BART CALPUFF
Class I Federal Area
Individual Source Attribution
Visibility Impairment Modeling Analysis
for
Tri-State Generation & Transmission Association
Craig Station Units 1 and 2
(Revised)

March 3, 2006

Colorado Department of Public Health & Environment
Air Pollution Control Division
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1. Executive Summary

Federal law requires Best Available Retrofit Technology (BART) for any BART-eligible source that ‘‘emits any air pollutant which may reasonably be anticipated to cause or contribute to any impairment of visibility” in any mandatory Class I federal area. Pursuant to federal regulations, states have the option of exempting a BART-eligible source from the BART requirements based on dispersion modeling demonstrating that the source cannot reasonably be anticipated to cause or contribute to visibility impairment in a Class I area.

The Division has proposed state regulations establishing criteria and procedures for determining which Colorado sources will be subject to the BART requirement. The Division’s proposal is scheduled for a March 16, 2006 hearing before the Air Quality Control Commission. In advance of the hearing, and in preparation for the submittal of a state implementation plan for regional haze, the Division has performed air quality modeling with the CALPUFF modeling system to assess which BART-eligible sources in Colorado are likely to be subject to BART based on the proposed state regulation.

According to 40 CFR Part 51, Appendix Y (BART guideline), a BART-eligible source is considered to “contribute” to visibility impairment in a Class I area if the modeled 98^{th} percentile change in deciviews is equal to or greater than the “contribution threshold.” Any BART-eligible source determined to cause or contribute to visibility impairment in any Class I area is subject to BART. In this report, the Division used a “contribution threshold” of 0.5 deciviews, as prescribed by the regulatory proposal pending before the Commission.

The Division has applied the CALPUFF modeling system with three years of meteorological data to determine if the 98^{th} percentile 24-hour change in visibility (delta-deciview) from a BART-eligible source is equal to or greater than a contribution threshold of 0.5 deciviews at any Class I area. This initial phase of the BART modeling process is referred to as the “subject-to-BART” analysis. The modeling includes SO_2, NOx, and direct PM10 emissions from all BART-eligible units at a given facility.

While the modeling results in this report may be used to support regulatory decision making, additional modeling performed by the Division or source operator may supersede the results. If additional modeling is performed, it should be consistent with recommendations in the Division’s modeling protocol. Subsequent modeling performed by the source operator will be subject to Division review and approval. Moreover, the contribution threshold and other criteria used for this modeling demonstration have not been finalized and may change in the final rule adopted by the Commission. Therefore, the results in this report are not a final agency action. Any source that the Division determines is subject to BART will receive a separate notice of the agency’s final determination. Such separate notice will occur after the Commission acts on the proposed regulations establishing criteria and procedures for determining which sources will be subject to the BART requirement.

The maximum 98^{th} percentile delta-deciview value from Craig Station Units 1 and 2 at any Class I federal area is 2.689 deciviews, assuming natural background conditions and monthly f(RH) values. The impact is above the contribution threshold of 0.5 deciviews. The maximum impact occurs at the Mount Zirkel Wilderness Area. For the three-year period modeled, there are 496 days with an estimated impact over the contribution threshold of 0.5 deciviews.

2. Introduction

Federal law requires Best Available Retrofit Technology (BART) for any BART-eligible source that ‘‘emits any air pollutant which may reasonably be anticipated to cause or contribute to any impairment of visibility” in any mandatory Class I federal area. Pursuant to federal regulations, states have the option of exempting a BART-eligible source from the BART requirements based on dispersion modeling demonstrating that the source cannot reasonably be anticipated to cause or contribute to visibility impairment in a Class I area.

Federal regulations implementing the BART requirement afford states some latitude in the criteria in determining whether a BART-eligible source is subject to BART. The Division has proposed state regulations establishing criteria and procedures for determining which Colorado sources will be subject to the BART requirement. The Division’s proposal is scheduled for a March 16, 2006 hearing before the Air Quality Control Commission. In advance of the hearing, and in preparation for the submittal of a state implementation plan for regional haze, the Division has performed air quality modeling with the CALPUFF modeling system to assess which BART-eligible sources in Colorado are likely to be subject to BART based on the proposed state regulation.

According to 40 CFR Part 51, Appendix Y (BART guideline), a BART-eligible source is considered to “contribute” to visibility impairment in a Class I area if the modeled 98th percentile change in deciviews is equal to or greater than the “contribution threshold.” Any BART-eligible source determined to cause or contribute to visibility impairment in any Class I area is subject to BART. The Division has proposed a state regulation establishing a “contribution threshold” of 0.5 deciviews. In this report, the assumed “contribution threshold” is 0.5 deciviews.

The Division has applied the CALPUFF modeling system with three years of meteorological data to determine if the 98th percentile 24-hour change in visibility (delta-deciview) from a BART-eligible source is equal to or greater than a contribution threshold of 0.5 deciviews at any Class I area. This initial phase of the BART modeling process is referred to as the “subject-to-BART” analysis. The modeling includes SO_2, NOx, and direct PM10 emissions from all BART-eligible units at a given facility.

While the modeling results in this report may be used to support regulatory decision making, additional modeling performed by the Division or source operator may supersede the results. If additional modeling is performed, it should be consistent with recommendations in the Division’s modeling protocol. Any subsequent modeling performed by the source operator will be subject to Division review and approval. Moreover, the contribution threshold and other criteria used for this modeling demonstration have not been finalized and may change in the final rule adopted by the Commission. Therefore, the results in this report are not a final agency action. Any source that the Division determines is subject to BART will receive a separate notice of the agency’s final determination. Such separate notice will occur after the Commission acts on the proposed regulations establishing criteria and procedures for determining which sources will be subject to the BART requirement.

Relevant language from the BART guideline is included, below, to show the modeling recommendations in context. Other sections of this report explain how the Division implemented the recommendations. The BART guidelines set out 40 CFR Part 51, Appendix Y, provide in part:

> ***III. HOW TO IDENTIFY SOURCES "SUBJECT TO BART"***
> *Once you have compiled your list of BART-eligible sources, you need to determine whether (1) to make BART determinations for all of them or (2) to consider exempting some of them from BART because they may not reasonably be anticipated to cause or contribute to any visibility impairment in a Class I area. If you decide to make BART determinations for all the BART-eligible sources on your list, you should work with your regional planning organization (RPO) to show that, collectively, they cause or contribute to visibility impairment in at least one Class I area. You should then make individual BART determinations by applying the five statutory factors discussed in Section IV below.*
>
> *On the other hand, you also may choose to perform an initial examination to determine whether a particular BART-eligible source or group of sources causes or contributes to visibility impairment in nearby Class I areas. If your analysis, or information submitted by the source, shows that an individual source or group of sources (or certain pollutants from those sources) is not reasonably anticipated to cause or contribute to any visibility impairment in a Class I area, then you do not need to make BART determinations for that source or group of sources (or for certain pollutants from those sources). In such a case, the source is not "subject to BART" and you do not need to apply the five statutory factors to make a BART determination. This section of the Guideline discusses several approaches that you can use to exempt sources from the BART determination process.*
>
> ***A. What Steps Do I Follow to Determine Whether A Source or Group of Sources Cause or Contribute to Visibility Impairment for Purposes of BART?***
> ***1. How Do I Establish a Threshold?***
> *One of the first steps in determining whether sources cause or contribute to visibility impairment for purposes of BART is to establish a threshold (measured in deciviews) against which to measure the visibility impact of one or more sources. A single source that is responsible for a 1.0 deciview change or more should be considered to "cause" visibility impairment; a source that causes less than a 1.0 deciview change may still contribute to visibility impairment and thus be subject to BART.*
>
> *Because of varying circumstances affecting different Class I areas, the appropriate threshold for determining whether a source "contributes to any visibility impairment" for the purposes of BART may reasonably differ across States. As a general matter, any threshold that you use for determining whether a source "contributes" to visibility impairment should not be higher than 0.5 deciviews.*
>
> *In setting a threshold for "contribution," you should consider the number of emissions sources affecting the Class I areas at issue and the magnitude of the individual sources'*

impacts.[5] *In general, a larger number of sources causing impacts in a Class I area may warrant a lower contribution threshold. States remain free to use a threshold lower than 0.5 deciviews if they conclude that the location of a large number of BART eligible sources within the State and in proximity to a Class I area justify this approach.*[6]

2. What Pollutants Do I Need to Consider?
You must look at SO2, NOx, and direct particulate matter (PM) emissions in determining whether sources cause or contribute to visibility impairment, including both PM10 and PM2.5. Consistent with the approach for identifying your BART-eligible sources, you do not need to consider less than de minimis emissions of these pollutants from a source.

As explained in section II, you must use your best judgement to determine whether VOC or ammonia emissions are likely to have an impact on visibility in an area. In addition, although as explained in Section II, you may use PM10 an indicator for particulate matter in determining whether a source is BART eligible, in determining whether a source contributes to visibility impairment, you should distinguish between the fine and coarse particle components of direct particulate emissions. Although both fine and coarse particulate matter contribute to visibility impairment, the long-range transport of fine particles is of particular concern in the formation of regional haze. Air quality modeling results used in the BART determination will provide a more accurate prediction of a source's impact on visibility if the inputs into the model account for the relative particle size of any directly emitted particulate matter (i.e. PM_{10} *vs.* $PM_{2.5}$*).*

3. What Kind of Modeling Should I Use to Determine Which Sources and Pollutants Need Not Be Subject to BART?
This section presents several options for determining that certain sources need not be subject to BART. These options rely on different modeling and/or emissions analysis approaches. They are provided for your guidance. You may also use other reasonable approaches for analyzing the visibility impacts of an individual source or group of sources.

Option 1: Individual Source Attribution Approach (Dispersion Modeling)
You can use dispersion modeling to determine that an individual source cannot reasonably be anticipated to cause or contribute to visibility impairment in a Class I area and thus is not subject to BART. Under this option, you can analyze an individual source's impact on visibility as a result of its emissions of SO_2*,* NO_x *and direct PM emissions. Dispersion modeling cannot currently be used to estimate the predicted impacts on visibility from an individual source's emissions of VOC or ammonia. You may use a more qualitative*

[5] *We expect that regional planning organizations will have modeling information that identifies sources affecting visibility in individual class I areas.*

[6] *Note that the contribution threshold should be used to determine whether an individual source is reasonably anticipated to contribute to visibility impairment. You should not aggregate the visibility effects of multiple sources and compare their collective effects against your contribution threshold because this would inappropriately create a "contribute to contribution" test.*

assessment to determine on a case-by-case basis which sources of VOC or ammonia emissions may be likely to impair visibility and should therefore be subject to BART review, as explained in section II.A.3. above.

You can use CALPUFF[7] or other appropriate model to predict the visibility impacts from a single source at a Class I area. CALPUFF is the best regulatory modeling application currently available for predicting a single source's contribution to visibility impairment and is currently the only EPA-approved model for use in estimating single source pollutant concentrations resulting from the long range transport of primary pollutants.[8] It can also be used for some other purposes, such as the visibility assessments addressed in today's rule, to account for the chemical transformation of SO_2 and NO_x.

There are several steps for making an individual source attribution using a dispersion model:

1. Develop a modeling protocol.

Some critical items to include in the protocol are the meteorological and terrain data that will be used, as well as the source-specific information (stack height, temperature, exit velocity, elevation, and emission rates of applicable pollutants) and receptor data from appropriate Class I areas. We recommend following EPA's Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 Summary Report and Recommendations for Modeling Long Range Transport Impacts[9] for parameter settings and meteorological data inputs. You may use other settings from those in IWAQM, but you should identify these settings and explain your selection of these settings.

One important element of the protocol is in establishing the receptors that will be used in the model. The receptors that you use should be located in the nearest Class I area with sufficient density to identify the likely visibility effects of the source. For other Class I areas in relatively close proximity to a BART-eligible source, you may model a few strategic receptors to determine whether effects at those areas may be greater than at the nearest Class I area. For example, you might chose to locate receptors at these areas at the closest point to the source, at the highest and lowest elevation in the Class I area, at the IMPROVE monitor, and at the approximate expected plume release height. If the highest modeled effects are observed at the nearest Class I area, you may choose not to analyze the other Class I areas any further as additional analyses might be unwarranted.

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[7] *The model code and its documentation are available at no cost for download from* http://www.epa.gov/scram001/tt22.htm#calpuff .

[8] *The Guideline on Air Quality Models, 40 CFR part 51, appendix W, addresses the regulatory application of air quality models for assessing criteria pollutants under the CAA, and describes further the procedures for using the CALPUFF model, as well as for obtaining approval for the use of other, nonguideline models.*

[9] *Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 Summary Report and Recommendations for Modeling Long Range Transport Impacts,* U.S. Environmental Protection Agency, EPA-454/R-98-019, December 1998.

You should bear in mind that some receptors within the relevant Class I area may be less than 50 km from the source while other receptors within that same Class I area may be greater than 50 km from the same source. As indicated by the Guideline on Air Quality Models, 40 CFR part 51, appendix W, this situation may call for the use of two different modeling approaches for the same Class I area and source, depending upon the State's chosen method for modeling sources less than 50 km. In situations where you are assessing visibility impacts for source-receptor distances less than 50 km, you should use expert modeling judgment in determining visibility impacts, giving consideration to both CALPUFF and other appropriate methods.

In developing your modeling protocol, you may want to consult with EPA and your regional planning organization (RPO). Up-front consultation will ensure that key technical issues are addressed before you conduct your modeling.

2. [Run model in accordance] with the accepted protocol and compare the predicted visibility impacts with your threshold for "contribution."

You should calculate daily visibility values for each receptor as the change in deciviews compared against natural visibility conditions. You can use EPA's "Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule," EPA-454/B-03-005 (September 2003) in making this calculation. To determine whether a source may reasonably be anticipated to cause or contribute to visibility impairment at Class I area, you then compare the impacts predicted by the model against the threshold that you have selected.

The emissions estimates used in the models are intended to reflect steady-state operating conditions during periods of high capacity utilization. We do not generally recommend that emissions reflecting periods of start-up, shutdown, and malfunction be used, as such emission rates could produce higher than normal effects than would be typical of most facilities. We recommend that States use the 24 hour average actual emission rate from the highest emitting day of the meteorological period modeled, unless this rate reflects periods start-up, shutdown, or malfunction. In addition, the monthly average relative humidity is used, rather than the daily average humidity – an approach that effectively lowers the peak values in daily model averages.

For these reasons, if you use the modeling approach we recommend, you should compare your "contribution" threshold against the 98th percentile of values. If the 98_{th} percentile value from your modeling is less than your contribution threshold, then you may conclude that the source does not contribute to visibility impairment and is not subject to BART.

2.1. Modeling Process Overview

For each BART-eligible source that emits SO_2, NOx, and/or direct PM10, the constant emission rates shown in section 4 are used in the CALPUFF modeling system to estimate the daily change in visibility compared against natural background conditions (delta-deciview) at each Class I federal area in the modeling domain. The 98th percentile delta-deciview value at each Class I area is compared to the "contribution threshold" to determine if the source contributes to visibility impairment.

The CALPUFF[1] modeling system consists of CALMET, CALPUFF, and CALPOST. CALMET is the meteorological model that generates hourly three-dimensional meteorological fields of variables such as wind and temperature. CALPUFF simulates the transport, dispersion, and transformation of pollutants emitted from the source and calculates hourly concentration and/or deposition flux values at each receptor in the modeling domain. CALPOST calculates time-averaged concentration and deposition flux values from the CALPUFF predictions and performs visibility calculations like those described in the section 2.2.

2.2. Visibility Calculations

The general theory for performing visibility calculations with the CALPUFF modeling system is described in several federal documents, including:

- "Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 Summary Report and Recommendations for Modeling Long Range Transport Impacts" (IWAQM, 1998)
- "Federal Land Manager's Air Quality Related Values Workgroup (FLAG): Phase I Report" (FLAG, 2000)
- "A User's Guide for the CALPUFF Dispersion Model" (Scire, 2000)

In general, visibility is characterized 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 light extinction by absorption (b_{abs}):

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

The scattering components of extinction can be represented by these components:

- light scattering due to air molecules = Rayleigh scattering = $b_{rayleigh}$
- light scattering due to particles = b_{sp}

The absorption components of extinction can be represented by these components:

- light absorption due to gaseous absorption = b_{ag}

[1] CALPUFF is a non-steady-state Lagrangian puff model.

- light absorption due to particle absorption = b_{ap}

Particle scattering, b_{sp}, can be expressed by its components:

$$b_{sp} = b_{SO4} + b_{NO3} + b_{OC} + b_{SOIL} + b_{Coarse}$$

where:

- b_{SO4} = scattering coefficient due to sulfates = $3[(NH_4)_2SO_4]f(RH)$
- b_{NO3} = scattering coefficient due to nitrates = $3[NH_4NO_3]f(RH)$
- b_{OC} = scattering coefficient due to organic aerosols = 4[OC]
- b_{SOIL}= scattering coefficient due to fine particles = 1[Soil]
- b_{Coarse}= scattering coefficient due to coarse particles = 0.6[Coarse Mass]

Particle absorption from soot is defined as:

- b_{ap} = absorption due to elemental carbon (soot) = 10[EC]

The concentration values (in brackets) are expressed in micrograms per cubic meter. The numeric coefficient at the beginning of each equation is the dry scattering or absorption efficiency in meters-squared per gram. The f(RH) term is the relative humidity adjustment factor.

The total atmospheric extinction can be expressed as:

$$b_{ext} = b_{SO4} + b_{NO3} + b_{OC} + b_{SOIL} + b_{Coarse} + b_{ap} + b_{rayleigh}$$

In this equation, the sulfate (SO4) and nitrate (NO3) components are referred to as hygroscopic components because the extinction coefficient depends upon relative humidity. The other components are non-hygroscopic.

The variation of the effect of relative humidity on the extinction coefficients for SO4 and NO3 can be determined in several ways. According to the BART guideline, monthly f(RH) values should be used.

The CALPUFF modeling techniques in this report will provide ground level concentrations of visibility impairing pollutants. The concentration estimates from CALPUFF are used with the previously shown equations to calculate the extinction coefficient.

As described in the IWAQM Phase 2 Report, the change in visibility is compared against background conditions. The delta-deciview, Δdv, value is calculated from the source's contribution to extinction, b_{source}, and background extinction, $b_{background}$, as follows:

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

3. Source Description

The Craig Station is a coal-fired power plant with a total net electric generating capacity of 1264 MW, consisting of three units, located at 2101 S. Ranney, in Craig. Units 1 and 2, rated at 4,318 mmBtu/hour each (net 428 MW), are BART-eligible emissions units. Under a January 2001 Consent Order, the existing ESPs were replaced with baghouses and the wet scrubbers were upgraded. The baghouses control PM emissions and limestone scrubbers control SO_2 emissions. The units use low-NO_x burners to control NO_x emissions. In addition, over-fire air and related NO_x control upgrades are in place to meet the requirements of the Consent Decree (CDPHE, 2005).

4. Emission Estimates

According to the BART guideline, "*The emissions estimates used in the models are intended to reflect steady-state operating conditions during periods of high capacity utilization. We do not generally recommend that emissions reflecting periods of start-up, shutdown, and malfunction be used, as such emission rates could produce higher than normal effects than would be typical of most facilities. We recommend that States use the 24 hour average actual emission rate from the highest emitting day of the meteorological period modeled, unless this rate reflects periods start-up, shutdown, or malfunction*."

Short-term emission rates (≤24-hours) for SO_2, NOx, and PM10 (including condensible and filterable direct PM10[2]) were modeled since visibility impacts are calculated for a 24-hour averaging period. All BART-eligible units at the facility were modeled together in CALPUFF. The Division initially used allowable emission rates or federally enforceable emission limits. If 24-hour emissions limits did not exist, limits of a different averaging period were used. Specifically, if limits did not exist, maximum hourly emissions based on emission factors and design capacity were used.

If the source operator elects to develop emission rates for future subject-to-BART modeling, case-by-case procedures should be developed in consultation with the Division. In general, the following emission rates are acceptable:

- Short-term (≤24-hours) allowable emission rates (e.g., emission rates calculated using the maximum rated capacity of the source).
- Federally enforceable short-term limits (≤24-hours).
- Peak 24-hour actual emission rates (or calculated emission rates) from the most recent 3 to 5 years of operation that account for "high capacity utilization" during normal operating conditions and fuel/material flexibility allowed under a source's permit. In situations where a unit is allowed to use more than one fuel, the fuel resulting in the highest emission rates should be used for the modeling, even if that fuel has not been used in the last 3 to 5 years.

If short-term rates are not available, emissions rates based on averaging periods longer than 24-hours are acceptable only in cases where the modeling shows that the source has impacts equal to or greater than the contribution threshold.

For Craig units 1 and 2, the modeled emission rates are shown in Table 1. The stack parameters are based on the best available information in Division files. To simplify the emissions estimation process, only filterable PM10 emissions were used because modeling with SO_2, NOx, and filterable PM10 shows impacts equal to or greater than the contribution threshold. The basis for the emission rates are shown below:

[2] Common speciated PM species for CALPUFF include fine particulate matter (PMF), coarse particulate matter (PMC), soot or elemental carbon (EC), organic aerosols (SOA), and sulfate (SO4). H_2SO_4, for example, is a PM10 species emitted from coal-fired units that is typically modeled as SO4 in CALPUFF.

- PM: 0.03 lb/mmBtu heat input - January 2001 Consent Decree
- SO_2 : 0.160 lb/mmBtu heat input on a 30 day rolling average - January 2001 Consent Decree
- NOx: 0.34 lbs/mmBtu heat input when burning coal, as estimated by the source operator to reflect peak 24 hour average emissions

Table 1. Stack parameters and emission rates.

