Recommendations for Making Attribution Determinations in the Context of Reasonably Attributable BART

Prepared by: The WESTAR Council

Prepared for: The Air Managers Committee, Western Regional Air Partnership

May 2003

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Prepared by:

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EXECUTIVE SUMMARY

This report recommends a general procedure and applicable technical approaches that may be used by states and tribes to assess reasonable attribution in response to a Federal land manager (FLM) certification of visibility impairment in a Class I area (Certification).

WESTAR formed the Reasonably Attributable Best Available Retrofit Technology (RA BART) Phase II Working Group with Federal land management agency staff and members of state and tribal air quality agencies knowledgeable about RA BART and associated monitoring and modeling techniques. To provide the necessary framework, the report provides background information about both the certification process and the attribution determination process. However, the recommendations focus on the general principles of the attribution assessment process and the technical criteria used in the assessment.

The recommendations are summarized below:

General Principles:

The attribution assessment should be:

- A collaborative process that relies on existing data with minimal additional analyses.
- Technically and legally defensible.
- Accomplished at a reasonable cost and within a reasonable time frame.
- No more complex than necessary.
- Performed by state or tribal agency staff.
- Adequate to determine whether or not visibility impairment is attributable to an existing stationary source potentially subject to BART.

Technical Criteria:

- Emissions from BART-eligible sources must “cause or contribute to” visibility impairment. Visibility-impairing pollutants of concern must be identified.
- Factors to consider in assessing impairment include: duration, frequency, geographic extent, magnitude, and time of occurrence.
- Identify distance from source to Class I area to determine appropriate tools for characterization of the impairment.
- Quantitative results are preferable, although qualitative results such as photographs may be adequate.
- Use as many different indicators of impairment as practicable rather than relying on a single indicator.
- Consider level of uncertainty in the assessment.
- Use EPA guideline models whenever practicable.

Table of Contents

I. BACKGROUND

A. Introduction and Purpose

Reasonably Attributable Best Available Retrofit Technology (RA BART) is the portion of EPA's visibility rule published in 1980 and codified in 40 CFR 51.302–51.306 that deals with visibility impacts from one source or a small groups of sources. RA BART refers to reasonably attributable visibility impairment and best available retrofit technology for eligible sources and emission limits, and emissions controls as defined by the statute and the rules. Some confusion exists regarding the application of RA BART, the process of assessing sources of visibility impairment, and the technical tools available for an RA BART attribution determination. RA BART is a statutory requirement, although certain of the requirements may no longer be applicable when a source complies with BART or installs BART-like controls or after a state implements a trading program under 51.308(e)(2) or any trading program under 51.309, and if no remaining visibility impacts continue from one source or a small group of sources.

This report, therefore, addresses the RA BART attribution process and builds upon case studies WESTAR developed in 2001 to examine and document how Reasonably Attributable Visibility Impairment (RAVI) had been addressed in previous assessments.[1]

The Federal land managers (FLMs) advocate maintaining RA BART as a tool because RA BART is effective when new monitoring indicates that a previously un-monitored area has visibility problems differing from the regional visibility impairment conditions at other areas. In addition, RA BART is effective when BART-eligible sources in the vicinity of the protected area are causing or contributing to identified visibility impairment.[2]

First, this report recommends attribution process principles and assessment techniques a state or tribe may consider in an attribution assessment to identify if, and to what degree, an existing source or small group of sources causes or contributes to visibility impairment. The report focuses on RAVI and does not specifically address impairment due to regional haze. Although this report includes references to regional haze, such references serve only to place the attribution process in the larger context of the broad regulatory framework that addresses visibility impairment, including the regional haze regulations.

Second, this report includes no recommendations with regard to establishing a threshold level at which reasonably attributable impairment exists. Instead, the working group outlined a recommended general process and recommended technical procedures that may be used as guidelines if an attribution assessment is necessary. Due to the circumstances unique to each attribution assessment and the requirement that the assessment be conducted on a case-by-case basis, recommending one specific analysis for every situation was not possible. A state or tribe should select from the techniques summarized in Section IV. Section IV(C) includes five examples of the attribution assessment process, each providing a range of techniques to be used

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[1] WESTAR Council, *RA BART and RA BART-like Case Studies*, June 2001.

[2] This document specifically relates to RA BART and does not address broader issues relating to long-term visibility strategies. FLMs generally do not intend to issue Certifications citing specific sources except for situations involving BART sources.

based on available data. The examples also recommend more refined analyses that may require additional data.

Third, this report includes specific information about the current policy of FLM agencies regarding certifications of impairment (Certification), but makes no recommendations regarding the certification process. This report makes no recommendations regarding state process following an attribution determination nor examines options for performing the Best Available Retrofit Technology (BART) analysis or the incorporation of BART requirements into State Implementation Plans (SIPs).

Tribal Implementation

The recommendations in this document are intended to help states assess reasonable attribution following Certification by an FLM. Subject to the requirements of the Clean Air Act, 42 USC 7601(d) and the Tribal Authority Rule, 40 CFR 49.1– 49.11, a tribe may accept responsibility for making reasonably attributable determinations in response to a Certification by an FLM when a BART-eligible source identified by the FLM in the Certification is on the tribe's land. The regional haze rule also explicitly recognizes the authority of tribes to implement the provisions of that rule on tribal lands. Those provisions create the following framework:

1. Absent special circumstances, reservation lands are not subject to state jurisdiction.
2. Federally recognized tribes may apply for and receive delegation of federal authority to implement CAA programs (including visibility regulation), or "reasonably severable" elements of such programs. The mechanism for this delegation is a Tribal Implementation Plan (TIP). A reasonably severable element is one that is not integrally related to program elements that are not included in the plan submittal, and is consistent with applicable statutory and regulatory requirements.
3. Where a tribe does not seek delegation through a TIP, the Environmental Protection Agency (EPA), as necessary and appropriate, will promulgate a Federal Implementation Plan (FIP) within a reasonable timeframe to protect air quality on tribal lands.

Accordingly, these recommendations also may assist a federally recognized tribe that chooses to adopt a TIP to implement the RA BART provisions. In some cases, a tribe may be able to utilize the recommendations in much the same way as states. In many other cases, however, the recommendations may be modified to meet the unique situation of the tribe and the nature of its air program, including its manner of defining "reasonably severable elements" and its method of dividing responsibilities between the tribe and EPA. Because of these differences, the recommendations that follow do not refer to tribes every time states are referenced.

B. Regulatory Context

The national goal for visibility is set forth in the Clean Air Act (CAA) at 42 USC 7491: "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from manmade air pollution." The requirements apply to 156 designated Class I areas.

As stated previously, Congress required that states provide a remedy for visibility impairment that was "reasonably attributable" to one source or a small group of sources. (42 USC 7491). Congress directed EPA to ensure that all SIPs contained measures necessary to make reasonable progress toward meeting the national goal, including requirements for identifying major sources of emissions causing or contributing to visibility impairment, and requirements for the application of BART on such sources. EPA promulgated rules pursuant to Congress's directive to provide guidelines to the states on appropriate techniques and methods for implementing the SIP requirements. (40 CFR 51.302(c)). (Note: when this report refers to a "source" within the meaning of this regulation, the phrase "or a small group of sources" is implied.)

The requirement to install Best Available Retrofit Technology controls on existing sources is a key element of the visibility protection provisions in the CAA demonstrating the need to focus on pollution emitted from a specific set of existing sources. Sources are potentially subject to BART controls if they meet the following criteria:

1. A major stationary source from 1 of 26 source categories identified in the CAA and regulations (see Appendix A);
2. Potential to Emit (PTE) 250 tons per year of any air pollutant; and,
3. Not in operation prior to August 7, 1962 and "in existence" on August 7, 1977.

In the 1980 visibility rule, EPA used the term "existing stationary facility" to define a facility that met the above criteria. However, to avoid any confusion about whether that term encompassed a larger group of sources, EPA now uses the term "BART-eligible source." The term "BART-eligible source" is used throughout this report for similar reasons, but the reader should be aware that some sections of the visibility rule still refer to "existing stationary facilities." For purposes of the attribution discussion in this paper, these terms are interchangeable.

In 1999, EPA added two new sections to the visibility rule to address regional haze (40 CFR 51.308 and 51.309). Pollutants causing regional haze may be transported hundreds of miles, and therefore, regional haze must be addressed as a broader regional issue. The 1980 visibility rule focused on direct visibility impacts of an individual source or small group of sources. The 1999 revisions are commonly referred to as the regional haze rule, although the 1999 rule incorporates the earlier requirements for BART as well as the new regional haze provisions.

To remedy RAVI, the regulations outline a process to identify and control emissions from sources that are directly impacting visibility at specific Class I areas (40 CFR 51.302). Three primary steps in this process are:

1. The Federal land manager certifies impairment;
2. The state identifies existing sources that cause or contribute to the visibility impairment; and

3. The state performs a BART analysis to determine what controls, if any, are required on any existing source that meets the BART criteria and has been identified as contributing to the impairment.

Attribution Process

The language of 40 CFR 51.302(c)(4)(i) provides the basic principle upon which the state will rely during the attribution process. That section states that the attribution must indicate each [BART-eligible source] "*which may reasonably be anticipated to cause or contribute to impairment of visibility*." Whether or not the impairment is "reasonably attributable" is determined by "visual observation or other technique the state deems appropriate." (40 CFR 51.301(s)). Because the state is responsible for identifying sources, this report provides recommendations for the state to consider when it undertakes an attribution determination.

Once visibility impairment is identified, RAVI is addressed on a case-by-case basis. Under the 1980 regulation, a state evaluates BART-eligible sources only after an FLM certifies the existence of visibility impairment. However, in the context of the current regional haze rule, states must also address BART requirements for regional haze (RH BART).[3] Several options exist for addressing RH BART. For example, rather than require a source-specific BART emission limit, a state may choose to develop a trading program, either regionally or within its own jurisdiction, that achieves greater reasonable progress than case-by-case RH BART.

If a state develops a trading program, the time period to achieve the emissions reductions may be extended. As a result, visibility conditions at a specific Class I area initially may remain static or even deteriorate during the early implementation period. During this time, FLMs have indicated that the RAVI process may be utilized to provide steady and continuing improvement in visibility. Within the context of the regional haze rule, this may be an example of a "geographic enhancement." As noted above, the recommendations in this report apply only to case-by-case applications of BART and are not intended to apply to the broader regional haze rule such as a market-based trading program implemented as part of the 1999 rule.

A state may find it difficult to determine a source/receptor link for RAVI difficult when there are other sources located in the area, including international sources. However, the regional haze rule provisions do not alter the requirement to undertake the attribution assessment.

State determines what controls, if any, are required

After the attribution determination, the state is required to perform a BART analysis to determine what types of controls, if any, should be placed on the source(s) found to be contributing to the impairment. The following factors affect the BART determination:

1. Available technology;
2. Costs of compliance;
3. Energy and non air quality environmental impacts of compliance;

[3] The RH BART provision was remanded to EPA by the U.S. Court of Appeals as a result of the ruling in *American Corn Growers Association v. EPA*, No. 9901348 (DC Cir. May 24, 2002)

4. Remaining useful life of the source; and,
5. Degree of improvement that can be anticipated to result from the use of the controls.

As noted above, this report does not provide guidance regarding state process following an attribution determination nor does it examine options for implementing the BART requirement.

II. FEDERAL LAND MANAGER CERTIFICATION OF IMPAIRMENT

The Federal land managers monitor visibility through a nationwide monitoring network, known as Interagency Monitoring of PROtected Visual Environments (IMPROVE). The IMPROVE network has recently been expanded and the FLMs anticipate reliable trend data for the new IMPROVE sites between the years 2006 and 2008. The FLMs plan to evaluate the current visibility conditions in Class I areas as well as trends occurring over time to identify areas where visibility is not improving.

The FLMs generally will use a screening process to identify Class I areas that may be affected by RAVI. This screening process will be influenced by the approach the state relies upon to address RH BART in its SIP. There are three approaches that may be used.

1. Case-by-Case Review of RH BART under 51.308

No distinction exists between emission reductions needed to address RH BART and reductions to address RAVI, therefore, the BART process will address both types of visibility impairment.

2. Trading Program under 51.308

The FLMs anticipate that the following screening criteria may be appropriate, but will not make a final decision until a 308 trading program has been developed. The screening criteria associated with this approach may be similar to the screening criteria associated with the trading program option under 51.309. However, the FLMs have indicated that the screening criteria ultimately selected for 51.308 will depend on how the trading program is structured, the selected emissions cap, and other aspects of the trading program.

Potential Screening Process Criteria:

(i) Sulfate, nitrate, organic carbon, other fine particulate, etc., levels in the Class I area are not decreasing.[4]
(ii) One or more BART-eligible sources of SO_2, NO_x, VOC, PM_{10}, etc., are located within 100 miles of the mandatory federal Class I area.
(iii) The BART-eligible sources identified in (ii) are not already well-controlled for pollutants that contribute to visibility impairment.

3. Milestones and Backstop Trading Program under 51.309

The FLMs plan to sign a Memorandum of Understanding (MOU) with the participating states to define the screening criteria the FLMs will use to certify impairment.

[4] The decrease of a pollutant (or secondary species of that pollutant) would be measured from the beginning of the market or emissions trading program, and such a trading program would take a long time (10 to 15 years) to reach the level of reduction that "meets" BART. The decrease would be tested over the first 5 to 10 years. A very quick time frame for reductions would negate the need for RA BART criteria.

