinates
NX	None	366	Number of X grid cells in meteorological grid
NY	None	234	Number of Y grid cells in meteorological grid
NZ	None	10	Number of vertical layers in meteorological grid
DGRIDKM	None	6	Grid spacing (km)
ZFACE	None	0, 20 40, 80, 160, 320, 640, 1200, 2000, 3000, 4000	Cell face heights in meteorological grid (m)
XORIGKM	None	-1008	Reference X coordinate for SW corner of grid cell (1,1) of meteorological grid (km)
YORIGKM	None	-864	Reference Y coordinate for SW corner of grid cell (1,1) of meteorological grid (km)
IBCOMP	None	1	X index of lower left corner of the computational grid
JBCOMP	None	1	Y index of lower left corner of the computational grids
IECOMP	None	366	X index of the upper right corner of the computational grid
JECOMP	None	234	Y index of the upper right corner of the computational grid
LSAMP	T	F	Sampling grid is not used
IBSAMP	None	1	X index of lower left corner of the sampling grid
JBSAMP	None	1	Y index of lower left corner of the sampling grid
IESAMP	None	366	X index of upper right corner of the sampling grid
JESAMP	None	234	Y index of upper right corner of the sampling grid
MESHDN	1	1	Nesting factor of the sampling grid

Table G-7 CALPUFF Model Input Group 5: Output Options

Parameter	Default	Value	Comments
ICON	1	1	Output file CONC.DAT containing concentrations is created
IDRY	1	1	Output file DFLX.DAT containing dry fluxes is created
IWET	1	1	Output file WFLX.DAT containing wet fluxes is created
IVIS	1	1	Output file containing relative humidity data is created
LCOMPRS	T	T	Perform data compression in output file
IMFLX	0	0	Do not calculate mass fluxes across specific boundaries
IMBAL	0	0	Mass balances for each species not reported hourly
ICPRT	0	1	Print concentration fields to the output list file
IDPRT	0	0	Do not print dry flux fields to the output list file
IWPRT	0	0	Do not print wet flux fields to the output list file
ICFRQ	1	1	Concentration fields are printed to output list file every hour (hr)
IDFRQ	1	1	Dry flux fields are printed to output list file every 1 hour
IWFRQ	1	1	Wet flux fields are printed to output list file every 1 hour
IPRTU	1	3	Units for line printer output are in g/m ³ for concentration and g/m ² /s for deposition
IMESG	2	2	Messages tracking the progress of run written to screen
LDEBUG	F	F	Logical value for debug output
IPFDEB	1	1	First puff to track
NPFDEB	1	1	Number of puffs to track
NN1	1	1	Meteorological period to start output
NN2	10	10	Meteorological period to end output

Table G-8 CALPUFF Model Input Group 6: Sub-Grid Scale Complex Terrain Input

Parameter	Default	Value	Comments
NHILL	0	0	Number of terrain features
NCTREC	0	0	Number of special complex terrain receptors
MHILL	-	2	Input terrain and receptor data for CTSG hills input in CTDM format
XHILL2M	1	1	Conversion factor for changing horizontal dimensions to meters
ZHILL2M	1	1	Conversion factor for changing vertical dimensions to meters
XCTDMKM	None	0.0 E+00	X origin of CTDM system relative to CALPUFF coordinate system (km)
YCTDMKM	None	0.0 E+00	Y origin of CTDM system relative to CALPUFF coordinate system (km)

Table G-9 CALPUFF Model Input Group 7: Dry Deposition Parameters for Gases

Species	Default	Value	Comments
SO ₂	0.1509	0.1509	Diffusivity
	1000.	1000.	Alpha star
	8.0	8.0	Reactivity
	0.0	0.0	Mesophyll resistance
	0.04	0.04	Henry's Law coefficient
NO _x	0.1656	0.1656	Diffusivity
	1.0	1.0	Alpha star
	8.0	8.0	Reactivity
	5.0	5.0	Mesophyll resistance
	3.5	3.5	Henry's Law coefficient
HNO ₃	0.1628	0.1628	Diffusivity
	1.0	1.0	Alpha star
	18.0	18.0	Reactivity
	0.0	0.0	Mesophyll resistance
	8.0E-8	8.0E-8	Henry's Law coefficient
	0.000359	0.000359	Henry's Law coefficient

Table G-10 CALPUFF Model Input Group 8: Dry Deposition Parameters for Particles

Species	Default	Value	Comments
SO ₄ ⁻²	0.48	0.48	Geometric mass mean diameter of SO ₄ ⁻² (μm)
NO ₃ ⁻	2.0	0.48	Geometric mass mean diameter of NO ₃ ⁻ (μm)
PM ₁₀	2.0	6.0	Geometric mass mean diameter of PMC (μm)
PMF	2.0	0.48	Geometric mass mean diameter of PMF (μm)
EC	2.0	0.48	Geometric mass mean diameter of EC (μm)
SOA	0.48	0.48	Geometric mass mean diameter of SOA (μm)

(Geometric Standard Deviation for all species assumed to be 2.0 μm).

Table G-11 CALPUFF Model Input Group 9: Miscellaneous Dry Deposition Parameters

Parameter	Default	Value	Comments
RCUTR	30	30	Reference cuticle resistance (s/cm)
RGR	10	10	Reference ground resistance (s/cm)
REACTR	8	8	Reference pollutant reactivity
NINT	9	9	Number of particle size intervals for effective particle deposition velocity
IVEG	1	1	Vegetation in non-irrigated areas is active and unstressed

Table G-12 CALPUFF Model Input Group 10: Wet Deposition Parameters

Species	Default	Value	Comments
SO ₂	3.21E-05	3.21E-05	Scavenging coefficient for liquid precipitation (s ⁻¹)
	0.0	0.0	Scavenging coefficient for frozen precipitation (s ⁻¹)
SO ₄ ⁻²	1.0E-04	1.0E-04	Scavenging coefficient for liquid precipitation (s ⁻¹)
	3.0E-05	3.0E-05	Scavenging coefficient for frozen precipitation (s ⁻¹)
HNO ₃	6.0E-05	6.0E-05	Scavenging coefficient for liquid precipitation (s ⁻¹)
	0.0	0.0	Scavenging coefficient for frozen precipitation (s ⁻¹)
NO ₃ ⁻	1.0E-04	1.0E-04	Scavenging coefficient for liquid precipitation (s ⁻¹)
	3.0E-05	3.0E-05	Scavenging coefficient for frozen precipitation (s ⁻¹)
NH ₃	8.0E-05	8.0E-05	Scavenging coefficient for liquid precipitation (s ⁻¹)
	0.0	0.0	Scavenging coefficient for frozen precipitation (s ⁻¹)
PM ₁₀	1.0E-04	1.0E-04	Scavenging coefficient for liquid precipitation (s ⁻¹)
	3.0E-05	3.0E-05	Scavenging coefficient for frozen precipitation (s ⁻¹)
PMF	1.0E-04	1.0E-04	Scavenging coefficient for liquid precipitation (s ⁻¹)
	3.0E-05	3.0E-05	Scavenging coefficient for frozen precipitation (s ⁻¹)
EC	1.0E-04	1.0E-04	Scavenging coefficient for liquid precipitation (s ⁻¹)
	3.0E-05	3.0E-05	Scavenging coefficient for frozen precipitation (s ⁻¹)
OC	1.0E-04	1.0E-04	Scavenging coefficient for liquid precipitation (s ⁻¹)
	3.0E-05	3.0E-05	Scavenging coefficient for frozen precipitation (s ⁻¹)

Table G-13 CALPUFF Model Input Group 11: Chemistry Parameters

Parameter	Default	Value	Comments
MOZ	1	1	Read ozone background concentrations from ozone.dat file (measured values).
BCKO ₃	12*80	12*40	Background ozone concentration (ppb)
BCKNH ₃	12*10	12*3	Background ammonia concentration (ppb)
RNITE1	0.2	0.2	Nighttime NO ₂ loss rate in percent/hour
RNITE2	2	2	Nighttime NO _x loss rate in percent/hour
RNITE3	2	2	Nighttime HNO ₃ loss rate in percent/hour
MH ₂ O ₂	1	1	Background H ₂ O ₂ concentrations (Aqueous phase transformations not modeled)
BCKH ₂ O ₂	1	1	Background monthly H ₂ O ₂ concentrations (Aqueous phase transformations not modeled)

Table G-14 CALPUFF Model Input Group 12: Dispersion/Computational Parameters

Parameter	Default	Value	Comments
SYDEP	550	550	Horizontal size of a puff in meters beyond which the time dependant dispersion equation of Heffter (1965) is used
MHFTSZ	0	0	Do not use Heffter formulas for sigma z
JSUP	5	5	Stability class used to determine dispersion rates for puffs above boundary layer
CONK1	0.01	0.01	Vertical dispersion constant for stable conditions
CONK2	0.1	0.1	Vertical dispersion constant for neutral/stable conditions
TBD	0.5	0.5	Use ISC transition point for determining the transition point between the Schulman-Scire to Huber-Snyder Building Downwash scheme
IURB1	10	10	Lower range of land use categories for which urban dispersion is assumed
IURB2	19	19	Upper range of land use categories for which urban dispersion is assumed
ILANDUIN	20	*	Land use category for modeling domain
XLAIIN	3.0	*	Leaf area index for modeling domain
ZOIN	-0.25	*	Roughness length in meters for modeling domain
ELEVIN	0.0	*	Elevation above sea level
XLATIN	-999	-	North latitude of station in degrees
XLONIN	-999	-	South latitude of station in degrees
ANEMHT	10	10	Anemometer height in meters
ISIGMAV	1	1	Sigma-v is read for lateral turbulence data
IMIXCTDM	0	0	Predicted mixing heights are used
XMXLN	1	1	Maximum length of emitted slug in meteorological grid units
XSAMLEN	1	10	Maximum travel distance of slug or puff in meteorological grid units during one sampling unit
MXNEW	99	60	Maximum number of puffs or slugs released from one source during one time step
MXSAM	99	60	Maximum number of sampling steps during one time step for a puff or slug
NCOUNT	2	2	Number of iterations used when computing the transport wind for a sampling step that includes transitional plume rise
SYMIN	1	1	Minimum sigma y in meters for a new puff or slug
SZMIN	1	1	Minimum sigma z in meters for a new puff or slug
SVMIN	.50	.50	Minimum lateral turbulence velocities (m/s)
SWMIN	0.20, 0.12, 0.08, 0.06,	0.20, 0.12, 0.08, 0.06,	Minimum vertical turbulence velocities (m/s)

	0.03, 0.016	0.03, 0.016	
WSCALM	0.5	0.5	Minimum non-calm wind speeds (m/s)
XMAXZI	3000.	3000.	Maximum mixing height (m)
XMINZI	50.	20.	Minimum mixing height (m)
SL2PF	10.	10.	Maximum Sy/puff length
PLXO	0.07, 0.07, 0.10, 0.15, 0.35, 0.55	0.07, 0.07, 0.10, 0.15, 0.35, 0.55	Wind speed power-law exponents
WSCAT	1.54, 3.09, 5.14, 8.23, 10.80	1.54, 3.09, 5.14, 8.23, 10.80	Upper bounds of 1 st 5 wind speed classes
PGGO	0.020, 0.035	0.020, 0.035	Potential temp gradients PG E & F (deg/km)
CDIV	0.01	0.01	Divergence criterion for dw/dz (1/s)
PPC	0.5, 0.5, 0.5, 0.5, 0.35, 0.35	0.5, 0.5, 0.5, 0.5, 0.35, 0.35	Plume path coefficients (only if MCTADJ=3)
NSPLIT	3	3	Number of puffs when puffs split
IRESPLIT	-	1900	Hour(s) when puff is eligible to split
ZISPLIT	100	100	Previous hour's minimum mixing height, m
ROLDMAX	0.25	0.25	Previous Max mixing height/current mixing height ratio, must be less than this value to allow puff to split
NSPLITH	5	5	Number of puffs resulting from a split
SYSPLITH	1.0	1.0	Minimum sigma-y of puff before it may split
SHSPLITH	2.0	2.0	Minimum puff elongation rate from wind shear before puff may split
CNSPLITH	1.0E-07	1.0E-07	Minimum species concentration before a puff may split
EPSSLUG	1.0E-04	1.0E-04	Criterion for SLUG sampling
EPSAREA	1.0E-06	1.0E-06	Criterion for area source integration
DSRISE	1.0	1.0	Trajectory step length for numerical rise algorithm
Note: Values indicated by an asterisk (*) were allowed to vary spatially across the domain and were obtained from CALMET			

Table G-15 CALPUFF Model Input Group 13: Point Source Parameters

Parameter	Default	Value	Comments
NPT1	None	Varies by scenario	Number of point sources with stack parameters
IPTU	1	1	Units for point source emission rates are g/s
NSPT1	0	0	Number of source-species combinations with variable emissions scaling factors
NPT2	None	0	Number of point sources with variable emission parameters provided in external file
MISC	None	Point source parameters and emission data	Point source inputs include stack height (H), stack diameter (d), exit temperature (T), exit velocity (v) emissions by species, and coordinate of stack (LCC)

Table G-16 CALPUFF Model Input Group 17: Discrete Receptor Information

Parameter	Default	Value	Comments
NREC	None	427	Number of discrete receptors

Please note that ADEQ will not be modeling area, line and volume sources which are input groups 14, 15, and 16 respectively.