Craig Station
Unit 1

Stack Parameters			Model Inputs		
Stack height	600	ft	Stack height	182.9	m
Stack diameter	28	ft	Stack diameter	8.53	m
Exit velocity	57.95	ft/s	Exit velocity	17.66	m/s
Exit temperature	118	°F	Exit temperature	321	K
Source: APEN dated April 27, 2005					
Stack Location					
UTM Easting	280421.16	m	LCC X Easting	-197.885	km
UTM Northing	4482341.4	m	LCC Y Northing	151.799	km
Elevation	6345	ft	Elevation	1934	m
Source: USGS Aerial Photo, NAD 83, Zone 13 N			*Converted with CALPUFF Coords*		
Emissions Information					
Design Input Rate	4318	mmBtu/hr			
SO_2 Rate (30-day)	0.16	lb/mmBtu	SO_2 Rate	87.05	g/s
NO_X Rate (3-hr)	0.34	lb/mmBtu	NO_X Rate	184.98	g/s
PM_{10} Rate (filterable only)	0.03	lb/mmBtu	PM_{10} Rate	16.32	g/s
Source: Colorado Department of Public Health & Environment					

Craig Station
Unit 2

Stack Parameters			Model Inputs		
Stack height	600	ft	Stack height	182.9	m
Stack diameter	28	ft	Stack diameter	8.53	m
Exit velocity	57.95	ft/s	Exit velocity	17.66	m/s
Exit temperature	118	°F	Exit temperature	321	K
Source: APEN dated April 27, 2005					
Stack Location					
UTM Easting	280313.02	m	LCC X Easting	-197.996	km
UTM Northing	4482345.1	m	LCC Y Northing	151.802	km
Elevation	6345	ft	Elevation	1934	m
Source: USGS Aerial Photo, NAD 83, Zone 13 N			*Converted with CALPUFF Coords*		
Emissions Information					
Design Input Rate	4318	mmBtu/hr			
SO_2 Rate (30-day)	0.16	lb/mmBtu	SO_2 Rate	87.05	g/s
NO_X Rate (3-hr)	0.34	lb/mmBtu	NO_X Rate	184.98	g/s
PM_{10} Rate (filterable only)	0.03	lb/mmBtu	PM_{10} Rate	16.32	g/s

Source: Colorado Department of Public Health & Environment

5. CALMET/CALPUFF Modeling Methodology

In this CALPUFF application, the CALMET/CALPUFF model setup is based on the January 2005 modeling performed by CH2M HILL for the Public Service Company Comanche Unit 3 PSD permit application because it underwent extensive review by the Division and by Federal Land Managers as part of the PSD permitting process. The Division modified the CALPUFF input files to include three additional Class I areas. It has also been modified as necessary to account for PM10 speciation. An additional post-processing step with POSTUTIL has been added to implement ammonia limiting. The CALPOST model setup was changed to make it consistent with the U.S. EPA's BART guideline. In addition, the Division reviewed available data to determine appropriate ammonia background values for various parts of Colorado. The Division also performed sensitivity tests to understand the response of the model to changes in ammonia background concentration levels. Since the currently available version of CALPOST does not generate 98th percentile results, the Division modified CALPOST to generate a file with a full distribution of daily delta-deciview values for each receptor. In addition, the Division wrote a FORTRAN processor to generate 98th percentile results.

This report is intended to provide sufficient technical documentation to support the application of CALPUFF at distances up to 300 kilometers. While CALPUFF has also been used at source-to-receptor distances less than 50 kilometers for some receptors, there is a Class I area within the 50 to 300 km range from every BART-eligible source in Colorado. Impacts at Class I areas greater than 300 km may be used, but it should be recognized that the use of puff splitting in CALPUFF would provide more accurate results for Class I areas beyond 300km.

According to "*Interagency Workgroup on Air Quality Modeling (IWAQM) Phase 2 Summary Report and Recommendations for Modeling Long Range Transport Impacts*" (IWAQM Phase 2 Report):

> *In the context of the Phase 2 recommendation, the focus of the visibility analysis is on haze. These techniques are applicable in the range of thirty to fifty kilometers and beyond from a source. At source-receptor distances less than thirty to fifty kilometers, the techniques for analyzing visual plumes (sometimes referred to as 'plume blight') should be applied.*

For the few cases where BART-eligible source-to-receptors distances are less than 50 kilometers, both the topography and the meteorological fields are complex and the use of CALPUFF appears to be appropriate based on the possibility of recirculation, stagnation, and complex flows. The shortest source-to-receptor distance modeled is about 25 kilometers, but it involves an elevation change of about 3000 ft. In addition, in each case, only a portion of the Class I area is less than 50 km from the source; many of the receptors are greater than 50 km. If there were issues regarding the 50 km distance, PLUVUEII would be an appropriate model to consider for source-to-receptor distances less than 50 kilometers.

5.1. CALMET/CALPUFF Model Selection

The following model versions are used:

- CALPUFF: July 2004 beta version 5.711a, level 040716
- CALMET: July 2004 beta version 5.53a, level 040716
- POSTUTIL: May 2003 version 1.31, level 030528
- CALPOST: July 2003 version 5.51, level 030709
    - Modified by Division for this analysis:
        - CALPOST_BART98_v3.EXE (version 5.51_CO_v3, level 030709)
        - BART98_v3.EXE

The use of CALPUFF is recommended in 40 CFR 51 Appendix Y (BART guideline). The primary niche for CALPUFF is as a long-range transport model. It is a multi-layer, non-steady-state puff dispersion model that can simulate the effects of time- and space-varying meteorological conditions on pollutant transport, chemical transformations, vertical wind shear, and deposition (Scire, 2000).

5.1.1. CALMET

The MM5/CALMET meteorological fields have been generated for 1996, 2001, and 2002. CALMET is based on the Diagnostic Wind Model (Douglas, S. and R. Kessler, 1988). It has been significantly enhanced by Earth Tech, Inc (Scire, 2000). For this particular study, the model uses a Lambert Conformal Projection coordinate system to account for the Earth's curvature.

CALMET uses a two-step approach to calculate wind fields. In the first step, an initial-guess wind field is adjusted for slope flows and terrain blocking effects, for example, to produce a Step 1 wind field. In the second step, an objective analysis is performed to introduce observational data into the Step 1 wind field.

In this application, the initial guess wind fields are based on 36-kilometer MM5[3] meteorological fields for 1996, 2001, and 2002 (i.e., IPROG=14). The MM5 files were provided to the Division by CH2M HILL as part of the Public Service Company (PSCo) Comanche Unit 3 PSD permit application. Alpine Geophysics extracted the MM5 data into a CALMET MM5.DAT format for 1996, 2001, and 2002. Both the 1996 and 2001 MM5 data were generated by the U.S. EPA. The 2002 MM5 data was originally developed for the Visibility Improvement State and Tribal Association of the Southeast (VISTAS).

The BART guideline does not specify the exact number of years of mesoscale meteorological data for use in CALPUFF. According to 40 CFR Part 51 Appendix W, the length of the modeled meteorological period should be long enough to ensure that worst-case meteorological conditions are adequately represented in the model results. The number of years of data needed to obtain a stable distribution of conditions depends on the variable of interest. U.S. EPA recommends that consecutive years from the most recent, readily available 5-year period are preferred. However, "less than five, but at least three,

[3] Fifth-Generation NCAR/Penn State Mesoscale Model.

years of meteorological data (need not be consecutive) may be used if mesoscale meteorological fields are available....”

At the time of this analysis, five years of agency-approved mesoscale meteorological data were not readily available at reasonable grid resolutions for Colorado. While the Division has the national 80km 1990 MM4 and 80km 1992 MM5 data sets, use of the coarse resolution 1990 and 1992 data sets would not improve the accuracy of the modeling results in Colorado.

5.1.1.1. CALMET Modeling Domain

The modeling domain is shown in Figure 1. It is based on a Lambert Conformal Conic projection. As determined by CH2M HILL, the Standard Parallels within the domain are 1/6th and 5/6th of the north-to-south extent instead of the 30-degree and 60-degree lines that are listed as defaults in CALMET. This was done to minimize distortion. See Figure 7 for specific parameter settings.

The domain includes all Class I areas in Colorado with the exception of Mesa Verde NP. Mesa Verde was excluded because it is more than 300 km from all of the BART-eligible sources in Colorado and because the BART-eligible sources in Colorado would have higher impacts at other Class I areas. That is, impacts are Mesa Verde would not be the controlling 98^{th} percentile values for this analysis. The domain does not include Class I areas in any nearby states because the 98^{th} percentile impacts from Colorado’s BART-eligible sources are expected to be highest at Class I areas in Colorado. The CALMET domain includes almost the entire state of Colorado. It is about 480 km x 480 km in the longitudinal and meridonal directions, respectively, with 4-kilometer CALMET grid cells.

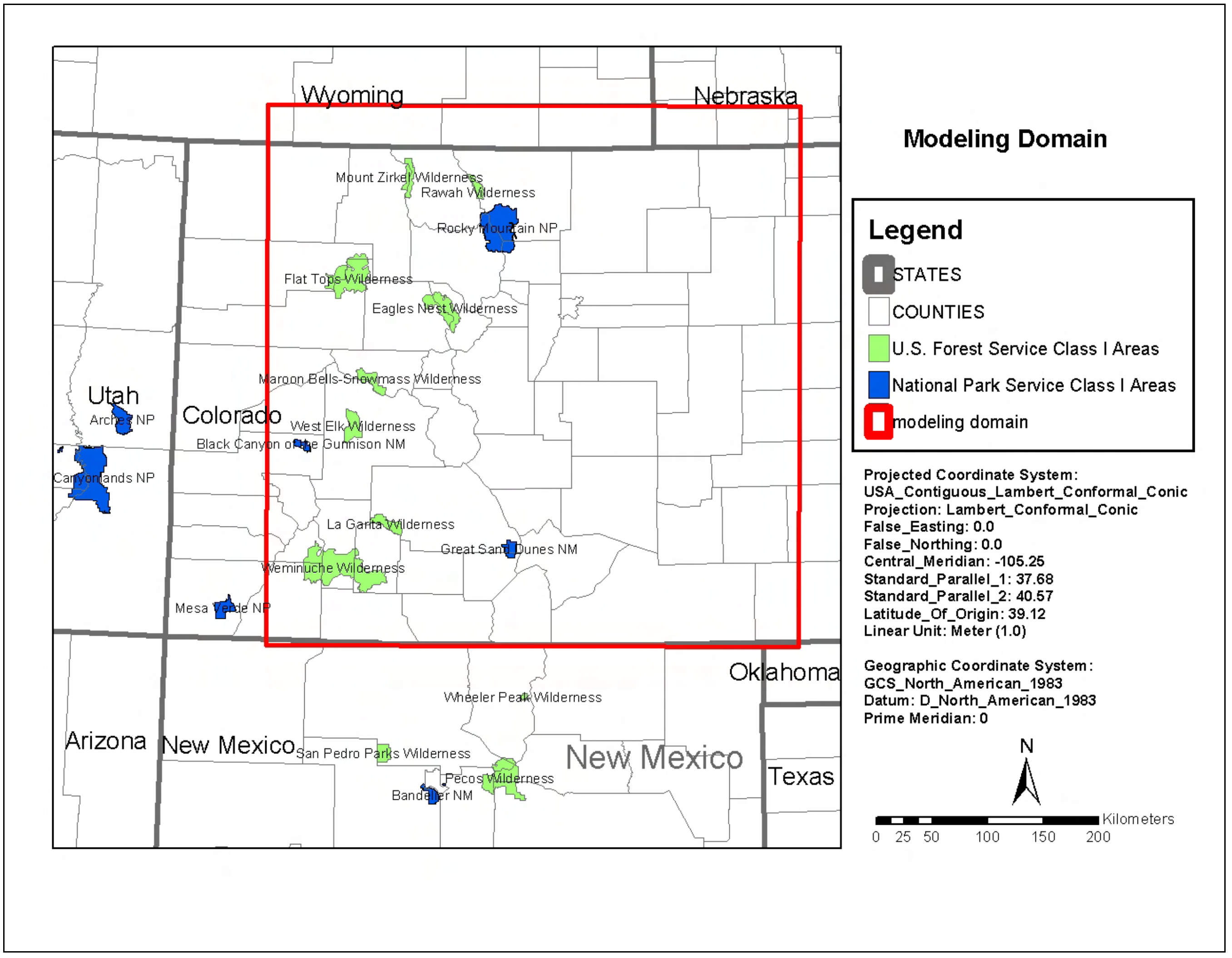

Figure 1. CALMET/CALPUFF modeling domain.

5.1.1.2. CALMET Performance Evaluation

The meteorological fields developed by the MM5/CALMET modeling system were evaluated by CH2M HILL for Xcel Energy as part of the PSCo Comanche Unit 3 PSD permit. Specifically, "CH2M HILL examined vector plots of selected periods within the CALMET output for validation of the wind fields with the CalDESK (Environmodeling Ltda.) program (CH2M HILL, 2005)." The Division replicated the CALMET modeling and performed additional review of the meteorological fields with the Lakes Environmental CALPUFF View software package. In general, the meteorological fields were found to be reasonable given the 36km MM5 resolution, although model performance could be improved with better resolution MM5/CALMET fields and the inclusion of more observations in CALMET.

5.1.1.3. Terrain

Gridded terrain elevations for the modeling domain are derived from 3 arc-second digital elevation models (DEMs) produced by the United States Geological Survey (USGS). The files cover 1-degree by 1-degree blocks of latitude and longitude. USGS 1:250,000 scale DEMs were used. The elevations are in meters relative to mean sea level and have a resolution of about 90 meters, shown in Figure 2.

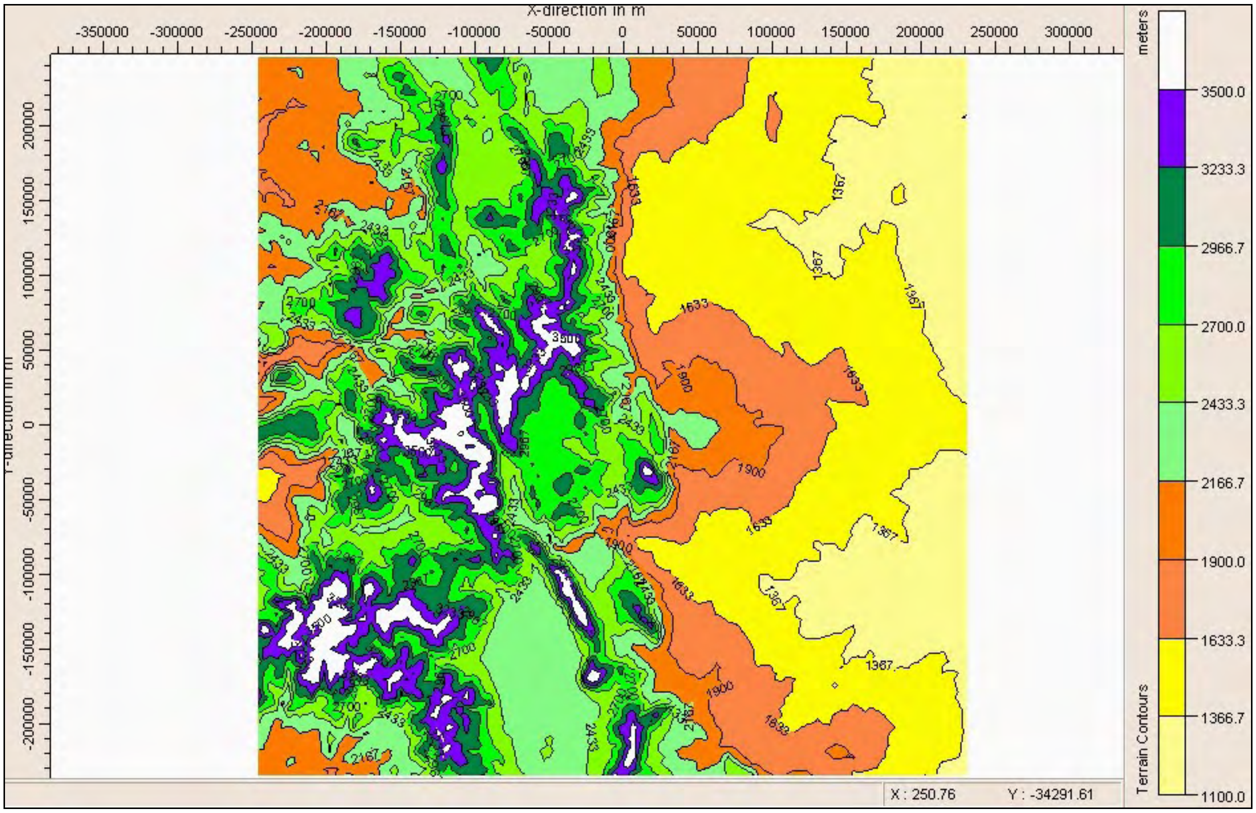

Figure 2. CALMET Terrain.

5.1.1.4. Land Use

The land use data is based on the Composite Theme Grid format (CTG) using Level I USGS land use categories were "mapped into the 14 primary CALMET land use categories (CH2M HILL, 2005)," shown in Figure 3. The land use categories are described in Figure 4.

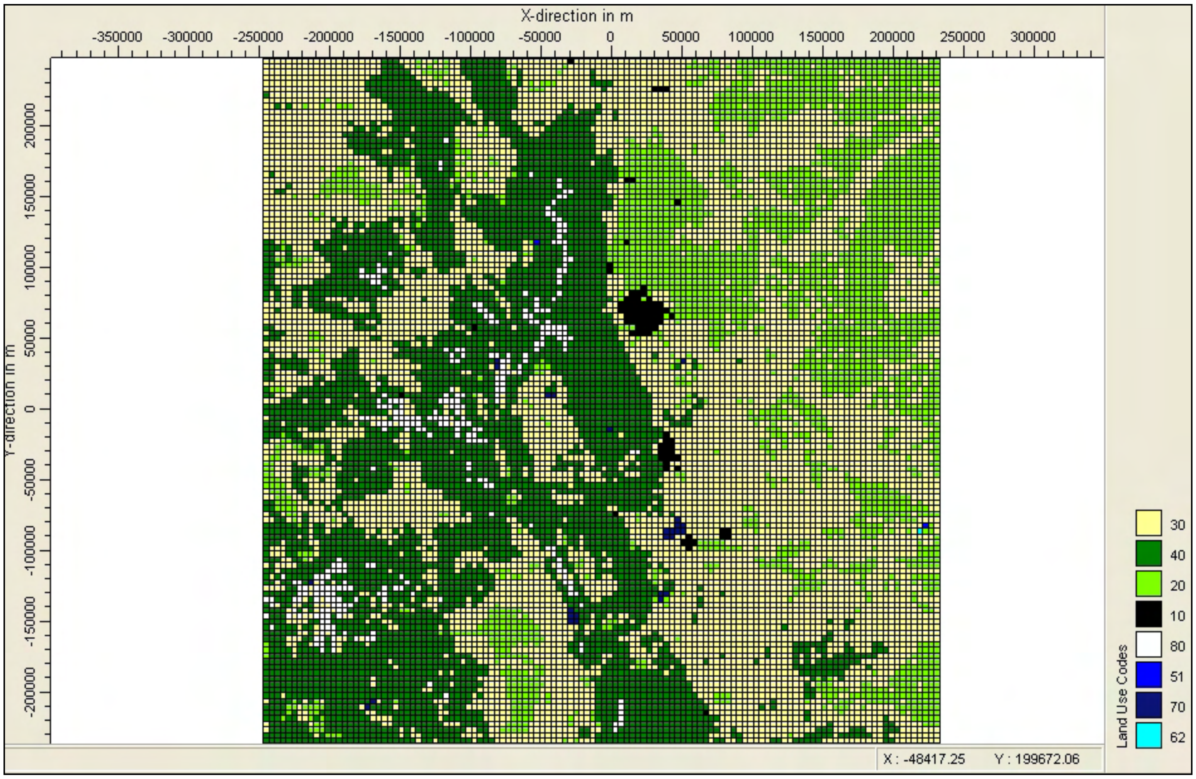

Figure 3. CALMET land use categories.

Default CALMET Land Use Categories and Associated Geophysical Parameters
Based on the U.S. Geological Survey Land Use Classification System
(14-Category System)

Land Use Type	Description	Surface Roughness (m)	Albedo	Bowen Ratio	Soil Heat Flux Parameter	Anthropogenic Heat Flux (W/m²)	Leaf Area Index
10	Urban or Built-up Land	1.0	0.18	1.5	.25	0.0	0.2
20	Agricultural Land - Unirrigated	0.25	0.15	1.0	.15	0.0	3.0
-20*	Agricultural Land - Irrigated	0.25	0.15	0.5	.15	0.0	3.0
30	Rangeland	0.05	0.25	1.0	.15	0.0	0.5
40	Forest Land	1.0	0.10	1.0	.15	0.0	7.0
51	Small Water Body	0.001	0.10	0.0	1.0	0.0	0.0
54	Bays and Estuaries	0.001	0.10	0.0	1.0	0.0	0.0
55	Large Water Body	0.001	0.10	0.0	1.0	0.0	0.0
60	Wetland	1.0	0.10	0.5	.25	0.0	2.0
61	Forested Wetland	1.0	0.1	0.5	0.25	0.0	2.0
62	Nonforested Wetland	0.2	0.1	0.1	0.25	0.0	1.0
70	Barren Land	0.05	0.30	1.0	.15	0.0	0.05
80	Tundra	.20	0.30	0.5	.15	0.0	0.0
90	Perennial Snow or Ice	.20	0.70	0.5	.15	0.0	0.0

* Negative values indicate "irrigated" land use

Figure 4. Land use categories table from CALMET User's Guide.

5.1.1.5. CALMET ZFACE and ZIMAX Settings

Eleven vertical layers have been used with vertical cell face (ZFACE) heights at: 0, 20, 100, 200, 350, 500, 750, 1000, 2000, 3000, 4000, and 5000 meters.

ZIMAX was set to 4500 meters based on analyses of soundings for summer ozone events. The analysis suggests mixing heights in Denver are often well above the CALMET default value of 3000 meters during the summer. For example, on some summer days, ozone levels are elevated all the way to 6000 meters MSL or beyond during some meteorological regimes, including some regimes associated with high ozone episodes. A sounding from the evening of July 1, 2002 (see Figure 5), which is a day the 8-hour ozone standard was exceeded at Rocky Mountain National Park, suggests the mixing height was probably around 6000 meters MSL. The mixing height estimate is based on the relative uniformity of the water vapor mixing ratio below 6000 meters, the temperature profile, the inverted "V" in the sounding, and data from a NOAA ozonesonde from Boulder that shows relatively constant ozone levels with height. Although low mixing heights can occur during the summer, maximum summertime daytime mixing heights in the Denver area often range from about 12,000 feet (3700 m) to 20,000 feet (6000 m) MSL. Since the CALMET ZIMAX setting is above ground level (AGL), not above mean sea level (MSL), the maximum summer daytime mixing height range over the plains would be about 15000 feet (4500 m) AGL. Thus, a ZIMAX setting of 4500 m is used.