Screening Process criteria:[5]

(i) Sulfate levels in the Class I area are not decreasing.
(ii) One or more BART-eligible sources of SO_2 are located within 100 miles of the mandatory federal Class I area.
(iii) The BART-eligible sources identified in (ii) are not already well-controlled for SO_2 (85% or better SO_2 control for coal-fired utility boilers).

Goal: For FLMs to complete the certification process between 2006 and 2008.[6]

These criteria were influenced by the design of the 309 trading program including emission reduction estimates, shape of the declining emission cap, inclusion of sources that were not BART-eligible, and inclusion of new source growth under the cap.

Although geographic enhancements do not need to be addressed under the first approach, they must be addressed in the two trading programs described above because emission reductions may occur more gradually in the context of a trading program. The FLMs do not anticipate certifying impairment under these circumstances but do intend to notify the state as part of the SIP development process if concerns arise regarding "hot spot" impacts from sources that may directly affect specific Class I areas.

Note: BART for regional haze has been addressed for SO_2 under this option. Regional haze BART for NO_x and PM will be addressed in SIP revisions that are due in 2008.

In all three cases discussed above, if the FLM determines that a certification of visibility impairment is necessary, the FLM will send an official Certification to the state. The Certification will generally include the following information:

1. Class I area(s) impacted;
2. Basis of certification (photographic documentation, monitoring, modeling, etc.);
3. Type of impairment certified: plume impact, or layered or uniform haze;
4. Pollutant(s) of interest; and,
5. Preliminary identification of source(s) believed responsible for impact.

FLM, State, and EPA roles in RA BART

FLMs are responsible for certifying impairment. The Certification demonstrates the FLM's determination that there is evidence of visibility impairment from one source or a small group of sources.

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[5] Within the context of established regional milestones for SO_2 and a backstop trading program, the FLMs have said it is appropriate to use the following screening process in making these recommendations as part of the Certification. Voluntary Emissions Reduction Program for Major Industrial Sources of Sulfur Dioxide in Nine Western States and A Backstop Trading Program. An Annex to the Report of the Grand Canyon Visibility Transport Commission. Submitted by the Western Regional Air Partnership to the U.S. Environmental Protection Agency, p. 61, September 29, 2000.
[6] This goal will not in any way restrict the ability of the FLMs to certify impairment at a later date if it is necessary to fulfill their statutory obligations. *ibid*.

Following the Certification, states have the following regulatory obligations: (1) identify facilities that "emit an air pollutant which may be reasonably anticipated to cause or contribute to any visibility impairment" in that Class I area, and (2) for sources subject to BART, the state must identify the BART level of control technology. If the source does not have adequate control in place, the state must establish a BART limit in the SIP.

EPA has two major responsibilities for the RA BART requirement. First, in the states that do not have a SIP in place to address the RA BART requirements, but where the program is implemented through a FIP, EPA will conduct the BART analysis and establish any BART emission limits. Second, for the states with SIPs that include RA BART regulations, EPA will provide federal enforcement of state-established BART emission limits.

III. THE ATTRIBUTION DETERMINATION PROCESS

This section recommends a process for the state to follow in order to complete an attribution determination after receipt of a Certification from an FLM under 40 CFR 51.302(c)(1).

The Certification focuses on the existence of visibility impairment. While the FLM may identify sources or even sources areas that contribute to the Certification, the formal identification of sources is a state responsibility.

The state should make a detailed review of the data supporting the Certification to determine which sources or source areas require further evaluation. If the data are insufficient to identify specific sources or source areas, the state may request that the FLM perform more detailed analyses to further substantiate the impairment set forth in the Certification.

If the state determines sufficient information exists to proceed, the state should begin the process by: (1) evaluating which sources are BART-eligible, and (2) reviewing the impairment information provided by the FLM in support of the Certification.

1. Evaluate which sources are BART-eligible

Congress and EPA established criteria to determine which sources are subject to BART. The categories of sources subject to BART are listed in 40 CFR 51.301, the definition of "existing stationary facility," and also are included in Appendix A of this report.

The state must confirm that the potential source or group of sources is subject to the RA BART process by examining the potential source emissions and the dates of operation.

The criteria for determining if a source is BART-eligible may be complicated if a source has multiple units that were constructed at different times and a state may be unable to determine if a specific source would qualify as BART-eligible. EPA published guidelines in 1980 to aid states in implementing the 1980 rule.[7] In addition to the 1980 guidelines for determining BART-eligibility, EPA also has proposed guidelines that include criteria for determining if a source is BART-eligible.[8] These guidelines are expected to be re-proposed in 2004, promulgated in 2005 and codified at 40 CFR Part 51 as Appendix Y. The state should refer to both sets of guidelines to determine if a source is BART-eligible, although the proposed guidelines are not binding until final promulgation occurs.

When using the applicability criteria in Appendix Y, the state should look for information readily available from existing state data such as permitting history, emission inventory, or other similar databases.

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[7] U.S. Environmental Protection Agency, *Guidelines for Determining Best Available Retrofit Technology for Coal-fired Power plans and Other Existing Stationary Facilities,* EPA-450/3-80-009(b), Office of Air Quality Planning and Standards, Research Triangle Park, N.D., November 1980 (1980 BART Guidelines).

[8] 66 FR 38108 *Proposed Guidelines for Best Available Retrofit Technology (BART)* (July 20, 2001). EPA will re-propose these guidelines as a result of the remand in *American Corn Growers v. EPA*.

1. If a database of Potential To Emit (PTE) is not available, state emission inventories can be a useful screening tool to determine whether a source meets the size criteria (for example, identify all sources with emissions greater than 100 tons/year of visibility impairing pollutants). Operating permit applications may also contain information about the PTE of a source, or individual units within a source.
2. State business records may be useful to determine when the facility was constructed or when it commenced operation. Newspaper article searches or a detailed historical review of each source may also provide useful information.
3. The state should require the source to provide information regarding the construction dates of individual emission units.
4. Institutional memory within the air agency can be invaluable if records of construction dates of major emission units are not available, although memories will not withstand legal challenges like hard documentary data.
5. New Source Review permitting records may be useful to identify new units that were constructed after 1977, determine the PTE of the source, or determine if reconstruction has occurred. (Note: the draft guidelines in Appendix Y state that modifications at a source do not affect applicability unless the change qualifies as reconstruction of the source).

If the source or group of sources identified in the Certification is not BART-eligible, the state should inform the FLM of its finding. The state should look in the vicinity of all the sources suspected of causing or contributing to the impairment identified in the Certification. If no BART-eligible sources exist, an attribution assessment is unnecessary.

2. Review Support Information in the FLM Certification

Initially, the state should acquire all the supporting information the FLM used in the Certification and independently evaluate the data. This initial review will help the state determine if the information is sufficient to support a reasonable attribution determination.

The state should consider the type of impairment in the Certification: (a) plume impact visibility impairment, (b) uniform haze visibility impairment, or (c) layered haze visibility impairment:

(a) Plume impact is the impairment addressed by the original visibility protection program under which the state must make a reasonable attribution determination before proceeding to the BART analysis (40 CFR 51.301-51.307).

(b) In some instances, uniform haze may be thought to be source-specific haze from a BART-eligible source. If a state can successfully demonstrate there is a source emitting any air pollutant that may reasonably be anticipated to cause or contribute to any impairment of visibility, the state should consider that portion of the uniform haze to be impact from the identified source(s) and, therefore, consider the source to be subject to BART.

(c) The visibility impairment may also be defined as layered haze, a condition that results when aerosols are “trapped” under stagnant air mass conditions.

Once the FLM has issued a Certification, the responsibility for the attribution assessment shifts to the state. If a state does attribute impairment to a source, the state must be able to defend its finding that one or more BART-eligible sources did cause or contribute to visibility impairment in the Class I area. However, the Ninth Circuit Court of Appeals established a low threshold for unacceptable visibility impairment.[9]

3. Evaluate Existing Data not included in the Certification

When analyzing supporting data, the state should determine if additional information exists that was not available to the FLM. Examples include special project camera studies or ambient monitoring data collected by the state or local air pollution control agency, the potential or actual PSD permit applicant,[10] or the university. In certain situations, another agency may have previously collected information that could be used in an attribution determination.[11] These data should be reviewed to determine whether they support the FLM Certification.

To conclude this portion of the attribution process, the state may wish to prepare a report that summarizes its initial evaluation of the Certification. The purpose of the report is to carefully document the state's findings and conclusions about its decisions. The report would address two questions:

First, the report would assess whether any BART-eligible source(s) exist that potentially contributed to visibility impairment as described in the Certification. The report would contain a preliminary determination of whether the sources are BART-eligible and, if possible, analyze each source's relative contribution to the impairment (based on available source/receptor information).

Second, the report would assess the impairment data. This assessment would include the state's evaluation of the supporting data in the Certification and an analysis of any additional data used in the attribution assessment. The data gaps found in this review would be identified along with any recommendations for strategies to obtain the missing information. The state may use these recommendations to determine the next steps in the attribution process.

If the state believes the Certification is supported by sufficient data, proceeds with an attribution assessment and makes a determination that the data does or does not indicate a source subject to BART, the attribution process is complete. However, if the state determines the data is insufficient to complete an attribution assessment, the evaluation process ends, and the state may proceed to the next step—identification of data gaps and the studies necessary to obtain this information.

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[9] See *Central Ariz. Water Conservation Dist v. EPA*, 990 F.2d 1531 (9th Cir. 1993); See also discussion in *RA BART and RA BART-like Case Studies*.

[10] For example, a PSD permit applicant may be required to obtain pre-application ambient air quality information, and that information may not have been available to or known to the FLM.

[11] In Washington state, the plume of a defunct copper smelter has been traced by its arsenic deposition. If this were an active facility, this ground tracing of the plume could be used to support a source/receptor connection in an attribution determination.

4. Identify data gaps and necessary studies to fill the gaps

As part of the data review, the state should note gaps or inconsistencies in the available data. Examples of data gaps and inconsistencies may include:

1. Missing photos in a sequence of photos,
2. Poor resolution of the plume or its source in the photos,
3. Back trajectory analyses done with a very large grid resolution or poor techniques,
4. IMPROVE monitor data missing at critical periods,
5. Lack of association between the source's emissions and monitored data at the receptor,
6. Special studies performed during a time when a source that potentially contributed to the impairment was not operating,
7. Contemporaneous studies with contradictory results that cannot be explained,
8. Ambient studies that use naturally occurring tracers and, when the suspected source(s) are tested, the tracers do not exist or exist at levels far below (or above) the level indicated by the ambient study results,
9. Tracer studies where the tracer was not found at the anticipated receptors,
10. No explicit exploration of whether wildfire or other natural events significantly caused or contributed to one or more of the impairment episodes,
11. Other differences or inconsistencies in the available data.

Once any data gaps have been identified, the state should decide which studies are necessary to obtain the missing information sufficient to complete an attribution assessment. The state should design potential studies and determine the resource needs of those studies. The amount of work necessary will depend on the availability of the information and how critical the information is to the attribution assessment. Section IV provides technical criteria and examples of the technical process the state may consider at this point in the process.

5. Consultation Process

The WESTAR review of previous RAVI assessments demonstrated the importance of including all stakeholders in the design of any data collection plans or modeling protocols. Competing studies can be very inefficient, expensive, and time-consuming, and ultimately may not help the state make a final decision.

If stakeholders are involved in the design of any data collection efforts or modeling protocols, disagreements may be resolved before the state or source continues with any additional studies. The state should consider involving the following stakeholders in the consultation process:

1. Affected sources
2. Neighboring states and tribes
3. Environmental Protection Agency
4. Federal land managers
5. Local environmental groups
6. Local permitting agencies

7. Local government representatives

6. Completion and Review of Additional Visibility Studies

When the additional visibility studies, if any, are complete, the state should evaluate the resulting data. The technical staff may wish to finalize the report and make recommendations based on the scientific aspects of the data.

7. Final Determination of Reasonably Attributable Visibility Impairment

The state may reach any one of the following conclusions:

1. The impairment certified by the FLM is reasonably attributable to the identified BART-eligible source(s) for specific pollutants;
2. The impairment certified by the FLM is reasonably attributable to the source(s) identified by the FLM and additional sources not identified by the FLM for specific pollutants;
3. There is inadequate data to support a determination that the impairment is due to the source(s) identified by the FLM;
4. The impairment is reasonably attributable to other adjacent BART-eligible sources for specific pollutants; or
5. The impairment certified by the FLM is not reasonably attributable to a BART-eligible source.

IV. GENERAL PRINCIPLES AND CRITERIA

This section provides general principles and technical criteria for the state to consider after receipt of an FLM Certification. After receipt of such a Certification, the state must determine whether BART-eligible sources "emit any air pollutant which may reasonably be anticipated to cause or contribute to any visibility impairment in any" Class I area. While these principles and technical criteria should generally be useful and applicable, each state must decide what is required to support its individual determination.

Part A contains general principles to guide the development of a conceptual framework for the attribution assessment process. Part B contains evaluation criteria to guide the decisions regarding a technical framework for the attribution assessment process.

Conceptually, the statutory framework for an attribution determination ("may reasonably be anticipated to cause or contribute to visibility impairment") should be the general principle guiding the attribution process. EPA maintains, and the Ninth Circuit agreed, that an affirmative attribution decision is possible even with considerable uncertainty and a low triggering threshold. However, each state should decide individually what is required to support its determination.