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Appendix H. POSTUTIL Input Control Parameters

Table H-1 Input Groups in the POSTUTIL Processor Control File

Sub Group	Description	Applicable
0a	Input and output file names	Yes
1	NMET – Number of CALMET data files (365)	Yes
2	NFILES – Number of CALPUFF data files	Yes

Table H-2 POSTUTIL Processor Input Group 1: General Run Control Parameters

Parameter	Default	Value	Comments
ISYR	None	See note 1 below	Starting year
ISMO	None	1	Starting month
ISDY	None	1	Starting day
ISHR	None	0	Starting hour
NPER	None	See note 2 below	Number of periods to process
NSPECINP	None	See note 3 below	Number of CALPUFF species to process
NSPECOUT	None	See note 3 below	Number of species to output
NSPECCMP	None	0	Number of species to derive
MDUPLCT	None	1	Stop run if duplicate name
NSCALED	None	0	Number of CALPUFF files to 'scale'
MNITRATE	None	1	Re-compute the HNO ₃ /NO ₃ partition for CALPUFF modeled concentrations? 1 = yes for all sources combined
BCKNH3	10.	3.	Default NH ₃ concentration (ppb) for HNO ₃ /NO ₃ partitioning

Note 1: Enter the modeled year for the CALPUFF run

Note 2: Enter 8760 for years 2001 and 2002, but enter 8748 for the year 2003

Note 3: Enter 6 for the no-obs run and 7 for the refined run

Table H-3 POSTUTIL Processor Input Group 2: Species Processing Information

Parameter	Default	Value	Comments
ASPECI	None	SO ₂ , SO ₄ , NO _x , HNO ₃ , NO ₃ , PM ₁₀ , PMF See Note 1 Below	Species to post-process
ASPECO	None	SO ₂ , SO ₄ , NO _x , HNO ₃ , NO ₃ , PM ₁₀ , PMF See Note 4 Below	Species to output
CSPECCMP	None	CSPECCMP = N SO ₂ = 0.0 SO ₄ = 0.291667 NO = 0.466667 NO ₂ = 0.304348 HNO ₃ = 0.222222 NO ₃ = 0.451613 PM ₁₀ = 0.0	Nitrogen species to be computed by scaling and summing one or more of the processed input species using the scaling factors for each of the NSPECINP input species
CSPECCMP	None	CSPECCMP = S SO ₂ = 0.50 SO ₄ = 0.333333 NO = 0.0 NO ₂ = 0.0 HNO ₃ = 0.0 NO ₃ = 0.0 PM ₁₀ = 0.0	Sulfur species to be computed by scaling and summing one or more of the processed input species using the scaling factors for each of the NSPECINP input species
MODDAT	None	A (Default=1.0) SO ₂ = 1.1 SO ₄ = 1.5 HNO ₃ = 0.8 NO ₃ = 0.1 B (Default=0.0) SO ₂ = 0.0 SO ₄ = 0.0 HNO ₃ = 0.0 NO ₃ = 0.0	Each species in NSCALED CALPUFF data files may be scaled before processing (e.g., to change the emission rate for all sources modeled in the run that produced a data file). For each scaled species the scaling factors are A and B where $x' = Ax + B$.

Note 4: In the no-obs run just enter PMF, but in the refined run enter PM₁₀ and PMF

Appendix I. CALPOST Input Control Parameters

Table I-1 Input Groups in the CALPOST Processor Control File

Group	Description	Applicable
0	Input and output file names	Yes
1	General Run Control Parameters	Yes
2	Visibility Parameters	Yes
3	Output Options	Yes

Table I-2 CALPOST Processor Input Group 1: General Run Control Parameters

Parameter	Default	Value	Comments
METRUN	0	1	1 = Run all met periods in CALPUFF data file
ISYR	None	2001, 2002, 2003	Starting year
ISMO	None	1	Starting month
ISDY	None	1	Starting day
ISHR	None	0	Starting hour
NPER	None	See note 1 below	Number of periods to process
NREP	1	1	Process every hour of data? Yes = 1
ASPEC	None	VISIB	Process species for visibility
ILAYER	1	1	Layer/deposition code; 1 for CALPUFF concentrations
A	0.0	0.0	Scaling factor, slope
B	0.0	0.0	Scaling factor, intercept
LBACK	F	F	Add hourly background concentrations or fluxes
MSOURCE	0	0	Process only total reported contribution
LG	F	F	Process gridded receptors
LD	F	T	Process discrete receptors
LCT	F	F	Process complex terrain receptors
LDRING	F	F	Report receptor ring results
NDRECP	-1	See note 2 below	To select the Class I area's receptors enter *1 after the number of receptors otherwise enter *0
IBGRID	-1	-1	X index of LL corner of receptor grid
JBGRID	-1	-1	Y index of LL corner of receptor grid
IEGRID	-1	-1	X index of UR corner of receptor grid
JEGRID	-1	-1	Y index of UR corner of receptor grid
NGONOFF	0	0	Number of gridded receptor rows
NGXRECP	1	0	Exclude specific gridded receptors, Yes = 0

Note 1: Enter 8760 for the years 2001 and 2002, but enter 8748 for the year 2003.

Note 2: CALPOST is to be run for each Class I area assessed.

- The following are the number of receptors for each Class I area being assessed:
 1. Caney Creek = 80
 2. Hercules-Glade = 47
 3. Mingo Wilderness = 80
 4. Sipsey = 148
 5. Upper Buffalo = 72

Table I-3 CALPOST Processor Input Group 2: Species Processing Information

Parameter	Default	Value	Comments
RHMAX	98	95	Maximum RH (%) used in particle growth curve
LVSO4	T	T	Compute light extinction for sulfate?
LVNO3	T	T	Compute light extinction for nitrate?
LVOC	T	T	Compute light extinction for organic carbon?
LVMPC	T	T	Compute light extinction for coarse particles?
LVMPF	T	T	Compute light extinction for fine particles?
LVEC	T	T	Compute light extinction for elemental carbon?
LVBK	T	T	Include background in extinction calculation?
SPECPMC	PMC	PMC	Coarse particulate species
SPECPMF	PMF	PMF	Fine particulate species
EEPMC	0.6	0.6	Extinction efficiency for coarse particulates
EEPMF	1.0	1.0	Extinction efficiency for fine particulates
EEPMCBK	0.6	0.6	Extinction efficiency for coarse part. background
EESO4	3.0	3.0	Extinction efficiency for ammonium sulfate
EENO3	3.0	3.0	Extinction efficiency for ammonium nitrate
EEOC	4.0	4.0	Extinction efficiency for organic carbon
EESOIL	1.0	1.0	Extinction efficiency for soil
EEEC	10.0	10.0	Extinction efficiency for elemental carbon
MVISBK	2	6	Method 6 for background light extinction: Compute extinction from speciated PM measurements. FLAG RH adjustment factor applied to observed & modeled sulfate and nitrate
BEXTBTBK	--	12	Background extinction for MVISBK=1 (1/Mm)
RHFRAC	--	10	Percentage of particles affected by RH
RHFAC	12*value	Depends on Class I Area	Extinction coefficients for modeled and background hygroscopic species computed using EPA (2003) monthly RH adjustment factors
BKSEC	0.02	0.02	Eastern background elemental carbon β_{ext}
BKSO4	0.23	0.23	Eastern background sulfate β_{ext}
BKNO3	0.10	0.10	Eastern background nitrate β_{ext}
BKPMC	3.00	3.00	Eastern background PMC β_{ext}
BKSOC	1.40	1.40	Easter background organic carbon β_{ext}
BKSSOIL	0.50	0.50	Eastern background soil β_{ext}
BKSEC	0.02	0.02	Eastern background elem. β_{ext}
BEXTRAY	10.0	10.0	Extinction due to Rayleigh scattering (1/Mm)

Table I-4 CALPOST Processor Input Group 3: Output Options

Parameter	Default	Value	Comments
LDOC	F	F	Print documentation image
IPRTU	1	3	Print output units ($\mu\text{g}/\text{m}^3$) for concentrations and ($\mu\text{g}/\text{m}^2/\text{sec}$) for deposition
L1HR	T	F	Report 1 hr averaging times
L3HR	T	F	Report 3 hr averaging times
L24HR	T	T	Report 24 hr averaging times
LRUNL	T	F	Report run-length (annual) averaging times
LT50	T	F	Top 50 table
LTOPN	F	F	Top 'N' table
NTOP	4	4	Number of 'Top-N' values at each receptor
ITOP	1,2,3,4	1,2,3,4	Ranks of 'Top-N' values at each receptor
LEXCD	F	F	Threshold exceedances counts
THRESH1	-1.0	-1.0	Averaging time threshold for 1 hr averages
THRESH3	-1.0	-1.0	Averaging time threshold for 3 hr averages
THRESH24	-1.0	-1.0	Averaging time threshold for 24 hr averages
THRESHN	-1.0	-1.0	Averaging time threshold for NAVG-hr averages
NDAY	0	0	Accumulation period, days
NCOUNT	1	1	Number of exceedances allowed
LECHO	F	F	Echo option
LTIME	F	F	Time series option
LPLT	F	F	Plot file option
LGRD	F	F	Use grid format instead of DATA format
LDEBUG	F	F	Output information for debugging?

Appendix J. Chapter 3 of the CENRAP BART Modeling Guidelines (Tesché, et al, 2005)

3.0 CALPUFF FORMULATION AND IMPLEMENTATION

The RHR relates visibility attenuation to extinction coefficient (b_{ext}) which is a measure of light scattering and absorption due to atmospheric constituents. Values for b_{ext} are estimated using an empirically derived equation which relates the extinction coefficient to relative humidity and the following components of particulate matter mass: (a) sulfates (SO_4); (b) nitrates (NO_3); (c) organic carbon (OC); (d) elemental carbon (EC); (f) particulate matter (IP) (“crustal material”); and (g) coarse mass (CM) (i.e., $\text{PM}_{10} - \text{PM}_{2.5}$). The BART guidance requires the use of modeled concentrations of these components, together with a “humidity correction factor”, to estimate values for b_{ext} on all days within a three year period. These estimates, when compared with naturally occurring background extinction, are used to determine whether a source is causing or contributing to visibility impairment and also to measure the effectiveness of emissions controls on the source aimed at mitigating such effects. EPA notes that secondary particulate matter constitutes an important fraction of $\text{PM}_{2.5}$ and that the modeling requirements for secondary and primary particulate matter differ in their need to consider atmospheric chemistry and in the degree of spatial resolution needed for the modeling (EPA, 2001, pg 22).

This chapter introduces the formulation of the CALPUFF modeling system. We summarize the model capabilities as described in the user’s manuals (Scire et al., 2000a,b) and discuss the capabilities and limitations of the model. Equipped with this information, states and source operators can identify those situations for which screening and/or source-specific applications of CALPUFF are appropriate.