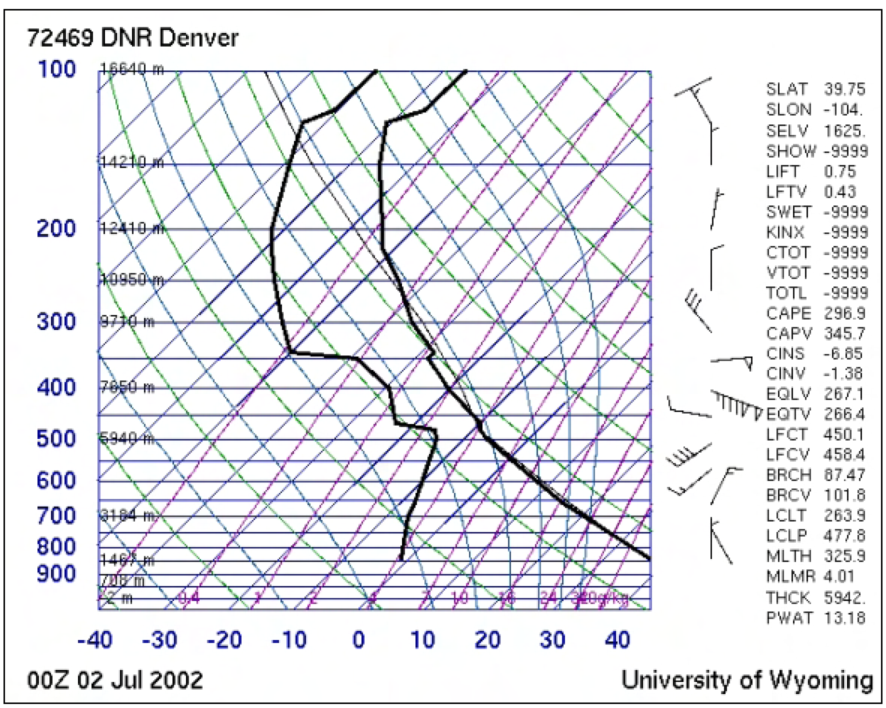

Figure 5. Example Denver summertime sounding.

5.1.1.6. CALMET BIAS Setting

The BIAS settings for each vertical cell determine the relative weight given to the vertically extrapolated surface meteorological observations and upper air soundings. The initial guess field is computed with an inverse distance weighting of the surface and upper air data. It can be modified by the layer-dependent bias factor (BIAS). The values for BIAS can range from –1.0 to 1.0. For example, if BIAS is set to +0.25, the weight of the surface wind observation is reduced by 25%. If BIAS is set to –0.25, the weight of the upper air wind observation is reduced by 25%. If BIAS is set to zero, there is no change in the weighting from the normal inverse distance squared weighting. As recommended by the NPS, the default values of 0.0 have been used for all 11 vertical layers in this analysis.

5.1.1.7. CALMET RMIN2 and IXTERP Settings

Vertical extrapolation of data from a surface station is skipped if the surface station is close to the upper air station. The variable RMIN2 sets the distance between an upper air station and a surface station that must exceeded in order for the extrapolation to take place. RMIN2 has been set to the default value of 4, as recommended by the NPS. The default value of –4 for IEXTRP is used. By setting IEXTRP to –4 (as opposed to +4), layer 1 data at upper air stations is ignored. When IEXTRP=±4, the van Ulden and Holtslag wind extrapolation method is used. The method uses similarity theory and observed data to extend the influence of the surface wind speed and direction aloft.

5.1.1.8. CALMET Settings: R1, R2, RMAX1, RMAX2, RMAX3

An inverse-distance method is used to determine the influence of observations in the Step 1 wind field. R1 controls weighting of the surface layer and R2 controls weighting of the layers aloft. For example, R1 is the distance from an observational station at which the observation and first guess field are equally weighted. In addition, RMAX1, RMAX2, and RMAX3 determine the radius of influence over land in the surface layer, over land in layers aloft, and over water, respectively. That is, an observation is excluded if the distance from the observational site to a given grid point exceeds the maximum radius of influence. As recommended by the NPS, R1 and RMAX1 have been set to 30 km so that the initial guess field does not overwhelm the surface observations. R2 is set to 50 km and RMAX2 is set to 100 km. RMAX3 is not much of a factor in Colorado given the lack of large water bodies. RMAX3 is set to 500 km.

5.1.1.9. CALMET Surface Stations

Eleven surface stations shown in Figure 6 were used, including Alamosa (ALS), Colorado Springs (CYS), Denver (DEN), Eagle (EGE), Limon (LIC), Pueblo (PUB), Trinidad (TAD), Cheyenne (CYS), Laramie (LAR), Rocky Mountain NP (ROM), and Gothic (GTH).

SURFACE STATIONS

Name	ID	X (km)	Y (km)	NLatitude (Deg)	WLongitude (Deg)	Time Zone	Anemometer Height (m)	Grid Coordinates X (Origin = (0,0))	Grid Coordinates Y
ALS	23061	-54.7	-187.7	37.427	105.868	7.0	9.1	48.061	12.333
CYS	24018	37.7	225.8	41.153	104.801	7.0	10.0	71.166	115.698
COS	93037	49.4	-33.2	38.820	104.681	7.0	6.7	74.086	50.952
DEN	3017	51.2	79.1	39.831	104.652	7.0	10.0	74.549	79.020
ROM	11111	-25.0	128.8	40.280	105.544	7.0	10.0	55.491	91.438
EGE	24675	-142.9	60.2	39.651	106.916	7.0	10.0	26.018	74.305
GTH	22222	-150.0	-16.8	38.956	106.981	7.0	10.0	24.239	55.053
LAR	25645	-35.1	244.6	41.323	105.669	7.0	10.0	52.976	120.412
LIC	24665	131.8	7.8	39.180	103.724	7.0	10.0	94.699	61.195
PUB	93058	65.4	-93.1	38.279	104.502	7.0	10.0	78.106	35.978
TAD	24645	81.4	-205.2	37.267	104.332	7.0	10.0	82.099	7.940

Figure 6. Surface meteorological stations.

5.1.1.10. CALMET Upper Air Stations

Two upper air stations were included: Grand Junction and Denver.

5.1.1.11. CALMET Precipitation Stations

CH2M HILL obtained precipitation data from the National Climatic Data Center (NCDC). All available data in fixed-length, TD-3240 format were ordered for the modeling domain. CH2M HILL processed the data with the PXTRACT and PMERGE processors. Stations with incomplete or poor quality data for a given year were excluded. The number of stations used for each year is as follows (CH2M HILL, 2005):

- 1996 - 84 stations
- 2001 - 82 stations
- 2002 - 86 stations

5.1.1.12. CALMET Sample Input File

Figure 7 summarizes some of the key CALMET parameters.

5.1.1.13. CALMET Parameter Summary

Figure 7 summarizes some of the key CALMET settings.

```
Map projection                                         Default: UTM    ! PMAP = LCC !
Latitude and Longitude (decimal degrees) of projection origin          ! RLAT0 = 39.12N !
                                                                       ! RLON0 = 105.25W !
Matching parallel(s) of latitude (decimal degrees) for projection      ! XLAT1 = 37.68N !
                                                                       ! XLAT2 = 40.57N !
(DATUM)                                              Default: WGS-G    ! DATUM = NAS-C  !
No. X grid cells (NX)                                No default        ! NX =   120  !
No. Y grid cells (NY)                                No default        ! NY =   121  !
Grid spacing (DGRIDKM)                               No default        ! DGRIDKM = 4. !
Reference grid coordinate of SW corner of grid cell (1,1)              ! XORIGKM = -246.984 !
                                                                       ! YORIGKM = -237.000 !
No. of vertical layers (NZ)                          No default        ! NZ =  11  !
Cell face heights in arbitrary vertical grid (ZFACE(NZ+1)):
   ! ZFACE = 0.,20.,100.,200.,350.,500.,750.,1000.,2000.,3000.,4000.,5000.!
NO OBSERVATION MODE                         (NOOBS)  Default: 0        ! NOOBS = 0  !
Number of surface stations                  (NSSTA)  No default        ! NSSTA =  11  !
Number of precipitation stations            (NPSTA)  No default        ! NPSTA =  86  !
Griddid cloud fields:                      (ICLOUD)  Default: 0        ! ICLOUD =  0  !
Model selection variable (IWFCOD)                    Default: 1        ! IWFCOD =  1  !
Compute Froude number adjustment effects ? (IFRADJ)  Default: 1        ! IFRADJ =  1  !
Compute kinematic effects ?                (IKINE)   Default: 0        ! IKINE  =  0  !
Use O'Brien procedure?                               Default: 0        ! IOBR =  0  !
Compute slope flow effects ?                (ISLOPE) Default: 1        ! ISLOPE  =  1  !
Extrapolate surface wind obs to upper layers?        Default: -4       ! IEXTRP =  -4  !
Extrapolate surface winds even if calm? (ICALM)      Default: 0        ! ICALM  =  0  !
Layer-dependent biases. Default: NZ*0        ! BIAS =  0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0  !
                                                     Default: 4.       ! RMIN2 = 4 !
Use gridded prognostic wind field model output fields as input to the diagnostic
  wind field model (IPROG)                           Default: 0        ! IPROG =  14  !
Maximum radius of influence over land in the surface layer             ! RMAX1 = 30. !
Maximum radius of influence over land aloft (RMAX2)                    ! RMAX2 = 100. !
Maximum radius of influence over water                                 ! RMAX3 = 500. !
Minimum radius of influence used in the wind field interpolation (RMIN)
                                                     Default: 0.1      ! RMIN = 0.1 !
Radius of influence of terrain features (TERRAD)     No default        ! TERRAD = 40. !
Relative weighting of the first guess field and observations in the SURFACE layer
                                                     No default        ! R1 = 30. !
Relative weighting of the first guess field and observations in the layers ALOFT
                                                     No default        ! R2 = 50. !
Minimum overland mixing height                       Default:  50.     ! ZIMIN = 50. !
Maximum overland mixing height                       Default: 3000.    ! ZIMAX = 4500. !
Interpolation type (1 = 1/R ; 2 = 1/R**2)            Default:1         ! IRAD =  1  !
Radius of influence for temperature interpolation    Default: 500.     ! TRADKM = 500. !
```

Figure 7. CALMET parameter summary.

5.1.2. CALPUFF

The default technical options in CALPUFF were used, except as specified otherwise in this report.

5.1.2.1. Receptor Network and Class I Federal Areas

The modeling domain contains eleven Class I federal areas:

- Flat Tops Wilderness Area
- Rawah Wilderness Area
- Mt Zirkel Wilderness Area
- Weminuche Wilderness Area
- Rocky Mountain National Park
- Maroon Bells-Snowmass Wilderness Area
- La Garita Wilderness Area
- Great Sand Dunes National Park
- West Elk Wilderness Area
- Eagles Nest Wilderness Area
- Black Canyon of the Gunnison National Park

The discrete receptors for eight of the Class I federal areas were generated by the National Park Service (NPS) for CH2M HILL using the *NPS Convert Class I Areas* (NCC) computer program. For the remaining three areas not included in the CH2M HILL modeling, receptors were generated by the Division with the NCC program. Receptor elevations provided by the NPS conversion program have been used. The receptors for each Class I area are shown in Figure 9

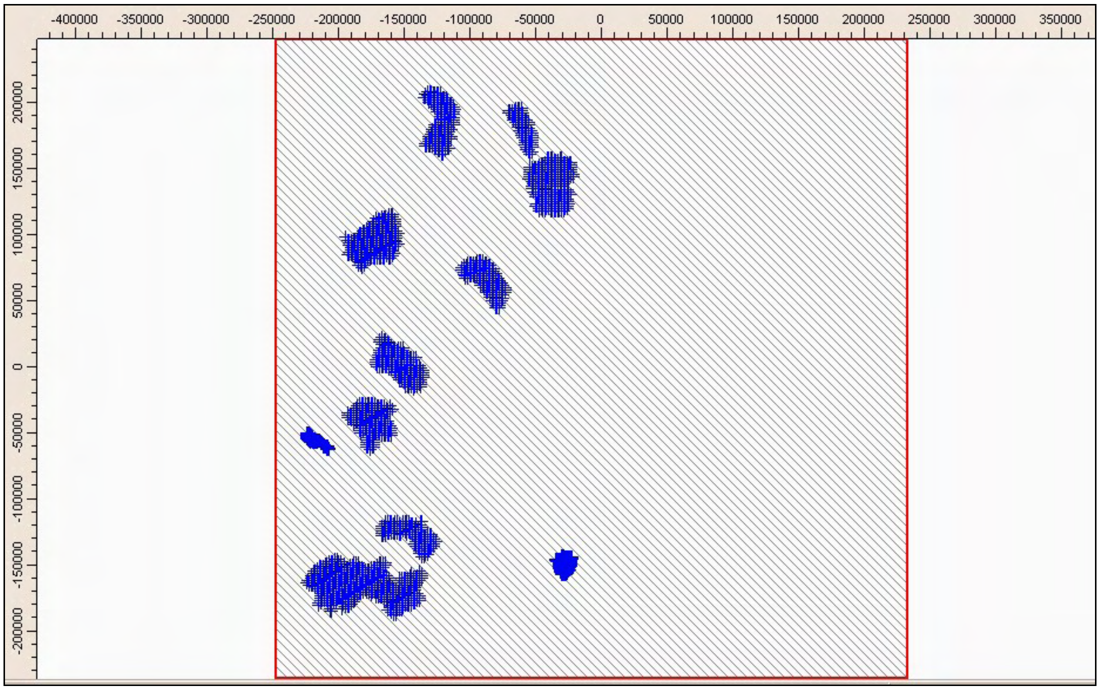

Figure 8. Class I federal area receptors.

All receptors are included in each CALPUFF simulation. In CALPOST, only the receptor ranges for specific Class I areas are processed. The range of receptors is shown in Figure 9.

	Receptors				
Class I Area	**start**	**end**	**leading 0's**	**sum**	**CALPOST setting for NCRECP**
Great Sand Dunes	1	195	0	195	195*1
RMNP	196	602	195	407	195*0, 407*1
La Garita	603	789	602	187	602*0, 187*1
Eagles Nest	790	1002	789	213	789*0, 213*1
Maroon Bells	1003	1281	1002	279	1002*0, 279*1
Weminuche	1282	2025	1281	744	1281*0, 744*1
West Elk	2026	2286	2025	261	2025*0, 261*1
Black Canyon of th	2287	2380	2286	94	2286*0, 94*1
Flat Tops	2381	2735	2380	355	2380*0, 355*1
Rawah	2736	2851	2735	116	2735*0, 116*1
Mt Zirkel	2852	3104	2851	253	2851*0, 253*1

Figure 9. Receptor numbers for specific Class I federal areas.

5.1.2.2. CALPUFF Meteorology
Refer to the CALMET section of the report for details.

5.1.2.3. CALPUFF Modeling Domain
The CALPUFF modeling domain is identical to the CALMET modeling domain.

5.1.2.4. CALPUFF Parameter Summary

Figure 10 summarizes some of the key CALPUFF settings.

```
Number of chemical species (NSPEC)                    Default: 5       ! NSPEC =  7 !
Number of chemical species emitted (NSE)              Default: 3       ! NSE =    5 !
(AVET)                                                Default: 60.0    ! AVET = 60. !
(PGTIME)                                              Default: 60.0    ! PGTIME = 60. !
Vertical distribution used in the near field (MGAUSS) Default: 1       ! MGAUSS =  1   !
Terrain adjustment method (MCTADJ)                    Default: 3       ! MCTADJ =  3   !
Subgrid-scale complex terrain flag (MCTSG)            Default: 0       ! MCTSG =   0   !
Near-field puffs modeled as elongated 0 (MSLUG)       Default: 0       ! MSLUG =   0   !
Transitional plume rise modeled?(MTRANS)              Default: 1       ! MTRANS =  1   !
Stack tip downwash? (MTIP)                            Default: 1       ! MTIP =    1   !
Vertical wind shear modeled above stack top? (MSHEAR) Default: 0       ! MSHEAR =  0   !
Puff splitting allowed? (MSPLIT)                      Default: 0       ! MSPLIT =  0   !
Chemical mechanism flag (MCHEM)                       Default: 1       ! MCHEM =   1   !
Aqueous phase transformation flag (MAQCHEM)           Default: 0       ! MAQCHEM =  0  !
Wet removal modeled ? (MWET)                          Default: 1       ! MWET =     1  !
Dry deposition modeled ? (MDRY)                       Default: 1       ! MDRY =     1  !
Method used to compute dispersion coefficients(MDISP) Default: 3       ! MDISP =    3  !
PG sigma-y,z adj. for roughness?                      Default: 0       ! MROUGH =  0  !
Partial plume penetration of elevated inversion?      Default: 1       ! MPARTL =  1  !
Strength of temperature inversion                     Default: 0       ! MTINV =  0  !
PDF used for dispersion under convective conditions?  Default: 0       ! MPDF =  0  !
Sub-Grid TIBL module used for shore line?             Default: 0       ! MSGTIBL = 0  !
Boundary conditions (concentration) modeled?          Default: 0       ! MBCON = 0  !
Configure for FOG Model output?                       Default: 0       ! MFOG =  0   !
Do options specified to see if they conform to regulatory values?      ! MREG =  1   !
    1 = Technical options must conform to USEPA Long Range Transport (LRT) guidance
```

Figure 10. CALPUFF parameter summary.

5.1.2.5. Chemical Mechanism

The MESOPUFF II pseudo-first-order chemical reaction mechanism (MCHEM=1) is used for the conversion of SO_2 to sulfate (SO4) and NOx to nitrate (NO4). Refer to the CALPUFF User's Guide for a description of the mechanism (Scire, 2000).

In the MESOPUFF II mechanism, the ammonia background concentration affects the equilibrium between nitric acid, ammonia, and ammonium nitrate. The equilibrium constant for the reaction is a non-linear function of temperature and relative humidity (Scire, 2000). Unlike sulfate, the calculated nitrate concentration is limited by the amount of available ammonia, which is preferentially scavenged by sulfate (Scire, 2000). In particular, the amount of ammonia available for the nitric acid, ammonium nitrate, and ammonia reactions is determined by subtracting sulfate from total ammonia.

While the chemical mechanism simulates both the gas phase and aqueous phase conversion of SO_2 to sulfate, the aqueous phase method, which is important when the plume interacts with clouds and fog, can significantly underestimate sulfate formation. In this report, as recommended by the IWAQM Phase 2 report, the "nighttime SO_2 loss rate (RNITE1)" is set to 0.2 percent per hour. The "nighttime

NOx loss rate (RNITE2)" is set to 2.0 percent per hour and the "nighttime HNO_3 formation rate (RNITE3)" is set to 2.0 percent per hour.

According to the 1996 "Mt. Zirkel Wilderness Area Reasonable Attribution Study of Visibility Impairment. Volume II: Results of Data Analysis and Modeling - Final Report,"

The CALPUFF chemical module is formulated around linear transformation rates for SO_2 to sulfate and NO_X to total nitrate. There are two options for specifying these transformation rates:

Option 1: An internal calculation of rates based on local values for several controlling variables (e.g., solar radiation, background ozone, relative humidity, and plume NO_X) as used in MESOPUFF-II. The parametric transformation rate relationships employed were derived from box model calculations using the mechanism of Atkinson et al. (1982).

Option 2: A user-specified input file of diurnally varying but spatially uniform conversion rates.

Morris et al. (1987) reviewed the MESOPUFF-II mechanism as part of the U.S. EPA Rocky Mountain Acid Deposition Model Assessment study. They found that it provided physically plausible responses to many of the controlling environmental parameters. However, the mechanism had no temperature dependence, which is an important factor in the Rocky Mountain region where there are wide variations in temperature. Furthermore, the MESOPUFF-II transformation scheme was based on box model simulations for conditions more representative of the Eastern U.S. than of the Rocky Mountains.

The largest deficiency in the MESOPUFF-II chemical transformation algorithm is the lack of explicit treatment for in-cloud (aqueous-phase) enhanced oxidation of SO_2 to sulfate. The MESOPUFF-II chemical transformation algorithm includes a surrogate reaction rate to account for aqueous-phase oxidation of SO_2 to sulfate as follows:

$$K_{aq} = 3 \times 10^{-8} \times RH^4 \; (\%/hr) \qquad (B.2\text{-}1)$$

Thus, at 100% relative humidity (RH), the MESOPUFF-II aqueous-phase surrogate SO_2 oxidation rate will be 3% per hour. Measurements in generating station plumes suggest spatially- and temporally-integrated SO_2 oxidation rates due to oxidants in clouds to be 10 times this value.

Another issue is the amount of ammonia available for nitrate chemistry. According to a paper by EarthTech (Escoffier-Czaja and Scire, 2002),

"In the CALPUFF model, total nitrate (TNO3 = HNO3 + NO3) is partitioned into each species according to the equilibrium relationship between HNO3 and NO3. This equilibrium varies as a function of time and space, in response to both the ambient temperature and relative humidity. In addition, the formation of nitrate is subject to the availability of NH3 to form ammonium nitrate (NH4NO3), the assumed form of nitrate in the model. In CALPUFF, a continuous plume is simulated as a series of puffs, or discrete plume elements. The total concentration

at any point in the model is the sum of the contribution of all nearby puffs from each source. Because CALPUFF allows the full amount of the specified background concentration of ammonia to be available to each puff for forming nitrate, the same ammonia may be used multiple times in forming nitrate, resulting in an overestimate of nitrate formation. In order to properly account for ammonia consumption, a program called POSTUTIL was introduced into the CALPUFF modeling system in 1999. POSTUTIL allows total nitrate to be repartitioned in a post-processing step to account for the total amount of sulfate scavenging ammonia from all sources (both project and background sources) and the total amount of TNO3 competing for the remaining ammonia. In POSTUTIL, ammonia availability is computed based on receptor concentrations of total sulfate and TNO3, not on a puff-by-puff basis."

Ammonia-limiting methods have been used for repartitioning nitric acid and nitrate on a receptor-by-receptor and hour-by-hour basis to account for over prediction due to overlapping puffs in CALPUFF. Specifically, the use of the MNIRATE=1 option in POSTUTIL is acceptable. At this time, other ammonia-limiting methods, including iterative techniques that use observational data to resolve backward the thermodynamic equilibrium equation between NO_3/HNO_3 for each hour to minimize available ammonia, are not acceptable. Generally, for regulatory CALPUFF modeling in Colorado, techniques that assume the atmosphere is always ammonia poor are not acceptable, particularly in eastern Colorado.

5.1.2.6. ***Chemical Mechanism – Ammonia Sensitivity Tests***

To better understand the response of the modeling system to background ammonia when a single point source with significant emissions of SO_2 and NOx is modeled, the Division performed sensitivity tests for a source in northeast Colorado and a source in northwest Colorado using the 2002 MM5/CALMET meteorology. In the test case, SO_2, NOx, and filterable PM10 emissions were modeled. The ammonia background value was varied from 0 to 100 ppb. In the northeast Colorado test case, the SO_2 emission rate is about 3 times higher than the NOx emission rate. In the northwest Colorado test case, the modeled NOx emission rate is about 4.4 times higher than the SO_2 rate.