A. General Principles of the Attribution Process

Attribution process criteria address factors likely to influence the performance of the state attribution assessment. These criteria provide parameters to define and implement the attribution assessment process given resource constraints, legal considerations, administrative decisionmaking requirements, and other relevant factors. The general principles include the following:

1. Whenever possible, an attribution assessment should be a collaborative process that relies on existing data with a minimum of additional analysis (*see* section III). If supplemental data are needed, field studies should be designed in a collaborative process between affected states and tribes, identified sources, Federal land managers, EPA, and the general public. Past experience has shown that competing technical studies often result in an unnecessarily expensive and unduly complicated process.

2. Attribution assessments should be technically and legally defensible.

3. Attribution assessments should be accomplished at a reasonable cost and within a reasonable time frame.

4. Attribution assessments should be no more complex than necessary, recognizing that the circumstances surrounding a Certification may vary greatly. State or tribal agency staff should be capable of performing the attribution assessment and making the final determination, although contractors may be used for certain types of modeling or monitoring.

5. Reasonably attributable visibility impairment can only be identified if a source/receptor

links a potentially BART-eligible source or small group of sources to a Class I area.

B. Technical Criteria

The technical criteria address the appropriateness of available analytical techniques from a scientific perspective. The rule defines visibility impairment to mean "any humanly perceptible change in visibility (light extinction, visual range, contrast, coloration) from that which would have existed under natural conditions."

The technical criteria include the following:

1. The BART source must emit an air pollutant that may reasonably be anticipated to cause or contribute to any of the impairment. The visibility-impairing pollutants of concern must be identified.

2. The attribution assessment should address the unique visibility impairment in the FLM Certification for the Class I area. Some factors to consider include:

    a. Duration: source's length of effect on visibility per episode;[12]

    b. Frequency: how often episodes of impairment occur;

    c. Geographic extent: how much of the Class I area is affected by the impairment;

    d. Magnitude: how much visibility impairment is due to the source's emissions; and

    e. Time of occurrence: including time of day and time of year.

    These factors need to be considered together, because they affect each other. An infrequent occurrence of a large magnitude episode may meet the criteria. A frequent occurrence of a small magnitude episode may also meet the criteria. The FLM may provide information about these criteria in the Certification, and the state should review this information as a starting point for its assessment. The state may consider other factors and data, as appropriate.

3. The attribution assessment should identify the distance from the source to the Class I area. This distance will affect the choice of tools appropriate for characterizing the specific source's impact on visibility impairment.

4. To the extent possible, the attribution assessment should be quantitative. Under certain circumstances, qualitative information, such as photographs or time-lapse video of distinct plumes or source-specific haze events, may be adequate.

5. The state should use as many approaches or indicators of impairment as practicable

[12] Based on previous cases, most impairment episodes are relatively short—lasting one to several hours—which may affect monitoring and other assessment techniques.

rather than relying on a single method. The assessment may rely on air monitoring and modeling techniques and other supporting scientific data. Consistency between source and observational techniques strengthens the analysis.[13]

6. The state should consider the level of uncertainty in the assessment.

7. EPA guideline models should be used whenever practicable. When other models are used, additional technical discussions with EPA may be necessary.

C. Examples of the Attribution Process

The state should consult this section after evaluation of the FLM Certification. At this point, the state will already have decided what gaps need to be filled to complete the attribution assessment.

The recommendations in this report recognize that each attribution determination will be unique. Because an attribution determination is a fact-specific and individual determination, it is not possible to recommended a single technical approach for a state to follow. A combination of monitoring and modeling techniques is usually appropriate, but instead of attempting to cover all possible combinations of techniques, this report provides five selected scenarios. The general principles and technical criteria identified in sections A and B are incorporated into these scenarios. The goal is to provide the state with references for use when it is creating its own individualized technical procedure.

In addition to the scenarios, this report provides detailed tables and narrative descriptions of techniques that may be considered and/or substituted for the techniques in the scenarios (see Section V).

Scenario 1: Limited data/one source

Data input: Small amount of existing data (i.e., one IMPROVE site with data for 2-3 years)
Evidence of "local" impact.
Limited meteorological data.

Where it is likely that one major source contributes to impairment, a combination of the following techniques is suggested:

1. Examine IMPROVE data, including quality assurance
2. Look at extinction budget to identify visibility-impairing pollutants
3. Perform some analysis of when the episodes are occurring
4. Perform a simple back trajectory analysis using a method such as HYSPLIT
5. Look at relationships between particulate species
6. Examine source emissions data for correlations with ambient monitoring
7. Perform dispersion model based on data and capabilities such as VISCREEN or CALPUFF Lite

[13] WESTAR Council, *RA BART and RA BART-like Case Studies*, June 2001.

8. Examine other data such as source owner data, deposition data, or photographic evidence

The results of this initial analysis may not always be conclusive. This level of review may be adequate if a source/receptor relationship can be identified. However, if the results are inconclusive, more data and/or more refined analyses may be necessary and may help the state reach an attribution determination. The state should consider how the available data and choice of techniques might affect its ability to assess the effectiveness of the controls in remedying the impairment.

It may be efficient to look ahead to the data and analytical needs of a potential BART analysis. For example, the state may wish to use a more refined model that would be useful for both attribution and remedy assessment.

Assuming there is a two-year time period[14] to collect data and analyze additional information, the following techniques also can be considered:

1. Better source characterization, including measurement of emissions of trace elements (source profiles) for use in CMB modeling
2. Met monitoring or modeling
3. Camera site, possibly with time-lapse video
4. Additional aerosol monitoring, episodic or saturation
5. In plume trajectory by aircraft, if available
6. Fine time-resolved optical monitoring, such as nephelometer, transmissometer, aethelometer combined with pollutant monitoring (e.g., SO_2, NOx, real time PM) for monitoring of episodes
7. More refined chemical visibility model, such as CALPUFF
8. Repeat initial techniques with new data

The technical criteria are listed below, followed by techniques that may be used to obtain results about the criteria.

1. The impairment must be related to emissions from specific sources. The visibility-impairing pollutants of concern should be identified.

   <u>Techniques</u>: Back trajectory, species relationships, relationship between source emissions and ambient monitoring, dispersion model refined by camera, aerosol, in plume, optical monitoring, and refined dispersion models.

2. The attribution assessment must address the unique visibility impairment certified by

[14] The 1999 regional haze rule revised the requirements for general plan requirements for visibility protection. As a result, plan revisions are required once every five years, rather than the Long Term Strategy review requirement of every three years. If an FLM certifies RAVI at least 6 months prior to a plan revision, section 51.302 requires that the State Plan revision address such Certifications. Given this 5-year cycle, we have presumed for this report that an attribution analysis should take about two years to complete in order to allow time for the BART engineering analysis, if needed.

the FLM for the Class I area. Some factors to consider include:

a. Duration: source's length of effect per episode
   Techniques: Monitoring, dispersion model, back trajectory, camera

b. Frequency: how often the impairment occurs
   Techniques: Monitoring, dispersion model, back trajectory, camera

c. Geographic extent: how much of the Class I area is impaired
   Techniques: Monitoring, dispersion model, additional data on deposition and other studies

d. Magnitude: how much impairment is due to the source
   Techniques: Dispersion model, receptor model

e. Time of occurrence
   Techniques: Monitoring, dispersion model, back trajectory, camera

3. Uncertainty of results: Each analytical method will have its own level of uncertainty. These individual uncertainties should be kept in mind as outputs are compared within the overall assessment. If the results of different techniques are the same or similar (within the uncertainties of the techniques), then the overall level of uncertainty is likely to decrease.

Scenario 2: Moderate data/multiple sources

Data input: Moderate amount of existing data (i.e., one IMPROVE site with data for six or more years)
Evidence of an increasing trend in sulfate
Meteorological data likely from several stations

Assuming the Certification identifies multiple BART sources of different types within a 100-mile radius, a combination of the following techniques is suggested:

1. Examine IMPROVE data, including quality assurance
2. Look at extinction budget to identify visibility-impairing pollutants
3. Perform some analysis of when the episodes are occurring
4. Perform multiple back trajectory analyses using a method such as HYSPLIT
5. Look at relationships between particulate species
6. Examine source emissions data for correlations with ambient monitoring
7. Perform dispersion model based on data and capabilities such as CALMET/CALPUFF
8. Examine other data such as source owner data, deposition data, or photographic evidence
9. Wind fields/Synoptic analyses
10. Comparison of different episodes
11. UNMIX, PMF and/or CMB

12. Analysis of any regional modeling already conducted, such as CMAQ
13. Long term visual monitoring, such as camera data or transmissometer data, compared to met data to identify quadrants of concern

The results of this initial analysis may not be conclusive. This level of review may be adequate if a source/receptor relationship can be identified.

However, if the results are inconclusive, more data and/or more refined analyses may be necessary and may help the state reach an attribution determination. The state should consider how the available data might affect the ability to assess the effectiveness of the controls in remedying the impairment. It may be efficient to look ahead to the data and analytical needs of a potential BART analysis. For example, the state may wish to use a more refined model that would be useful for both attribution and remedy assessment.

Assuming there is a two-year time period to collect data and analyze additional information, the following techniques also can be considered:

1. Emissions inventory
2. Analysis of a nested domain within the regional model
3. Source profiles (natural tracers)
4. Additional source measurements, such as stack testing
5. Met monitoring or modeling
6. Camera
7. Additional aerosol monitoring, episodic or saturation
8. Monitoring to measure additional parameters, such as precursors, ammonia and oxidants
9. In plume trajectory by aircraft, if available, to characterize plume chemistry
10. Fine time-resolved optical monitoring, such as nephelometer, transmissometer, aethelometer combined with pollutant monitoring (e.g., SO_2, NOx, real time PM) for monitoring episodes.
11. Repeat initial techniques with new data

The technical criteria are listed below, followed by techniques that may be used to obtain results about the criteria.

1. The impairment must be related to emissions from specific sources. The visibility-impairing pollutants of concern should be identified.

   Techniques: Back trajectory, species relationships, relationship between source emissions and ambient monitoring, dispersion model refined by camera, aerosol, in plume, optical monitoring, and refined dispersion models.

2. The attribution assessment must address the unique visibility impairment certified by the FLM for the Class I area. Some factors to consider include:

   a. Duration: each source’s length of effect per episode

Techniques: Monitoring, dispersion model, back trajectory, camera

b. Frequency: how often the impairment occurs by source
Techniques: Monitoring, dispersion model, back trajectory, receptor model, camera

c. Geographic extent: how much of the Class I area is impaired
Techniques: Monitoring, dispersion model, additional data on deposition and other studies

d. Magnitude: how much impairment is due to each individual source
Techniques: Dispersion model, receptor model

e. Time of occurrence
Techniques: Monitoring, dispersion model, back trajectory, camera

Scenario 3: No IMPROVE data, Certification by modeling evidence

Data input: Detailed modeling of a source and specific visibility impairment using a CALPUFF run, or detailed (nested) run of regional model.
Detailed emissions data and meteorological data were input to the model.
No IMPROVE data available for this specific Class I area (monitoring may be at a "representative site")
Some optical data, photographic data, and limited aerosol data from other networks

Assuming the Certification points to a specific source, a combination of the following techniques is suggested:

1. Examine IMPROVE data for any nearby Class I areas (especially those included in the modeling domain) to better understand the regional conditions and compare with model outputs of the unique effect
2. Review the model's outputs on "high impact" days and compare with actual meteorological data of the area (to confirm transport, inversions, or other aspects of the model which may create the unique impact)
3. Review source emissions data used in the model
4. Review other monitoring data (optical measurements, deposition data, ozone data, etc.) to collaborate model predictions
5. Examine any photographic evidence

The results of this initial analysis may not always be conclusive. This level of review may be adequate if a source/receptor relationship can be identified. Because no visibility-specific particle monitoring is available in this case, the key to attribution is to determine that the source emissions are indeed reaching the Class I area on days when impairment exists. If the results are inconclusive, more data and/or more refined analyses may be necessary and may help the state reach an attribution determination. The state should consider if the available data and modeling information supplied with this Certification could be used to determine the effectiveness of the controls in remedying the impairment. It may be efficient to look ahead to the data and analytical needs of a potential BART analysis if additional or different modeling will be necessary.

Additional data collection and analyses that might be considered:

1. Better source profiles or newer emissions information
2. Met monitoring or modeling
3. Camera
4. New aerosol monitoring (episodic or saturation)
5. In plume trajectory by aircraft, if available
6. Repeat initial analytical techniques with new data

The technical criteria are listed below, followed by techniques that may be used to obtain results about the criteria.

1. The impairment must be related to emissions from specific sources. The visibility-impairing pollutants of concern should be identified.

   <u>Techniques</u>: Confirm model inputs, compare with any new particle monitoring at Class I area. Examine performance of the model, and perform uncertainty analyses.

2. The attribution assessment must address the unique visibility impairment certified by the FLM for the Class I area. Some factors to consider include:

   a. Duration: source's length of effect per episode
      <u>Techniques</u>: Monitoring, dispersion model, back trajectory, camera

   b. Frequency: how often the impairment occurs
      <u>Techniques</u>: Monitoring, dispersion model, back trajectory, camera

   c. Geographic extent: how much of the Class I area is impaired
      <u>Techniques</u>: New monitoring and examination of dispersion model outputs, additional data on deposition and other studies

   d. Magnitude: how much impairment is due to the source
      <u>Techniques</u>: Dispersion model

   e. Time of occurrence
      <u>Techniques</u>: Monitoring, dispersion model, back trajectory, camera

<u>Scenario 4</u>: Direct Photographic Evidence

Data input: The FLM certified impairment in a wilderness area based on photographic evidence. Photographs taken over a period of two years showed a distinct haze in a valley located in the wilderness area when the wind is from the east. A series of photographs during two episodes showed a distinct plume that originates at an existing stationary source constructed in 1965 and located ten miles east of the wilderness area. The photographic series showed that the plume traveled into the wilderness area.