In most cases, we expect that application of the CALPUFF system will be sufficient to meet the BART Rule requirements. For that subset of conditions requiring advanced methods, Chapter 5 provides details on full-science alternative models and available data bases for BART modeling. Such conditions might include a situation where the default modeling shows that a source just barely causes or contributes to visibility degradation or in negotiations over the final BART determination that weighs technical and economic feasibility against expected air quality benefits. In both situations, a more accurate estimate of a source’s impacts may be very important to source operators.

3.1 Original Model Development

The CALPUFF modeling system was originally developed as a component of a three-part modeling system sponsored by the California Air Resources Board (ARB) in the mid-1980s. The ARB sought to develop a new puff-based model, a new grid-based model and an improved meteorological processor that would support application of the two. CALGRID was the urban-scale photochemical grid model resulting from the

project (Yamartino et al., 1992) comparable in science and capabilities to the Urban Airshed Model (UAM-IV) (Scheffe and Morris, 1993). The model formulation was aimed at overcoming the deficiencies in EPA's steady-state Gaussian plume models that were routinely used in California for inert and linearly reactive materials (principally SO₂) from elevated point sources. Thus, the CALGRID model was designed to treat the complexities of urban-scale photochemical processes while CALPUFF was formulated to treat the non-steady state transport, diffusion, linear reaction, and deposition of primary pollutants from point sources. CALPUFF was not designed to address photochemical oxidants or and secondary aerosol formation production processes in a scientifically rigorous manner.

In recent years, CALPUFF and its meteorological pre-processor (CALMET) have been used in a range of regulatory modeling studies to address point source issues that include complexities posed by complex terrain, large source-receptor distances, parameterized chemical transformation and deposition, and issues related to Class I visibility impacts. These applications are more complex than the California ARB's non-steady-state, linear chemistry formulation of the mid-1980s.

The CALPUFF modeling system has been adopted by the EPA as a guideline model for source-receptor distances greater than 50 km, and for use on a case-by-case basis in complex flow situations for shorter distances. It was recommended for Class I impact assessments by the FLM Workgroup (FLAG, 2000) and the Interagency Workgroup on Air Quality Modeling (IWAQM) (EPA, 1998). As directed in the BART guidance, CALPUFF is the primary modeling system for screening and source-specific BART applications in the CENRAP region. Thus, examination of the model's formulation provides the context for assessing the extent to which it is suitable for simulating the various physical processes and gas-phase, aerosol, and aqueous-phase chemical processes that influence visibility.

3.2 CALPUFF Model Formulation

The CALPUFF user's guide (Scire et al., 2000a) depicts the modeling system as shown in Figure 3-1. CALMET is a diagnostic/interpolation model that provides meteorological inputs to CALPUFF. These fields include hourly-averaged three-dimensional wind and temperature fields and two-dimensional fields of mixing heights and other meteorological parameters. CALMET uses routine surface and aloft meteorological observations and/or three-dimensional output from prognostic numerical models such as MM5 (Grell et al., 1995) or RUC (Benjamin et al., 2004) to construct the meteorological inputs. Other inputs to the air quality program include emissions information, receptor locations, ancillary geophysical information, and estimated concentrations of ambient pollutants that are entrained by the modeled puffs as each is carried downwind. Tables 3-1 and 3-2 summarize the key features of the CALMET/CALPUFF models as described in the user's guides.

Two post-processor routines are included to facilitate cumulative source impacts (POSTUTIL) and estimates of light extinction and visibility attenuation at Class I

receptors of interest (CALPOST). In particular, CALPOST contains several options for computing change in extinction and deciviews for visibility assessments while the POSTUTIL postprocessor includes options for summing contributions of individual sources or groups of sources to assess cumulative impacts. POSTUTIL also contains an empirical nitric acid-nitrate chemical equilibrium module to estimate the cumulative effects of ammonia consumption by background sources once the simulation is completed.

3.2.1 Model Concept and Governing Equations

The starting point for the CALPUFF development was the choice of the fundamental reference system of which there are two: Eulerian and Lagrangian. Consistent with the original ARB design criteria, the Lagrangian (moving puff) reference system was chosen for CALPUFF. In the Eulerian approach, the behavior of pollutants is described relative to a fixed coordinate system. The Lagrangian reference frame, in contrast, relates the behavior of pollutants relative to a coordinate system that moves with the average wind. These two approaches yield different mathematical relationships for pollutant concentrations *that are equally valid*. The choice of which approach to adopt depends upon the specific design goals of the modeling system.

The advantages and drawbacks of each approach are thoroughly discussed in the literature (Tesché, 1983; Seinfeld and Pandis, 1998; Jacobson, 1999; Russell and Dennis, 2000). One of the criticisms of early Eulerian grid models was their ‘over-dilution’ of point source emissions into the fixed grid cells; but for the past twenty years, this limitation has been overcome through with the development of sub-grid-scale, plume-in-grid algorithms (Seigneur, et al., 1981; Godowitch, 2004; Karamchandani et al., 2005; Emery and Yarwood, 2005) and the use of multi-scale nested grids (Russell and Dennis, 2000). While the Lagrangian approach is conceptually simple, flexible, and computationally inexpensive, the governing equations are not directly applicable to situations involving non-linear chemical reactions (Seinfeld and Pandis, (1998) and it is awkward to handle a large number of sources realistically.

3.2.2 Transport and Dispersion

Adopting the Lagrangian concept, CALPUFF simulates the transport, dispersion, linear chemical transformation, and deposition of individual puffs carried downwind by the three-dimensional fields generated by CALMET. The model’s implementation follows puffs from the near source region (a few tens of meters) to hundreds of kilometers downwind. Its puff-based formulation, in conjunction with three-dimensional hourly meteorological data, allow CALPUFF to simulate the effects of time- and space-varying meteorological conditions on pollutants emitted from a variety of source types. The major features and options of the CALPUFF model are summarized below:

Building Downwash: The Huber-Snyder and Schulman-Scire downwash models are both incorporated into CALPUFF. An option is provided to use either model for all stacks, or make the choice on a stack-by-stack and wind sector-by-wind sector basis. Both

algorithms have been implemented in such a way as to allow the use of wind direction specific building dimensions. The PRIME building downwash model (Schulman et al., 2000) is also included in CALPUFF as an option.

Dispersion Coefficients: Turbulent dispersion in CALPUFF is treated with the K-theory (flux-gradient) closure scheme, defined for a Lagrangian frame of reference. Several options are provided in CALPUFF for the computation of dispersion coefficients, including the use of turbulence measurements (σ_v and σ_w), the use of similarity theory to estimate σ_v and σ_w from modeled surface heat and momentum fluxes, or the use of Pasquill-Gifford (PG) or McElroy-Pooler (MP) dispersion coefficients, or dispersion equations based on the CTDM. Options are provided to apply an averaging time correction or surface roughness length adjustments to the PG coefficients. Recently, the EPA AERMOD dispersion parameters have been included in CALPUFF and are used regularly.

Puff Sampling Functions: Puff sampling routines are included in CALPUFF to address computational difficulties encountered when applying a puff model to near-field releases. For near-field applications during rapidly-varying meteorological conditions, an elongated puff (slug) sampling function may be used. An integrated puff approach may be used during less demanding conditions. Both techniques reproduce continuous plume results under the appropriate steady state conditions.

Wind Shear Effects: A key underpinning of the Lagrangian concept is that the modeled puffs retain their identity over the time- and spatial-scale associated with the effects the model is attempting to predict (i.e., visibility impairment at 200 km or beyond). While discrete puffs emitted from a source retain their physical integrity for a period of time, at some point the action of horizontal and vertical variations in wind speed and direction (i.e. 'wind shear') shred the puff into multiple elements. These new puff parcels, composed of remnants of the old puff, continue to be diffused and dispersed by the wind. The point where significant puff shredding occurs is difficult to define since it depends substantially upon the complexity of the meteorological conditions and the underlying terrain. But when shredding occurs, the Lagrangian concept in CALPUFF breaks down. By ignoring puff shredding (i.e., by keeping puffs intact), the model will systematically over-predict pollutant concentrations.

To deal with this conceptual limitation, CALPUFF contains an optional puff splitting algorithm to simulate vertical wind shear effects across individual puffs. Differential rates of dispersion and transport among the "new" puffs generated from the original, well-mixed puff act to increase the effective rate of horizontal spread of the material as would be expected in the real atmosphere. Puffs may also be split in the horizontal when the puff size becomes large relative to the grid size to account for wind shear across the puffs. Detailed guidance on when and how the puff-splitting algorithm should be used and actual verification studies demonstrating that the technique operates as intended are not discussed in the model documentation or presented in the science literature.

Complex Terrain: Effects of complex terrain on puff transport are derived from the CALMET winds. In addition, puff-terrain interactions at gridded and discrete receptor locations are simulated using one of two algorithms that modify the puff-height (either that of ISCST3 or a general “plume path coefficient” adjustment), or an algorithm that simulates enhanced vertical dispersion derived from the weakly-stratified flow and dispersion module of the Complex Terrain Dispersion Model (CTDMPLUS) (Perry et al., 1989). The puff-height adjustment algorithms rely on the receptor elevation (relative to the elevation at the source) and the height of the puff above the surface. The enhanced dispersion adjustment relies on the slope of the gridded terrain in the direction of transport during the time step.

Subgrid Scale Complex Terrain (CTSG): An optional module, CTSG treats terrain features that are not resolved by the gridded terrain field, and is based on the CTDMPLUS (Perry et al., 1989). Plume impingement on subgrid-scale hills is evaluated at the CTSG subgroup of receptors using a dividing streamline height (H_d) to determine which pollutant material is deflected around the sides of a hill (below H_d) and which material is advected over the hill (above H_d). The local flow (near the feature) used to define H_d is taken from the gridded CALMET fields. As in CTDMPLUS, each feature is modeled in isolation with its own set of receptors.

Overwater and Coastal Interaction Effects: The CALMET processor contains overwater and overland boundary layer parameterizations allowing certain of the effects of water bodies on plume transport, dispersion, and deposition to be estimated. In a sense, CALPUFF operates as a hybrid model, by utilizing gridded fields of meteorology and dispersion conditions as well as grid-based descriptions of underlying land use. This includes the abrupt changes that occur at the coastline of a major body of water.

Dry Deposition: A resistance model is used for the computation of dry deposition rates of gases and particulate matter as a function of geophysical parameters, meteorological conditions, and pollutant species. For particles, source-specific mass distributions may be provided for use in the resistance model. Of particular interest for BART analyses is the ability to separately model the deposition of fine particulate matter ($< 2.5 \mu\text{m}$ diameter) from coarse particulate matter ($2.5\text{-}10 \mu\text{m}$ diameter).

Wet Deposition: An empirical scavenging coefficient approach is used to compute the depletion and wet deposition fluxes due to precipitation scavenging. The scavenging coefficients are specified as a function of the pollutant and precipitation type (i.e., frozen vs. liquid precipitation).

3.2.3 Primary Particulates

CALPUFF is designed to simulate PM_{10} or $\text{PM}_{2.5}$ or other user defined size distributions of particles. The smaller the particles, the more they disperse like an inert gas. In most cases, the dispersion of inert $\text{PM}_{2.5}$ particles will differ only slightly from that of an inert gas. A key primary $\text{PM}_{2.5}$ emission from coal-fired electric generating units (EGUs) of relevance to visibility calculations is particulate sulfate. Although

primary sulfate emissions account for only a small fraction of the total sulfur emissions from such sources, it is appropriate to include their effect if reasonable estimates of primary sulfate emissions from the source are available. Treating primary sulfate emissions is likely to be most important at short distances from the stack before significant SO₂ to secondary sulfate conversion has taken place.

3.2.4 Gas-Phase Chemistry

Chemical reactions in the gas-phase play an important role in secondary aerosol formation by generating radical concentrations (e.g., the hydroxyl radical). These radical species oxidize SO₂ and NO_x, providing the precursors to aqueous-phase chemistry (i.e., chemistry in liquid water droplets) that convert SO₂ to sulfate (e.g., H₂O₂ and O₃), and form condensable gases from some volatile organic compounds (VOCs) that can then condense into particulate secondary organic aerosols (SOA). The levels of NO_x, VOC, and O₃ concentrations along with the reactivity of the VOCs, sunlight, temperature, and water vapor are all key variables that influence the radical cycle and consequent sulfate and nitrate formation rates.