In both cases, when the background ammonia concentration is zero, the model produces no nitrate, as expected; however, it produces sulfate.

For the northeast Colorado sensitivity test (see Figure 11), where the modeled SO_2 emission rate is significantly higher than the NOx emission rate, the change in visibility (delta-deciview) is not very sensitive to the background ammonia concentration across the range from 1.0 ppb to 100.0 ppb because of the high SO_2 emission rates relative to NOx and the way sulfate is produced in the MESOPUFF II chemical mechanism. Visibility impacts drop significantly when the ammonia background is less than 1.0 ppb, but even at 0.0 ppb of ammonia, sulfate impacts remain relative high.

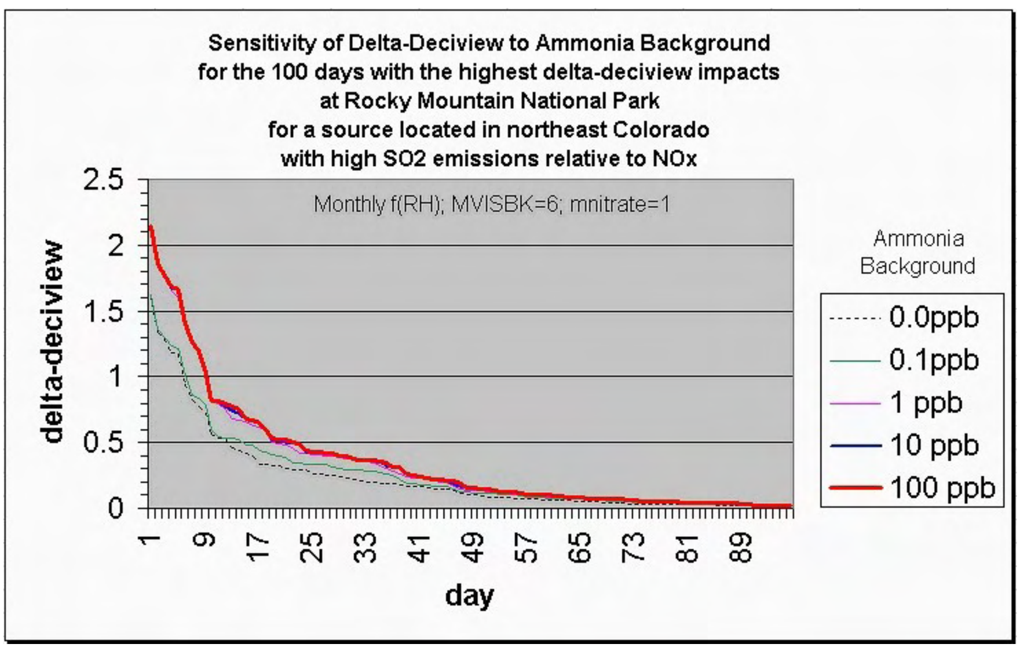

Figure 11. Sensitivity of CALPUFF visibility impacts (delta-deciview) to ammonia backgrounds from 0 ppb to 100 ppb from a source with high SO_2 emissions relative to NOx.

For the northeast Colorado case, on days with the highest visibility impacts, the relative contribution of nitrate and sulfate vary (see Figure 12 and Figure 13), but most of the modeled visibility impairment is due to sulfate. When comparing these figures, be aware the relative rank for some days is different. For example, day 85 is the 2nd worst day for the 0.1 ppb ammonia case, but it's the 3rd worst day for the 100 ppb case. On the day with the highest impact (day 84), the contribution from sulfate is 98.8% for the 0.1 ppb ammonia case and 72.7% for the 100 ppb ammonia case. For the 8th high delta-deciview value, the contribution from sulfate is 86.3% for the 0.1 ppb case and 67.9% for the 100 ppb case.

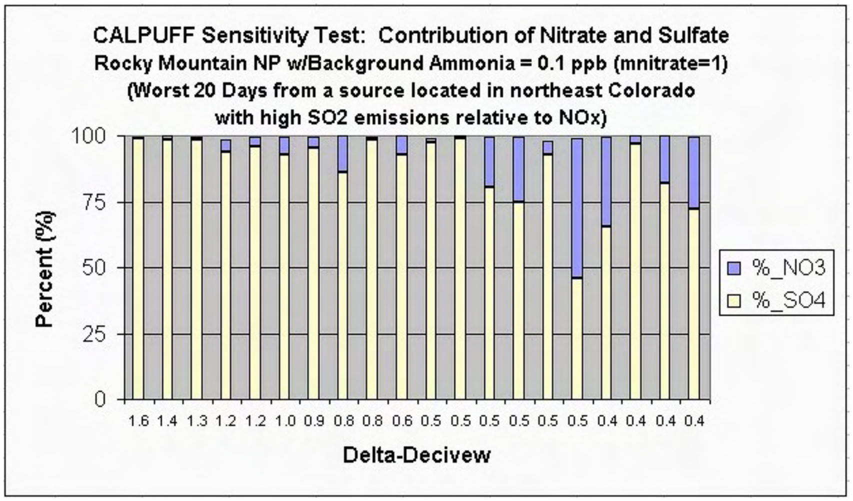

Figure 12. Contribution of sulfate and nitrate to the modeled change in deciviews, assuming a background ammonia of 0.1 ppb in CALPUFF.

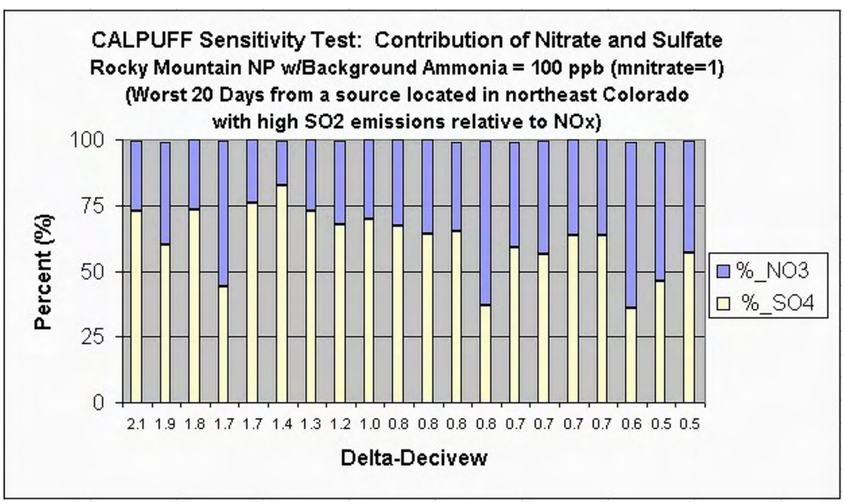

Figure 13. Contribution of sulfate and nitrate to the modeled change in deciviews, assuming a background ammonia of 100 ppb.

For the northwest Colorado sensitivity test (see Figure 14), where the modeled NOx emission rate is significantly higher than the SO_2 emission rate, the change in visibility (delta-deciview) is not sensitive to the background ammonia concentration across the range from 10 ppb to 100 ppb. While there is a moderate drop in impacts when ammonia is dropped from 10 ppb to 1.0 ppb, the model is very sensitive to ammonia when the background ammonia level is less than 1.0 ppb.

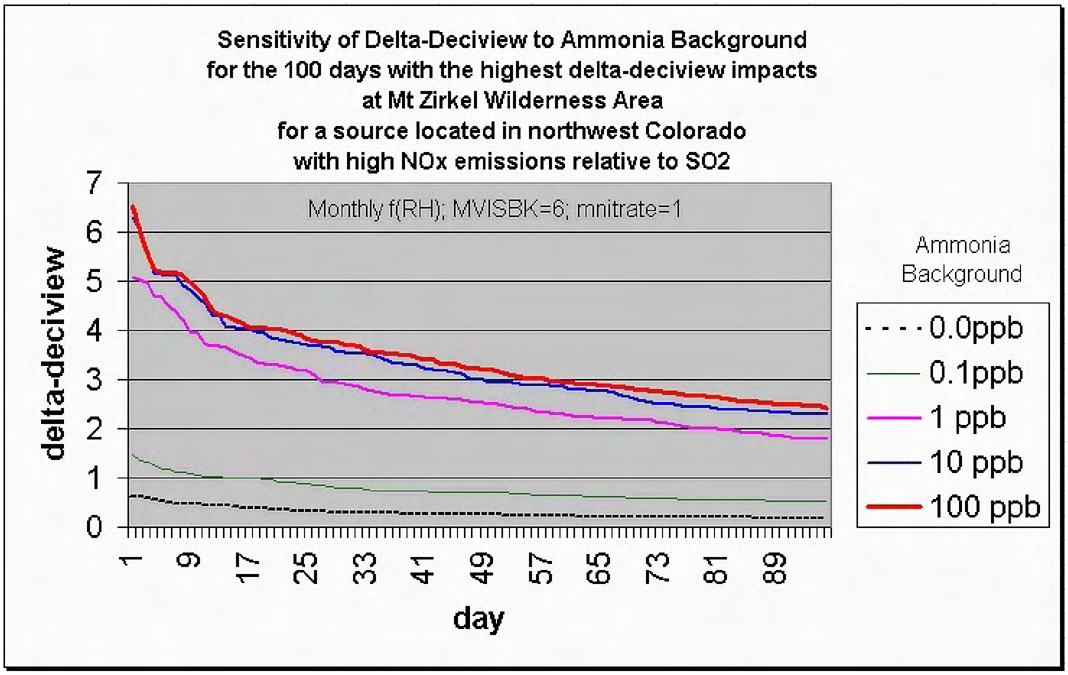

Figure 14. Sensitivity of CALPUFF visibility impacts (delta-deciview) to ammonia backgrounds from 0 ppb to 100 ppb from a source with high NOx emissions relative to SO_2.

For the northwest Colorado test case, according to CALPUFF as implemented here, impairment is primarily due to nitrate (see Figure 15 and Figure 16), but the contribution due to nitrate varies significantly depending on the assumed ammonia background level. For the 100 ppb background case, the nitrate contribution is greater than 90% for the top 20 days. However, for the 0.1 ppb case, the nitrate contribution varies from 43% to 81% for the top 20 days.

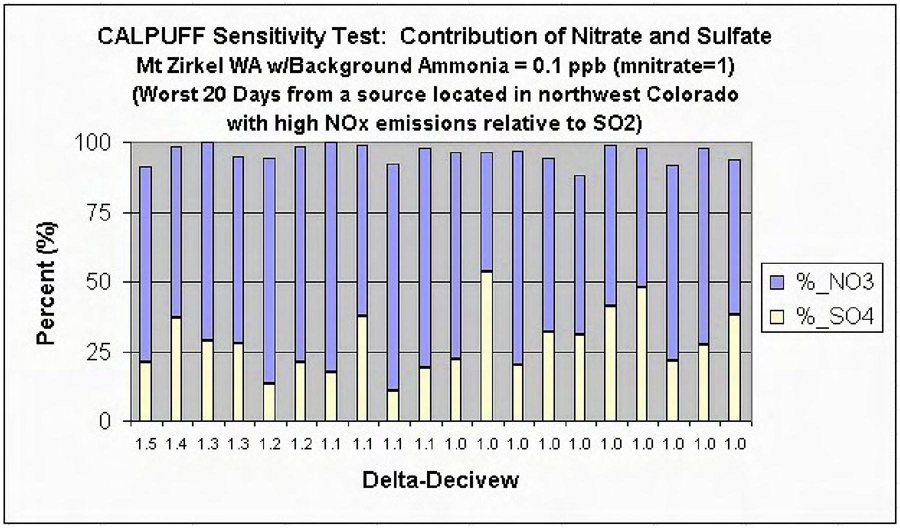

Figure 15. Contribution of sulfate and nitrate to the modeled change in deciviews, assuming a background ammonia of 0.1 ppb in CALPUFF.

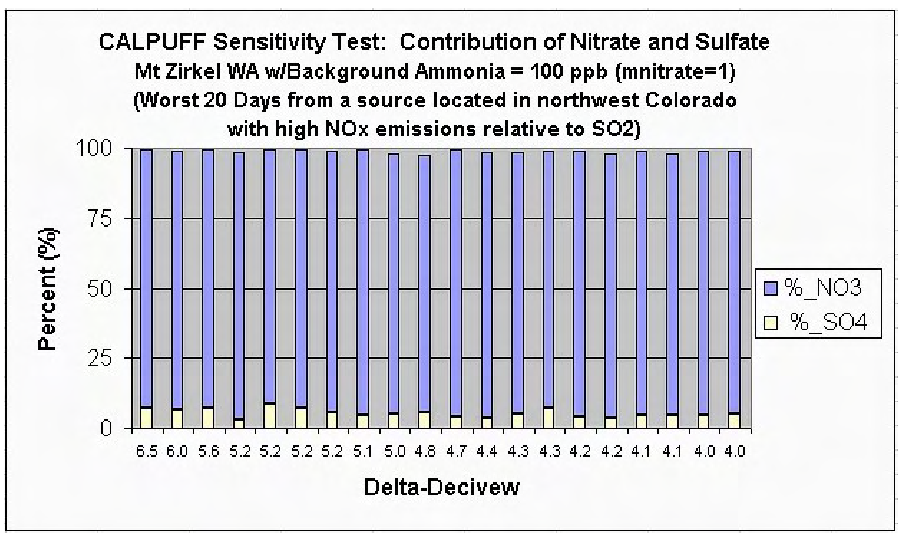

Figure 16. Contribution of sulfate and nitrate to the modeled change in deciviews, assuming a background ammonia of 100 ppb in CALPUFF.

Caution should be used when extrapolating the results of these tests to other CALPUFF applications.

Since the MESOPUFF II chemical mechanism used in this analysis depends on several parameters, including ozone and ammonia background concentrations, the methods for determining the background ozone and ammonia concentration fields are discussed in more detail in the next two sections.

5.1.2.7. Ammonia Assumptions - Discussion

In CALPUFF, as used in this application, the background ammonia concentration is temporally and spatially uniform. It is likely that some portions of the modeling domain are ammonia poor and some are ammonia rich. Thus, setting a domain-wide background is problematic. As discussed in the previous section, when modeling a single large source with high SO_2 emission rates relative to NOx, the assumed background ammonia concentration is not a critical parameter for determining visibility impacts.

According to the IWAQM Phase 2 Report,

> *A further complication is that the formation of particulate nitrate is dependent on the ambient concentration of ammonia, which preferentially reacts with sulfate. The ambient ammonia concentration is an input to the model. Accurate specification of this parameter is critical to the accurate estimation of particulate nitrate concentrations. Based on a review of available data, Langford et al. (1992) suggest that typical (within a factor of 2) background values of ammonia are: 10 ppb for grasslands, 0.5 ppb for forest, and 1 ppb for arid lands at 20 C. Langford et al. (1992) provide strong evidence that background levels of ammonia show strong dependence with ambient temperature (variations of a factor of 3 or 4) and a strong dependence on the soil pH. However, given all the uncertainties in ammonia data, IWAQM recommends use of the background levels provided above, unless specific data are available for the modeling domain that would discredit the values cited. It should be noted, however, that in areas where there are high ambient levels of sulfate, values such as 10 ppb might overestimate the formation of particulate nitrate from a given source, for these polluted conditions. Furthermore, areas in the vicinity of strong point sources of ammonia, such as feed lots or other agricultural areas, may experience locally high levels of background ammonia.*

The Northern Front Range is assumed to be ammonia rich. "Sulfate along the Northern Front Range is completely neutralized by available ammonium and is present in the form of ammonium sulfate....The Northern Front Range is ammonia rich. There was sufficient ammonia, on most days during winter, to completely neutralize available nitric acid (NFRAQS, 1998)."

For northeast Colorado, a background ammonia concentration of 30.4 $\mu g/m^3$ (about 44 ppb) or less appears to be reasonable based on measurements for this modeling study. According to monitoring conducted for NFRAQS,

- *"With respect to gaseous measurements, only ammonia was acquired at all nine sites with the denuder difference method at the Brighton and Welby sites and with the filter-pack method (i.e., impregnated cellulose-fiber filters behind Teflon-membrane filters) at the other sites. Average ammonia concentrations* *were 30.4 ± 53.4 µg/m3 at the core sites and 10.3 ±12.6 µg/m3 at the satellite sites. The large standard deviation is mainly due to elevated ammonia concentrations found at the Evans site. Maximum 24-hour ammonia concentrations were 187.0 ± 5.4 µg/m3 at the Evans core site on 01/17/97 and 66.7 ± 3.5 µg/m3 at the Masters site on 01/20/97. Figure 6.3-5 shows that during the mid-January episode, 24-hour ammonia concentrations varied by orders of magnitude at the nine NFRAQS sites."*

- *"For the 6- and 12-hour samples, Figure 6.4-3*[not included in this report] *ammonia concentrations were rather consistent throughout the day, with apparent site -to-site and season-to-season variation. Average ammonia concentrations at the Brighton site were double those at the Welby site during Winter 97. Summertime ammonia concentrations were ~1 to 2 µg/m3 higher than the wintertime at the Welby site. Since ammonia concentrations closely reflect the vicinity of the sampling area, site-to-site variations were more pronounced than seasonal or diurnal variations. This is evidenced by the graph in Figure 6.4-4*[not included in this report]*, which shows ammonia concentrations were factors of 10 to 20 higher at the Evans site than at most of the other sites during Winter 97. Elevated concentrations exceeded 50 µg/m3 on 20% of the days at the Evans site. Twenty-four hour ammonia concentrations at the Masters and Longmont sites were also factors of 5 to 10 higher than at the other sites."*

For other areas like northwest Colorado, an annual background ammonia concentration of about 1 ppb or less is probably more reasonable, based on ammonia measurements from the Mt. Zirkel Visibility Study.

In the Aerosol Evolution Model (AEM) simulations done for the Mt Zirkel Study for a specific period, "*base case background air concentrations for ammonia were assumed to be 0.5 $\mu g/m^3$ and 30 ppb_v for ozone, consistent with measured values at the Hayden VOR site*." An ammonia concentration of 0.5$\mu g/m^3$ is about 0.7 ppb.

In the CALPUFF modeling section of the Mt Zirkel Study report,

> *"The CALPUFF default value for background ammonia concentrations of 10 ppb was also considered far too high as a representative area-average. Measurements from the Buffalo Pass and Gilpin Creek sites were used to adjust ammonia concentration to episode and site-mean values."*

Based on a review of CALUFF files used for the Mt. Zirkel Study, for the August simulations, the assumed ammonia background (BCKNH3) was 1.6 ppb; for the October simulation, the assumed background was 0.5 ppb; and for the September simulation, the assumed background was 0.8 ppb.

5.1.2.8. Ammonia Assumptions

Based on information in the previous section, for sources located in northeast Colorado and along the South Platte River, a domain-wide ammonia background value of 44 ppb is used. For sources located in northwest Colorado, a background ammonia concentration of 1.0 ppb is used. For sources located in southeastern Colorado and for source located along the Arkansas River, a background value of 10 ppb is used.

5.1.2.9. Ozone Assumptions

According to the IWAQM Phase 2 Report,

> *CALPUFF provides two options for providing the ozone background data: (1) a single, typical background value appropriate for the modeling region, or (2) hourly ozone data from one or more ozone monitoring stations. The second and preferred option requires the creation of the OZONE.DAT file containing the necessary data. For the Demonstration Assessment, the domain was large (700 km by 1000 km) such that the second option was necessary. The IWAQM does not anticipate such large domains as being the typical application. Rather, it is anticipated that the more typical application will involve domains of order 400 km by 400 km or smaller. But even for smaller domains, the ability to provide at least monthly background values of ozone is deemed desirable. The problem in developing time (and perhaps spatial) varying background ozone values is having access to representative background ozone data. Ozone data are available from EPA's Aerometric Information Retrieval System (AIRS); however, AIRS data must be used with caution. Many ozone sites are located in urban and suburban centers and are not representative of oxidant levels experienced by plumes undergoing long range transport.*

In this study, "*CH2M HILL obtained hourly ozone data from the following stations located within the modeling domain for some or all of the years 1996, 2001, and 2002:*

- *Gothic (Gunnison County, Colorado)*
- *Rocky Mountain National Park*

Additional, hourly data for 1996, 2001, and 2002 were provided to CH2M HILL by the APCD for the following stations along the Front Range:

- *Greeley*
- *Highlands Ranch*
- *Colorado Springs*

Data recovery for the years 2001 and 2002 for the Greeley station was very low, and therefore data from the nearby Fort Collins station were used instead. Any data missing from the hourly records were replaced with a domain-wide default concentration of 60 parts per billion (ppb), as determined by the APCD/NPS (CH2M HILL, 2005)."

5.1.3. CALPOST Settings and Visibility Post-Processing

The CALPUFF results have been post-processed with a modified version of CALPOST (version 5.51_CO_v3, level: 030709), POSTUTIL (version 1.31, level 030528), and BART98_v3. The CALPOST modifications were performed by the Division and do not affect any of the calculations in CALPOST for the deciview values used in this report; however, some simple calculations were done within CALPOST in order to output delta-deciview values (instead of percent change values) for the individual species that contribute to the overall delta-deciview value, but these values are not used for the subject-to-BART modeling. Otherwise, the CALPOST code modification consists of a "write" statement and supporting code. It outputs all daily delta-deciview values for every receptor to a file called "deciview24.dat." The 98^{th} percentile values are computed from "deciview24.dat" by a separate FORTRAN processor (BART98_v3) written by the Division specifically for this analysis.

For the initial modeling analysis, all PM10 was assumed to have a extinction efficiency of 1.0 since the contribution of direct PM10 emissions is expected to be relatively small compared to visibility impairment caused by SO_2 and NOx emissions. However, if modeled impacts were below the contribution threshold, condensible and filterable PM10 emissions were quantified and speciated or a sensitivity test was performed to determine if PM10 speciation could change the outcome of the analysis. If speciated PM10 emissions were modeled, the following species were considered: fine particulates (PMF), coarse particulates (PMC), elemental carbon (EC), organic carbon (SOA), and sulfate (SO4). To see how PM10 was modeled for this source, refer to sections 4 and 5.1.3.2.

In this study, to calculate background light extinction, MVISBK has been set to 6. That is, monthly RH adjustment factors are applied directly to the background and modeled sulfate and nitrate concentrations, as recommended by the BART guideline. The RHMAX parameter, which is the maximum relative humidity factor used in the particle growth equation for visibility processing, is not used when method 6 is selected. Similarly, the relative humidity adjustment factor (f(RH)) curves in CALPOST (e.g., IWAQM growth curve and the 1996 IMPROVE curve) are not used when MVISBK is equal to 6.