Aerial photos during one episode also show a distinct plume that travels into the wilderness area. The wilderness area does not have an IMPROVE site. A Class I area located 50 miles to the north has an IMPROVE site that was representative for the area. This monitoring site does not show decreased visibility on the days when haze was photographed in the wilderness valley.

Assuming the Certification identifies one BART source, the following steps are suggested:

1. Review the photographic evidence and determine whether the photographs show a clear connection between the source and the haze documented in the wilderness area.

   In this example, the photographic evidence showed a clear connection between the source and the haze in the wilderness area. Qualitative information, such as photographic evidence that establishes a source/receptor link, is allowed under EPA regulations that define reasonable attribution as determined by "visual observation or other technique the State deems appropriate." (40 CFR 51.301(s)).

The results of this initial analysis may not always be conclusive. If the photographic evidence is not compelling, the state may reach a different conclusion. The state may determine that the impairment, as documented by the FLM, was not reasonably attributable to the source identified in the Certification. The FLM would then need to gather additional information to support a Certification. Alternatively, if the state determines that the source may be causing the haze but the qualitative evidence is not quite sufficient to determine attribution, the state could initiate a data collection effort to provide better information regarding visibility impairment at the Class I area. Such techniques may include:

1. Better source characterization, including measurement of emissions of trace elements (source profiles) for use in CMB modeling
2. Met monitoring or modeling
3. Additional aerosol monitoring (episodic or saturation)
4. In plume trajectory by aircraft, if available
5. Fine time-resolved optical monitoring, such as nephelometer, transmissometer, or aethelometer combined with pollutant monitoring (e.g., SO_2, NOx, real time PM) for monitoring of episodes.
6. More refined chemical visibility model, such as CALPUFF

The technical criteria are listed below, followed by techniques that may be used to obtain results about the criteria.

1. The impairment must be related to emissions from specific sources. The visibility-impairing pollutants of concern should be identified.
   Techniques: Back trajectory, species relationships, relationship between source emissions and ambient monitoring, dispersion model refined by camera, aerosol, in

plume, optical monitoring, and refined dispersion models.

2. The attribution assessment must address the unique visibility impairment certified by the FLM for the Class I area. Some factors to consider include:

    a. Duration: source's length of effect per episode
    <u>Techniques</u>: Monitoring, dispersion model, back trajectory, camera

    b. Frequency: how often the impairment occurs
    <u>Techniques</u>: Monitoring, dispersion model, back trajectory, camera

    c. Geographic extent: how much of the Class I area is impaired
    <u>Techniques</u>: Monitoring, dispersion model, additional data on deposition and other studies

    d. Magnitude: how much impairment is due to the source
    <u>Techniques</u>: Dispersion model, receptor model

    e. Time of occurrence
    <u>Techniques</u>: Monitoring, dispersion model, back trajectory, camera

3. Uncertainty of results: Each analytical method will have its own level of uncertainty. These individual uncertainties should be kept in mind as outputs are compared within the overall assessment. If the results of different techniques are the same or similar (within the uncertainties of the techniques), then the overall level of uncertainty is likely to decrease.

The final step in the attribution process scenario would be to verify that the source was operating on the days when the haze was observed in the area. The state should also determine if the source was experiencing unusual upset conditions during the times identified. In this example, the source was determined to have been operating normally. The state would then issue a determination that the visibility impairment at the Class I area was reasonably attributable to the existing stationary facility.

<u>Scenario 5</u>: Data Rich

Data input: A large special visibility study recently was conducted.
Four months of data spanning two seasons was collected including:

1. At one "receptor" site in a Class I area there were multiple meteorological, optical, and particulate samplers including extensive measurements of particle compositions, size distributions, scattering, absorption, light extinction, ions, oxidants, relative humidity, temperature, vertical wind profiles, SO_2, photographs, and concentrations of four unique tracers released from four different sources of interest. There were co-located samplers measuring several parameters in more than one way. There are at least some one, six, and twelve-hour particle measurements in addition to twenty-four hour samples.

2. This receptor site has been an IMPROVE site for several years and these data are also available.
3. At thirty-five other sites in the region, called “satellite” sites there was an IMPROVE Module-A sampler taking daily twenty-four hour samples which were analyzed for fine mass, S, soil elements, trace metals, and elemental H from which organics can be estimated. The unique tracers were also measured at many of these sites.
4. Aircraft sampling of plumes from source(s) of interest was conducted.
5. An extensive current emissions inventory was created.
6. Wind profilers were deployed at two to three sites in addition to the receptor site.
7. Measurements of the chemical composition of resuspended local dust, smoke from burning local fuels, and emissions from local point and area sources of interest were collected in order to create “source profiles” to be used in receptor modeling.

Assuming the certification identifies a BART source within 100 miles of the Class I area from which a unique tracer was released, a combination of the following techniques is suggested:

1. Examine fine particle data, including quality assurance. Use the collocated data to assess accuracy and precision. The one, six, and twelve-hour data should average up to match the twenty-four hour data and if reasonable, be used to examine the diurnal cycles in the fine particle concentrations.
2. Look at the extinction budget to identify visibility-impairing pollutants. Because size distributions were measured, the extinction budget can be estimated from Mie scattering calculations as well as by using simple techniques that assume bulk scattering and absorption efficiencies. Check to see if measured scattering plus absorption add up to the measured and reconstructed extinction.
3. Compare the special study data to historical IMPROVE and archived meteorological data to determine the representativeness of the study period.
4. Perform some analysis of when the episodes are occurring. EOF analysis can be helpful to summarize the massive data set. Use the photographs to create a time-lapse visualization of the scene at the receptor site.
5. Perform back trajectory analyses using HYSPLIT, CAPITA Monte Carlo or ATAD. Examine whether the trajectories change substantially when the study’s wind-profiler data are included. Determine whether trajectories are consistent with tracer concentrations.
6. Look at relationships between particulate species (factor analysis) to see if they identify source types.
7. Look at the spatial and temporal patterns of trace elements and the major constituents of the fine mass. This may suggest dominant source areas and transport patterns for different source types. Use EOF analysis to determine the patterns that explain most of the covariance in the data. Check to see how well these are reconciled with the back trajectory modeling and the deterministic modeling. Check to see if the same dominant sources were indicated.
8. Examine source emissions data for correlations with ambient monitoring.
9. Perform dispersion model such as CALMET/CALPUFF.

10. Analyze wind fields, synoptic conditions, and satellite photos. Check to see if they were consistent with more sophisticated meteorological modeling. Look for unusual conditions such as wild fires, hurricanes, stagnation episodes, etc. Look to see if modeled and observed cloud patterns were comparable.
11. Compare the meteorological and chemical characteristics of different episodes
12. UNMIX, PMF and CMB can help determine major source types and when they were important.

If, at this point, similar source/receptor relationships have been identified using several different techniques, this level of review is adequate. If the results are inconclusive, and there are differing points of view about the frequency, duration, or significance of the attribution to the BART-eligible source, more analyses may be necessary. Often in a large study, measurements are made, but not immediately analyzed in the lab due to cost. If this is the case, more samples could be analyzed. It is unlikely that any additional field monitoring would be required.

The technical criteria are listed below, followed by techniques that may be used to obtain results about the criteria.

1. The impairment must be related to emissions from specific sources. The visibility-impairing pollutants of concern should be identified.

   Techniques: Reconstructed particle mass and light extinction including examination of the reconstructions in different size ranges and at different sites in the region, analysis of responses of light scattering to relative humidity, back trajectory analyses, examination of inter-species relationships compared to measured source profiles, dispersion modeling with sophisticated models such as REMSAD and CMAQ, analysis of wind fields and dispersion by comparison to measured tracer concentrations, computer animation of spatial patterns of species of interest, use of receptor models such as TMBR, DMB, and TAGIT that utilize unique tracer information, or other receptor models such as CMB, UNMIX, and PMF that do not require tracer information, but can use it. When so many different models can be used, model reconciliation is usually a part of a data-rich scenario.

2. The attribution assessment must address the unique visibility impairment certified by the FLM for the Class I area. Some factors to consider include:

   a. Duration: each source's length of effect per episode
      Techniques: Monitoring, dispersion model, back trajectory, camera

   b. Frequency: how often the impairment occurs by source
      Techniques: Monitoring, dispersion model, back trajectory, receptor model, camera

   c. Geographic extent: how much of the Class I area is impaired
      Techniques: Monitoring, dispersion model, analysis of spatial patterns using data from the satellite sites.

d. Magnitude: how much impairment is due to each individual source
Techniques: Dispersion model, receptor model

e. Time of occurrence
Techniques: Monitoring, dispersion model, back trajectory, camera

3. Uncertainty of results: In this case, the ability of a model to predict the observed tracer concentrations is an indicator of the model's uncertainty.

V. TECHNIQUES

A. Monitoring

Introduction

This section describes a variety of ambient air monitoring methods that, if appropriate, might be used to support an attribution analysis. The methods described include those most commonly used in pollution studies or ambient monitoring programs and should not be considered an exhaustive list of potential methods. Methods include, IMPROVE, filter based aerosol, continuous aerosol (includes optical methods such as the nephelometer), continuous gas and canister sampling, transmissometer, scene (includes film, video, digital), and tracer or aircraft methods.

Several of the methods described are currently in use as a part of national, state, local, tribal, or private ambient monitoring networks. These sites are generally located in urban areas, but those near the area of study could be used in the attribution analysis thereby reducing the cost of monitoring.

The IMPROVE network is designed to assess visibility in Class I areas and routinely measure visibility impairing pollutants. These sites offer value to the attribution analysis if they are located in the area of study.

The RA BART case studies show additional examples of the methods used during source attribution studies. The case studies also show that methods, other than ambient monitoring, may be used to support the analysis. Existing programs such as CASTNET (dry deposition network), surface water deposition studies, or snow deposition studies may provide additional data for the attribution analysis.

Although not specifically listed as a monitoring technique, meteorological monitoring is an important element the attribution analysis. Collection of meteorological data can range from simple wind, temperature, and relative humidity measurement to an array of acoustic wind profilers. The complexity of the meteorological monitoring program depends on data needs and the availability of existing data. As with ambient monitoring, meteorological data may be available at sites located near the study area and offers reduced monitoring cost.

1. IMPROVE

Overview: The Interagency Monitoring of PROtected Visual Environments (IMPROVE) program is a cooperative measurement effort governed by a steering committee composed of representatives from Federal and regional-state organizations. The IMPROVE monitoring program was established in 1985 to aid the creation of Federal and State implementation plans for the protection of visibility in Class I areas (156 national parks and wilderness areas) as stipulated in the 1977 amendments to the Clean Air Act. The objectives of IMPROVE are to: (1) establish current visibility and aerosol conditions in mandatory class I areas; (2) identify chemical species and emission sources responsible for existing man-made visibility impairment;

(3) document long-term trends for assessing progress towards the national visibility goal; and (4) with the enactment of the regional haze rule, provide regional haze monitoring representing all visibility-protected federal class I areas where practical.

Magnitude: Possible when used in conjunction with appropriate analytical techniques.

Frequency: Possible when used in conjunction with appropriate analytical techniques; Limited by twenty-four hour sample integration, and one-in-three day sampling frequency.

Duration: Possible when used in conjunction with appropriate analytical techniques; Limited by 24 hour sample integration, and one-in-three day sampling frequency.

Principle: Twenty-four hour integrated filter-based ambient monitor; Gravimetric analysis for $PM_{2.5}$ (Module D) and PM_{10}); S from Particle Induced X-ray Emission (PIXE); NO_3 from ion chromatography (denuded nylon filter from Module C); Organic and elemental carbon from Thermal Optical Reflectance (TOR); H from Proton Elastic Scattering (PESA).

Uncertainty: All elemental S if from sulfate; All sulfate is ammonium sulfate; NO_3 (Denuder efficiency is close to 100%. All nitrate is from ammonium nitrate);
Average organic molecule is 70% carbon; Carbon (organic and elemental) is defined by the analytical method; Fine soil based on elemental composition; Course mass (PM_{10} – $PM_{2.5}$) consists only of insoluble soil particles.

Strengths: Regulatory indicator for regional haze rule; Long term data record in or near many federal Class I areas; Extensive network currently in place.

Limitations: Integrated twenty-four hour sample; one-in-three day sampling interval; Nitrate losses due to volatilization from filter; Not capable of distinguishing between primary particulate and atmospherically transformed particulate.

Level of Expertise Required: Standard operating procedures available for routine operation and maintenance; Chemical analysis must be conducted by appropriate laboratory.

Regulatory Context: Regional Haze rule; Included in SIP Visibility Plan

2. FILTER-BASED AEROSOL

Overview: Filter-based aerosol monitoring is used to identify chemical species and obtain concentration measurements of atmospheric constituents that contribute to visibility impairment. Primary techniques include filter-based aerosol samplers that collect samples on various substrates in various size ranges such as $PM_{2.5}$ or PM_{10}. Aerosol monitoring can provide fine mass concentration, course mass concentration, optical absorption, major and trace elements, organic and elemental carbon, and sulfate, nitrate, and chloride ions. A variety of methods are available to conduct filter based aerosol monitoring. Many methods are approved as an EPA reference method, while some are not, but may offer variability that the reference method does not.

Magnitude: Possible when used in conjunction with appropriate analytical techniques.

Frequency: Possible when used in conjunction with appropriate analytical techniques; Limited by 24-hour sample integration and sampling frequency (daily sampling is possible depending on instrument selected).