CALPUFF neglects realistic gas-phase processes entirely. The chemistry in CALPUFF parameterizes chemical transformation effects using five species (SO₂, SO₄⁼, NO_x, HNO₃, and NO₃⁻) via a set of user-specified, diurnally-varying transformation rates. The model estimates secondary fine particulate matter (sulfate and nitrate) from emissions of gas-phase SO₂ and NO_x. Rather than simulating important non-linear gas phase oxidant chemistry, the model employs a user-supplied hourly ozone concentration as a surrogate for the hydroxyl radical and other oxidizing radical species. Ambient ammonia concentrations are also a user input along with temperature and relative humidity.

Although simplifications of photochemistry have been attempted in the past, correct representation of the gas-phase photochemistry and the radical cycles are critically important in order to properly characterize sulfate and nitrate formation in the real atmosphere. Seigneur et al., (2000) demonstrated this fact in their evaluation of full-science representations of photochemistry against simplified representations (but more advanced than CALPUFF). They concluded that simplified linearized transformation schemes are inadequate for describing sulfate and nitrate formation processes:

“These results indicate that the accurate prediction of source-receptor relationships for PM_{2.5} requires a comprehensive treatment of PM_{2.5} formation from gaseous precursors for the secondary components of PM_{2.5} and a spatially resolved treatment of transport processes for primary PM_{2.5}. Simplified treatments of either atmospheric chemistry or transport are appropriate only when the secondary or primary components of PM_{2.5}, respectively, are not significant. Therefore, the development of source-receptor relationships for PM_{2.5} should be based on air quality models that provide comprehensive descriptions of atmospheric chemistry and transport.”

Morris et al., (1998) also compared the sulfate and nitrate particulate estimates from a comprehensive full-science regional model with those from a model incorporating a simplified empirical chemical mechanism developed in a manner similar to the mechanism in CALPUFF. Evaluating the full-science and empirical chemistry models against observed concentrations, Morris and co-workers concluded:

“Given the importance of the radical cycle for determining secondary PM formation rates, it appears that empirical gas-phase algorithms are inadequate for determining secondary PM formation.”

The uncertainty and potential biases introduced into the CALPUFF visibility estimates due to neglect of gas phase oxidant chemistry remain unknown.

3.2.5 Aerosol Chemistry

Formation of secondary fine particulate matter (e. g., nitrates, sulfates, organic aerosols) in point source plumes is strongly dependent on the rate of mixing with ambient (background) air and the chemical composition of this background. The rates of oxidation of sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) to sulfate and nitric acid can be very different within a power plant or industrial plume compared to that in the background air (Gillani and Godowitch, 1999; Karamchandani et al., 2000). Similarly, the formation of secondary organic aerosols from emitted VOCs and those from other anthropogenic and biogenic sources, adds yet another pathway in the formation of visibility-impairing aerosols. The presence of atmospheric ammonia introduces further nonlinearities into the gas phase and aerosol reactions. Accordingly, for a model to realistically simulate the production of secondary particulate sulfate, nitrate, and organic aerosols from a potential BART source, the mixing processes and chemical reactions within and outside of the plume must be treated realistically. If the chemical interactions between these two fundamentally different and interactive chemical environments are overly-simplified or neglected altogether, the ability of the model to correctly calculate plume concentrations, deposition, or visibility impacts is lost.

Sulfate and Nitrate Formation. Two SO_2 and NO_x chemical transformation schemes are available in CALPUFF: the MESOPUFF-II algorithm (Scire et al., 1983; Atkinson et al., 1982) and the RIVAD algorithm (Latimer et al., 1986). These algorithms calculate sulfate and nitrate formation rates based on the puff concentrations, background environmental parameters provided by CALMET, and background ozone and ammonia concentrations provided as input by the user. SOA particulates are not treated by either mechanism. The parameters used are as follows (note that each method does not use all of these parameters).

Puff Average Concentrations (from CALPUFF)

- NO_x concentration
- SO_2 concentration

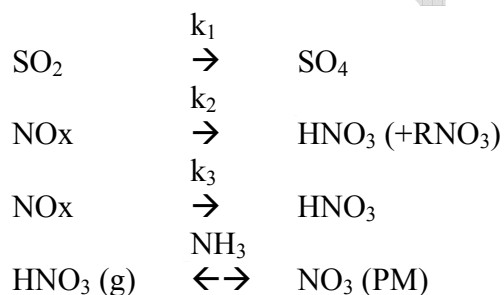
Environmental Parameters (from CALMET)

- Temperature
- Surface Relative Humidity (RH)
- Atmospheric Stability
- Solar Radiation

Background Concentrations (User Input)

- Ozone (O₃)
- Ammonia (NH₃)

The MESOPUFF-II chemical transformation scheme is EPA's recommended approach for Class I area impact assessment (IWAQM, 1998). It entails pathways for five active pollutants (SO₂, SO₄, NO_x, HNO₃, and NO₃) as follows:



where,

SO₂ is the puff average sulfur dioxide concentration;
 NO_x is the puff average oxides of nitrogen concentrations;
 SO₄ is sulfate concentrations formed from the SO₂;
 HNO₃ is the nitric acid formed from the NO_x;
 NO₃ is the particulate nitrate that is in equilibrium with the nitric acid; and
 NH₃ is the background ammonia concentration.

Daytime Rates

$$k_1 = 36 \times R^{0.55} \times [\text{O}_3]^{0.71} \times S^{-1.29} + k_{1(\text{aq})}$$

$$k_{1(\text{aq})} = 3 \times 10^{-8} \times \text{RH}^4 \text{ (added to } k_1 \text{ above during the day)}$$

$$k_2 = 1206 \times [\text{O}_3]^{1.5} \times S^{-1.41} \times [\text{NO}_x]^{-0.33}$$

$$k_3 = 1261 \times [\text{O}_3]^{1.45} \times S^{-1.34} \times [\text{NO}_x]^{-0.12}$$

Nighttime Rates

$$k_1 = 0.20 \text{ (\%/hr)}$$

$$k_2 = 0.00 \text{ (\%/hr)}$$

$$k_3 = 2.00 \text{ (\%/hr)}$$

with,

k_1	is the SO ₂ to SO ₄ gas-phase transformation rate (%/hr)
$k_{1(aq)}$	is the SO ₂ to SO ₄ aqueous-phase transformation rate (%/hr)
k_2	is the NO _x to HNO ₃ +RNO ₃ transformation rate (%/hr)
k_3	is the NO _x to HNO ₃ (only) transformation rate (%/hr)
S	is the stability index ranging from 2 to 6 (PGT class A&B=2, C=3, D=4, E=5, F=6)
R	is the total solar radiation intensity (kw/m ²)
RH	is the relative humidity (%)
[O ₃]	is the user provided background ozone concentrations (ppm)
[NO _x]	is the plume average NO _x concentration (ppm)
NH ₃	is the user provided background ammonia concentrations

Daytime chemical transformations are based on statistically analyzed hourly transformation rates (Scire et al., 1983) obtained from box model simulations using the Atkinson et al., (1982) photochemical mechanism. In this scheme, gas-phase oxidation of SO₂ and NO_x depends on the hydroxyl (OH) radical concentrations for which background ozone, solar intensity (R), and stability index are used as surrogates. At night, OH concentrations are much lower and default SO₂ and NO_x oxidation rates of 0.2 %/hr and 2.0 %/hr are assumed. The $k_{1(aq)}$ sulfate formation rate is added to the k_1 rate during the day as a surrogate for aqueous-phase sulfate formation which begins to assume importance above approximately 50% RH (~0.2 %/hr sulfate formation rate) and peaks at 100% RH (3%/hr sulfate formation rate).

The sulfate and nitrate formation rate equations used in the MESOPUFF II scheme were originally generated by developing regression equations for a few key variables on the results of 144 box model simulations that used the 1982 photochemical mechanism of Atkinson et al. These box model simulations varied ambient temperature, ozone concentration, sunlight intensity, VOC concentrations, atmospheric stability, and plume NO_x concentrations as shown in Table 3-1. The actual environmental conditions used to generate the sulfate and nitrate transformation equations were extremely limited. For example, the transformation rates did not cover temperatures below 10 deg C (50 deg F) or cleaner rural atmospheric conditions with VOC concentrations less than 50 ppbC.

The CALPUFF MESOPUFF-II chemistry clearly neglects several environmental parameters and chemical processes that are important in simulating sulfate and nitrate formation in NO_x/SO₂ emissions source plumes. In many cases these deficiencies lead to an overestimation bias of the source's sulfate and nitrate impacts. Factors that lead such a bias include:

Lack of Temperature Effects: Photochemistry is known to be highly temperature sensitive, as evidenced by the fact that elevated ozone concentrations tend to occur on hot summer days. Lower temperatures produce lower OH and other radical concentrations and consequently lower sulfate and nitrate formation rates. The CALPUFF sulfate and nitrate formation rates, however, do not adequately incorporate temperature effects. The MESOPUFF-II chemical transformation algorithm was developed under conditions with a minimum temperature of only

10° C (50° F). Thus, under conditions colder than 10° C, CALPUFF will overpredict sulfate and nitrate formation rates and impacts. CALPUFF typically estimates maximum sulfate and visibility impacts during the late fall/early spring and winter months; these are the same months when the CALPUFF overestimation bias from not considering temperature effects will be greatest. In addition, under colder temperatures, NO_x will be converted to peroxyacetyl nitrate (PAN) so that the NO_x is no longer available to be converted to nitrate. Since the CALPUFF chemistry ignores the PAN sink for NO_x, it will systematically overpredict nitrate impacts.

Effects of NO_x Emissions on Sulfate Chemistry: Downwind of a point source with significant NO_x/SO₂ emissions, high NO_x and SO₂ concentrations co-exist. Under high NO_x concentrations, radical concentrations are greatly reduced, resulting in very low ozone, sulfate, and nitrate formation rates. This is due to the NO_x inhibition effect on photochemistry whereby: (1) the titration of NO with ozone eliminates ozone and its source as a radical generator; and (2) the high NO₂ concentrations eliminate the OH radical via the NO₂ + OH reaction thereby effectively shutting down photochemistry. Thus, in a NO_x/SO₂ point source plume near the source, there will be very low OH radical and ozone concentrations and consequently very low sulfate and nitrate formation. Since the simple MESOPUFF-II transformation equations cannot account for the NO_x effect on the sulfate formation, CALPUFF will tend to over-predict sulfate formation rate in a NO_x/SO₂ point source plume near the source, which in turn leads to overstating the sulfate formation rate. Because NO_x/SO₂ point sources are typically buoyant, they are frequently emitted aloft in a stable layer where the high NO_x concentrations and inhibited sulfate and nitrate formation rates could persist 100 km or more downwind.

Aqueous-Phase Sulfate Formation Algorithm. CALPUFF's MESOPUFF-II chemistry treats aqueous-phase sulfate formation solely as a function of relative humidity (RH), which actually has no direct affect on aqueous-phase sulfate formation chemistry. The CALPUFF MESOPUFF-II aqueous-phase sulfate formation rate ranges from values of approximately 0.2 %/hr at 50% RH to 3.0 %/hr at 100% RH. Relative humidity (RH) is a measure of the content of water vapor in the atmosphere. However, in reality aqueous-phase sulfate formation will depend on the amount of atmospheric liquid water content (LWC) in cloud or fog droplets, the pH of the water droplets, and the level of H₂O₂, ozone, and SO₂ concentrations. Accordingly, in the atmosphere, aqueous-phase sulfate formation chemistry is not affected by RH. Thus, the CALPUFF aqueous-phase chemistry parameterization is incorrect. Although under conditions of clouds and fog there will be high RH, the occurrence of high RH with very little or no clouds or fog can be quite frequent.