The natural background is based on the 20 percent best visibility days, as recommended by the BART guideline preamble:

> *Finally, these BART guidelines use the natural visibility baseline for the 20 percent best visibility days for comparison to the "cause or contribute" applicability thresholds. We believe this estimated baseline is likely to be reasonably conservative and consistent with the goal of natural conditions* (70 FR 39125).

The method for estimating natural background is presented in section 5.1.3.1. Specifically, for hygroscopic components, BKSO4 in CALPOST has been set to 0.0893 for all months. For non-hygroscopic components, BKSOIL has been set to 1.620 for all months. The BKSO4 and BKSOIL values have been computed specifically for the Colorado Class I areas in the modeling domain.

The extinction due to Rayleigh scattering (i.e., the scattering of light by natural particles much smaller than the wavelength of the light) has been set to 10 Mm^{-1} (BEXTRAY = 10.0).

5.1.3.1. Natural Conditions - Determining Hygroscopic And Non-Hygroscopic Values For the Best 20% Visibility Days

5.1.3.1.1. Natural Background - Objective

The spreadsheet shown in Figure 17 was created to determine the hygroscopic (3[BKSO4]) and non-hygroscopic (equivalent to [BKSOIL]) portions of natural background for the best 20% visibility days (Best Days) at all Class I areas in Colorado's BART modeling. These concentrations, [BKSO4] and [BKSOIL], are used in CALPOST with monthly relative humidity adjustment factors (f(RH)) to determine monthly natural background visibility that would, on average, represent the average natural background visibility for the best 20% days in EPA's "Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Program" (EPA, 2003).

5.1.3.1.2. Natural Background - Discussion

"Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Program" (EPA, 2003), section 2.4, describes the calculation of the annual average background extinction (in 1/Mm) for a Class I area using the area's annual f(RH) and average natural concentrations based on the area's geographic location (east versus west). Annual average background extinction values (in 1/Mm) are converted to annual average Haze Index (HI) values (in deciview or dv). Then, the average HI value for the 20% best visibility days (Best Days (dv)) is estimated from 10th percentile of the annual average HI value for a Class I area assuming normal distribution. Thus, no average natural concentrations are provided for determining extinction for the 20% best visibility days.

For background extinction computation methods 2, 3, and 6 in CALPOST, background extinction is calculated with user-supplied monthly concentrations of SO4, NO3, PM coarse, organic carbon, soil, and elemental carbon species. In practice, concentrations for only 2 species, SO4 ([BKSO4]) and soil ([BKSOIL]), are supplied in the CALPOST input file to represent hygroscopic and non-hygroscopic portions of background extinction, respectively.

To determine background extinction for the BART analysis with CALPOST, average natural concentrations that represent average natural background visibility for the best 20% days need to be determined.

5.1.3.1.3. Natural Background - Method

Following EPA's approach of using regional average natural concentrations and the concept of using simplified inputs in CALPOST, the same hygroscopic ($3[BKSO4]_{best20}$) and non-hygroscopic ($[BKSOIL]_{best20}$) values would be used in CALPOST for all Class I areas in Colorado's BART modeling.

The spreadsheet calculates an average background (dv) based on monthly background extinction (1/Mm) for each Class I area in Colorado's BART modeling using the following equations:

1. Monthly background extinction in 1/Mm ($bext_{month}$) = $3[BKSO4]_{best20}f(RH)$ + $[BKSOIL]_{best20}$ + Rayleigh
2. Annual average background extinction in 1/Mm ($bext_{annual\_ave}$) = ($bext_{Jan}$ + $bext_{Feb}$ + … + $bext_{Dec}$)/12
3. Calculated Best Days in dv = 10ln($bext_{annual\_ave}$/10)

EPA guidance provides f(RH) values based on the centroid of the Class I area (see Appendix B – Monthly f(RH) Values) and a Best Days (dv) value for each of the Class I areas (see Appendix A – Natural Background Values).

The hygroscopic (3[BKSO4]) and non-hygroscopic ([BKSOIL]) values determined yielded the lowest sum of the absolute differences between the published Best Days (dv) and calculated Best Days (dv) for all Class I areas in the analysis:

where: n = number of Class I areas in analysis

The "hygro (3[BKSO4])" and "non-hygro ([BKSOIL])" values of 0.268 and 1.620 were calculated in Microsoft Excel using the "solver add-in" tool for optimization and equation solving (Figure 17). As can be seen from the "difference" values in Figure 17, the annual 20% best visibility days background concentrations for each Class I area calculated with this method are within 0.01 deciviews or less of the annual 20% best visibility days background values recommended by EPA. For CALPOST, the hygroscopic component of extinction is divided by 3 (the extinction coefficient of sulfate and nitrate) and input as BKSO4 (i.e., BKSO4 = 0.268/3 = 0.0893). The non-hygroscopic component is used directly (i.e., BKSOIL = 1.620).

hygro (3[BKSO4])	**0.268**
non-hygro ([BKSOIL])	**1.620**

	f(RH)											Background Extinction (1/Mm)										
Month	BC	EN	FT	GSD	LG	MB	MZ	RW	RM	WEM	WELK	BC	EN	FT	GSD	LG	MB	MZ	RW	RM	WEM	WELK
1	2.4	2.2	2.3	2.4	2.3	2.2	2.2	2.1	1.7	2.4	2.3	12.3	12.2	12.2	12.3	12.2	12.2	12.2	12.2	12.1	12.3	12.2
2	2.2	2.2	2.2	2.3	2.2	2.1	2.2	2.1	1.9	2.2	2.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.1	12.2	12.2
3	1.9	2.0	2.0	2.0	1.9	2.0	2.0	2.0	1.9	1.9	1.9	12.1	12.2	12.2	12.2	12.1	12.2	12.2	12.2	12.1	12.1	12.1
4	1.9	2.0	2.0	1.9	1.8	2.0	2.1	2.1	2.1	1.7	1.9	12.1	12.2	12.2	12.1	12.1	12.2	12.2	12.2	12.2	12.1	12.1
5	1.9	2.1	2.0	1.9	1.8	2.1	2.2	2.3	2.3	1.7	1.9	12.1	12.2	12.2	12.1	12.1	12.2	12.2	12.2	12.2	12.1	12.1
6	1.6	1.9	1.8	1.8	1.6	1.7	1.9	2.0	2.0	1.5	1.7	12.0	12.1	12.1	12.1	12.0	12.1	12.1	12.2	12.2	12.0	12.1
7	1.7	1.8	1.7	1.9	1.7	1.9	1.7	1.8	1.8	1.6	1.8	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.0	12.1
8	1.9	2.0	1.9	2.3	2.1	2.2	1.9	2.0	2.0	2.0	2.1	12.1	12.2	12.1	12.2	12.2	12.2	12.1	12.2	12.2	12.2	12.2
9	2.0	2.0	1.9	2.2	2.0	2.1	2.0	2.0	1.9	1.9	2.0	12.2	12.2	12.1	12.2	12.2	12.2	12.2	12.2	12.1	12.1	12.2
10	1.8	1.9	1.8	1.9	1.8	1.8	1.9	1.9	1.8	1.7	1.8	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1	12.1
11	2.1	2.1	2.2	2.4	2.2	2.1	2.1	2.1	1.8	2.1	2.1	12.2	12.2	12.2	12.3	12.2	12.2	12.2	12.2	12.1	12.2	12.2
12	2.3	2.1	2.2	2.4	2.3	2.1	2.1	2.0	1.7	2.3	2.2	12.2	12.2	12.2	12.3	12.2	12.2	12.2	12.2	12.1	12.2	12.2
											Annual Ave (dv)	1.95	1.96	1.95	1.98	1.95	1.96	1.96	1.96	1.93	1.93	1.95
											Target Annual Best Days (dv)	1.94	1.96	1.95	1.98	1.94	1.95	1.96	1.96	1.93	1.94	1.95
											Difference	0.01	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.00
											Sum of Differences	0.039										

Figure 17. Spreadsheet showing the "hygro (3[BKSO4])" (0.268)and "non-hygro ([BKSOIL])" (1.620) values calculated in Microsoft Excel using the "solver add-in" tool for optimization and equation solving.

5.1.3.2. CALPOST and POSTUTIL Parameters

For this modeling analysis, if PM10 speciation was performed (see section 4), then example #1 from this section was used. If PM10 speciation was not performed, then example #2 from this section was used. In example #1, fine particulate emissions are speciated into PMF, PMC, EC, SOA, and SO4 and explicitly included as species in CALPUFF. Emission rates for each species are included in CALPUFF. Figure 18 summarizes some of the key CALPOST settings. The monthly f(RH) values (RHFAC), which are different for each Class I area, are from Appendix B – Monthly f(RH) Values.

```
Modeled species to be included in computing the light extinction
     Include SULFATE?          (LVSO4) -- Default: T   ! LVSO4  = T  !
     Include NITRATE?          (LVNO3) -- Default: T   ! LVNO3  = T  !
     Include ORGANIC CARBON?   (LVOC)  -- Default: T   ! LVOC   = T  !
     Include COARSE PARTICLES? (LVPMC) -- Default: T   ! LVPMC  = T  !
     Include FINE PARTICLES?   (LVPMF) -- Default: T   ! LVPMF  = T  !
     Include ELEMENTAL CARBON? (LVEC)  -- Default: T   ! LVEC   = T  !
Species name used for particulates in MODEL.DAT file
                   COARSE    (SPECPMC) -- Default: PMC ! SPECPMC = PMC !
                   FINE      (SPECPMF) -- Default: PMF ! SPECPMF = PMF !
MODELED particulate species:
               PM  COARSE      (EEPMC) -- Default: 0.6 ! EEPMC  = 0.6 !
               PM  FINE        (EEPMF) -- Default: 1.0 ! EEPMF  = 1.0 !
BACKGROUND particulate species:
               PM  COARSE    (EEPMCBK) -- Default: 0.6 ! EEPMCBK = 0.6 !
Other species:
              AMMONIUM SULFATE (EESO4) -- Default: 3.0 ! EESO4  = 3.0 !
              AMMONIUM NITRATE (EENO3) -- Default: 3.0 ! EENO3  = 3.0 !
              ORGANIC CARBON   (EEOC)  -- Default: 4.0 ! EEOC   = 4.0 !
              SOIL             (EESOIL)-- Default: 1.0 ! EESOIL = 1.0 !
              ELEMENTAL CARBON (EEEC)  -- Default: 10. ! EEEC   = 10.0 !
Method used for background light extinction
                              (MVISBK) -- Default: 2   ! MVISBK =  6  !

(RHFAC)  -- No default     ! RHFAC = 2.4,2.2,1.9,1.7,
                                     1.7,1.5,1.6,2.0,
                                     1.9,1.7,2.1,2.3 !
(BKSO4)  -- No default     ! BKSO4 = 0.0893, 0.0893, 0.0893, 0.0893,
                                     0.0893, 0.0893, 0.0893, 0.0893,
                                     0.0893, 0.0893, 0.0893, 0.0893 !
(BKNO3)  -- No default     ! BKNO3 = 0.0, 0.0, 0.0, 0.0,
                                     0.0, 0.0, 0.0, 0.0,
                                     0.0, 0.0, 0.0, 0.0 !
(BKPMC)  -- No default     ! BKPMC = 0.0, 0.0, 0.0, 0.0,
                                     0.0, 0.0, 0.0, 0.0,
                                     0.0, 0.0, 0.0, 0.0 !
(BKOC)   -- No default     ! BKOC  = 0.0, 0.0, 0.0, 0.0,
                                     0.0, 0.0, 0.0, 0.0,
                                     0.0, 0.0, 0.0, 0.0 !
(BKSOIL) -- No default     ! BKSOIL= 1.620, 1.620, 1.620, 1.620,
                                     1.620, 1.620, 1.620, 1.620,
                                     1.620, 1.620, 1.620, 1.620 !
(BKEC)   -- No default     ! BKEC  = 0.0, 0.0, 0.0, 0.0,
                                     0.0, 0.0, 0.0, 0.0,
                                     0.0, 0.0, 0.0, 0.0 !
Extinction due to Rayleigh scattering is added (1/Mm)
                             (BEXTRAY) -- Default: 10.0 ! BEXTRAY = 10.0 !
```

Figure 18. CALPOST - key parameters (example #1 setup).

POSTUTIL is used to compute the partition for the total concentration fields with MNITRATE=1 and the appropriate ammonia background concentration. The ammonia background concentration, BCKNH3, in POSTUTIL is the same as the background value presented in section Figure 18. In POSTUIL, the input species include SO2, SO4, NOX, HNO3, NO3, SOA, PMF, PMC, and EC and the output species include SO4, HNO3, NO3, SOA, PMF, PMC, and EC. Key POSTUTIL parameters are shown in Figure 19.

```
Number of species to process from CALPUFF runs
                              (NSPECINP) -- No default    ! NSPECINP = 9 !
Number of species to write to output file
                              (NSPECOUT) -- No default    ! NSPECOUT = 7 !
Number of species to compute from those modeled
      (must be no greater than NSPECOUT)
                              (NSPECCMP) -- No default    ! NSPECCMP = 0 !
Number of CALPUFF data files that will be scaled
      (must be no greater than NFILES)
      (NSCALED)                         Default: 0       ! NSCALED = 0 !
Recompute the HNO3/NO3 partition for concentrations?
      (MNITRATE)                       Default: 0       ! MNITRATE  =  1  !
The following NSPECINP species will be processed:

 ! ASPECI =            SO4  !         !END!
 ! ASPECI =            SO2  !         !END!
 ! ASPECI =            NOx  !         !END!
 ! ASPECI =            NO3  !         !END!
 ! ASPECI =            HNO3 !         !END!
 ! ASPECI =            PMF  !         !END!
 ! ASPECI =            PMC  !         !END!
 ! ASPECI =            EC   !         !END!
 ! ASPECI =            SOA  !         !END!


The following NSPECOUT species will be written:

 ! ASPECO =             SO4  !         !END!
 ! ASPECO =             NO3  !         !END!
 ! ASPECO =             HNO3 !         !END!
 ! ASPECO =             PMF  !         !END!
 ! ASPECO =             PMC  !         !END!
 ! ASPECO =             EC   !         !END!
 ! ASPECO =             SOA  !         !END!
```

Figure 19. POSTUTIL - key parameters for cases with nitrate partitioning and speciated PM10 concentrations (example #1 setup).

In example #2, PM10 is included as a species in CALPUFF and ammonia limiting is performed. The CALPOST setup is the same as the example #1 setup (see Figure 18) except LVPMC=F, since there are is no coarse PM, and SPECPMF=SOIL because the PM10 emissions from CALPUFF are reallocated to the species SOIL and EC in the first of two POSTUTIL runs. The first POSTUTIL setup (see Figure 20) was intended to provide a post-processing opportunity to divide the PM10 concentrations into SOIL and EC components; however, in the setup shown in Figure 20, all of the PM10 was allocated to SOIL and none was allocated to EC.

```
Number of species to process from CALPUFF runs
                             (NSPECINP) -- No default    ! NSPECINP = 5 !
Number of species to write to output file
                             (NSPECOUT) -- No default    ! NSPECOUT = 6 !
Number of species to compute from those modeled
      (must be no greater than NSPECOUT)
                             (NSPECCMP) -- No default    ! NSPECCMP = 2 !
Recompute the HNO3/NO3 partition for concentrations?
      (MNITRATE)                     Default: 0        ! MNITRATE  =  0  !
The following NSPECINP species will be processed:
 ! ASPECI =          SO4 !         !END!
 ! ASPECI =          NO3 !         !END!
 ! ASPECI =         HNO3 !         !END!
 ! ASPECI =         PM10 !         !END!
 ! ASPECI =          SOA !         !END!

The following NSPECOUT species will be written:
 ! ASPECO =            SO4  !         !END!
 ! ASPECO =            NO3  !         !END!
 ! ASPECO =           HNO3  !         !END!
 ! ASPECO =             EC  !         !END!
 ! ASPECO =           SOIL  !         !END!
 ! ASPECO =            SOA  !         !END!

The following NSPECCMP species will be computed by scaling and summing
one or more of the processed input species.  Identify the name(s) of
the computed species and provide the scaling factors for each of the
NSPECINP input species (NSPECCMP groups of NSPECINP+1 lines each):

 ! CSPECCMP =      EC !
 !      SO4  =      0.0       !
 !      NO3  =      0.0       !
 !     PM10  =      0.00   !
 !      SOA  =      0.0       !
 !END!

 ! CSPECCMP =      SOIL !
 !      SO4  =      0.0       !
 !      NO3  =      0.0       !
 !     PM10  =      1.0   !
 !      SOA  =      0.0       !
 !END!
```

Figure 20. POSTUTIL setup for simulations where PM10 is divided into SOIL and EC species (example #2 setup).

In the second POSTUTIL setup for example#2, POSTUTIL is used to compute the partition for the total concentration fields with MNITRATE=1 and the appropriate ammonia background concentration. The ammonia background concentration, BCKNH3, in POSTUTIL is the same as the background value presented in section 5.1.2.8. In this POSTUIL setup, the input species include SO4, NO3, HNO3, EC, SOIL, and SOA and the output species include SO4, NO3, HNO3, EC, SOIL, and SOA. Key POSTUTIL parameters are shown in Figure 19.

```
      Number of species to process from CALPUFF runs
                            (NSPECINP) -- No default    ! NSPECINP = 6 !
      Number of species to write to output file
                            (NSPECOUT) -- No default    ! NSPECOUT = 6 !
      Number of species to compute from those modeled
      (must be no greater than NSPECOUT)
                            (NSPECCMP) -- No default    ! NSPECCMP = 0 !
      Recompute the HNO3/NO3 partition for concentrations?
      (MNITRATE)                    Default: 0        ! MNITRATE  =  1  !
The following NSPECINP species will be processed:

 ! ASPECI =            SO4  !          !END!
 ! ASPECI =            NO3  !          !END!
 ! ASPECI =            HNO3 !          !END!
 ! ASPECI =            EC   !          !END!
 ! ASPECI =            SOIL !          !END!
 ! ASPECI =            SOA  !          !END!

The following NSPECOUT species will be written:

 ! ASPECO =            SO4  !          !END!
 ! ASPECO =            NO3  !          !END!
 ! ASPECO =            HNO3 !          !END!
 ! ASPECO =            EC   !          !END!
 ! ASPECO =            SOIL !          !END!
 ! ASPECO =            SOA  !          !END!
```

Figure 21. POSTUTIL setup for simulations where ammonia limiting is performed using the output file generated from the POSTUTIL setup in Figure 20 (example#2 setup).

5.1.3.3. 98th Percentile Methods

According the BART guideline:

...you should compare your "contribution" threshold against the 98th percentile of values. If the 98th percentile value from your modeling is less than your contribution threshold, then you may conclude that the source does not contribute to visibility impairment and is not subject to BART. (70 FR 39162)

The BART guideline does not contain a specific method for calculating the "98th percentile value" and CALPOST version 5.51 does not generate a 98th percentile delta-deciview value. Consequently, the Division developed a FORTRAN program (BART98_v3) to compute 98th percentile results. The program implements several methods because, at the time the code was written, U.S. EPA had not yet specified an explicit method for determining the 98th percentile value.

The U.S.EPA recommends using the 98th percentile value from the distribution of values containing the highest modeled delta-deciview value for each day of the simulation from all modeled receptors at a given Class I area. The 98th percentile delta-deciview value can be determined in several ways:

- The 8th highest value for each year modeled
- The 3-year average of the annual 8th high values
- The 22nd highest value for the 3-year modeling period

The highest value from the methods above is compared to the contribution threshold. The contribution threshold has an implied level of precision equal to the level of precision reported from CALPOST. Specifically, the 98th percentile results are reported to three decimal places.

The Division's processor BART98_v3 calculates the 98th percentile value with the method recommended by U.S. EPA. The Division refers to the method as the "day-specific method" or "method 1." The first step in the method is to find the highest modeled delta-deciview value for each day of the simulation from all modeled receptors for the selected time period. While this set of delta-deciview values is generated by CALPOST in an unranked format, the Division's processor BART98_v3 outputs all daily delta-deciview values for each receptor from CALPOST and finds the highest impact for each day. Next, the processor ranks the daily delta-deciview maxima in descending order for the number of days processed in CALPOST. Then, the processor determines the 98th percentile value from the distribution of ranked modeled daily maximum values, irrespective of receptor location. For example, for a 365-day simulation, the 98th percentile value would be the 8th highest modeled delta-deciview value from the list of ranked delta-deciview values. That is, the top 7 days are ignored, even though the values being ignored may be at different receptors. Similarly, for a 3-year period, the 98th percentile would be the 22nd highest modeled delta-deciview value.

The processor BART98_v3 also generates 98th percentile values using the "receptor-specific method" or "method 2." This method, which calculates 98th percentile values on a receptor-by-receptor basis, is not used for the subject-to-BART modeling in Colorado.

In order to make the processor more general and to handle missing data, the "8th high" (for one year) and "22nd high" (for 3 years) values recommended by U.S. EPA are not hardwired into the processor; rather, the processor contains an algorithm that calculates the appropriate "nth high" value from the distribution of data. The 8th high and 22nd high values recommended by U.S. EPA are consistent with the values that would be generated from the equations in 40 CFR 50 Appendix N - "Interpretation of the National Ambient Air Quality Standards for PM2.5" – for determining 98th percentile values for PM2.5 monitoring. Thus, the Appendix N method is used in the processor. For the exact algorithm, see Appendix N, the BART98_v3 source code, or the BART98_v3 "readme" file.

6. Results

The CALPUFF modeling results include eleven of the twelve Class I areas in Colorado. Mesa Verde was excluded because it is more than 300 km from all of the BART-eligible sources in Colorado. In addition, the BART-eligible sources in Colorado would have higher impacts at other Class I areas. That is, impacts at Mesa Verde would not be the controlling 98th percentile values for this analysis. The modeling domain does not include Class I areas in any nearby states because the maximum 98th percentile impact from the Craig Station is expected to occur at a Class I area in Colorado.

The results for source-to-receptor distances beyond 300 kilometers may be used, but they may overestimate impacts because puff splitting has not been used. The model setup used here should provide reasonable estimates for source-to-receptor distances up to 300 kilometers. Figure 22 shows the 50km and 300 km radius circles around the modeled BART-eligible source.