Duration: Possible when used in conjunction with appropriate analytical techniques; Limited by 24-hour sample integration and sampling frequency (daily sampling is possible depending on instrument selected).

Principle: The methods used for analyses of these filter media include gravimetry (electro-microbalance) for mass; X-ray fluorescence (XRF) and particle induced X-ray emission (PIXE) for trace elements; Ion chromatography (IC) for anions and selected cations; Controlled-combustion for carbon; Gas chromatography/mass spectroscopy (GC/MS) for semi-volatile organic particles; Special measurement needs may include determining particle size and morphology through optical and/or electron microscopy.

Strengths: Large network of urban monitoring available; Filter based sampling allows for a variety of chemical/elemental analysis.

Limitations: Integrated twenty-four hour sample; Generally operated on one-in-three or one-in-six day sampling interval (daily sampling is possible depending on instrument selected); Not capable of distinguishing between primary particulate and atmospherically transformed particulate.

Level of Expertise Required: Standard operating procedures available for routine operation and maintenance; Chemical analysis must be conducted by appropriate laboratory.

Regulatory Context: Commonly used in NAAQS/SIP compliance monitoring networks.

3. CONTINUOUS AEROSOL

Overview: Aerosols can be measured continuously using several different methods. Optical measurement of aerosols can be measured using an instrument such as a nephelometer to measure light scattering (bscat) or a aethelometer to measure light absorption (babs) by aerosols (black carbon). Continuous instruments such as TEOM or BETA can provide PM_{10} or $PM_{2.5}$ aerosol concentration.

Magnitude: Possible when used in conjunction with appropriate analytical techniques.

Frequency: Possible when used in conjunction with appropriate analytical techniques; Limited by twenty-four hour sample integration and sampling frequency (daily sampling is possible depending on instrument selected).

Duration: Possible when used in conjunction with appropriate analytical techniques; Limited by twenty-four hour sample integration and sampling frequency (daily sampling is possible depending on instrument selected).

Strengths: Continuous measurement with at least hourly time resolution; Nephelometers and Aethelometers are commonly used to support Class I area monitoring programs and an existing data record may be available in some areas.

Limitations: Continuous aerosol measurement with methods such as TEOM and BETA are generally made in urban areas to support NAAQS compliance networks; Not capable of distinguishing between primary particulate and atmospherically transformed particulate.

Level of Expertise Required: Standard operating procedures available for routine operation and maintenance.

Regulatory Context: Commonly used in Class I area monitoring networks or urban NAAQS compliance networks.

4. CONTINUOUS GASEOUS

Overview: A variety of gaseous pollutants, such as Ozone (O_3), Carbon Monoxide (CO), Nitrogen Dioxide (NOx), nitric oxide (NO), ammonia (NH_3), hydrogen peroxide (H_2O_2), sulfur dioxide (SO_2), Organics, and HAPS/TOXICS, can be measured continuously. Gaseous monitoring is generally conducted with instruments that continuously draw sample air and periodically (as frequently as once per second) analyze the sample. Canister systems collect an ambient air sample over a specific period of time in clean evacuated canisters. The canisters are then subject to subsequent analysis at a laboratory using a method such as GC/FID. This method is able to provide time-integrated samples from several hours to twenty-four hours or more. Regular checks of the flow rate, stability, reproducibility, precision, and accuracy of these instruments must be conducted on a regular schedule in order to ensure data quality.

Magnitude: Possible when used in conjunction with appropriate analytical techniques.

Frequency: Possible when used in conjunction with appropriate analytical techniques.

Duration: Possible when used in conjunction with appropriate analytical techniques.

Strengths: Continuous measurement with hourly time resolution; Monitors available to identify variety of pollutants.

Weaknesses/Limitations: Generally require conditioned environment and frequent performance checks.

Practical Considerations: Data may be available from established urban area monitoring networks and some Class I area monitoring networks; Additional cost ($/year) for new sites.

Level of Expertise Required: Standard operating procedures available for routine operation and maintenance.

Regulatory Context: Commonly used in urban NAAQS compliance and HAPS/TOXICS networks.

5. TRANSMISSOMETER

Overview: Transmissometers measure the amount of light transmitted through the atmosphere over a known distance (generally between 0.5 km and 10.0 km) between a light source of known intensity and a receiver. The transmission measurements are electronically converted to hourly averaged light extinction (b_{ext}).

Magnitude: Possible when used in conjunction with appropriate analytical techniques.

Frequency: Possible when used in conjunction with appropriate analytical techniques.

Duration: Possible when used in conjunction with appropriate analytical techniques.

Uncertainties: A transmissometer must be installed in stable locations with a clear and unobstructed path to avoid interference with the signal.

Strengths: Continuous measurement of b_{ext} in many Class I areas and some urban areas.

Limitations: Not capable of identifying pollutants contributing to visibility impairment.

Level of Expertise Required: Standard operating procedures available for routine operation and maintenance; Data processing/quality assurance requires high level of expertise.

Regulatory Context: Commonly used in Class I area monitoring networks and in some urban areas.

6. SCENE

Overview: Scene monitoring refers to the use of still and/or time-lapse photography (including digital imagery) to provide a qualitative representation of visual air quality. Scene monitoring data quality objective recommendations are to document the appearance of scenes of interest under a variety of air quality and illumination conditions at different times of day and different seasons. Scene monitoring documents the visual condition observed at a monitoring site. The data collection schedule can be tailored to capture the periods when visibility impairment is most likely to occur at specific sites. Time-lapse movies (generally time-lapse video or super 8 mm film) can be used at monitoring sites and during special studies to document the visual dynamics of a scene or source.

Magnitude: Cannot provide a quantitative measurement of visibility impairment but can qualitatively illustrate various levels of visibility impairment.

Frequency: Possible depending on the method used. Time-lapse video may be able to demonstrate the frequency of the impairment. The use of still photography to document impairment frequency depends upon the number of images acquired over time.

Duration: Possible depending on the method used. Time-lapse video may be able to demonstrate the impairment frequency. The use of still photography to document impairment frequency depends upon the number of images acquired over time.

Uncertainties: n/a

Strengths: Provides image/video record

Limitations: Not capable of identifying pollutants contributing to visibility impairment.

Level of Expertise Required: Standard operating procedures available for routine operation and maintenance.

Regulatory Context: Commonly used in Class I area monitoring networks and in some urban areas.

7. TRACER METHODS, LIDAR SYSTEMS, AIRCRAFT BASED MEASUREMENTS

Overview: The methods described in this section are more specialized methods generally reserved for special studies as opposed to the previously described methods that are used more routinely. Tracer methods, lidar systems and aircraft based measurements will be described individually.

Tracer Methods:
A tracer element or compound is a substance with unique characteristics that allows positive identification at very low concentrations. The tracer compound of choice will vary by source type and composition of the plume being tracked. In general, the tracer must have very low natural background concentrations and ideally would have the same chemical form and properties as the compound being tracked. In ambient applications where use of the ideal tracer is not possible due to potential environmental risk, a near-substitute compound may be used. When used to determine potential source impacts, the chosen compound is released from a source stack and downwind monitors are used to detect the presence of the compound.

Lidar Methods:
A lidar transmits short pulses of laser light into the atmosphere. The laser beam loses light to scattering as it travels. At each range, some of the light is backscattered into a detector. Because the light takes longer to return from the more distant ranges, the time delay of the return pulses can be converted to the corresponding distance between the atmospheric scatterer and the lidar. The end result is a profile of atmospheric scattering versus distance. Analysis of this signal can yield information about the distribution of aerosols in the atmosphere. The amount of backscatter indicates the density of the scatters. This can be used to measure cloud base height or track

plumes of pollution. Other properties of the atmosphere can also be deduced from the lidar return signals. A frequency shift in the light because of the Doppler effect permits measurement of wind speeds. By detecting the amount of depolarization, one can discriminate between liquid droplets and nonspherical ice particles. Differential Absorption Lidar (DIAL) uses absorption, as evidenced by reduced backscatter from greater distances, to measure the concentration of atmospheric gases. A Raman lidar detects particular atmospheric components (such as water vapor) by measuring the wavelength-shifted return from selected molecules (NOAA).

Aircraft Based Measurements:
Aircraft based measurement systems utilize specially equipped aircraft to make pollutant and meteorological measurements at various elevations throughout the study domain. The aircraft can be equipped with a multitude of gaseous, aerosol, optical and meteorological equipment. This measurement method provides the advantage of vertical profiles of various parameters, the ability to track point source plumes, and the ability to establish boundary conditions for future analytical and modeling exercises.

References:

NOAA, Atmospheric Light Division, Environmental Technology Laboratory, http://www2.etl.noaa.gov/DIAL_lidar.html

U.S. Environmental Protection Agency, Visibility Monitoring Guidance (EPA-454/R-99-003), June 1999.

National Research Council, Protecting Visibility in National Parks and Wilderness Areas, National Academy Press, Washington D.C., 1993, pp. 315-357.

Table 1. Monitoring Techniques

Criteria	Monitoring Method						
	IMPROVE	Filter Based Aerosol	Continuous Aerosol	Gaseous; Continuous methods, canister sampling, etc.	Transmissometer	Scene 35mmfilm/8mm video, digital	Tracer Methods, Lidar systems, Aircraft based measurements
Pollutant							
PM_{10}	Yes	Yes	Yes	No	No	No	All Possible
$PM_{2.5}$	Yes	Yes	Yes	Yes	No	No	
NOx	(Site specific)	No	No	Yes	No	No	
SO_2	(Site specific)	No	No	Yes	No	No	
Sulfate	Yes	Yes	No	No	No	No	
Nitrate	Yes	Yes	No	No	No	No	
Carbon	Yes	Yes	No	No	No	No	
Organics	Yes	Yes	No	Yes	No	No	
Other	Reconstructed extinction		Nephelometer - Bscat Aethelometer - Babs	HAPS, TOXICS	Total Extinction	Visual Parameters	
Visibility/Concentration Changes							
Magnitude	Yes	Yes	All Possible	All Possible	All Possible	No	All Possible
Frequency	Yes	Yes	All Possible	All Possible	All Possible	Yes	All Possible
Duration	Yes	Yes				Yes	
Time of Day	No	No				Yes	
Likely Part of FLM Certification?	Possible						No

Monitoring Techniques (continued)

Principal							
Qualitative/ Quantitative	Quantitative					Qualitative	Qualitative/Quantitative
Strengths	Reconstructed extinction calculation, historical record	various chemical analysis, large network nationwide	Continuous measurement, nephelometer commonly located in or near Class I areas	Continuous measurement, variety of possible pollutants	Continuous measurement, provides light extinction value, historical record	Relatively inexpensive, uncomplicated operational requirements	Lidar and airplane based systems can provided temporal and spatial results, tracer methods can provide source-receptor data
Weaknesses/ Limitations	Fixed location in or near Class I areas, also located in several urban areas	Integrated 24 hour sample generally collected on one-in-three schedule, commonly in urban areas	TEOM, BETA, etc, commonly located in urban areas	Generally require conditioned environment for proper operation, commonly located in urban areas	Fixed location in or near Class I areas	Number of still images limited, video requires storage and routine review	Complex and relatively expensive to operate, requires specialized training and knowledge to operate and analyze results
Distinguish BART Sources?	Possible with other analysis	Possible with other analysis	No	Possible with other analysis	No	Possible with other analysis	Possible with other analysis
Practical Considerations							
Cost	Moderate; varies depending on the number of instruments					Low	High

B. Source Modeling

Introduction

Given the complex natural environment, the state must choose the configuration of modeling techniques that will provide the most information on the contributing source or sources of impairment within the limited resources of current technology, data, budgets, time and staff availability.

1. Physical Models

Physical models are those that simulate the meteorology and air quality over an area. Modeling relies on a numerical or analytical model to estimate particulate concentrations in space and time. Because of its nature and sources, particulate matter is difficult to model over all spatial scales. Many air quality models that are currently available were designed to be applied over the regional scale with grid sizes from four to forty kilometers. Modeling requires detailed meteorological fields and emissions inventory over the entire domain. The compilation of data required to run these models can require much effort and expertise. Efforts are underway by government agencies in the U.S. to generate and archive both emissions and estimated activity levels of many source types in geographical information systems.

Numerical source-oriented models are designed to simulate atmospheric diffusion or dispersion and estimate concentrations at defined receptors. Numerical source models can be grouped as kinematic, first-order closure, or second-order closure models (Bowne and Lundergan, 1983). Kinematic models are the simplest both mathematically and conceptually. These models simplify the non-linear equations of turbulent motion, thereby permitting a closed analytical approximation to describe pollutant concentration (Green *et al.*, 1980). First-order closure models are based on the assumption of an isotropic pollutant concentration field. Consequently, turbulent eddy fluxes are estimated as being proportional to the local spatial gradient of the transport quantities. The Eulerian grid models, Lagrangian particle models, and trajectory puff/plume models are included in this category. Second-order closure models involve a series of algorithm transformations of the equations of state, mass continuity, momentum, and energy by using the Boussinesque approximation and Reynold's decomposition theory (Holton, 1992; Stull, 1988).

2. Spatial Scales

The model's applicable spatial scales play a large role meeting the analysis' objectives and its ability to accurately assess spatial variability. PM_{10} and $PM_{2.5}$ concentrations modeled or measured at any receptor result from the complex interaction of meteorology, chemical transformations and emissions from nearby and distant sources. For example, a monitor located near an operating construction site will be impacted more by the daily construction activity than the surrounding area. That site may be classified as representing an area of a few tens of meters to no more than one kilometer depending on the size of the construction area and fugitive dust control measures.