In a liquid water droplet, the reaction of SO₂ with H₂O₂ to form sulfate is essentially instantaneous and is usually limited by the amount of H₂O₂ present (i.e., oxidant limited) for a NO_x/SO₂ point source. Once the H₂O₂ is reacted away within the water droplet, sulfate formation via this pathway slows to the rate of H₂O₂ formation,

which would be extremely slow to nonexistent in a large point source plume due to the scavenging of radicals by the high NO_x concentrations. This introduces an inaccurate representation of sulfate formation in CALPUFF that creates uncertainties and bias in modeled visibility impacts. Whether this uncertainty results in an under- or overestimate of sulfate formation is difficult to determine since the approach is scientifically invalid. Under conditions of high RH and little clouds or little plume interaction with clouds, it will clearly overstate sulfate formation. However, under conditions of cloudy conditions with available photochemical oxidants (i.e., H₂O₂ and O₃) and a dilute NO_x/SO_x point source plume, it may understate sulfate formation. Near large NO_x/SO₂ point source where the elevated NO_x concentrations scavenge and limit photochemical oxidants, the MESOPUFF-II algorithm will likely overstates sulfate formation.

Thus, the CALPUFF aerosol chemistry fails to account for many environmental parameters that are necessary to simulate sulfate and nitrate formation rates, including VOCs and their reactivity, temperature, liquid water content, and NO_x concentrations. In their evaluations against full-science PM models and observations, Seigneur et al., (2000) and Morris et al., (1998) both independently found that the empirical chemistry modules, such as employed by CALPUFF, are inadequate for estimating sulfate and nitrate formation. These findings are supported by EPA's PM_{2.5} and Regional Haze SIP modeling guidance (EPA, 2001) that recommends against using Lagrangian models such as CALPUFF for simulating secondary PM.

From the foregoing, it is clear that the CALPUFF chemical transformation algorithms neglect important chemical processes necessary to accurately estimate the sulfate and nitrate impacts due to SO₂ and NO_x emissions. Given that EPA recommends the model for BART determinations, a key question is "What is the influence of the simplified chemistry on modeled estimates of visibility impacts from BART sources? In some cases, the inadequacies in the CALPUFF chemistry algorithms may simply introduce broader uncertainties into the calculation of estimated sulfate and nitrate impacts. In many cases, however, the simplifications made in the CALPUFF description of chemical processes result in a systematic bias in the estimated concentrations and visibility impacts due to SO₂ and NO_x emissions sources. For large point sources that emit SO₂ and NO_x emissions, such as EGUs, petrochemical process heaters, cement plant kilns, etc., many of the limitations in the CALPUFF MESOPUFF-II SO₂ and NO_x transformation algorithms would result in an overestimation bias. While models that are systematically biased high (i.e., over-predict impacts) may be appealing to regulatory decision-makers because they are 'conservative', the overprediction tendency may well lead to unwarranted and excessive control of emissions from some sources. Thus, the tradeoff between simplicity and conservatism on the one hand and technical credibility and unbiased answers on the other is a key element in the negotiation of modeling protocols developed by the states or source operators.

3.2.6 Surface Removal

An especially important contributor to particulate concentrations is the rate of deposition to the surface. PM_{2.5} particles, which have a mass median diameter around 0.5

μm , have an average net deposition velocity of about 1 cm/min (or about 14 m/day) and thus the deposition of fine particles is not usually significant except for ground-level emissions. On the other hand, coarse particles (those PM_{10} particles larger than $\text{PM}_{2.5}$) have an average deposition velocity of more than 1 m/min (or 1440 m/day), which is significant, even for emissions from elevated stacks.

CALPUFF includes parametric representations of particle and gas deposition in terms of atmospheric, deposition layer, and vegetation layer “resistances” and, for particles, the gravitational settling speed. Gravitational settling, which is of particular importance for the coarse fraction of PM_{10} , is accounted for in the calculation of the deposition velocity. Effects of inertial impaction (important for the upper part of the PM_{10} distribution) and Brownian motion (important for small, sub-micron particles) and wet scavenging are also addressed. The BART guidance recommends that fine particulate matter (less than 2.5 μm diameter), which has higher light extinction efficiency than coarse particulate matter (2.5-10 μm diameters), should be treated separately in the model. CALPUFF allows for user-specified size categories to be treated as separate species, which includes calculating size-specific dry deposition velocities for each size category.

3.3 CALMET Meteorological Preprocessor

The CALMET meteorological model consists of a diagnostic wind field module and micrometeorological modules for over-water and overland boundary layers. When modeling a large geographical area such as the CENRAP domain, the user has the option to use a Lambert Conformal Projection coordinate system to account for Earth’s curvature. The major features and options of the meteorological model are summarized in Table 3-1. The techniques used in the CALMET model are briefly described below.

3.3.1 Boundary Layer Modules

The CALMET processor contains two boundary layer modules for application to overland and overwater grid cells.

Overland Boundary Layer Module: Over land surfaces, the energy balance method of Holtslag and van Ulden (1983) is used to compute hourly gridded fields of the sensible heat flux, surface friction velocity, Monin-Obukhov length, and convective velocity scale. Mixing heights are determined from the computed hourly surface heat fluxes and observed temperature soundings using a modified Carson (1973) method based on Maul (1980). The module also determines gridded fields of PGT stability class and hourly precipitation rates.

Overwater Boundary Layer Module: The aerodynamic and thermal properties of water surfaces suggest that a different method is needed for estimating boundary layer parameters in the marine environment. A profile technique, using air-sea temperature differences, is used in CALMET to compute the micro-meteorological parameters in the marine boundary layer. An upwind-looking spatial averaging scheme is optionally

applied to the mixing heights and three-dimensional temperature fields in order to account for important advective effects.

3.3.2 CALMET Diagnostic Wind Field Module

The CALMET wind model was constructed from two other meteorological models used in California in the late 1970s. One was the California Institute of Technology (CIT) mass consistent interpolation model described by Goodin et al., (1980). The other was the Complex Terrain Wind Model (CTWM) developed at Systems Applications, Inc. (Tesche and Yocke, 1978; Yocke and Liu, 1978). The CTWM terrain adjustments used to modify the flow fields were assembled in the 1970s as part of research into fire spread and avalanche forecasting in mountainous regions of California. Various heuristic algorithms were developed to approximate down slope drainage flows, terrain blocking and channeling (Geiger, 1965), thermal heat islands (Stern and Malkus, 1953), surface friction retardation, capping by an elevated inversion and so on. These algorithms were based on empirical studies in wind tunnels, numerical modeling experiments, and field studies in the Alps, some dating back to the 1930s (Defant, 1933). Later work by Tesche et al., (1986), Kessler et al., (1987) and Douglas and Kessler (1988) integrated the CIT and CTWM modeling system into a single meteorological model that included algorithms to blend observational data with prognostic meteorological model output. The combined model was used extensively for urban-scale ozone studies throughout the U.S. prior to the switch to MM5 as the preferred meteorological model for SIP studies in the mid-1990s.

The CALMET model development incorporated the main features of the CTWM and CIT wind model and significantly updated the physical parameterizations and improved model input/output (I/O) schemes (Scire et al., 2000a). Today, CALMET uses the CTWM two-step approach to the computation of the wind fields. In the first step, an 'initial-guess' wind field is constructed and then adjusted to approximate the kinematic effects of terrain, slope flows, and terrain blocking. Currently, the gridded MM5 field is used as the initial guess prior to terrain-perturbation. The second step consists of an objective analysis procedure to blend the MM5 field with observational data to produce a final wind field. This introduction of observational data in the second step of the CALMET wind field development is optional. It is also possible to run the model in "no observations" (No-Obs) mode, which involves the use only of MM5 gridded data for the initial guess field followed by fine-scale terrain adjustments on the scale of the CALMET domain.

Normally, the CALMET computational domain is specified to be at smaller grid spacing than the MM5 dataset used to initialize the initial guess field. For example, 36/12 km MM5 data sets available for 2000-2003 over the CENRAP domain have been used to develop the 6 km CALMET grids shown in Figures 5-1 through 5-4.

The current thermal, kinematic, and dynamic effects parameterized in CALMET, used in the first step of the windfield development, are as follows:

Kinematic Effects of Terrain: The CTWM algorithms for kinematic effects (Liu and Yocke, 1980) is used to evaluate the influence of the terrain on the wind field. The initial guess field winds are used to compute a terrain-forced vertical velocity, subject to an exponential, stability-dependent decay function. The effects of terrain on the horizontal wind components are evaluated by applying a divergence-minimization scheme to the initial guess wind field. The divergence minimization scheme is applied iteratively until the three-dimensional divergence is less than a threshold value.

Slope Flows: The original slope flow algorithm (Defant, 1933) has been upgraded (Scire and Robe, 1997) based on the shooting flow algorithm of Mahrt (1982). This scheme includes both advective-gravity and equilibrium flow regimes. At night, the slope flow model parameterizes the flow down the sides of the valley walls into the floor of the valley, and during the day, upslope flows are parameterized. The magnitude of the slope flow depends on the local surface sensible heat flux and local terrain gradients. The slope flow wind components are added to the wind field adjusted for kinematic effects.

Blocking Effects: The thermodynamic blocking effects of terrain on the wind flow are parameterized in terms of the local Froude number (Allwine and Whiteman, 1985). If the Froude number at a particular grid point is less than a critical value and the wind has an uphill component, the wind direction is adjusted to be tangent to the terrain.

3.4 Estimation of Regional Haze Contributions

The default procedure for quantifying visibility impacts is described in several documents (IWAQM, 1998; FLAG, 2000). Implementation of these procedures in CALPUFF is described in the user's documentation (Scire et al., 2000b). Generally, 'visibility' may be quantified either by visual range (the greatest distance that a large object can be seen) or by the light extinction coefficient, which is a measure of the light attenuation per unit distance due to scattering and absorption by gases and particles. Visibility is impaired when light is scattered in and out of the line of sight and by light absorbed along the line of sight. The light extinction coefficient (b_{ext}) considers light extinction by scattering (b_{scat}) and absorption (b_{abs}):

$$b_{ext} = b_{scat} + b_{abs}$$

The scattering components of extinction (b_{scat}) are represented by light scattering due to air molecules (i.e., Rayleigh scattering, $b_{rayleigh}$) and light scattering due to particles, b_{sp} . The absorption components of extinction (b_{abs}) include light absorption due to gases (b_{ag}) and particles (b_{ap}). Furthermore, particle scattering, b_{sp} , can be expressed by its components:

$$b_{sp} = b_{SO_4} + b_{NO_3} + b_{OC} + b_{SOIL} + b_{Coarse}$$

where the chemical species and soot scattering coefficients are given as:

$$b_{\text{SO}_4} = 3 [(\text{NH}_4)_2\text{SO}_4] f(\text{RH})$$

$$b_{\text{NO}_3} = 3 [\text{NH}_4\text{NO}_3] f(\text{RH})$$

$$b_{\text{OC}} = 4 [\text{OC}]$$

$$b_{\text{SOIL}} = [\text{Soil}]$$

$$b_{\text{Coarse}} = 0.6 [\text{Coarse Mass}]$$

$$b_{\text{ap}} = 10 [\text{EC}]$$

The numeric coefficient at the beginning of each equation is the dry scattering or absorption efficiency in meters-squared per gram. The $f(\text{RH})$ term is a monthly-average relative humidity adjustment factor. The terms in the brackets are the estimated concentrations from CALPUFF (or other model) in micrograms per cubic meter ($\mu\text{g}/\text{m}^3$).

Finally, the total atmospheric extinction is estimated as:

$$b_{\text{ext}} = b_{\text{SO}_4} + b_{\text{NO}_3} + b_{\text{OC}} + b_{\text{SOIL}} + b_{\text{Coarse}} + b_{\text{ap}} + b_{\text{rayleigh}}$$

or, substituting in the above terms,

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

This is the so-called IMPROVE extinction equation currently recommended by EPA (2003). Note that the sulfate (SO_4) and nitrate (NO_3) components are hygroscopic because their extinction coefficients depend upon relative humidity. The concentrations, in square brackets, are in $\mu\text{g}/\text{m}^3$ and b_{ext} is in units of Mm^{-1} . The Rayleigh scattering term (b_{Ray}) has a default value of 10 Mm^{-1} , as recommended in EPA guidance for tracking reasonable progress (EPA, 2003a). The effect of relative humidity variability on the extinction coefficients for SO_4 and NO_3 can be estimated in several ways, but following the EPA BART guidelines, the Class I area-specific monthly $f(\text{RH})$ values shown in Table 6-1 should be used.