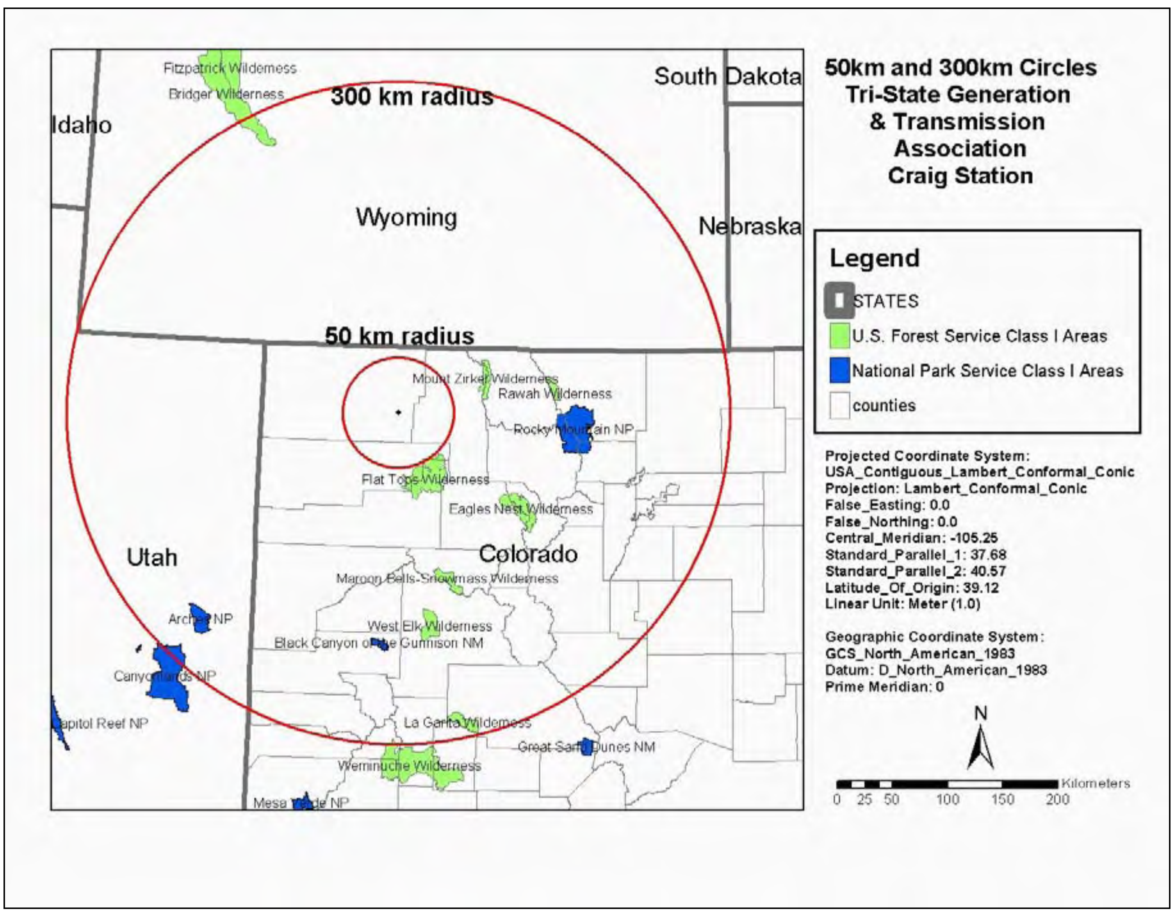

Figure 22. Class I areas within 50 and 300 kilometers of the BART-eligible source.

6.1. Results

The Division has applied the CALPUFF modeling system with three years of meteorological data to determine if the 98th percentile 24-hour change in visibility (delta-deciview) from a BART-eligible source is greater than a contribution threshold of 0.5 deciviews at any Class I area. This initial phase of the BART modeling process is referred to as the "subject to BART" analysis. The modeling includes SO_2, NOx, and direct PM10 emissions from all BART-eligible units at a given facility.

While the modeling results in this report may be used to support regulatory decision making, additional modeling performed by the Division or source operator may supersede the results in this report. If additional modeling is performed, it should be consistent with recommendations in the Division's modeling protocol. Any subsequent modeling performed by the source operator will be subject to Division review and approval. Moreover, the contribution threshold and other criteria used for this modeling demonstration have not been finalized and may change in the final rule adopted by the Commission. Therefore, the results in this report are not a final agency action. Any source that the Division determines is subject to BART will receive a separate notice of the agency's final determination. Such separate notice will occur after the Commission acts on the proposed regulations establishing criteria and procedures for determining which sources will be subject to the BART requirement.

Table 2 and Figure 23 show the 98th percentile daily delta-deciview values for each Class I area in the modeling domain. The 98th percentile delta-deciview value is determined several ways:

- The 8th highest value for each year modeled
- The 3-year average of the annual 8th high values
- The 22nd highest value for the 3-year modeling period

The highest value from the methods above is compared to the contribution threshold. The contribution threshold has an implied level of precision equal to the level of precision reported from CALPOST. Specifically, the 98th percentile results are reported to three decimal places.

The maximum 98th percentile delta-deciview value from Craig Station Units 1 and 2 at any Class I federal area is 2.689 deciviews, assuming natural background conditions and monthly f(RH) values. The impact is above the contribution threshold of 0.5 deciviews. The maximum impact occurs at the Mount Zirkel Wilderness Area. For the three-year period modeled, there are 496 days with an estimated impact over the contribution threshold of 0.5 deciviews.

Table 3 shows the summary report generated by the Division's 98th percentile postprocessor (BART98_v3) for the maximum 98th percentile value. Figure 24 and Figure 25 show the distribution of delta-deciview values used to generate the maximum 98th percentile value. Figure 24 shows the top 25 delta-deciview values at the Class I federal area with the maximum impact from this BART-eligible source.

Table 2. Maximum 98th percentile value, 98th percentile values calculated with several methods, and the number of days the impact is equal to or greater than 0.5 deciviews for the entire period modeled.

CALPUFF Individual Source Attribution Analysis — **Maximum 98th Percentile Value = 2.689**

BART-eligible source name: Craig Station - Units 1 & 2

Class I federal area	98th Percentile Daily Change in Visibility from BART-Eligible Source Compared Against Natural Background Conditions					Number of Days Impact >0.5dv (1996, 2001, 2002)
	8th High Delta-Deciview Value				22nd High Delta-Deciview Value from 3-year Modeling Period	
	1996[1]	2001	2002	3-year Average		
Flat Tops WA	2.093	1.615	2.095	1.934	1.996	168
Rawah WA	1.587	1.393	1.929	1.636	1.588	190
Mt Zirkel WA	2.131	2.226	2.689	2.349	2.315	496
Weminuche WA	0.172	0.097	0.194	0.154	0.165	4
Rocky Mountain NP	1.753	1.267	1.935	1.652	1.765	205
Maroon Bells-Snowmass WA	0.983	0.621	0.563	0.722	0.652	37
La Garita WA	0.279	0.154	0.234	0.222	0.205	3
Great Sand Dunes NP	0.468	0.323	0.360	0.384	0.403	11
West Elk WA	0.566	0.505	0.433	0.501	0.515	26
Eagles Nest WA	1.560	1.106	1.211	1.292	1.260	109
Black Canyon of the Gunnison NP	0.467	0.265	0.338	0.357	0.382	17

[1] *1996, 2001, and 2002 are the years of meteorological data modeled.*

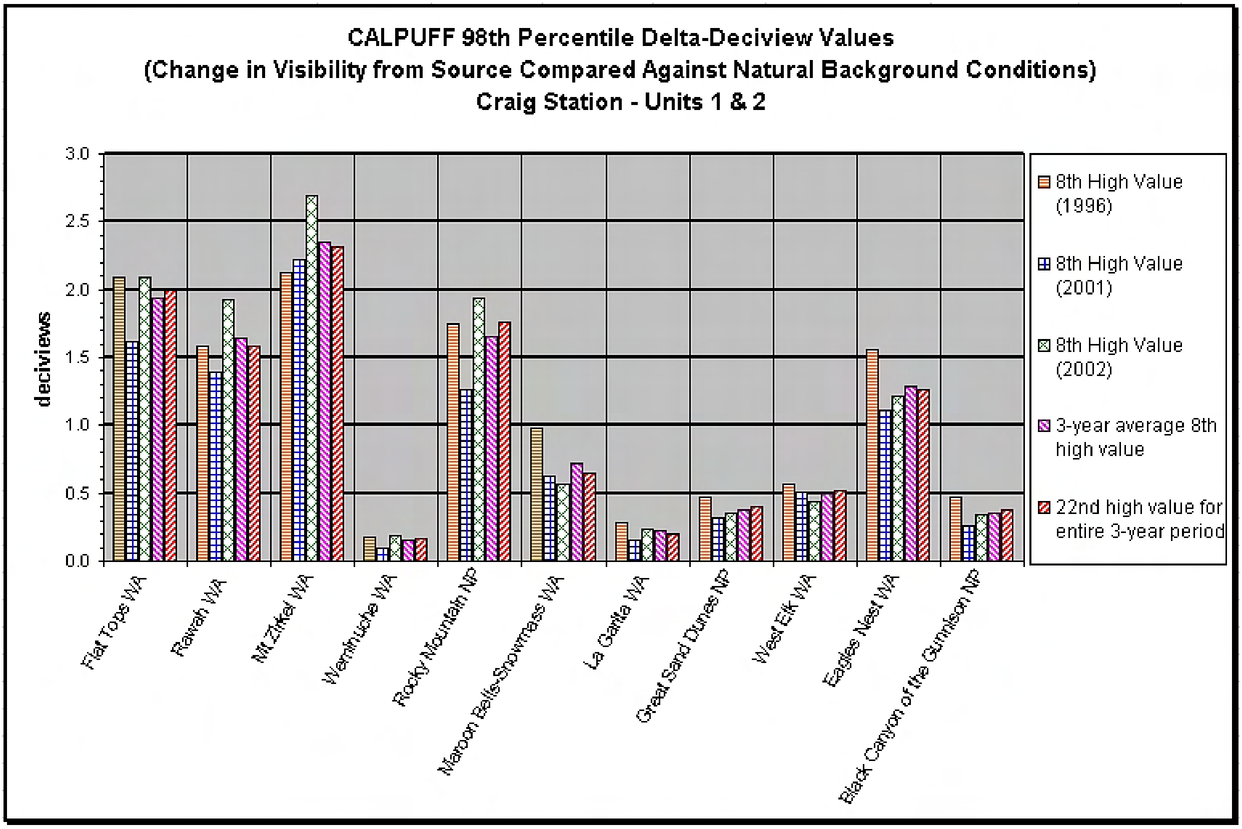

Figure 23. Comparison of 98th percentile daily change in visibility values (delta-deciviews). The highest value is compared to the contribution threshold of 0.5 deciviews.

Table 3. Summary report with results from the Division's 98th percentile postprocessor (BART98_v3) that correspond to the maximum delta-deciview value from Table 2. The 98th percentile value from "Method 1" (in bold) corresponds to the method recommended by U.S. EPA.

```
Title from CALPOST:
APCD BART - Mt Zirkel WA (MOZ); 2/22/06 v1_so2at0.16NOxat0.34_mnitrate1ppb
MVISBK=6; EPA2003 centroid monthly f(RH); EPA2003 20%bestdays natural backgrd
2002 36km MM5, 4km CALMET, hourly ozone; BART-eligible source= CRAIG

Days processed:  364
Receptors processed:      253
CALPOST species: ALL
Contribution threshold: 0.5

Summary of delta-deciview results:

The 'High  1st High' from the model is:   3.489 dv
    Number of days 'High 1 High' delta-deciview => 0.5: 199
    Number of days 'High 1 High' delta-deciview => 1.00:  96


98th Percentile Results:
-------------------------------------------------------------
Method 1. DAY-SPECIFIC - closest modeled value:
    The ' 8 High' value from the model is:  2.689 dv
       at receptor    3021 on day  118(2002)

Method 2a. RECEPTOR-SPECIFIC - closest modeled value:
    The 'High  8 High' value from the model is:  2.041 dv
       at receptor    2868 on day  325(2002)
    Number of days with delta-deciview => 0.5: 198
    Number of days with delta-deciview => 1.00:  95

Method 2b. RECEPTOR-SPECIFIC - Weighted Average at X[(n+1)p]:
    The calculated 98th percentile value
    using a weighted averaging method is:    2.050 dv
       at receptor    2868
       using days   12(2002) and 325(2002)
-------------------------------------------------------------
```

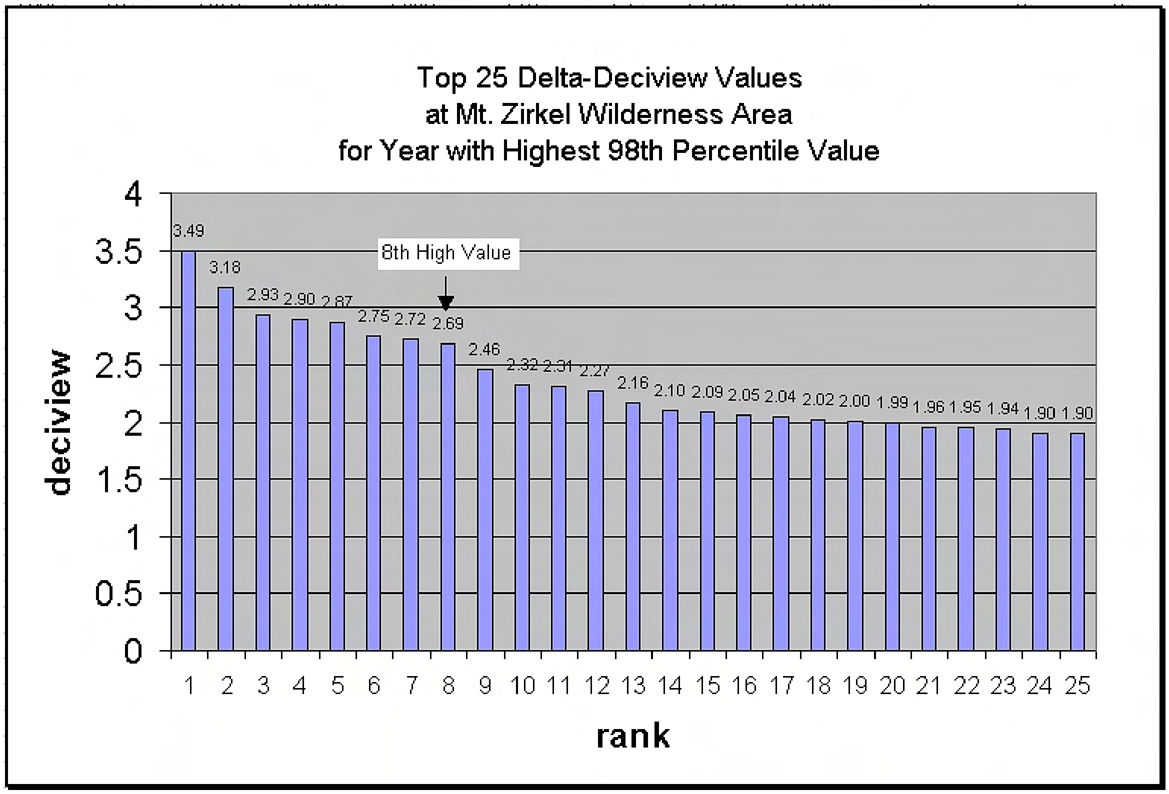

Figure 24. Distribution of delta-deciview values used to generate the maximum 98th percentile value.

YEAR	DAY	RECEPTOR	DV(Total)	DV(BKG)	DELTA DV	F(RH)	%_SO4	%_NO3	%_OC	%_EC	%_PMC	%_PMF
2002	359	2948	5.463	1.974	3.489	2.1	13.11	85.07	0	0	0	1.82
2002	38	2880	5.175	1.996	3.179	2.2	14.75	84.68	0	0	0	0.57
2002	335	3075	4.907	1.974	2.932	2.1	9.33	89.78	0	0	0	0.89
2002	34	3075	4.894	1.996	2.898	2.2	14.56	84.88	0	0	0	0.56
2002	332	2880	4.84	1.974	2.866	2.1	11.01	86.83	0	0	0	2.16
2002	30	2855	4.749	1.996	2.753	2.2	10.62	85.03	0	0	0	4.34
2002	293	2949	4.653	1.93	2.723	1.9	20.07	79.15	0	0	0	0.77
2002	118	3021	4.663	1.974	**2.689**	2.1	11.02	84.89	0	0	0	4.08
2002	145	2852	4.457	1.996	2.461	2.2	13.94	83.72	0	0	0	2.34
2002	124	2855	4.32	1.996	2.324	2.2	7.85	87.48	0	0	0	4.67
2002	344	3011	4.285	1.974	2.311	2.1	9.64	89.05	0	0	0	1.31
2002	360	2868	4.242	1.974	2.268	2.1	8.63	87.81	0	0	0	3.56
2002	298	3075	4.092	1.93	2.162	1.9	10.59	86.24	0	0	0	3.17
2002	341	3075	4.075	1.974	2.101	2.1	9.22	89.47	0	0	0	1.31
2002	84	3075	4.042	1.952	2.09	2	11.32	86.58	0	0	0	2.1
2002	12	2868	4.05	1.996	2.054	2.2	11.58	87.69	0	0	0	0.73
2002	325	2868	4.016	1.974	2.041	2.1	10.67	87.59	0	0	0	1.73
2002	137	2855	4.013	1.996	2.017	2.2	11.59	86.75	0	0	0	1.66
2002	326	2915	3.976	1.974	2.002	2.1	9.79	89.47	0	0	0	0.74
2002	255	3011	3.94	1.952	1.988	2	9.08	87.74	0	0	0	3.18
2002	85	2852	3.91	1.952	1.958	2	12.86	84.85	0	0	0	2.28
2002	292	2855	3.878	1.93	1.948	1.9	20.83	77.8	0	0	0	1.37
2002	51	2852	3.94	1.996	1.944	2.2	5.78	89.7	0	0	0	4.52
2002	297	3032	3.832	1.93	1.901	1.9	12.23	83.26	0	0	0	4.51
2002	302	2915	3.83	1.93	1.9	1.9	10.98	85.65	0	0	0	3.36

Figure 25. Top 25 delta-deciview (DELTA DV) values from the Mt Zirkel Wilderness Area for the year with the highest 98th percentile value.

7. References

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Appendix A – Natural Background Values

Appendix B
Default Natural b_{ext}, *dv*, and 10th and 90th Percentile *dv* Values at All Mandatory Federal Class I Areas

Mandatory Federal Class I Area	State	Lat.	Lon.	bext (Mm-1)	Ann. Avg. (dv)	Best Days (dv) [a]	Worst Days (dv) [a]
Acadia NP	ME	44.35	-68.24	21.40	7.61	3.77	11.45
Agua Tibia Wilderness	CA	33.42	-116.99	15.86	4.61	2.05	7.17
Alpine Lake Wilderness	WA	47.55	-121.16	16.99	5.30	2.74	7.86
Anaconda-Pintler Wilderness	MT	45.95	-113.5	16.03	4.72	2.16	7.28
Arches NP	UT	38.73	-109.58	15.58	4.43	1.87	6.99
Badlands NP	SD	43.81	-102.36	16.06	4.74	2.18	7.30
Bandelier NM	NM	35.79	-106.34	15.62	4.46	1.90	7.02
Bering Sea	AK	60.46	-172.75				
Big Bend NP	TX	29.33	-103.31	15.48	4.37	1.81	6.93
Black Canyon of the Gunnison NM	CO	38.57	-107.75	15.68	4.50	1.94	7.06
Bob Marshall Wilderness	MT	47.68	-113.23	16.17	4.80	2.24	7.36
Bosque del Apache	NM	33.79	-106.85	15.54	4.41	1.85	6.97
Boundary Waters Canoe Area	MN	48.06	-91.43	20.89	7.37	3.53	11.21
Breton	LA	29.87	-88.82	21.57	7.69	3.85	11.53
Bridger Wilderness	WY	42.99	-109.49	15.71	4.52	1.96	7.08
Brigantine	NJ	39.49	-74.39	21.05	7.44	3.60	11.28
Bryce Canyon NP	UT	37.57	-112.17	15.58	4.43	1.87	6.99
Cabinet Mountains Wilderness	MT	48.18	-115.68	16.27	4.87	2.31	7.43
Caney Creek Wilderness	AR	34.41	-94.08	21.14	7.49	3.65	11.33
Canyonlands NP	UT	38.23	-109.91	15.60	4.45	1.89	7.01
Cape Romain	SC	32.99	-79.49	21.22	7.52	3.68	11.36
Capitol Reef NP	UT	38.06	-111.15	15.63	4.47	1.91	7.03
Caribou Wilderness	CA	40.49	-121.21	16.05	4.73	2.17	7.29
Carlsbad Caverns NP	NM	32.12	-104.59	15.61	4.46	1.90	7.02
Chassahowitzka	FL	28.69	-82.66	21.46	7.63	3.79	11.47
Chiricahua NM	AZ	32.01	-109.34	15.47	4.36	1.80	6.92
Chiricahua Wilderness	AZ	31.86	-109.28	15.45	4.35	1.79	6.91
Cohutta Wilderness	GA	34.93	-84.57	21.39	7.60	3.76	11.44
Crater Lake NP	OR	42.92	-122.13	16.74	5.15	2.59	7.71
Craters of the Moon NM	ID	43.39	-113.54	15.80	4.57	2.01	7.13
Cucamonga Wilderness	CA	34.24	-117.59	15.85	4.61	2.05	7.17
Denali Preserve NP	AK	63.31	-151.19	16.27	4.86	2.30	7.42
Desolation Wilderness	CA	38.9	-120.17	15.80	4.57	2.01	7.13
Diamond Peak Wilderness	OR	43.53	-122.1	16.84	5.21	2.65	7.77
Dolly Sods Wilderness	WV	39	-79.37	21.13	7.48	3.64	11.32
Dome Land Wilderness	CA	35.84	-118.23	15.70	4.51	1.95	7.07
Eagle Cap Wilderness	OR	45.22	-117.37	16.12	4.78	2.22	7.34

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Appendix B
Default Natural b_{ext}, *dv*, and 10th and 90th Percentile *dv* Values at All Mandatory Federal Class I Areas