The dimensions given below are nominal rather than exact and are presented as defined in 40 CFR part 58.

a. Micro-Scale (10 to 100 m): This scale does not apply to scenarios relevant to the attribution problem. Modeling at the microscale is usually done by simple Gaussian plume models such as ISCST3. Measurements in urban areas can show considerable variations at this scale while those in pristine areas would not. Variations often occur when monitors are located close to a low-level emissions source, such as a busy roadway, construction site, within a community that uses wood stoves, or a short industrial stack. Fortunately, compliance monitoring site exposure criteria avoids microscale influences even for source-oriented monitoring sites.

b. Middle Scale (100 to 500 m): Middle-scale monitors show significant differences between locations that are ~0.1 to 0.5 km apart. These differences may occur near large industrial areas with many different operations or near large construction sites. Monitors with middle-scale zones of representation are often source-oriented, used to determine the contributions from emitting activities with multiple, individual sources to nearby community exposure monitors.

c. Neighborhood Scale (500 m to 4 km): Neighborhood-scale monitors do not show significant differences in particulate concentrations with spacing of a few kilometers. This dimension is often the size of emissions and modeling grids used in large urban areas for PM source assessment, so this zone of representation of a monitor is the only one that should be used to evaluate such models. Sources affecting neighborhood-scale sites typically consist of small individual emitters, such as clean, paved, curbed roads, uncongested traffic flow without a significant fraction of heavy-duty vehicles, or neighborhood use of residential heating devices such as fireplaces and wood stoves.

d. Urban Scale (4 to 100 km): Urban-scale monitors show consistency among measurements with monitor separations of tens of kilometers. These monitors represent a mixture of particles from many sources within the urban complex, including those from the smaller scales. PM measurements at urban-scale locations are not dominated by any particular neighborhood, however. Urban-scale sites are often located at higher elevations and away from highly traveled roads, industries, and residential heating.

e. Regional-Scale Background (100 to 1,000 km): Regional-scale background monitors show consistency among measurements for monitor separations of a few hundred kilometers. Background concentrations are often more consistent for specific chemical compounds, such as sulfate or nitrate, than they are for PM mass concentrations. Regional-scale PM is a combination of naturally-occurring aerosol from windblown dust and marine aerosol as well as particles generated in urban and industrial areas that may be more than 1,000 km distant. Regional-scale sites are best located in rural areas away from local sources, and at higher elevations. National parks, national wilderness areas, and many state and county parks and reserves are appropriate areas for regional-scale sites. Many of the IMPROVE sites characterize PM regional scale background in different regions of the United States.

f. Continental-Scale Background (1,000 to 10,000 km): Continental-scale background monitors show little variation even when they are separated by more than 1,000 km. They are hundreds of kilometers from the nearest significant emitters. Though these sites measure a mixture of natural and diluted manmade source contributions, the manmade component is at its minimum expected concentration. The Jarbidge Wilderness IMPROVE site in northern Nevada is a good example of a continental-scale background site for particulate matter in North America.

e. Global-Scale Background (>10,000 km): Global-scale background monitors are intended to quantify concentrations transported between different continents as well as naturally-emitted particles and precursors from sea spray, volcanoes, and windblown dust. Yellow sand from China has been detected at the Mauna Loa, HI, laboratory (Darzi and Winchester, 1982; Braaten and Cahill, 1986), as well as on the North American continent. Red dust from Africa's Sahara desert has been detected at Mt. Yunque, Puerto Rico and over the southeastern United States. Other global-scale sites include McMurdo, Palmer, and Ahmundson-Scott stations in Antarctica (Lowenthal *et al.*, 1996), Pt. Barrow, Alaska, and Mace Head, Ireland.

3. Chemical Composition

This section illustrates how the chemical composition of aerosols is an important consideration in the choice of particulate matter models. The knowledge of how the aerosol's composition varies over an area will play a key role in the attribution study design.

The relative abundance of chemical components in the atmosphere closely reflect the characteristics of emission sources. Major chemical components of $PM_{2.5}$ and PM_{10} mass in urban and rural areas consist of nitrate, sulfate, ammonium, carbon, geological material, sodium chloride, and liquid water.

Chemical compositions can vary spatially in all scales of the atmosphere and depend on sources surrounding the monitoring site. For example, on the continental scale, the eastern U.S. fine particulate chemical compositions are different than those of the western states. In the eastern portion of the U.S., nonurban $PM_{2.5}$ is dominated by secondary sulfate, organics and elemental carbon (EPA, 1996). The data to support this conclusion are based on the IMPROVE and CASTNET networks. These networks provide a background fine-fraction aerosol database because the monitoring sites are primarily located in national parks and wilderness areas. Analysis of this network shows that the western U.S. nonurban $PM_{2.5}$ aerosol is predominantly carbon in nature. Nitrate also contributes significantly to the fine particle mass budget particularly in central and coastal California. Within these generalizations, obvious departures will be found especially near sources such as near the ocean and urban areas where the aerosol will be primarily influenced by sea salt and combustion particles, respectively.

The typical $PM_{2.5}$ chemical compositions vary by season (Chow et al., 1993a; 1996a, Watson et al., 1997), and consist of the following major components:

a. Organic Carbon: Organic carbon is composed of gases and particles containing combinations of carbon and hydrogen atoms. Organic compounds found in ambient air may also be associated with other elements and compounds, particularly oxygen, nitrogen, sulfur, halogens, and metals. Particulate organic carbon consists of hundreds, possibly thousands, of separate compounds (Rogge et al., 1993a). The mass concentration of organic carbon can be accurately measured, as can carbonate carbon (Chow et al., 1993b), but only about ten percent of the specific organic compounds that it contains have been measured. Vehicle exhaust (Rogge et al., 1993b), residential and agricultural burning (Rogge et al., 1998), meat cooking (Rogge et al., 1991), fuel combustion (Rogge et al., 1997), road dust (Rogge et al., 1993c), and particle formation from heavy hydrocarbon gases (Pandis et al., 1992), are the major sources of organic carbon in $PM_{2.5}$.

b. Elemental Carbon: Elemental carbon is black, often called “soot.” Elemental carbon contains pure, graphitic carbon, but it also contains high molecular weight, dark-colored, nonvolatile organic materials such as tar, biological material (e.g., coffee), and coke. Elemental carbon usually accompanies organic carbon in combustion emissions, with diesel exhaust (Watson et al., 1994a, 1998) being the largest contributor.

c. Sulfate: Ammonium sulfate ((NH_4SO_4), ammonium bisulfate (NH_4HSO_4), and sulfuric acid (H_2SO_4), are the most common sulfate compounds in $PM_{2.5}$. These compounds are water-soluble and reside almost exclusively in the $PM_{2.5}$ size fraction. Sodium sulfate (Na_2SO_4) has been found in coastal areas where sulfuric acid has been neutralized by sodium chloride (NaCl) in sea salt. Although gypsum (Ca_2SO_4) and some other geological compounds contain sulfate, these are not easily dissolved in water for chemical analysis and are more abundant in the coarse fraction than in $PM_{2.5}$; they are usually classified in the geological fraction.

d. Nitrate: Ammonium nitrate (NH_4NO_3) is the most abundant nitrate compound, a large fraction of $PM_{2.5}$ occurs during winter, and a moderate fraction occurs during fall. Sodium nitrate ($NaNO_3$) is found in the $PM_{2.5}$ and coarse fractions near the oceans and salt playas. Small quantities of sodium nitrate have been found in summertime particulate matter inland owing to transport from the ocean (Chow et al., 1996b).

e. Ammonium: Ammonium sulfate (NH_4SO_4) and ammonium nitrate (NH_4NO_3) are the most common compounds containing ammonium from reactions between sulfuric acid, nitric acid, and ammonia gases. While most of the sulfur dioxide and oxides of nitrogen originate from fuel combustion in stationary and mobile sources, most of the ammonia derives from living things, especially animal husbandry practiced in dairies and feedlots.

f. Geological Material: Suspended dust consists mainly of oxides of aluminum, silicon, calcium, titanium, iron, and other metal oxides. In areas surrounded by substantial terrain (i.e., mountains), eons of runoff produce mineral compositions in soils that can be fairly homogeneous, with the exception of places where dry lake beds exist that have accumulated salt deposits. Industrial processes such as steel making, smelting, and mining have distinct geological compositions. For instance, cement production and distribution facilities may use alcareous, siliceous, argillaceous, and ferriferous minerals that may not be natural to the region, with limestone ($CaCO_3$) being the most abundant (Greer et al., 1992). Suspended geological material resides mostly in the coarse particle fraction (Houck et al, 1989,1990), and typically constitutes ~50% of PM_{10} while only contributing 5 to 15% of $PM_{2.5}$ (Watson et al., 1994b).

g. Sodium Chloride: Salt is found in suspended particles near oceans, open playas, and after de-icing materials are applied. Bulk sea water contains 57±7% chloride, 32±4% sodium, 8±1% sulfate, 1.1±0.1% soluble potassium, and 1.2±0.2% calcium (Pytkowicz and Kester, 1971). As noted above, sodium chloride is often neutralized by nitric or sulfuric acid in urban air where it is encountered as sodium nitrate or sodium sulfate.

h. Liquid Water: Soluble nitrates, sulfates, ammonium, sodium, other inorganic ions, and some organic material (Saxena and Hildemann, 1997) absorb water vapor from the atmosphere, especially when relative humidity exceeds 70% (Tang and Munkelwitz, 1993). Sulfuric acid absorbs some water or deliquesces at all humidities. Particles containing these compounds grow into the droplet mode as they take on liquid water. Some of this water is retained when particles are sampled and weighed for mass concentration. The precise amount of water quantified in a $PM_{2.5}$ depends on its ionic composition and the equilibration relative humidity applied prior to laboratory weighing.

Ambient mass concentrations contain both primary and secondary particles. Primary particles are directly emitted by sources and usually undergo few changes between source and receptor. Atmospheric concentrations of primary particles are, on average, proportional to the quantities that are emitted.

Secondary particles are those that form in the atmosphere from gases that are directly emitted by sources. Sulfur dioxide, ammonia, and oxides of nitrogen are the precursors for sulfuric acid, ammonium bisulfate, ammonium sulfate, and ammonium nitrate particles. "Heavy" volatile organic compounds or HVOC (those containing more than eight carbon atoms) may also change into particles. The majority of these transformations result from intense photochemical reactions that also create high ozone levels. Secondary particles usually form over several hours or days and attain aerodynamic diameters in the accumulation mode between 0.1 and 1 μm. Several of these particles, notably those containing ammonium nitrate, are volatile and transfer mass between the gas and particle phase to maintain a chemical equilibrium. This volatility has implications for ambient concentration measurements as well as for gas and particle concentrations in the atmosphere.

Ambient concentrations of secondary aerosols are not necessarily proportional to quantities of emissions since the rate at which they form may be limited by factors other than the concentration of the precursor gases. Secondary particulate ammonium nitrate concentrations depend on gaseous ammonia and nitric acid concentrations as well as temperature and relative humidity. A nearby source of ammonia may cause a localized increase in $PM_{2.5}$ concentrations by shifting the equilibrium from the gas to the particulate ammonium nitrate phase (Watson et al., 1994c). Ammonium sulfate may form rapidly from sulfur dioxide and ammonia gases in the presence of clouds and fogs, or slowly in dry air. Because fine particle deposition velocities are slower than those of the gaseous precursors, $PM_{2.5}$ may travel much farther than the precursors, and secondary particles precursors are often found far from their emissions sources and may extend over scales exceeding 1,000 km.

4. Particle Formation

Ammonium nitrate and ammonium sulfate aerosols are the most prevalent secondary particles found at urban and non-urban sites throughout the U.S. during the winter. These particles can form when gas molecules are attracted to and adhere to existing particles.

Sulfur dioxide gas changes to particulate sulfate through gas- and aqueous-phase transformation pathways. In the gas-phase pathway, ultraviolet sunlight induces photochemical reactions creating oxidizing species that react with a wide variety of atmospheric constituents. The gas-phase transformation rate appears to be controlled more by the presence or absence of the hydroxyl radical and its competing reactions of other gases than by the sulfur dioxide concentrations.

In the presence of fogs or clouds, sulfur dioxide dissolves in droplets where it experiences aqueous reactions that are much faster than gas-phase reactions. When ozone and hydrogen peroxide are dissolved in the droplet, the sulfur dioxide is quickly oxidized to sulfuric acid. When ammonia is dissolved in the droplet, the sulfuric acid is neutralized to ammonium sulfate. If the fog or cloud evaporates and relative humidity decreases below 100 percent, the sulfate particle exists as a small droplet that includes a portion of liquid water. As the relative humidity further decreases below 70 percent, the droplet evaporates and a small, solid sulfate particle remains. The reactions within the fog droplet are very fast, and the rate is controlled by the solubility of the precursor gases. Aqueous transformation rates of sulfur dioxide to sulfate are 10 to 100 times as fast as gas-phase rates. These chemical reactions are critical to understanding PM concentrations in areas and downwind of areas that emits large amounts of SO_2. The location and SO_2 emissions output of large point sources such as coal and oil fired power plants need to be mapped and compared with transport patterns in order to determine the impact of ammonium sulfate particles on ambient surface concentrations.

Fogs serve as an environment for creating particles and as vehicles for particle removal. During heavy fogs, particles and precursor gases are scavenged as fog droplets grow to sizes that settle rapidly to the surface. The extent and intensity of these fogs is so poorly characterized, however, that it is not yet possible to determine where and when particle formation overtakes particle deposition, thereby adding to the $PM_{2.5}$ concentration loading.