Modeled ground level concentrations of each of the above visibility impairing pollutants are used with the IMPROVE equation to deduce the extinction coefficient. The change in visibility (measured in terms of 'deciviews') is compared against background conditions. The delta-deciview, Δdv , value is

calculated from the source's contribution to extinction, b_{source} , and background extinction, $b_{\text{background}}$, as follows:

$$\Delta dv = 10 \ln((b_{\text{background}} + b_{\text{source}}) / b_{\text{background}})$$

The impact of a source is determined by comparing the Δdv , or haze index (HI), for estimated natural background conditions with the impact of the source and without the impact of the source. *If the Δdv value is greater than the 0.5 dv threshold the source is said to contribute to visibility impairment and is thus subject to BART controls.*

CALPOST uses a previous IMPROVE $f(RH)$ curve (FLAG, 2000) which differs slightly from the $f(RH)$ now used by IMPROVE and EPA (2003), mainly at high relative humidity. Also, CALPOST sets the maximum RH at 98% by default (although the user can change it), while the EPA's guidance now caps it at 95% (easily modified in the CALPUFF input file).

For regional haze light extinction calculations, use of a plume-simulating model such as CALPUFF is appropriate only when the plume is sufficiently diffuse that it is not visually discernible as a plume *per se*, but nevertheless its presence could alter the visibility through the background haze. The IWAQM Phase 2 report states that such conditions occur starting 30 to 50 km from a source. This is consistent with the BART guidance recommendation for using CALPUFF for source-receptor distances greater than 50 km. But, CALPUFF is also recommended by EPA as an option that can be considered for shorter transport distances when the plume may in fact be discernible from the background haze.

Apart from the chemistry issues discussed previously, there do not appear to be any major reasons why CALPUFF cannot be used for even shorter transport distances than 30 km, as long as the scale of the plume is larger than the scale of the output grid so that the maximum concentrations and the width of the plume are adequately represented and so that the sub-grid details of plume structure can be ignored when estimating effects on light extinction. The standard 1-km output grid that has been established for Class I area analyses should serve down to source-receptor distances somewhat under 30 km; how much closer than 30 km will depend on the topography and meteorology of the area and should be evaluated on a case-by-case basis with individual CENRAP State modelers. (For reference, the width of a Gaussian plume, $2\sigma_y$, is roughly 1 km after 10 km of travel distance, assuming Pasquill-Gifford dispersion rates under neutral conditions.)

3.4.1 CALPOST Methods

Calculation of the impact of the simulated plume particulate matter component concentrations on light extinction is carried out in the CALPOST postprocessor. For BART applications, this processor is of considerable importance.

CALPOST is used to process the CALPUFF outputs, producing tabulations that summarize the results of the simulations, identifying for example, the highest and second-highest hourly-average concentrations at each receptor. When performing visibility-related modeling, CALPOST uses concentrations from CALPUFF to compute light extinction and related measures of visibility (deciviews), reporting these for a 24-hour averaging time. The CALPOST processor contains several options for evaluating visibility impacts, including the method described in the BART guidance, which uses monthly average relative humidity values. CALPOST contains implementations of the IWAQM-recommended and FLAG-recommended visibility techniques and additional options to evaluate the impact of natural weather events (fog, rain and snow) on background visibility and visibility impacts from modeled sources. CALPOST uses Equation 3-1 to calculate the extinction increment due to the source of interest and provides various methods for estimating the background extinction against which the increment is compared in terms of percent or deciviews.

For background extinction, the CALPOST processor contains seven techniques for computing the change in light extinction due to a source or group of sources (i.e., Methods 1 through 7). These are usually reported as 24-hour average values, consistent with EPA and FLM guidance. In addition, there are two techniques for computing the 24-hour average change in extinction (i.e., as the ratio of 24-hour average extinctions, or as the average of 24-hour ratios). Method 2 is the current default, recommended by both IWAQM (EPA, 1998) and FLAG (2000) for source-specific. Method 6 is recommended by EPA's BART guidance (70 FR 39162).

In Method 2, user-specified, speciated monthly concentration values are used to describe the background. When applied to natural conditions, for which EPA's default natural conditions concentrations are annual averages, the same component concentrations would have to be used throughout the year (unless potential refinements to those default values resulted in concentrations that vary during the year). Hourly background extinction is then calculated using these concentrations and hourly, site-specific $f(RH)$ from a 1993 IWAQM curve or, optionally, the EPA regional haze $f(RH)$ curve.² Again the RH is capped at either 98% (default) or a user-selected value (most commonly at 95%).

Method 6 is similar to Method 2, except monthly $f(RH)$ values (e.g., EPA's monthly climatologically representative values) are used in place of hourly values for calculating both the extinction impact of the source emissions and the background conditions extinction. Hourly source impacts, with the effect on extinction due to sulfates and nitrates calculated using the monthly-average relative humidity in $f(RH)$, are compared against the monthly default natural background concentrations. Thus the monthly-averaged relative humidity is applied to the hygroscopic components (i.e., sulfate and nitrate) of both the source impact and the background extinction with Method 6.

² Note that the hourly-varying natural background extinction here is not consistent with that prescribed by the EPA's natural conditions guidance (EPA, 2003b), for which a "climatologically-representative" $f(RH)$ that only varies monthly is to be used. Method 6 uses these monthly average humidity values.

3.4.2 POSTUTIL

The POSTUTIL processor allows the cumulative impacts of multiple sources from different simulations to be summed, including computing the difference between two sets of predicted impacts (useful for evaluating the benefits of BART controls). It also contains a chemistry module to evaluate the equilibrium relationship between nitric acid and nitrate aerosols. This capability allows the potential non-linear effects of ammonia scavenging by background sulfate and nitrate sources to be approximated in the formation of nitrate from an individual source. The processor can compute the impacts of individual sources or groups of sources on sulfur and nitrogen deposition into aquatic, forest and coastal ecosystems, thereby allowing changes in deposition fluxes resulting from changes in emissions to be quantified.

The POSTUTIL processor attempts to overcome the bias introduced when CALPUFF assumes that the full background ammonia concentration is entrained into each discrete puff. For a single puff, this may be satisfactory, but the model overestimates the production of ammonium nitrate when multiple puffs co-exist and overlap. The POSTUTIL processor re-partitions the ammonia and nitric acid concentrations to conform to the ammonia-limiting processes influencing nitrate formation. Though based on recognized science, this approximate post-processing method is fundamentally dependent on reliable estimates of ambient NH_3 at the Class I receptor of interest.

3.4.3 Refined Extinction and Background Visibility Estimates

EPA, the IMPROVE Steering Committee, and the RPOs are evaluating whether refinements are warranted to the methods recommended for calculating extinction and the default estimate of natural background visibility. Whether EPA will approve of any changes to the IMPROVE equation is uncertain at this time. Also, the responsibility for incorporating any changes to the algorithms in CALPUFF (e.g., new $f(\text{RH})$ curves) is unclear. If changes to these methods are recommended by EPA, CENRAP is encouraged to adopt them. However, details of the process for incorporation of any refinements to the IMPROVE equations in the CALPUFF system should be addressed in the State's or source operators modeling protocol.

3.5 Model Availability

The EPA-approved version of the CALPUFF modeling system is available from Earth Tech, Inc., (<http://www.src.com/calpuff/calpuff1.htm>). The main models (CALMET, CALPUFF, and CALPOST), their GUIs, and many of the processors are available to download. One may also register to receive notices of model updates. The most recent update to the system (25 May 2005) is a new version of CALMM5 (MM5 V3) that has been added to the Download BETA-Test page. This version of CALMM5 processes MM5 Version 3 output data directly.

Earth Tech offers CALPUFF training courses that include a description of the technical formulation of the models, overviews of each of the processor programs, and hands-on application of the models to several case study data sets. Attendees of the course receive a training notebook, a workbook of case study problems, exercises, and data sets, updates on recent and future model enhancements, and the latest (proprietary) versions of the models and Graphical User Interfaces (GUIs). Other third-party training courses and materials are also available.

3.6 CALPUFF Evaluation Studies

Tesche (2002, 2003) reviewed results of various CALPUFF evaluation studies and reached the following conclusions:

- > There is a paucity of model evaluation information for CALPUFF at scales of 50 to 200 km and beyond;
- > Based on the limited information available, CALPUFF may be able to give unbiased estimates of short-term (i.e., 3-10 hr) concentrations of *non-reactive contaminants* to within a factor of two (e.g. 200%) out to distances of about 200 km from a source. This level of uncertainty in a 200 km radius around a source is increased if one examines CALPUFF's predictions in a particular modeling cell (e.g., one containing a population center) at a specific hour as opposed to considering the question of bias generally over the entire 200 km region irrespective of location and time of occurrence;
- > For time periods of a day or less, CALPUFF is unable to produce reliable predictions of non-reactive concentrations at a specific location and time;
- > What limited experimental data do exist suggest that the accuracy and reliability of the model's predictions degrade as the distance scale increases;
- > While the IWAQM recommendations on the range of applicability of the CALPUFF model (50 to 200 km) rests on very sparse model evaluation information, EPA's suggestion that the model can be used for scales beyond 200 km, even with case-by-case approval, is not based on model evaluation data; and
- > For chemically reactive pollutants such as SO₂, NO_x, sulfate, nitrate, nitric acid, and other secondary reaction products, the testing of CALPUFF model over extended spatial scales (50 km and beyond) has not been attempted in a rigorous manner.

Scire et al., (2001) report an evaluation of CALPUFF sulfate, nitrate, light extinction, and sulfur and nitrogen deposition at a Class I areas over a range of source-

receptor distances. In this study, in which a large number of sources were modeled simultaneously, sulfate and nitrate predictions at the CASTNet monitoring site in Pinedale, Wyoming were evaluated against observations, and light extinction predictions were evaluated using transmissometer measurements. Wet sulfur and nitrogen predictions were compared to observations at several acid deposition monitoring sites. This study is especially relevant because it evaluates the performance of the model to predict variables of direct interest in Class I visibility analyses, such as sulfate and nitrate concentrations and light extinction coefficients

More recently, Chang et al., (2003) reported an intercomparison of CALPUFF with two other transport and dispersion models with high resolution field data. CALPUFF predictions for inert SF₆ were compared using two recent mesoscale field datasets: the Dipole Pride 26 (DP26) and the Overland Along-wind Dispersion (OLAD). Both field experiments involved instantaneous releases of sulfur hexafluoride tracer gas in a mesoscale region with desert basins and mountains. Tracer concentrations were observed along lines of samplers at distances up to 20 km. CALPUFF predictions were evaluated using the maximum 3-h dosage (concentration integrated over time) along a sampling line. At the DP26 sampler array, CALPUFF had mean biases within 35% and random scatters of about a factor of 3–4. About 50%–60% of the CALPUFF predictions were within a factor of 2 of the observations. At the OLAD site, the model underpredicted by a factor of 2–3, on average, with random scatters of a factor of 3–7. Only about 25%–30% of the CALPUFF predictions of inert SF₆ were within a factor of 2 of observations.

The tracer studies with which CALPUFF transport and diffusion capabilities were evaluated in the IWAQM Phase 2 report were generally over distances greater than 50 km. More recently, model performance has been performed at shorter distances including a power plant in Illinois in simple terrain at source-receptor distances in arcs ranging from 0.5 km to 50 km from the stack (Strimaitis et al., 1998). Another CALPUFF evaluation study over short-distances is reported by Morrison et al. (2003). These studies address model performance over source-receptor distances from a few hundred meters to 50 km.