Mandatory Federal Class I Area	State	Lat.	Lon.	bext (Mm-1)	Ann. Avg. (dv)	Best Days (dv) [a]	Worst Days (dv) [a]
Eagles Nest Wilderness	CO	39.67	-106.29	15.72	4.52	1.96	7.08
Emigrant Wilderness	CA	38.18	-119.77	15.81	4.58	2.02	7.14
Everglades NP	FL	25.35	-80.98	20.77	7.31	3.47	11.15
Fitzpatrick Wilderness	WY	43.24	-109.6	15.73	4.53	1.97	7.09
Flat Tops Wilderness	CO	39.95	-107.3	15.70	4.51	1.95	7.07
Galiuro Wilderness	AZ	32.6	-110.39	15.40	4.32	1.76	6.88
Gates of the Mountains Wilderness	MT	46.86	-111.82	15.93	4.66	2.10	7.22
Gearhart Mountain Wilderness	OR	42.51	-120.86	16.33	4.90	2.34	7.46
Gila Wilderness	NM	33.21	-108.47	15.51	4.39	1.83	6.95
Glacier NP	MT	48.64	-113.84	16.48	5.00	2.44	7.56
Glacier Peak Wilderness	WA	48.21	-121	16.88	5.24	2.68	7.80
Goat Rocks Wilderness	WA	46.52	-121.47	16.93	5.26	2.70	7.82
Grand Canyon NP	AZ	36.3	-112.79	15.51	4.39	1.83	6.95
Grand Teton NP	WY	43.82	-110.71	15.74	4.53	1.97	7.09
Great Gulf Wilderness	NH	44.3	-71.28	21.10	7.47	3.63	11.31
Great Sand Dunes NM	CO	37.77	-105.57	15.74	4.54	1.98	7.10
Great Smoky Mountains NP	TN	35.6	-83.52	21.39	7.60	3.76	11.44
Guadalupe Mountains NP	TX	31.91	-104.85	15.64	4.47	1.91	7.03
Haleakala NP	HI	20.71	-156.16	16.02	4.71	2.15	7.27
Hawaii Volcanoes NP	HI	19.41	-155.34	16.33	4.91	2.35	7.47
Hells Canyon Wilderness	OR	45.54	-116.59	16.09	4.76	2.20	7.32
Hercules-Glades Wilderness	MO	36.68	-92.9	21.03	7.43	3.59	11.27
Hoover Wilderness	CA	38.11	-119.37	15.78	4.56	2.00	7.12
Isle Royale NP	MI	48.01	-88.83	20.91	7.38	3.54	11.22
James River Face Wilderness	VA	37.59	-79.44	20.96	7.40	3.56	11.24
Jarbidge Wilderness	NV	41.77	-115.35	15.75	4.54	1.98	7.10
John Muir Wilderness	CA	36.97	-118.88	15.80	4.58	2.02	7.14
Joshua Tree NM	CA	33.92	-115.88	15.72	4.52	1.96	7.08
Joyce-Kilmer-Slickrock Wilderness	TN	35.44	-83.99	21.40	7.61	3.77	11.45
Kaiser Wilderness	CA	37.28	-119.17	15.80	4.57	2.01	7.13
Kalmiopsis Wilderness	OR	42.26	-123.92	16.74	5.15	2.59	7.71
Kings Canyon NP	CA	36.92	-118.61	15.79	4.57	2.01	7.13
La Garita Wilderness	CO	37.95	-106.83	15.69	4.50	1.94	7.06
Lassen Volcanic NP	CA	40.49	-121.41	16.08	4.75	2.19	7.31
Lava Beds NM	CA	41.76	-121.52	16.37	4.93	2.37	7.49
Linville Gorge Wilderness	NC	35.88	-81.9	21.36	7.59	3.75	11.43
Lostwood	ND	48.59	-102.46	16.11	4.77	2.21	7.33

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Appendix B
Default Natural b_{ext}, *dv*, and 10[th] and 90[th] Percentile *dv* Values at All Mandatory Federal Class I Areas

Mandatory Federal Class I Area	State	Lat.	Lon.	bext (Mm-1)	Ann. Avg. (dv)	Best Days (dv) [a]	Worst Days (dv) [a]
Lye Brook Wilderness	VT	43.13	-73.02	20.99	7.41	3.57	11.25
Mammoth Cave NP	KY	37.2	-86.15	21.58	7.69	3.85	11.53
Marble Mountain Wilderness	CA	41.51	-123.21	16.65	5.10	2.54	7.66
Maroon Bells-Snowmass Wilderness	CO	39.1	-107.02	15.70	4.51	1.95	7.07
Mazatzal Wilderness	AZ	34.13	-111.56	15.44	4.35	1.79	6.91
Medicine Lake	MT	48.49	-104.35	16.07	4.74	2.18	7.30
Mesa Verde NP	CO	37.25	-108.45	15.73	4.53	1.97	7.09
Minarets Wilderness	CA	37.74	-119.19	15.78	4.56	2.00	7.12
Mingo	MO	37	-90.19	21.03	7.43	3.59	11.27
Mission Mountains Wilderness	MT	47.48	-113.87	16.21	4.83	2.27	7.39
Mokelumne Wilderness	CA	38.57	-120.06	15.80	4.58	2.02	7.14
Moosehorn	ME	45.09	-67.29	21.22	7.52	3.68	11.36
Mount Adams Wilderness	WA	46.2	-121.49	16.86	5.22	2.66	7.78
Mount Baldy Wilderness	AZ	33.95	-109.54	15.51	4.39	1.83	6.95
Mount Hood Wilderness	OR	45.37	-121.73	16.83	5.21	2.65	7.77
Mount Jefferson Wilderness	OR	44.61	-121.84	16.91	5.25	2.69	7.81
Mount Rainier NP	WA	46.86	-121.72	17.05	5.34	2.78	7.90
Mount Washington Wilderness	OR	44.3	-121.88	17.03	5.33	2.77	7.89
Mount Zirkel Wilderness	CO	40.75	-106.68	15.71	4.52	1.96	7.08
Mountain Lakes Wilderness	OR	42.33	-122.11	16.50	5.01	2.45	7.57
North Absaroka Wilderness	WY	44.74	-109.8	15.74	4.53	1.97	7.09
North Cascades NP	WA	48.83	-121.35	16.86	5.22	2.66	7.78
Okefenokee	GA	30.82	-82.33	21.41	7.61	3.77	11.45
Olympic NP	WA	47.77	-123.74	17.02	5.32	2.76	7.88
Otter Creek Wilderness	WV	38.99	-79.65	21.14	7.49	3.65	11.33
Pasayten Wilderness	WA	48.89	-120.44	16.84	5.21	2.65	7.77
Pecos Wilderness	NM	35.9	-105.62	15.65	4.48	1.92	7.04
Petrified Forest NP	AZ	34.99	-109.79	15.54	4.41	1.85	6.97
Pine Mountain Wilderness	AZ	34.31	-111.8	15.47	4.36	1.80	6.92
Pinnacles NM	CA	36.48	-121.19	16.12	4.78	2.22	7.34
Point Reyes NS	CA	38.06	-122.9	16.20	4.83	2.27	7.39
Presidential Range-Dry River Wilderness	NH	44.2	-71.34	21.15	7.49	3.65	11.33
Rainbow Lake Wilderness	WI	46.42	-91.31	20.99	7.42	3.58	11.26
Rawah Wilderness	CO	40.69	-105.95	15.72	4.52	1.96	7.08
Red Rock Lakes	MT	44.64	-111.78	15.81	4.58	2.02	7.14
Redwood NP	CA	41.44	-124.03	16.90	5.25	2.69	7.81
Rocky Mountain NP	CO	40.35	-105.7	15.67	4.49	1.93	7.05

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Appendix B
Default Natural b_{ext}, *dv*, and 10[th] and 90[th] Percentile *dv* Values at All Mandatory Federal Class I Areas

Mandatory Federal Class I Area	State	Lat.	Lon.	bext (Mm-1)	Ann. Avg. (dv)	Best Days (dv) [a]	Worst Days (dv) [a]
Roosevelt Campobello International Park	ME	44.85	-66.94	21.22	7.52	3.68	11.36
Saguaro NM	AZ	32.17	-110.61	15.35	4.28	1.72	6.84
Salt Creek	NM	33.6	-104.41	15.58	4.43	1.87	6.99
San Gabriel Wilderness	CA	34.27	-117.94	15.86	4.61	2.05	7.17
San Gorgonio Wilderness	CA	34.12	-116.84	15.74	4.54	1.98	7.10
San Jacinto Wilderness	CA	33.75	-116.64	15.78	4.56	2.00	7.12
San Pedro Parks Wilderness	NM	36.11	-106.81	15.63	4.47	1.91	7.03
San Rafael Wilderness	CA	34.76	-119.81	16.03	4.72	2.16	7.28
Sawtooth Wilderness	ID	43.99	-115.06	15.82	4.59	2.03	7.15
Scapegoat Wilderness	MT	47.16	-112.74	16.05	4.73	2.17	7.29
Selway-Bitterroot Wilderness	ID	46.12	-114.86	16.09	4.76	2.20	7.32
Seney	MI	46.25	-86.09	21.23	7.53	3.69	11.37
Sequoia NP	CA	36.51	-118.56	15.79	4.57	2.01	7.13
Shenandoah NP	VA	38.47	-78.49	20.98	7.41	3.57	11.25
Shining Rock Wilderness	NC	35.38	-82.85	21.40	7.61	3.77	11.45
Sierra Ancha Wilderness	AZ	33.85	-110.9	15.46	4.36	1.80	6.92
Simeonof	AK	54.91	-159.28	17.21	5.43	2.87	7.99
Sipsey Wilderness	AL	34.32	-87.44	21.28	7.55	3.71	11.39
South Warner Wilderness	CA	41.31	-120.2	16.09	4.76	2.20	7.32
St. Marks	FL	30.11	-84.15	21.54	7.67	3.83	11.51
Strawberry Mountain Wilderness	OR	44.29	-118.74	16.37	4.93	2.37	7.49
Superstition Wilderness	AZ	33.5	-111.27	15.40	4.32	1.76	6.88
Swanquarter	NC	35.39	-76.39	20.91	7.38	3.54	11.22
Sycamore Canyon Wilderness	AZ	35.01	-112.09	15.53	4.40	1.84	6.96
Teton Wilderness	WY	44.04	-110.17	15.74	4.53	1.97	7.09
Theodore Roosevelt NP	ND	46.96	-103.46	16.08	4.75	2.19	7.31
Thousand Lakes Wilderness	CA	40.7	-121.58	16.10	4.76	2.20	7.32
Three Sisters Wilderness	OR	44.04	-121.91	17.01	5.31	2.75	7.87
Tuxedni	AK	60.14	-152.61	16.58	5.06	2.50	7.62
UL Bend	MT	47.54	-107.89	15.87	4.62	2.06	7.18
Upper Buffalo Wilderness	AR	36.17	-92.41	21.04	7.44	3.60	11.28
Ventana Wilderness	CA	36.21	-121.6	16.09	4.76	2.20	7.32
Virgin Islands NP **(b)**	VI	18.35	-64.74				
Voyageurs NP	MN	48.47	-92.8	20.64	7.25	3.41	11.09
Washakie Wilderness	WY	44.1	-109.57	15.73	4.53	1.97	7.09
Weminuche Wilderness	CO	37.61	-107.25	15.68	4.50	1.94	7.06
West Elk Wilderness	CO	38.75	-107.21	15.71	4.51	1.95	7.07

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Appendix B
Default Natural b_{ext}, dv, and 10[th] and 90[th] Percentile dv Values at All Mandatory Federal Class I Areas

Mandatory Federal Class I Area	State	Lat.	Lon.	bext (Mm-1)	Ann. Avg. (dv)	Best Days (dv) (a)	Worst Days (dv) (a)
Wheeler Peak Wilderness	NM	36.57	-105.4	15.70	4.51	1.95	7.07
White Mountain Wilderness	NM	33.48	-105.85	15.56	4.42	1.86	6.98
Wichita Mountains	OK	34.75	-98.65	20.60	7.23	3.39	11.07
Wind Cave NP	SD	43.58	-103.47	15.97	4.68	2.12	7.24
Wolf Island	GA	31.33	-81.3	21.33	7.58	3.74	11.42
Yellowstone NP	WY	44.63	-110.51	15.77	4.56	2.00	7.12
Yolla Bolly Middle Eel Wilderness	CA	40.09	-122.96	16.25	4.85	2.29	7.41
Yosemite NP	CA	37.85	-119.54	15.81	4.58	2.02	7.14
Zion NP	UT	37.32	-113.04	15.56	4.42	1.86	6.98

(a) Values for the best and worst days are estimated from a statistical approach described in Section 2.6 of this document.
(b) *f(RH)* values for Virgin Islands National Park were not calculated because of the limited RH data available. As such no estimates for Natural Visibility Conditions are presented at this time.

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Appendix B – Monthly f(RH) Values

Table A-3 Monthly Site-Specific f(RH) Values for Each Mandatory Federal Class I Area, Based on the Centroid of the Area (Supplemental Information)

Class I Area	Site Name	Map ID	Code	Site St	LAT	LONG	Jan f(RH)	Feb f(RH)	Mar f(RH)	Apr f(RH)	May f(RH)	Jun f(RH)	Jul f(RH)	Aug f(RH)	Sep f(RH)	Oct f(RH)	Nov f(RH)	Dec f(RH)
Acadia	Acadia	1	ACAD1	ME	44.37	68.26	3.3	2.9	2.8	3.4	3.1	3.0	3.4	3.8	4.0	3.8	3.6	3.5
Agua Tibia	Agua Tibia	100	AGTI1	CA	33.41	116.98	2.4	2.4	2.4	2.2	2.2	2.2	2.3	2.3	2.3	2.3	2.1	2.2
Alpine Lakes	Snoqualmie Pass	80	SNPA1	WA	47.42	121.42	4.3	3.8	3.5	3.9	2.9	3.2	2.9	3.1	3.3	3.9	4.5	4.5
Anaconda - Pintler	Sula	71	SULA1	MT	45.98	113.42	3.3	2.9	2.5	2.4	2.4	2.3	2.0	1.9	2.1	2.5	3.2	3.3
Ansel Adams	Kaiser	110	KAIS1	CA	37.65	119.20	3.0	2.7	2.4	2.1	1.9	1.7	1.6	1.6	1.6	1.8	2.3	2.7
Arches	Canyonlands	50	CANY1	UT	38.64	109.58	2.6	2.3	1.8	1.6	1.6	1.3	1.4	1.5	1.6	1.6	2.0	2.3
Badlands	Badlands	59	BADL1	SD	43.74	101.94	2.6	2.7	2.6	2.4	2.8	2.7	2.5	2.4	2.2	2.3	2.7	2.7
Bandelier	Bandelier	33	BAND1	NM	35.78	106.27	2.2	2.1	1.8	1.6	1.6	1.4	1.7	2.1	1.9	1.7	2.0	2.2
Bering Sea (a)					60.45	172.79												
Big Bend	Big Bend	31	BIBE1	TX	29.31	103.19	2.0	1.9	1.6	1.5	1.6	1.6	1.7	2.0	2.1	1.9	1.8	1.9
Black Canyon of the Gunnison	Weminuche	55	WEMI1	CO	38.58	107.70	2.4	2.2	1.9	1.9	1.9	1.6	1.7	1.9	2.0	1.8	2.1	2.3
Bob Marshall	Monture	73	MONT1	MT	47.75	113.38	3.6	3.1	2.8	2.6	2.7	2.7	2.3	2.2	2.6	2.9	3.5	3.5
Bosque del Apache	Bosque del Apache	38	BOAP1	NM	33.79	106.83	2.1	1.9	1.6	1.4	1.4	1.3	1.8	2.0	1.9	1.6	1.8	2.2
Boundary Waters Canoe Area	Boundary Waters	23	BOWA1	MN	47.95	91.50	3.0	2.6	2.7	2.4	2.3	2.9	3.1	3.4	3.5	2.8	3.2	3.2
Breton	Breton	20	BRET1	LA	29.73	88.88	3.7	3.5	3.7	3.6	3.8	4.0	4.3	4.3	4.2	3.7	3.7	3.7
Bridger	Bridger	65	BRID1	WY	42.98	109.76	2.5	2.4	2.3	2.2	2.1	1.8	1.5	1.5	1.7	2.0	2.4	2.4
Brigantine	Brigantine	5	BRIG1	NJ	39.46	74.45	2.8	2.6	2.7	2.6	3.0	3.2	3.4	3.7	3.6	3.3	2.9	2.8
Bryce Canyon	Bryce Canyon	49	BRCA1	UT	37.62	112.17	2.6	2.4	1.9	1.6	1.5	1.3	1.3	1.5	1.5	1.6	2.0	2.4
Cabinet Mountains	Cabinet Mountains	75	CABI1	MT	48.21	115.71	3.8	3.3	2.9	2.6	2.7	2.7	2.3	2.2	2.6	3.0	3.7	3.9
Caney Creek	Caney Creek	29	CACR1	AR	34.41	94.08	3.4	3.1	2.9	3.0	3.6	3.6	3.4	3.4	3.6	3.5	3.4	3.5
Canyonlands	Canyonlands	50	CANY1	UT	38.46	109.82	2.6	2.3	1.7	1.6	1.5	1.2	1.3	1.5	1.6	1.6	2.0	2.3
Cape Romain	Cape Romain	15	ROMA1	SC	32.94	79.66	3.3	3.0	2.9	2.8	3.2	3.7	3.6	4.1	4.0	3.7	3.4	3.2
Capitol Reef	Capitol Reef	52	CAPI1	UT	38.36	111.05	2.7	2.4	2.0	1.7	1.6	1.4	1.4	1.6	1.6	1.7	2.1	2.5
Caribou	Lassen Volcanic	90	LAVO1	CA	40.50	121.18	3.7	3.1	2.8	2.5	2.4	2.2	2.1	2.1	2.2	2.4	3.0	3.4
Carlsbad Caverns	Guadalupe Mountains	32	GUMO1	TX	32.14	104.48	2.1	2.0	1.6	1.5	1.6	1.6	1.8	2.1	2.2	1.8	1.9	2.1
Chassahowitzka	Chassahowitzka	18	CHAS1	FL	28.75	82.55	3.8	3.5	3.4	3.2	3.3	3.9	3.9	4.2	4.1	3.9	3.7	3.9
Chiricahua NM	Chiricahua	39	CHIR1	AZ	32.01	109.39	2.0	2.0	1.6	1.3	1.3	1.1	1.8	2.1	1.8	1.5	1.6	2.2
Chiricahua W	Chiricahua	39	CHIR1	AZ	31.84	109.27	2.0	1.9	1.6	1.2	1.3	1.1	1.8	2.1	1.8	1.5	1.6	2.2
Cohutta	Cohutta	12	COHU1	GA	34.92	84.58	3.3	3.1	3.0	2.8	3.4	3.8	4.0	4.2	4.2	3.8	3.4	3.5
Crater Lake	Crater Lake	86	CRLA1	OR	42.90	122.13	4.6	3.9	3.7	3.4	3.2	3.0	2.8	2.9	3.1	3.6	4.6	4.6
Craters of the Moon	Craters of the Moon	69	CRMO1	ID	43.47	113.55	3.1	2.7	2.3	2.0	2.0	1.8	1.4	1.4	1.6	2.0	2.8	3.0
Cucamonga	San Gabriel	93	SAGA1	CA	34.25	117.57	2.5	2.4	2.4	2.2	2.1	2.1	2.1	2.2	2.2	2.2	2.1	2.2
Denali	Denali	102	DENA1	AK	63.72	148.97	2.5	2.3	2.1	1.9	1.9	2.2	2.5	3.0	2.8	2.9	3.0	3.1
Desolation	Bliss	95	BLIS1	CA	38.98	120.12	3.2	2.8	2.4	2.0	1.8	1.6	1.5	1.6	1.7	1.9	2.4	3.0
Diamond Peak	Crater Lake	86	CRLA1	OR	43.53	122.10	4.5	4.0	3.6	3.7	3.2	3.1	2.9	2.9	3.1	3.7	4.6	4.6
Dolly Sods	Dolly Sods	8	DOSO1	WV	39.11	79.43	3.0	2.8	2.8	2.6	3.1	3.4	3.5	3.9	3.9	3.3	3.0	3.1

Table A-3 Monthly Site-Specific f(RH) Values for Each Mandatory Federal Class I Area, Based on the Centroid of the Area (Supplemental Information)