Nitrogen oxide converts to nitrogen dioxide, primarily by reaction with ozone. Nitrogen dioxide can: 1) change back to nitrogen oxide in the presence of ultraviolet radiation; 2) change to short-lived species which take place in other chemical reactions; 3) form organic nitrates; or 4) oxidize to form nitric acid. The major pathway to nitric acid is a reaction with hydroxyl radicals that transforms nitrogen dioxide to nitric acid. Nitric acid deposits from the atmosphere fairly rapidly but, in the presence of ammonia, it is neutralized to particulate ammonium nitrate. This is an important process in secondary particle production because many agricultural areas surrounding populated urban areas contain large ammonia sources. Chow and Egami (1997) show that San Joaquin Valley ammonia concentrations are large during winter. Conversion rates for nitrogen dioxide to nitric acid, ranging from less than one percent per hour to ninety percent per hour. These rates are typically five to ten times the conversion rates for sulfate formation. Though they vary throughout a twenty-four hour period, these rates are significant during both daytime and nighttime hours, in contrast to the gas-phase sulfate chemistry that is most active during daylight hours. The important nitric acid-ammonia reaction has implications to network design by the need to locate and map possible sources of ammonia. Significant sources of ammonia are associated with animal husbandry and fertilizer applications. Locating and estimating ammonia emissions will be a difficult task because it is not traditionally tabulated in emission inventories and requires further research to refine the methodology to measure the emissions.

While ammonium sulfate is a fairly stable compound, ammonium nitrate is not. Its equilibrium with gaseous ammonia and nitric acid is strongly influenced by temperature and relative humidity. Atmospheric particle nitrate can occur in atmospheric aerosol particles as solid ammonium nitrate or as ionized ammonium nitrate in aerosol particles containing water. In both the solid and ionized forms, ammonium nitrate is in equilibrium with gas-phase nitric acid and ammonia.

For fixed relative humidity, increasing temperature decreases the particle nitrate fraction. This is a consequence of the direct relation between the equilibrium constants and temperature. As temperature increases, the equilibrium constants increase, which means higher gas-phase pressures can be supported, thereby reducing the particle nitrate fraction. For fixed humidity, decreasing temperature increases the particle nitrate fraction. As temperatures approach 0°C, the curves approach limiting values. Particle fractions of one are used for ion ratios greater than or equal to one, and particle fractions are determined by the amount of available ammonia for ion ratios less than one. For the higher temperatures, increasing relative humidity increases the particle nitrate fraction. This is a consequence of liquid water present for the 60% and 80% relative humidity cases. When there is sufficient ammonia present with 30% relative humidity, more than 90% of the nitrate is in the particle phase for temperatures less than 20°C. More than half of the particle nitrate is gone at temperatures above 30°C, and all of it disappears at temperatures above 40°C.

Atmospheric water is another important component of suspended particulate matter. The sharp rise in liquid water content at relative humidities between 55% and 75% is known as deliquescence. A precise humidity at which soluble particles take on liquid water depends on the chemical mixture and temperature. Particles containing these compounds grow into the droplet mode as they take on liquid water, so the same concentration of sulfate or nitrate makes a much larger contribution to light extinction when humidities are high (>70 percent) than when they are low (<30 percent). Excess liquid water is also measured as part of the $PM_{2.5}$ mass when sampled by light scattering continuous monitors or when filters have not been equilibrated at relative humidities less than 30% prior to weighing.

Some of the organic carbon in suspended particles is also of secondary origin. Secondary organic compounds in particulate matter include aliphatic acids, alcohols, aromatic acids, nitro-aromatics, carbonyls, esters, phenols, and aliphatic nitrates (Grosjean and Seinfeld, 1989; Grosjean, 1992, Pandis et al., 1992, 1993; Seinfeld and Pandis, 1998). Normally, primary organic carbon particles are more prevalent than secondary organics with exceptions such as those found in Los Angeles where conditions of clear skies and high photochemical smog are frequent. Although secondary organic aerosol was thought to be minimal during winter in central California, recent analyses (Strader et al., 1998) demonstrate that it could be as much as 20% of twenty-four hour organic carbon in some samples. This occurs because low wintertime temperatures lower the saturation vapor pressure for semi-volatile organic compounds. This is probably minor during winter and fall when photochemical reactions are not dominant.

The exact precursors of secondary organics are not well understood, but they are believed to consist of heavy hydrocarbons with more than seven carbon atoms. Odum (1997) identifies aromatics as the major group of commonly measured reactive organic gases that affect both ozone and secondary aerosol formation.

5. Source Modeling Techniques

Before selecting a modeling technique, it is wise to establish a conceptual model. A conceptual model describes the relevant physical and chemical processes that affect emissions, transport, and transformation specific to the region of interest. It is the starting point for any source apportionment process. Conceptual models take advantage of the large body of scientific knowledge already acquired. They identify the sources that are likely to be present and eliminate those that are not. They examine meteorological conditions that affect concentrations and focus further modeling on the conditions conducive to the high concentrations.

Modeling techniques relevant to attribution are split into several categories depending complexity, physical attributes, purpose and cost to execute. The following tables on pages 55 to 62 provide a matrix of detailed information on specific models grouped in these categories.

a. Puff Modeling Techniques

These models are based on a Lagrangian framework where air parcels are tracked spatially and temporally. They can include chemical mechanisms as well as deposition effects. The most commonly used puff model is the CALMET/CALPUFF (Scire et al., 2000).

b. Grid Modeling Techniques

For estimating $PM_{2.5}$ levels, Eulerian models that include aerosol modules simulating the physical and chemical processes governing particulate concentrations in the atmosphere are more suitable than Lagrangian models such as plume trajectory models. Eulerian three-dimensional models may use either a simplified treatment of atmospheric chemistry (usually used to address long-term particulate concentrations at urban sites) or include a more detailed atmospheric chemistry treatment (usually used to simulate only a few days of episodes due to their compositional cost).

Commonly used long-term Eulerian models with simplified atmospheric processes include (Seigneur et al., 1997):

- Urban Airshed Model Version V (UAM-V).
- Urban Airshed Model with version V with Linear Chemistry (UAM-LC)
- Regulatory Modeling System for Aerosol and Deposition (REMSAD).

Short-term Eulerian models with complex atmospheric processes include:

- Urban Airshed Model Version V with Aerosols (UAM-AERO),
- Urban Airshed Model with Aerosol Inorganic Module (UAM-AIM).
- SARMAP Air Quality Model with Aerosols (SAQM-AERO).
- Community Multi-scale Air Quality Model (CMAQ)

- Comprehensive Air Quality Model with extensions (CAMx)

All of the above mentioned Eulerian models have been developed by various scientists from universities, federal and state agencies, and the private sector. These particulate air quality models provide a three-dimensional treatment to simulate the fate and transport of atmospheric contaminants. All of these Eulerian models include gas phase chemistry and aerosol dynamics and simulate atmospheric inorganics (such as sulfate, nitrate, and ammonium), but some of these models do not include the treatment of organics (i.e., REMSAD and UAM-LC).

c. Lagrangian Trajectory Model Techniques

The advantages of using Lagrangian models are the ease of use, the ability to perform many trajectories and perform back trajectories. Commonly used Lagrangian models include HYSPLIT (Draxler and Hess, 1997) and FLEXPART (Stohl and Siebert, 2001).

d. Meteorological Modeling Techniques

Meteorological models describe transport, dispersion, vertical mixing, and moisture in time and space. Meteorological models consist of straight line, interpolation (termed diagnostic), and first principle (termed prognostic) formulations, with increasing levels of complexity and requirements for computational and data resources.

The straight line model is applied to hourly wind directions from a single monitor, assuming an air mass travels a distance equal to the wind velocity in the measured direction, regardless of the distance from the monitoring site. This model is applicable for a few hours of transport in flat terrain, typically for evaluating a single emissions source.

Interpolation models integrate wind speed and directions from multiple measurement locations, including upper air measurements provide by remote sensors or balloon launches. The more advanced of these models allow barriers, such as mountains, to be placed between monitors. Wind fields, therefore, show different directions and velocities at different horizontal and vertical positions. Interpolation wind models are applicable to domains with a large number of well-placed monitors and for estimating the movement of air masses from many sources over transport times of more than half a day. The number and placement of monitors, especially upper air monitors, is especially important in mountainous terrain and in coastal areas where winds are unusual.

First principle models (Stauffer and Seaman, 1994; Seaman et al., 1995; Koracin and Enger, 1994) embody scientists' best knowledge of atmospheric physics and thermodynamics, employing basic equations for conservation and transfer of energy and momentum. Also known as "prognostic models," first principle models purport to need no data other than values from a sparse upper air network for interpolation. They are computationally intensive, often requiring supercomputers but have become more practical and cost-effective as workstation and desktop computers become more powerful. Modern versions use "four-dimensional data assimilation" or FDDA that compare model-calculated wind, humidity, and temperature fields with measurements and "nudge" model outputs toward observations.

A more complex meteorological model is not necessarily a better model for a specific application. One of the most widely used first principle model is the Fifth-Generation NCAR/Penn State Mesoscale Model or MM5 model (Grell et al., 1995). The MM5 meteorological model has been adopted as the platform for central California air quality studies (Seaman et. al., 1995). MM5 input data consist of wind speed, wind direction, temperature, atmospheric pressure, and relative humidity at ground level, within the boundary layer, and above the boundary layer. In many cases in valley situations ten-meter vertical resolution is needed within the surface layer, 30-50 m resolution is needed in the valley wide layer, and 100 m resolution is needed above the valleywide layer up to ~2000 m agl (Watson et al., 1998). Time resolution is at least hourly for these measurements. Measurements are needed where large differences are expected, although this is largely unknown for winter.

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Source Modeling and Back Trajectory Attribution Techniques

Table 2. Puff, Visibility and Trajectory Modeling Attribution Techniques

	Air Quality Models					
Evaluation Criteria		**Visibility Models**		**Lagrangian Trajectory Models**		
	CALPUFF	VISCREEN	PLUVUEII	HYSPLIT	RAPTAD	FLEXPART
Chemical Mechanisms						
Does the model simulate aqueous phase chemistry? (If it does what chemistry mechanism is used and does it include fog/cloud chemistry)	Yes; reactions for SO_4 and NO_3	NO	NO	NO	NO	NO
Does the model simulate gas phase chemistry? (if it does, what chemical mechanism is implemented)	Yes	NO	NO	NO	NO	NO
Simulate secondary organic aerosols	4 species model	NO	NO	NO	NO	NO
Inorganic PM (i.e. ions, SO_4, NO_3, etc)	SO_4, NO_3	NO	NO	NO	NO	NO
Size distributions (sectional or modal)	Coarse and fine modes	NO	NO	Only for deposition	NO	
Applicable spatial scales	Micro- to regional scale	Neighbor-hood to urban scale		Neighborhood to global scale	Neighborhood to global scale	Neighborhood to global scale
Applicable temporal scales (episodic or long term applications)	Episodic or Long term	N/A	N/A	Episodic or Long term	Episodic or Long term	Episodic or Long term
Does the model have the capability to distinguish BART sources?	YES	YES	YES	YES	YES	YES
Does the model have the capability to ingest field measurements (PM, HNO_3, H_2O_2, NH3, etc)	NO; only as background values	NO	NO	NO	NO	NO

Air Quality Models (continued)

Evaluation Criteria	CALPUFF	**Visibility Models** VISCREEN	PLUVUEII	**Lagrangian Trajectory Models** HYSPLIT	RAPTAD	FLEXPART
Visibility Modeling						
Does the model simulate background regional haze	NO	NO	NO	NO	NO	NO
Point source treatment (plume rise, plume in grid)	YES	YES	YES	YES	YES	YES
Does the model have the capability to calculate wet and dry deposition?	YES	NO	NO	YES	NO	YES
Visibility treatment: (extinction, deciview, visual range)	Extinction (total and for SO_4, NO_3, EC, OC, fine, coarse), Deciviews	*	*	NO	NO	NO
Input Requirements						
Meteorological data required (single site, gridded, number of levels, etc)	Gridded; able to run with single site	*	*	Gridded (FNL, EDAS, MM5)	Gridded (Use HOTMAC's prediction)	Gridded (ECMWF, MM5)
Emission data required (single stack, multiple point sources, gridded, etc)	Multiple point, area, volume	*	*	Multiple point sources, gridded inventory	Single stack or multiple point sources	*
Allow for initial and boundary conditions (is it required or not applicable)	YES	NO	NO	NO	NO	NO
Has the model been compared against field program data? Has the model been peer reviewed?	YES	YES	YES	YES	YES	NO
Does enough data exist now to run the model (Does data exist in a format ready for the model? Are current databases adequate for the model?)	Use CALMET with existing stations or MM data	YES	YES	Gridded met data available on NOAA ARL ftp site (FNL, EDAS); adaptable to read in MM5	Use HOTMAC to obtain wind and turbulence data	*

Air Quality Models (continued)