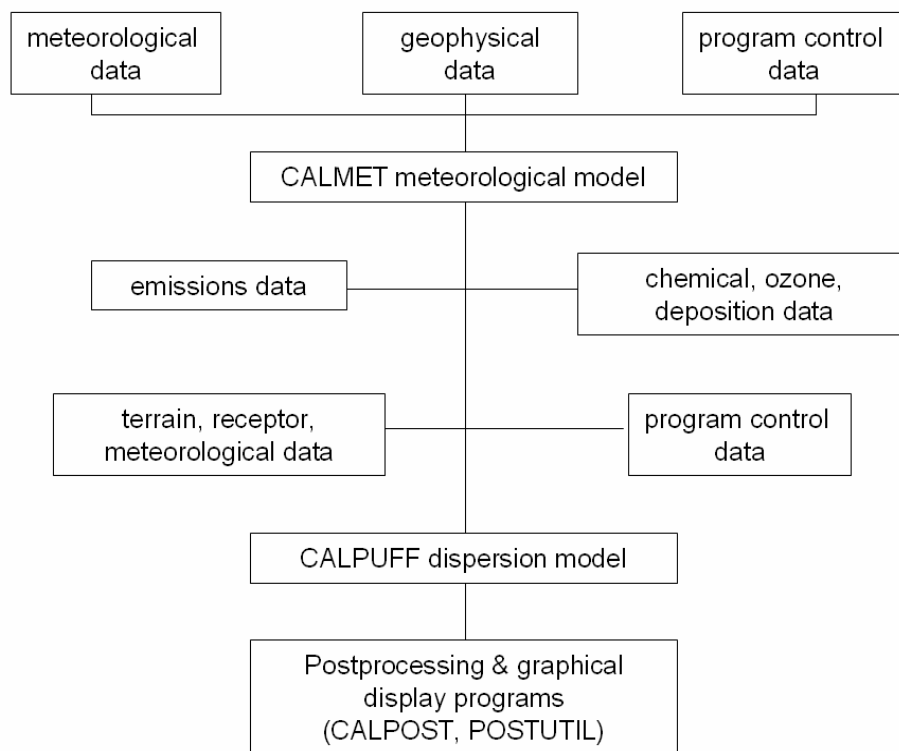


Figure 3-1. CALPUFF Modeling System Components. (Scire et al., 2000a)

Table 3-1. Major Features of the CALMET Meteorological Model. (Scire et al., 2000b)

- **Boundary Layer Modules of CALMET**
 - Overland Boundary Layer - Energy Balance Method
 - Overwater Boundary Layer - Profile Method
 - Produces Gridded Fields of:
 - Surface Friction Velocity
 - Convective Velocity Scale
 - Monin-Obukhov Length
 - Mixing Height
 - PGT Stability Class
 - Air Temperature (3-D)
 - Precipitation Rate
- **Diagnostic Wind Field Module of CALMET**
 - Slope Flows
 - Kinematic Terrain Effects
 - Terrain Blocking Effects
 - Divergence Minimization
 - Produces Gridded Fields of U, V, W Wind Components
 - Inputs Include Domain-Scale Winds, Observations, and (optionally) Coarse-Grid Prognostic Model Winds
 - Lambert Conformal Projection Capability

Table 3-2. Major Features of the CALPUFF Dispersion Model (Scire et al., 2000a)

	<ul style="list-style-type: none"> • Source types <ul style="list-style-type: none"> - Point sources (constant or variable emissions) - Line sources (constant or variable emissions) - Volume sources (constant or variable emissions) - Area sources (constant or variable emissions)
sources	<ul style="list-style-type: none"> • Non-steady-state emissions and meteorological conditions <ul style="list-style-type: none"> - Gridded 3-D fields of meteorological variables (winds, temperature) - Spatially-variable fields of mixing height, friction velocity, convective velocity scale, Monin-Obukhov length, precipitation rate - Vertically and horizontally-varying turbulence and dispersion rates - Time-dependent source and emissions data for point, area, and volume
source types	<ul style="list-style-type: none"> - Temporal or wind-dependent scaling factors for emission rates, for all
wildfires	<ul style="list-style-type: none"> • Interface to the Emissions Production Model (EPM) <ul style="list-style-type: none"> - Time-varying heat flux and emissions from controlled burns and
	<ul style="list-style-type: none"> • Efficient sampling functions <ul style="list-style-type: none"> - Integrated puff formulation - Elongated puff (slug) formulation
	<ul style="list-style-type: none"> • Dispersion coefficient (σ_y, σ_z) options <ul style="list-style-type: none"> - Direct measurements of σ_v and σ_w - Estimated values of σ_v and σ_w based on similarity theory - Pasquill-Gifford (PG) dispersion coefficients (rural areas) - McElroy-Pooler (MP) dispersion coefficients (urban areas) - CTDM dispersion coefficients (neutral/stable)
	<ul style="list-style-type: none"> • Vertical wind shear <ul style="list-style-type: none"> - Puff splitting - Differential advection and dispersion
	<ul style="list-style-type: none"> • Plume rise <ul style="list-style-type: none"> - Buoyant and momentum rise - Stack tip effects - Building downwash effects - Partial penetration - Vertical wind shear
	<ul style="list-style-type: none"> • Building downwash

- Huber-Snyder method
- Schulman-Scire method
- PRIME method

Table 3-2. Major Features of the CALPUFF Dispersion Model (Concluded).

CTDMPLUS)	<ul style="list-style-type: none"> • Complex terrain <ul style="list-style-type: none"> - Steering effects in CALMET wind field - Optional puff height adjustment: ISC3 or "plume path coefficient" - Optional enhanced vertical dispersion (neutral/weakly stable flow in
diffusion rates around the hill	<ul style="list-style-type: none"> • Subgrid scale complex terrain (CTSG option) <ul style="list-style-type: none"> - Dividing streamline, H_d, as in CTDMPLUS: <ul style="list-style-type: none"> - Above H_d, material flows over the hill and experiences altered - Below H_d, material deflects around the hill, splits, and wraps
coastal boundary	<ul style="list-style-type: none"> • Dry Deposition <ul style="list-style-type: none"> - Gases and particulate matter - Three options: <ul style="list-style-type: none"> - Full treatment of space and time variations of deposition with a resistance model - User-specified diurnal cycles for each pollutant - No dry deposition • Overwater and coastal interaction effects <ul style="list-style-type: none"> - Overwater boundary layer parameters - Abrupt change in meteorological conditions, plume dispersion at - Plume fumigation
	<ul style="list-style-type: none"> • Chemical transformation options <ul style="list-style-type: none"> - Pseudo-first-order chemical mechanism for SO_2, SO_4^-, NO_x, HNO_3, and NO_3^- (MESOPUFF II method) - Pseudo-first-order chemical mechanism for SO_2, SO_4^-, NO, NO_2, HNO_3, and NO_3^- (RIVAD/ARM3 method) - User-specified diurnal cycles of transformation rates - No chemical conversion

- **Wet Removal**

- Scavenging coefficient approach
- Removal rate a function of precipitation intensity and precipitation type

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Table 3-3. Parameter Variations in Box Model Simulations Used to Develop the CALPUFF Sulfate and Nitrate Formation Algorithms. (Morris et al., 2003).

Surrogate Parameter	Number of Variations	Model Input Parameters And Variations										
Season	3	Temperatures of 30, 20 and 10 °C were used for the, respectively, summer, fall and winter seasons. Diurnally varying clear skies solar radiation was assumed for each season corresponding to a latitude of 40°.										
Background Air Reactivity	4	<div>For the summer season the following four levels of background ozone and VOCs were used:</div> <table><tr><th>Ozone (ppb)</th><th>VOC (ppbC)</th></tr><tr><td>20</td><td>50</td></tr><tr><td>50</td><td>250</td></tr><tr><td>80</td><td>500</td></tr><tr><td>200</td><td>2,000</td></tr></table> <div>For fall and winter the ozone concentrations were assumed to be 75% and 50% of the summer levels.</div>	Ozone (ppb)	VOC (ppbC)	20	50	50	250	80	500	200	2,000
Ozone (ppb)	VOC (ppbC)											
20	50											
50	250											
80	500											
200	2,000											
Dispersion	2	Two different rates of plume dispersion were used: (1) a stable case with a wind speed of 1.5 m/s and; (2) a slightly unstable case with a wind speed of 5.0 m/s.										
Release Time	2	Photochemical box model simulations were performed with release times of sunrise and noon.										
Plume NOx Concentration	3	Initial plume NOx concentrations of 7, 350 and 1400 ppb were used.										

APPENDIX B – CONTROLS COST ANALYSES

Estimated Average Cost (\$/ton) of Methane DeNOx on No. 1 Power Boiler - NOx Control

CAPITAL COSTS		Costs (\$)
Direct Costs		
Purchased Equipment Cost ^a	\$	1,050,000
Budgetary Qualifier (+/-25%)		262,500
		1,312,500
Direct installation costs		
Foundation and supports		
Handling and erection		
Electrical		
Piping		
Insulation		
Painting		
Direct installation Costs		656,250
Total Direct Capital Cost = Equip Cost + 1.5*Equip Cost^b	\$	1,968,750
Indirect Capital Costs		=1.0 x Total Direct Cost
Engineering		
Construction and field expenses		
Contrator fees		
Start-up		
Performance test		
Contingencies		
Structural Modification (4%)		
Total Indirect Capital Costs^b	\$	1,968,750
TOTAL CAPITAL INVESTMENT (TCI = DC+IC)	\$	3,937,500
OPERATING COSTS		
Direct Operating Costs		
Operating Labor ^c		9,022
Operating Labor Supervision ^d		1,353
Maintenance Labor ^e		9,922
Maintenance Materials ^f		9,922
Utilities - Electricity ^g		112,560
Utilities - Natural Gas ^l		3,108,000
Waste Treatment & Disposal		
Total Direct Operating Costs	\$	3,250,779
Indirect Operating Costs		
Overhead ^h		18,131
Property Tax ⁱ		39,375
Insurance ^j		39,375
Administration ^j		78,750
Capital Recovery (5% interest, 10 year life) ^k		509,924
Total Indirect Operating	\$	685,555
TOTAL ANNUALIZED COSTS (TAC = DOC + IOC)	\$	3,936,334
Total Annualized Costs		3,936,334
Total Uncontrolled NOx Emissions (tpy)		1084
Removal Efficiency		0.5
Pollutant Removed(tpy)		542
Cost/Ton Pollutant Removed	\$	7,262

^aBased on the equipment cost estimate from Energy Systems Associates

^bFactored estimate based on recent capital project installations

^cOperating labor = 0.75 hours/day @ \$34.37/hr rate for 350 days/year

^dSupervisor pay = 15% of Operator pay

^eMaintenance = 240 hours @ \$41.34/hr

^fMaintenance Materials = 100% of Maintenance Labor

^gElectrical usage (335kW) associated with running fans; from Energy Systems Associates estimate for OFA/FGR combo

^hOverhead = 60% of Labor & Material

ⁱ=1% TCI (Total Capital Investment)

^j=2% TCI (Total Capital Investment)

^k=factor of 0.129504575 for 5% interest on 10 year life

^l= Natural gas usage at \$370/hr at \$8/MMBTU

Estimated Average Cost (\$/ton) of OFA System Upgrade on No. 1 Power Boiler - NOx Control

CAPITAL COSTS		Costs (\$)
Direct Costs		
Purchased Equipment Cost^a	\$	2,980,000
Budgetary Qualifier (+/-25%)		745,000
		3,725,000
Direct installation costs		
Foundation and supports		
Handling and erection		
Electrical		
Piping		
Insulation		
Painting		
Direct installation Costs		1,862,500
Total Direct Capital Cost = Equip Cost + 1.5*Equip Cost^b	\$	5,587,500
Indirect Capital Costs	=1.0 x Total Direct Cost	
Engineering		
Construction and field expenses		
Contrator fees		
Start-up		
Performance test		
Contingencies		
Structural Modification (4%)		
Total Indirect Capital Costs^b	\$	5,587,500
TOTAL CAPITAL INVESTMENT (TCI = DC+IC)	\$	11,175,000
OPERATING COSTS		
Direct Operating Costs		
Operating Labor ^c		9,022
Operating Labor Supervision ^d		1,353
Maintenance Labor ^e		9,922
Maintenance Materials ^f		9,922
Utilities - Electricity ^g		112,560
Utilities - Water		
Waste Treatment & Disposal		
Total Direct Operating Costs	\$	142,779
Indirect Operating Costs		
Overhead ^h		18,131
Property Tax ⁱ		111,750
Insurance ⁱ		111,750
Administration ^j		223,500
Capital Recovery (5% interest, 10 year life) ^k		1,447,214
Total Indirect Operating	\$	1,912,345
TOTAL ANNUALIZED COSTS (TAC = DOC + IOC)	\$	2,055,123
Total Annualized Costs		2,055,123
Total Uncontrolled NOx Emissions (tpy)		1084
Removal Efficiency		0.4
Pollutant Removed(tpy)		434
Cost/Ton Pollutant Removed	\$	4,740

^aBased on the equipment cost estimate provided by Jansen Combustion and Boiler Technologies Inc.