Class I Area	Site Name	Map ID	Code	Site St	LAT	LONG	Jan f(RH)	Feb f(RH)	Mar f(RH)	Apr f(RH)	May f(RH)	Jun f(RH)	Jul f(RH)	Aug f(RH)	Sep f(RH)	Oct f(RH)	Nov f(RH)	Dec f(RH)
Dome Land	Dome Land	109	DOME1	CA	35.70	118.19	2.5	2.3	2.2	1.9	1.8	1.8	1.8	1.8	1.8	1.9	2.0	2.2
Eagle Cap	Starkey	76	STAR1	OR	45.10	117.29	3.8	3.2	2.5	2.1	2.0	1.9	1.6	1.6	1.6	2.3	3.4	4.0
Eagles Nest	White River	56	WHRI1	CO	39.69	106.25	2.2	2.2	2.0	2.0	2.1	1.9	1.8	2.0	2.0	1.9	2.1	2.1
Emigrant	Yosemite	96	YOSE1	CA	38.20	119.75	3.2	2.8	2.5	2.1	1.9	1.7	1.5	1.6	1.6	1.9	2.4	2.9
Everglades	Everglades	19	EVER1	FL	25.39	80.68	2.7	2.6	2.6	2.4	2.4	2.7	2.6	2.9	3.0	2.8	2.6	2.7
Fitzpatrick	Bridger	65	BRID1	WY	43.27	109.57	2.5	2.3	2.2	2.1	2.1	1.8	1.5	1.5	1.7	2.0	2.4	2.4
Flat Tops	White River	56	WHRI1	CO	39.97	107.25	2.3	2.2	2.0	2.0	2.0	1.8	1.7	1.9	1.9	1.8	2.2	2.2
Galiuro	Chiricahua	39	CHIR1	AZ	32.56	110.32	2.0	1.8	1.5	1.2	1.2	1.1	1.5	1.8	1.6	1.5	1.6	2.1
Gates of the Mountains	Gates of the Mountains	74	GAMO1	MT	46.87	111.81	2.9	2.6	2.4	2.3	2.3	2.3	2.0	1.9	2.1	2.4	2.8	2.8
Gearhart Mountain	Crater Lake	86	CRLA1	OR	42.49	120.85	4.0	3.4	3.1	2.8	2.7	2.5	2.3	2.3	2.4	2.8	3.7	3.8
Gila	Gila Cliffs	42	GICL1	NM	33.22	108.25	2.1	1.9	1.6	1.3	1.4	1.2	2.1	2.0	1.8	1.6	1.8	2.2
Glacier	Glacier	72	GLAC1	MT	48.51	114.00	4.0	3.5	3.2	3.1	3.2	3.4	2.8	2.6	3.2	3.5	3.8	3.9
Glacier Peak	North Cascades	81	NOCA1	WA	48.21	121.04	4.2	3.7	3.4	3.8	2.9	3.2	2.9	3.1	3.3	3.9	4.4	4.4
Goat Rocks	White Pass	79	WHPA1	WA	46.54	121.48	4.3	3.8	3.4	4.2	2.8	3.4	3.0	3.2	3.1	3.8	4.4	4.6
Grand Canyon	Grand Canyon, Hance	48	GRCA2	AZ	35.97	111.98	2.4	2.3	1.9	1.5	1.4	1.2	1.4	1.7	1.6	1.6	1.9	2.3
Grand Teton	Yellowstone	66	YELL2	WY	43.68	110.73	2.6	2.4	2.2	2.1	2.1	1.8	1.5	1.5	1.7	2.0	2.4	2.6
Great Gulf	Great Gulf	4	GRGU1	NH	44.31	71.22	2.8	2.6	2.6	2.8	2.9	3.2	3.5	3.8	4.0	3.4	3.1	2.9
Great Sand Dunes	Great Sand Dunes	53	GRSA1	CO	37.73	105.52	2.4	2.3	2.0	1.9	1.9	1.8	1.9	2.3	2.2	1.9	2.4	2.4
Great Smoky Mountains	Great Smoky Mountains	10	GRSM1	TN	35.63	83.94	3.3	3.0	2.9	2.7	3.2	3.9	3.8	4.0	4.2	3.8	3.3	3.4
Guadalupe Mountains	Guadalupe Mountains	32	GUMO1	TX	31.83	104.80	2.0	2.0	1.6	1.5	1.6	1.5	1.9	2.2	2.2	1.8	1.9	2.2
Haleakala	Haleakala	108	HALE1	HI	20.81	156.28	2.7	2.6	2.6	2.5	2.4	2.3	2.5	2.4	2.4	2.5	2.8	2.7
Hawaii Volcanoes	Hawaii Volcanoes	107	HAVO1	HI	19.43	155.27	3.2	2.9	3.0	3.0	3.0	2.9	3.1	3.2	3.2	3.2	3.7	3.2
Hells Canyon	Hells Canyon	77	HECA1	OR	45.34	116.57	3.7	3.1	2.5	2.2	2.1	2.0	1.6	1.6	1.8	2.4	3.5	3.9
Hercules - Glade	Hercules - Glade	28	HEGL1	MO	36.69	92.90	3.2	2.9	2.7	2.7	3.3	3.3	3.3	3.3	3.4	3.1	3.1	3.3
Hoover	Hoover	97	HOOV1	CA	38.14	119.45	3.1	2.8	2.5	2.1	1.9	1.6	1.5	1.5	1.6	1.8	2.3	2.8
Isle Royale	Isle Royale	25	ISLE1	MI	47.99	88.83	3.1	2.5	2.7	2.4	2.2	2.6	3.0	3.2	3.8	2.7	3.3	3.3
James River Face	James River Face	7	JARI1	VA	37.62	79.48	2.8	2.6	2.7	2.4	3.0	3.3	3.4	3.7	3.6	3.2	2.8	3.0
Jarbidge	Jarbidge	68	JARB1	NV	41.89	115.43	3.0	2.6	2.1	2.1	2.2	2.2	1.6	1.4	1.4	1.6	2.4	2.8
John Muir	Kaiser	110	KAIS1	CA	37.39	118.84	2.9	2.6	2.4	2.1	1.9	1.7	1.7	1.7	1.7	1.9	2.2	2.6
Joshua Tree	Joshua Tree	101	JOSH1	CA	34.03	116.18	2.4	2.3	2.2	2.0	2.0	1.9	2.0	2.0	2.0	2.0	1.9	2.0
Joyce Kilmer - Slickrock	Great Smoky Mountains	10	GRSM1	TN	35.43	84.00	3.3	3.1	2.9	2.7	3.3	3.8	4.0	4.2	4.2	3.8	3.3	3.5
Kaiser	Kaiser	110	KAIS1	CA	37.28	119.18	3.0	2.7	2.5	2.1	1.9	1.7	1.6	1.7	1.7	1.9	2.3	2.7
Kalmiopsis	Kalmiopsis	89	KALM1	OR	42.27	123.93	4.5	3.9	3.8	3.5	3.5	3.3	3.2	3.2	3.3	3.6	4.4	4.3
Kings Canyon	Sequoia	98	SEQU1	CA	36.82	118.76	2.8	2.6	2.4	2.1	1.9	1.8	1.7	1.7	1.8	1.9	2.3	2.5
La Garita	Weminuche	55	WEMI1	CO	37.96	106.81	2.3	2.2	1.9	1.8	1.8	1.6	1.7	2.1	2.0	1.8	2.2	2.3
Lassen Volcanic	Lassen Volcanic	90	LAVO1	CA	40.54	121.57	3.8	3.2	2.9	2.5	2.4	2.2	2.1	2.1	2.2	2.4	3.1	3.5

Table A-3 Monthly Site-Specific f(RH) Values for Each Mandatory Federal Class I Area, Based on the Centroid of the Area (Supplemental Information)

Class I Area	Site Name	Map ID	Code	Site St	LAT	LONG	Jan f(RH)	Feb f(RH)	Mar f(RH)	Apr f(RH)	May f(RH)	Jun f(RH)	Jul f(RH)	Aug f(RH)	Sep f(RH)	Oct f(RH)	Nov f(RH)	Dec f(RH)
Lava Beds	Lava Beds	87	LABE1	CA	41.71	121.34	4.0	3.4	3.1	2.7	2.6	2.4	2.3	2.3	2.4	2.7	3.5	3.8
Linville Gorge	Linville Gorge	13	LIGO1	NC	35.89	81.89	3.3	3.0	3.0	2.7	3.3	3.9	4.1	4.5	4.4	3.7	3.2	3.4
Lostwood	Lostwood	62	LOST1	ND	48.60	102.48	3.0	2.9	2.9	2.3	2.3	2.6	2.7	2.4	2.3	2.4	3.2	3.2
Lye Brook	Lye Brook	3	LYBR1	VT	43.15	73.12	2.7	2.6	2.6	2.6	2.8	3.0	3.3	3.6	3.7	3.3	2.9	2.8
Mammoth Cave	Mammoth Cave	9	MACA1	KY	37.22	86.07	3.4	3.1	2.9	2.6	3.2	3.5	3.7	3.9	3.9	3.4	3.2	3.5
Marble Mountain	Trinity	104	TRIN1	CA	41.52	123.21	4.4	3.8	3.7	3.3	3.4	3.2	3.2	3.2	3.2	3.4	4.1	4.2
Maroon Bells - Snowmass	White River	56	WHRI1	CO	39.15	106.82	2.2	2.1	2.0	2.0	2.1	1.7	1.9	2.2	2.1	1.8	2.1	2.1
Mazatzal	Ike's Backbone	46	IKBA1	AZ	33.92	111.43	2.1	1.9	1.7	1.3	1.3	1.1	1.5	1.7	1.6	1.5	1.7	2.1
Medicine Lake	Medicine Lake	63	MELA1	MT	48.50	104.29	3.0	2.9	2.9	2.3	2.2	2.5	2.5	2.2	2.2	2.4	3.2	3.2
Mesa Verde	Mesa Verde	54	MEVE1	CO	37.20	108.49	2.5	2.3	1.9	1.5	1.5	1.3	1.6	2.0	1.9	1.7	2.1	2.3
Mingo	Mingo	26	MING1	MO	36.98	90.20	3.3	3.0	2.8	2.6	3.0	3.2	3.3	3.5	3.5	3.1	3.1	3.3
Mission Mountains	Monture	73	MONT1	MT	47.40	113.85	3.6	3.1	2.7	2.5	2.6	2.6	2.3	2.2	2.5	2.9	3.5	3.6
Mokelumne	Bliss	95	BLIS1	CA	38.58	120.03	3.2	2.8	2.4	2.0	1.9	1.6	1.5	1.6	1.7	1.9	2.4	2.9
Moosehorn	Moosehorn	2	MOOS1	ME	45.12	67.26	3.0	2.7	2.7	3.0	3.0	3.1	3.4	3.8	3.9	3.5	3.2	3.2
Mount Adams	White Pass	79	WHPA1	WA	46.19	121.50	4.3	3.8	3.4	4.4	2.9	3.5	3.1	3.3	3.1	3.9	4.5	4.6
Mount Baldy	Mount Baldy	43	BALD1	AZ	34.12	109.57	2.2	2.0	1.7	1.4	1.3	1.2	1.6	1.9	1.7	1.6	1.8	2.2
Mount Hood	Mount Hood	85	MOHO1	OR	45.38	121.69	4.3	3.8	3.5	3.9	3.0	3.2	2.9	3.0	3.1	3.9	4.5	4.6
Mount Jefferson	Three Sisters	84	THSI1	OR	44.55	121.83	4.4	3.9	3.6	3.7	3.1	3.1	2.9	2.9	3.0	3.8	4.6	4.5
Mount Rainier	Mount Rainier	78	MORA1	WA	46.76	122.12	4.4	4.0	3.6	4.7	3.1	3.7	3.3	3.5	3.4	4.1	4.7	4.7
Mount Washington	Three Sisters	84	THSI1	OR	44.30	121.87	4.4	3.9	3.6	3.7	3.1	3.1	3.0	2.9	3.0	3.8	4.6	4.6
Mount Zirkel	Mount Zirkel	58	MOZI1	CO	40.55	106.70	2.2	2.2	2.0	2.1	2.2	1.9	1.7	1.9	2.0	1.9	2.1	2.1
Mountain Lakes	Crater Lake	86	CRLA1	OR	42.34	122.11	4.3	3.6	3.3	3.0	2.9	2.6	2.5	2.5	2.6	3.1	4.1	4.3
North Absaroka	North Absoraka	67	NOAB1	WY	44.77	109.78	2.4	2.3	2.2	2.2	2.1	1.9	1.7	1.6	1.8	2.0	2.4	2.4
North Cascades	North Cascades	81	NOCA1	WA	48.54	121.44	4.1	3.7	3.4	3.7	2.9	3.2	2.9	3.2	3.5	3.9	4.4	4.4
Okefenokee	Okefenokee	16	OKEF1	GA	30.74	82.13	3.5	3.2	3.1	3.0	3.6	3.7	3.7	4.1	4.0	3.8	3.5	3.6
Olympic	Olympic	83	OLYM1	WA	47.32	123.35	4.5	4.1	3.8	4.1	3.2	3.5	3.1	3.5	3.7	4.4	4.8	4.8
Otter Creek	Dolly Sods	8	DOSO1	WV	39.00	79.65	3.0	2.8	2.8	2.6	3.2	3.5	3.7	4.1	4.0	3.3	3.0	3.1
Pasayten	Pasayten	82	PASA1	WA	48.85	120.52	4.2	3.7	3.4	3.7	2.9	3.2	2.9	3.2	3.3	3.9	4.4	4.5
Pecos	Wheeler Peak	35	WHPE1	NM	35.93	105.64	2.3	2.1	1.8	1.7	1.7	1.5	1.8	2.1	2.0	1.7	2.0	2.2
Petrified Forest	Petrified Forest	41	PEFO1	AZ	35.08	109.77	2.4	2.2	1.7	1.4	1.3	1.2	1.5	1.8	1.7	1.6	1.9	2.3
Pine Mountain	Ike's Backbone	46	IKBA1	AZ	34.31	111.80	2.2	2.0	1.7	1.4	1.3	1.1	1.4	1.8	1.6	1.5	1.7	2.1
Pinnacles	Pinnacles	92	PINN1	CA	36.49	121.16	3.2	2.8	2.6	2.4	2.3	2.0	2.0	2.1	2.1	2.3	2.5	2.9
Point Reyes	Point Reyes	91	PORE1	CA	38.12	122.90	3.6	3.3	3.1	2.7	2.5	2.3	2.5	2.6	2.6	2.7	2.9	3.3
Presidential Range - Dry River	Great Gulf	4	GRGU1	NH	44.21	71.35	2.8	2.6	2.6	2.8	3.0	3.4	3.7	4.0	4.3	3.5	3.1	3.0
Rawah	Mount Zirkel	58	MOZI1	CO	40.70	105.94	2.1	2.1	2.0	2.1	2.3	2.0	1.8	2.0	2.0	1.9	2.1	2.0
Red Rock Lakes	Yellowstone	66	YELL2	WY	44.67	111.70	2.7	2.5	2.3	2.1	2.1	1.9	1.7	1.6	1.8	2.1	2.6	2.7

Guidance for Tracking Progress Under the Regional Haze Rule

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Class I Area	Site Name	Map ID	Code	Site St	LAT	LONG	Jan f(RH)	Feb f(RH)	Mar f(RH)	Apr f(RH)	May f(RH)	Jun f(RH)	Jul f(RH)	Aug f(RH)	Sep f(RH)	Oct f(RH)	Nov f(RH)	Dec f(RH)
Redwood	Redwood	88	REDW1	CA	41.56	124.08	4.4	3.9	4.6	3.9	4.5	4.7	4.9	4.7	4.3	3.7	3.8	3.4
Rocky Mountain	Rocky Mountain	57	ROMO1	CO	40.28	105.55	1.7	1.9	1.9	2.1	2.3	2.0	1.8	2.0	1.9	1.8	1.8	1.7
Roosevelt Campobello	Moosehorn	2	MOOS1	ME	44.88	66.95	3.0	2.7	2.7	3.0	3.0	3.1	3.4	3.8	3.9	3.5	3.3	3.2
Saguaro	Saguaro	40	SAGU1	AZ	32.25	110.73	1.8	1.6	1.4	1.1	1.1	1.1	1.4	1.8	1.6	1.4	1.6	2.1
Saint Marks	Saint Marks	17	SAMA1	FL	30.12	84.08	3.7	3.4	3.4	3.4	3.5	4.0	4.1	4.4	4.2	3.8	3.7	3.8
Salt Creek	Salt Creek	36	SACR1	NM	33.81	104.37	2.1	1.9	1.5	1.5	1.7	1.6	1.8	2.0	2.1	1.8	1.8	2.1
San Gabriel	San Gabriel	93	SAGA1	CA	34.27	117.94	2.5	2.5	2.4	2.2	2.2	2.1	2.2	2.2	2.2	2.3	2.1	2.2
San Gorgonio	San Gorgonio	99	SAGO1	CA	34.18	116.90	2.7	2.8	2.6	2.3	2.2	1.9	1.8	1.9	1.9	1.9	1.9	2.2
San Jacinto	San Gorgonio	99	SAGO1	CA	33.75	116.65	2.5	2.4	2.4	2.2	2.1	2.0	2.1	2.1	2.1	2.1	2.0	2.1
San Pedro Parks	San Pedro Parks	34	SAPE1	NM	36.11	106.81	2.3	2.1	1.8	1.6	1.6	1.4	1.7	2.0	1.9	1.7	2.1	2.2
San Rafael	San Rafael	94	RAFA1	CA	34.78	119.83	2.8	2.7	2.7	2.4	2.3	2.3	2.5	2.5	2.4	2.5	2.3	2.5
Sawtooth	Sawtooth	70	SAWT1	ID	44.18	114.93	3.3	2.9	2.3	2.0	2.0	1.8	1.4	1.4	1.5	2.0	2.9	3.3
Scapegoat	Monture	73	MONT1	MT	47.17	112.73	3.2	2.8	2.6	2.4	2.5	2.4	2.1	2.0	2.3	2.6	3.1	3.1
Selway - Bitterroot	Sula	71	SULA1	MT	45.86	114.00	3.5	3.0	2.6	2.3	2.4	2.3	1.9	1.9	2.1	2.6	3.3	3.5
Seney	Seney	22	SENE1	MI	46.26	86.03	3.3	2.8	2.9	2.7	2.6	3.1	3.6	4.0	4.1	3.4	3.6	3.5
Sequoia	Sequoia	98	SEQU1	CA	36.50	118.82	2.5	2.4	2.4	2.2	1.9	1.8	1.7	1.6	1.8	1.9	2.3	2.3
Shenandoah	Shenandoah	6	SHEN1	VA	38.52	78.44	3.1	2.8	2.8	2.5	3.1	3.4	3.5	3.9	3.9	3.2	3.0	3.1
Shining Rock	Shining Rock	11	SHRO1	NC	35.39	82.78	3.3	3.0	2.9	2.7	3.4	3.9	4.1	4.5	4.4	3.8	3.3	3.4
Sierra Ancha	Sierra Ancha	45	SIAN1	AZ	33.82	110.88	2.1	2.0	1.7	1.3	1.3	1.1	1.5	1.8	1.6	1.5	1.7	2.1
Simeonof	Simeonof	105	SIME1	AK	54.92	159.28	4.3	4.1	3.6	3.9	3.9	4.3	5.0	5.2	4.5	3.8	4.0	4.3
Sipsey	Sipsey	21	SIPS1	AL	34.34	87.34	3.4	3.1	2.9	2.8	3.3	3.7	3.9	3.9	3.9	3.6	3.3	3.4
South Warner	Lava Beds	87	LABE1	CA	41.33	120.20	3.6	3.1	2.7	2.4	2.3	2.1	1.9	1.9	2.0	2.3	3.1	3.4
Strawberry Mountain	Starkey	76	STAR1	OR	44.30	118.73	3.9	3.3	2.8	2.9	2.3	2.4	2.0	2.0	1.9	2.6	3.7	4.1
Superstition	Tonto	44	TONT1	AZ	33.63	111.10	2.1	1.9	1.6	1.3	1.3	1.1	1.5	1.7	1.6	1.5	1.7	2.1
Swanquarter	Swanquarter	14	SWAN1	NC	35.31	76.28	2.9	2.7	2.6	2.5	2.9	3.2	3.4	3.5	3.4	3.1	2.8	2.9
Sycamore Canyon	Sycamore Canyon	47	SYCA1	AZ	34.03	116.18	2.4	2.3	2.2	2.0	2.0	1.9	2.0	2.0	2.0	2.0	1.9	2.0
Teton	Yellowstone	66	YELL2	WY	44.09	110.18	2.5	2.4	2.2	2.1	2.1	1.9	1.6	1.5	1.7	2.0	2.4	2.5
Theodore Roosevelt	Theodore Roosevelt	61	THRO1	ND	47.30	104.00	2.9	2.8	2.8	2.3	2.3	2.5	2.4	2.2	2.2	2.3	3.0	3.0
Thousand Lakes	Lassen Volcanic	90	LAVO1	CA	40.70	121.58	3.8	3.2	2.9	2.5	2.4	2.2	2.1	2.1	2.2	2.4	3.1	3.5
Three Sisters	Three Sisters	84	THSI1	OR	44.29	122.04	4.5	4.0	3.6	3.7	3.1	3.1	3.0	2.9	3.0	3.8	4.6	4.6
Tuxedni	Tuxedni	103	TUXE1	AK	60.15	152.60	3.5	3.3	2.9	2.7	2.7	2.9	3.6	4.0	3.9	3.5	3.5	3.7
UL Bend	UL Bend	64	ULBE1	MT	47.55	107.87	2.7	2.5	2.5	2.3	2.2	2.2	2.0	1.8	1.9	2.2	2.7	2.7
Upper Buffalo	Upper Buffalo	27	UPBU1	AR	35.83	93.21	3.3	3.0	2.7	2.8	3.4	3.4	3.4	3.4	3.6	3.3	3.2	3.3
Ventana	Pinnacles	92	PINN1	CA	36.22	121.59	3.2	2.9	2.8	2.4	2.3	2.1	2.2	2.3	2.2	2.4	2.5	2.9
Virgin Islands (b)	Virgin Islands	106	VIIS1	VI	18.33	64.79												
Voyageurs	Voyageurs	24	VOYA2	MN	48.59	93.17	2.8	2.4	2.4	2.3	2.3	3.1	2.7	3.0	3.2	2.6	2.9	2.8

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Class I Area	Site Name	Map ID	Code	Site St	LAT	LONG	Jan f(RH)	Feb f(RH)	Mar f(RH)	Apr f(RH)	May f(RH)	Jun f(RH)	Jul f(RH)	Aug f(RH)	Sep f(RH)	Oct f(RH)	Nov f(RH)	Dec f(RH)
Washakie	North Absoraka	67	NOAB1	WY	43.95	109.59	2.5	2.3	2.2	2.1	2.1	1.8	1.6	1.5	1.8	2.0	2.4	2.5
Weminuche	Weminuche	55	WEMI1	CO	37.65	107.80	2.4	2.2	1.9	1.7	1.7	1.5	1.6	2.0	1.9	1.7	2.1	2.3
West Elk	White River	56	WHRI1	CO	38.69	107.19	2.3	2.2	1.9	1.9	1.9	1.7	1.8	2.1	2.0	1.8	2.1	2.2
Wheeler Peak	Wheeler Peak	35	WHPE1	NM	36.57	105.42	2.3	2.2	1.9	1.8	1.8	1.6	1.8	2.2	2.1	1.8	2.2	2.3
White Mountain	White Mountain	37	WHIT1	NM	33.49	105.83	2.1	1.9	1.6	1.5	1.5	1.4	1.8	2.0	2.0	1.7	1.8	2.1
Wichita Mountains	Wichita Mountains	30	WIMO1	OK	34.74	98.59	2.7	2.6	2.4	2.4	3.0	2.7	2.3	2.5	2.9	2.6	2.7	2.8
Wind Cave	Wind Cave	60	WICA1	SD	43.55	103.48	2.5	2.5	2.5	2.5	2.7	2.5	2.3	2.3	2.2	2.2	2.6	2.6
Wolf Island	Okefenokee	16	OKEF1	GA	31.31	81.30	3.4	3.1	3.1	3.0	3.3	3.7	3.7	4.1	4.0	3.7	3.5	3.5
Yellowstone	Yellowstone	66	YELL2	WY	44.55	110.40	2.5	2.4	2.3	2.2	2.2	1.9	1.7	1.6	1.8	2.1	2.5	2.5
Yolla Bolly - Middle Eel	Trinity	104	TRIN1	CA	40.11	122.96	4.0	3.4	3.1	2.8	2.7	2.5	2.4	2.5	2.6	2.7	3.3	3.6
Yosemite	Yosemite	96	YOSE1	CA	37.71	119.70	3.3	3.0	2.8	2.3	2.1	1.8	1.5	1.5	1.5	1.8	2.4	2.8
Zion	Zion	51	ZION1	UT	37.25	113.01	2.7	2.4	2.0	1.6	1.5	1.3	1.2	1.4	1.4	1.6	2.0	2.4

a: No particulate matter sampling or visibility monitoring is conducted in the Bering Sea Wilderness.
b: *f(RH)* values for Virgin Islands National Park were not calculated because of the limited RH data available.