^bFactored estimate based on recent capital project installations

^cOperating labor = 0.75 hours/day @ \$34.37/hr rate for 350 days/yea

^dSupervisor pay = 15% of Operator pay

^eMaintenance = 240 hours @ \$41.34/h

^fMaintenance Materials = 100% of Maintenance Labo

^gElectrical usage (335kW) associated with running fans; from Energy Systems Associates estimate for OFA/FGR combc

^hOverhead = 60% of Labor & Material

ⁱ=1% TCI (Total Capital Investment)

^j=2% TCI (Total Capital Investment)

^k=factor of 0.129504575 for 5% interest on 10 year life

Estimated Average Cost (\$/ton) of Methane DeNOx on No. 2 Power Boiler - NOx Control

CAPITAL COSTS		Costs (\$)
Direct Costs		
Purchased Equipment Cost ^a	\$	1,200,000
Budgetary Qualifier (+/-25%)		300,000
		1,500,000
Direct installation costs		
Foundation and supports		
Handling and erection		
Electrical		
Piping		
Insulation		
Painting		
Direct installation Costs		750,000
Total Direct Capital Cost = Equip Cost + 1.5*Equip Cost^b	\$	2,250,000
Indirect Capital Costs		=1.0 x Total Direct Cost
Engineering		
Construction and field expenses		
Contrator fees		
Start-up		
Performance test		
Contingencies		
Structural Modification (4%)		
Total Indirect Capital Costs^b	\$	2,250,000
TOTAL CAPITAL INVESTMENT (TCI = DC+IC)	\$	4,500,000
OPERATING COSTS		
Direct Operating Costs		
Operating Labor ^c		9,022
Operating Labor Supervision ^d		1,353
Maintenance Labor ^e		9,922
Maintenance Materials ^f		9,922
Utilities - Electricity ^g		141,120
Utilities - Natural Gas ^l		4,401,600
Waste Treatment & Disposal		
Total Direct Operating Costs	\$	4,572,939
Indirect Operating Costs		
Overhead ^h		18,131
Property Tax ⁱ		45,000
Insurance ^j		45,000
Administration ^j		90,000
Capital Recovery (5% interest, 10 year life) ^k		582,771
Total Indirect Operating	\$	780,902
TOTAL ANNUALIZED COSTS (TAC = DOC + IOC)	\$	5,353,840
Total Annualized Costs		5,353,840
Total Uncontrolled NOx Emissions (tpy)		2514
Removal Efficiency		0.5
Pollutant Removed(tpy)		1257
Cost/Ton Pollutant Removed	\$	4,259

^aBased on the equipment cost estimate from Energy Systems Associates

^bFactored estimate based on recent capital project installations

^cOperating labor = 0.75 hours/day @ \$34.37/hr rate for 350 days/year

^dSupervisor pay = 15% of Operator pay

^eMaintenance = 240 hours @ \$41.34/hr

^fMaintenance Materials = 100% of Maintenance Labor

^gElectrical usage (420kW) associated with running fans; from Energy Systems Associates estimate for OFA/FGR combo

^hOverhead = 60% of Labor & Material

ⁱ =1% TCI (Total Capital Investment)

^j =2% TCI (Total Capital Investment)

^k =factor of 0.129504575 for 5% interest on 10 year life

^l = Natural gas usage at \$524/hr at \$8/MMBTU

Estimated Average Cost (\$/ton) of OFA System Upgrade on No. 2 Power Boiler - NOx Control

CAPITAL COSTS		Costs (\$)
Direct Costs		
Purchased Equipment Cost^a	\$	4,338,880
Budgetary Qualifier (+/-25%)		1,084,720
		5,423,600
Direct installation costs		
Foundation and supports		
Handling and erection		
Electrical		
Piping		
Insulation		
Painting		
Direct installation Costs		2,711,800
Total Direct Capital Cost = Equip Cost + 1.5*Equip Cost^b	\$	8,135,400
Indirect Capital Costs	=1.0 x Total Direct Cost	
Engineering		
Construction and field expenses		
Contrator fees		
Start-up		
Performance test		
Contingencies		
Structural Modification (4%)		
Total Indirect Capital Costs^b	\$	8,135,400
TOTAL CAPITAL INVESTMENT (TCI = DC+IC)	\$	16,270,800
OPERATING COSTS		
Direct Operating Costs		
Operating Labor ^c		9,022
Operating Labor Supervision ^d		1,353
Maintenance Labor ^e		9,922
Maintenance Materials ^f		9,922
Utilities - Electricity ^g		141,120
Utilities - Water		
Waste Treatment & Disposal		
Total Direct Operating Costs	\$	171,339
Indirect Operating Costs		
Overhead ^h		18,131
Property Tax ⁱ		162,708
Insurance ⁱ		162,708
Administration ^j		325,416
Capital Recovery (5% interest, 10 year life) ^k		2,107,143
Total Indirect Operating	\$	2,776,106
TOTAL ANNUALIZED COSTS (TAC = DOC + IOC)	\$	2,947,445
Total Annualized Costs		2,947,445
Total Uncontrolled NOx Emissions (tpy)		2514
Removal Efficiency		0.4
Pollutant Removed(tpy)		1006
Cost/Ton Pollutant Removed	\$	2,931

^aScaled from quote for #1 PB based on six-tenths factor rule for cost estimation from Peters, Max S. and Timmerhaus, Klaus D., Plant Design and Economics for Chemical Engineers, Fourth Edition, McGraw-Hill, Inc., 1991, p. 169.

^bFactored estimate based on recent capital project installations

^cOperating labor = 0.75 hours/day @ \$34.37/hr rate for 350 days/year

^dSupervisor pay = 15% of Operator pay

^eMaintenance = 240 hours @ \$41.34/hr

^fMaintenance Materials = 100% of Maintenance Labor

^gElectrical usage assumption (420kW) associated with running auxiliary equipment; from Energy Systems Associates estimate for OFA/FGR combo

^hOverhead = 60% of Labor & Material

ⁱ=1% TCI (Total Capital Investment)

^j=2% TCI (Total Capital Investment)

^k=factor of 0.129504575 for 5% interest on 10 year life

Estimated Average Cost (\$/ton) of Low NOx Burners on No. 2 Power Boiler - NOx Control

CAPITAL COSTS		Costs (\$)
Direct Costs		
Purchased Equipment Cost^a	\$	1,800,000
Direct installation costs		
Foundation and supports		
Handling and erection		
Electrical		
Piping		
Insulation		
Painting		
Direct installation Costs		900,000
Total Direct Capital Cost = Equip Cost + 1.5*Equip Cost^b	\$	2,700,000
Indirect Capital Costs	=1.0 x Total Direct Cost	
Engineering		
Construction and field expenses		
Contrator fees		
Start-up		
Performance test		
Contingencies		
Structural Modification (4%)		
Total Indirect Capital Costs^b	\$	2,700,000
TOTAL CAPITAL INVESTMENT (TCI = DC+IC)	\$	5,400,000
OPERATING COSTS		
Direct Operating Costs		
Operating Labor ^c		9,022
Operating Labor Supervision ^d		1,353
Maintenance Labor ^e		9,922
Maintenance Materials ^f		9,922
Utilities - Electricity ^g		141,120
Utilities - Water		
Waste Treatment & Disposal		
Total Direct Operating Costs	\$	171,339
Indirect Operating Costs		
Overhead ^h		18,131
Property Tax ⁱ		54,000
Insurance ⁱ		54,000
Administration ^j		108,000
Capital Recovery (5% interest, 10 year life) ^k		699,325
Total Indirect Operating	\$	933,456
TOTAL ANNUALIZED COSTS (TAC = DOC + IOC)	\$	1,104,795
Total Annualized Costs		1,104,795
Total Uncontrolled NOx Emissions (tpy)		2514
Removal Efficiency		0.3
Pollutant Removed(tpy)		754
Cost/Ton Pollutant Removed	\$	1,465

APPENDIX C – COMPLIANCE PLAN AND SCHEDULE

Domtar will implement control measures or other options for reducing emissions to comply with the proposed BART limits as expeditiously as possible and before the date five years after EPA approval of ADEQ's BART State Implementation Plan (SIP), as required by Regional Haze Rule and BART Guidelines.

Proposed BART Compliance Timeline

May 14-20, 2007	Installation of WESP on No. 1 Power Boiler complete
May 21, 2007	Tentative startup of WESP on No. 1 Power Boiler
September 13, 2007	Boiler MACT Compliance Deadline
March 11, 2008	Last day to show compliance with Boiler MACT = Date achieve BART Particulate Matter limits
Early 2010	NO _x Reduction Technology Evaluation
Late 2011	NO _x Reduction Technology Selected
Late 2012	Installation of selected NO _x Reduction Technology
Early 2013	BART Compliance Deadline

APPENDIX D – REQUESTED DESIGN DETAILS OF NO. 1 POWER BOILER

The No. 1 power boiler, built by Babcock & Wilcox in 1967, is a balanced draft, two drum sterling boiler designed to burn natural gas, fuel oil and bark for the production of steam.

The No. 1 power boiler has a maximum continuous steam rating of 275,000 lbs/hr at 850 psig and 850°F. The boiler discharges steam into the mill's 850# high pressure header system.

The No. 1 power boiler is typically a swing boiler (adjusts its fuel firing rate) to follow the 850 psig header pressure.

The fuel system consists of the three separate subsystems listed below that deliver combustible material into the boiler furnace.

- Bark System - supplies bark, wood waste, pelletized paper fuel, tire-derived fuel and municipal yard waste from the woodyard area and distributes it onto the grate for burning. Bark is the primary fuel source for No. 1 power boiler.
- Natural Gas System - supplies gas from the main mill pipeline to the boiler's six burners and ignitors. Natural gas is used to warm up the boiler during start-up and to supplement bark combustion to maintain load.
- No. 6 Fuel Oil System - prepares and supplies No. 6 fuel oil, used oil generated on site or reprocessed fuel oil to the boiler's burners. Oil serves primarily as a backup to natural gas and is not normally fired.

The combustion air system consists of the three subsystems listed below that provide the oxygen for fuel combustion.

- Air Supply & Preheat System - provides a steady supply of combustion air at the necessary flows and temperatures to ensure efficient combustion.
- Burner Air System - provides air for the combustion of natural gas and/or fuel oil at the burners.
- Bark Air System - provides air for drying and burning of bark system fuels on the grates (undergrate air), combustion of bark system fuels above the grates (overfire air) and distribution of bark system fuels onto the grates (distribution air).

The flue gas system consists of several components listed below that handle the by-products of combustion.

- Tubular Air Heater - transfers heat from the flue gas to the combustion air.

- Mechanical Dust Collector - removes environmentally harmful particulate from the flue gas prior to atmospheric discharge.
- ID Fan - removes the flue gas from the furnace at a controlled rate to maintain a balanced draft.
- Stack - discharges the flue gas to atmosphere.
- Sootblowers - clean the tube surfaces of ash and slag deposited from the flue gas.

The No. 1 Power Boiler will undergo a modification in May 2007 that will entail the installation of a Wet Electrostatic Precipitator to bring the boiler into compliance with the Boiler MACT regulation for particulate matter emissions.