Evaluation Criteria	CALPUFF	**Visibility Models** VISCREEN	PLUVUEII	**Lagrangian Trajectory Models** HYSPLIT	RAPTAD	FLEXPART
Practical Considerations						
Costs to run (hardware platforms, file storage, operating system)	Inexpensive; PC, Windows, up to 20GB (with CALMET)	Inexpensive; PC, DOS, 1MB	Inexpensive; PC, DOS, 1MB	Inexpensive; PC, Windows, 20MB	Inexpensive: Linux PC, Redhat	Inexpensive; Linux PC, Redhat; can be compiled on PC
Have protocols or procedures been developed to run and interpret the model?	FLAG for Class I AQRVs	FLAG for Class I AQRVs	FLAG for Class I AQRVs	NO	NO	NO
Is the source code available?	YES	YES	YES	NO	YES	YES
Are beginning user training classes available?	YES; by EarthTech, BEE-Line	EPA; APTI	EPA; APTI	NO	YES	NO
Are user support groups available?	YES; one list-serve	YES; through EPA SCRAM	YES; through EPA SCRAM	NO	YES	NO
Level of expertise required to run and interpret results (Level of Linux, UNIX, PC skills required)	Moderate; able to run PC DOS programs; knowledge of atmospheric chemistry & physics	Simple; able to run on PC DOS and windows	Simple; able to run on PC DOS and Windows	Simple; able to run on PC running Windows	Simple to run: GUI allows the user to easily run the program Knowledge is needed to interpret results	Moderate; must compile source code for PC, Linux or UNIX; knowledge of met input formats
Output visualization required to interpret output numbers	YES	NO	NO	YES; has built in visualization	YES; has built in visualization	YES
Other strengths	*	*	*	*	Applicable from building scale to terrain scale.	*
Availability	EarthTech www.src.com	EPA	EPA	NOAA Air Resource Laboratory; www.arl.noaa.gov/ss/models/hysplit.html	Yamada Science & Art; http://www.ysasoft.com	http://www.forst.uni-muenchen.de/EXT/LST/METEO/stohl/flexpart.html

* No information available at this time

Source Modeling and Back Trajectory Attribution Techniques

Table 3. Eulerian Grid Based Modeling Attribution Techniques

Evaluation Criteria	Air Quality Models – Grid Models: CMAQ	REMSAD	CAMx	UAM-AERO	UAM-VPM	URM	CalGrid
Chemical Mechanisms							
Does the model simulate aqueous phase chemistry? (If it does, what chemistry mechanism is used and does it include fog/cloud chemistry)	35 equilibria and 99 reactions for SO_4 and NO_3	1 reaction for SO_4	1 reaction for SO_4	35 equilibria and 99 reactions for SO_4 and NO_3	*	2 reactions for sulfate	NO
Does the model simulate gas phase chemistry? (if it does, what chemical mechanism is implemented)	CBM-IV (93 reactions) or RADM2 (158 reactions)	CBM-IV (93 reactions) or RADM2 (158 reactions)	CB-IV with enhanced isoprene or SAPRC97	SAPRC97 (185 reactions)	CB	LCC (about 100 reactions)	YES (both CBM-IV and SAPRC)
Simulate secondary organic aerosols	Primary from emissions; secondary from organics	Primary from emissions	Primary from emissions; secondary from gas phase reactions of organic precursors using yields	Secondary from gas phase reactions of organic precursors using yields	Primary from emissions	Primary from emissions; secondary from gas phase reactions of organic precursors using production fractions	NO
Inorganic PM (i.e. ions, SO_4, NO_3, etc)	SO_4, NO_3 and other material	SO_4, NO_3, NH_4, and other material	SO_4, NO_3, NH_4, Cl, other ions and materials	SO_4, NO_3, NH_4, Cl, other ions and materials	SO_4, NO_3, NH_4, and other materials	SO_4, NO_3, NH_4, Cl, other ions and materials	NO
Size distributions (sectional or modal)	Lognormal; three modes: Aitken, Accumulation and coase	$PM_{2.5}$ fraction, coarse mode	Discrete bins, user specified up to 10	Discrete bins, user specified up to 10	Lognormal bins; user specified	Discrete bins; user specified	NO
Applicable spatial scales	Mesoscale	Mesoscale	Mesoscale	Urban scale	Urban scale	Mesoscale	Urban to Regional
Applicable temporal scales (episodic or long term applications)	Episodic	Long term	Episodic	Episodic	Episodic	Episodic	Episodic
Does the model have the capability to distinguish BART sources?	YES; using plume in grid	NO	YES	NO	NO	NO	NO

Evaluation Criteria	Grid Models CMAQ	REMSAD	CAMx	UAM-AERO	UAM-VPM	URM	CalGrid
Chemical Mechanisms (continued)							
Does the model have the capability to ingest field measurements (PM, HNO_3, H_2O_2, NH_3, etc)	YES; as initial and boundary conditions	Uses default profiles	YES; as initial and boundary conditions	YES; as initial and boundary conditions	YES; as initial and boundary conditions	YES; as initial and boundary conditions	YES; as initial and boundary conditions
Visibility Modeling							
Does the model simulate background regional haze	YES	YES	YES	YES (with processing)	YES	YES	NO
Point source treatment (plume rise, plume in grid)	Plume in grid	NO	Plume in grid	NO	NO	NO	NO
Does the model have the capability to calculate wet and dry deposition?	YES	YES	YES	YES	YES	YES	YES
Visibility treatment: (extinction, deciview, visual range)	Extinction (total and for SO_4, NO_3, EC, OC, fine, coarse), Deciviews	Extinction (total and for SO_4, NO_3, EC, OC, fine, coarse), Deciviews	NO	YES (with processing)	*	*	NO
Input Requirements							
Meteorological data required (single site, gridded, number of levels, etc)	Gridded	Gridded	Gridded	Gridded	Gridded	Gridded	Gridded CALMET date
Emission data required (single stack, multiple point sources, gridded, etc)	Gridded	Gridded	Gridded	Gridded	Gridded	Gridded	Gridded
Allow for initial and boundary conditions (is it required or not applicable)	YES	YES	YES	YES	YES	YES	YES
Has the model been compared against field program data? Has the model been peer reviewed?	YES	YES	YES	YES	YES	YES	YES
Does enough data exist now to run the model (Does data exist in a format ready for the model? Are current databases adequate for the model?)	Extensive need for detailed emissions and meteorological fields	Extensive need for detailed emissions and meteorological fields	Extensive need for detailed emissions and meteorological fields	Extensive need for detailed emissions and meteorological fields	Extensive need for detailed emissions and meteorological fields	*	Extensive need for detailed emissions and meteorological fields

Air Quality Models (continued)

Evaluation Criteria	Grid Models CMAQ	REMSAD	CAMx	UAM-AERO	UAM-VPM	URM	CalGrid
Practical Considerations							
Costs to run (hardware platforms, file storage, operating system)	Can be run inexpensively; Linux PC, up to 1 TB (annual runs)	Can be run inexpensive; Linux PC	Can be run inexpensively; Linux PC	Can be run inexpensively; Linux PC	Can be run inexpensively; Linux PC	Can be run inexpensively; Linux PC	Can be run inexpensively; Linux PC
Has a protocol or procedures been developed to run the model?	NO; but RPOs have regional haze protocols	NO; but RPOs have regional haze protocols	NO	NO	NO	NO	NO
Is the source code available?	YES	*	YES	YES	YES	YES	YES
Are beginning user training classes available?	YES; through EPA and RPOs	NO	YES; through SAI and RPOs	NO	NO	NO	NO
Are user support groups available?	YES; through EPA and RPOs	NO	NO	NO	NO	NO	NO
Level of expertise required to run and interpret results (Level of Linux, UNIX, PC skills required)	Considerable expertise in UNIX or Linux; knowledge of atmospheric chemistry & physics	*	Moderate to extensive	Moderate to extensive	*	*	Moderate
Output visualization required to interpret output numbers	YES; use PAVE	YES; use PAVE	YES	YES	YES	YES	YES
Availability	EPA; Sharon LeDuc 919-541-1335	SAI; Sharon Douglas 415-507-7108	ENVIRON; Ralph Morris 415-899-0700	SAI; Sharon Douglas 415-507-7108	SAI; Sharon Douglas 415-507-7108	Georgia Tech; Ted Russel, Talat Odman	California Air Resources Board

* No information available at this time

Table 4. Meteorological Modeling Attribution Techniques

Evaluation Criteria	Diagnostic Models		Mesoscale Prognostic Models				
	CALMET	Diagnostic Wind Model	RAMS	MM5	Eta *	ARPS	HOTMAC
Applicable spatial scales	Urban to regional scale	Urban to regional scale	Urban to global scale	Urban to global scale	Urban to global scale	Urban to global scale	Urban to mesoscale
Applicable temporal scales	Hourly to annual	Hourly to annual	Hourly to annual	Hourly to annual	Hourly to annual	Hourly to annual	Hourly to annual
Does enough data exist in organization now to run the model? Are the existing monitoring networks adequate within the domain?	Depends on area	Depends on area	Depends on area	Depends on area	Depends on area	Depends on area	Depends on area
For the prognostic models: Capable of FDDA?	N/A	N/A	Yes	Yes	Yes	Yes	Yes
For the prognostic models: Are files available (archived) from real-time?	N/A	N/A	NOAA is running the model for the east coast	Several federal agencies and regional consortiums are running MM5	NOAA is running the Eta model and fields available through NCEP ftp site	It can be initialized using NCEP analyses files as well as individual observations	No
Data storage/archival requirements for simulation of episodic and annual events	Depends on modeling domain, grid size, number of species and length of simulation	Depends on modeling domain, grid size, number of species and length of simulation	Depends on modeling domain, grid size, number of species and length of simulation	Depends on modeling domain, grid size, number of species and length of simulation	Depends on modeling domain, grid size, number of species and length of simulation	Depends on modeling domain, grid size, number of species and length of simulation	Depends on modeling domain, grid size, number of species and length of simulation
Simulate clouds/precipitation fields? At what time intervals?	No	No	Yes – minutes to days	Yes – minutes to days	Yes – minutes to days	Yes – minutes to days	Yes – minutes to days
Has the model been compared against field program data? Has the model been peer reviewed?	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Meteorological Modeling Attribution Techniques (continued)

Evaluation Criteria	Diagnostic Models		Mesoscale Prognostic Models				
	CALMET	Diagnostic Wind Model	RAMS	MM5	Eta *	ARPS	HOTMAC
Tools available to visualize output fields? What operating systems?	Yes – Unix, Linux, Windows	Yes – Unix, Linux, Windows	Yes – Unix, Linux	Yes – Unix, Linux	Yes – Unix, Linux	Yes – Unix, Linux	Yes – Built-in GUI; Unix, Linux, Windows
Are user groups, listservers available when problems arise?	Yes	Yes	Yes	Yes	No	Yes	Yes
Cost to run (hardware, software)	PC Windows, PC Linux; Free source code	PC Linux, UNIX; Free	PC Linux; licensed source code	PC Linux, UNIX; Free source code	PC Linux, UNIX; Free source code	PC Linux, UNIX; Free source code	PC Linux; licensed source code
Level of expertise required to run and interpret results (Level of Linux, UNIX, PC skills required)	Moderate	Moderate	High	High	High	High	High
Availability of user training	Yes	Yes	Yes	Yes	No	Yes	Yes
Is the source code available?	Yes	Yes	Yes	Yes	No	Yes	Yes
Has a protocol or procedures been developed to run the model?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Strengths	Relatively easy to use; little observed data needed	Relatively easy to use; little observed data needed	Detailed 3-D, complex flow in time	Detailed 3-D, complex flow in time	Detailed 3-D, complex flow in time	Detailed 3-D, complex flow in time	Detailed 3-D, complex flow in time
Weaknesses/ Limitations	Parameterization depended; may not capture various flows	Parameterization depended; may not capture various flows	Large computer time; time consuming to debug	Large computer time; time consuming to debug	Large computer time; time consuming to debug	Large computer time; time consuming to debug	No real time data initialization

* While the Eta is not considered a mesoscale model, it has been used to simulate meteorology down to 10 km grid scales. The workstation Eta is available from NOAA and used experimentally by some NWS offices.
* No information available at this time

C. Observational Modeling Techniques

Introduction

Observational or receptor modeling refers to a group of analysis techniques in which monitoring data collected at or in the region of a receptor are analyzed in various ways in order to infer information about the pollutants and the sources of the pollutants causing visibility impairment.

These types of models often are used as the first technique for source apportionment in order to get an initial understanding of the source-receptor relationships in a region. They are also used to verify or reconcile deterministic models, and to aid in planning intensive monitoring studies.

Results of observational models can either be quantitative or qualitative. Quantitative results are estimates of the fractions of a measured species that can be attributed to a single source or attributed among several sources or source areas. Qualitative results include such information as the wind directions and other meteorological conditions most associated with high concentrations, or inferences about probable source types based on the relationships between trace elements at a single site, or information about source areas based on the spatial and temporal patterns in the concentrations of a single species. Often several observational models are used together to form hypotheses about the important source areas and source types affecting the concentrations at a receptor.

Advantages of receptor models are that they are generally quick and inexpensive to run and require relatively little input data. Disadvantages include the necessity of employing simplifying assumptions such as linear relationships and often the results are limited to averages over long periods of time or large spatial areas. Subjective user judgment is required to choose appropriate input data and/or interpret the results of many receptor models. As an example, suppose the UNMIX model data located a source associated with high concentrations of Br, K, elemental carbon, and organic carbon, and another source associated with high Se and S. It is the judgment of the modeler regarding the relationship of the individual species to a specific source that determines that first source is "smoke" and the second is "coal-fired power plants."

Receptor models could potentially be grouped in several different ways, based on their different attributes. Here they are somewhat arbitrarily put into four categories, with each category requiring incrementally more particulate data at the receptor: 1) back-trajectory analyses; 2) analyses of interspecies relationships; 3) analyses of spatial and temporal patterns; and 4) analyses that require a unique tracer. Some models that fall into each category are listed below:

Category 1. Back-Trajectory Analyses

a. Residence Time Analyses including residence time, source contribution function, conditional probability, and so forth. These give qualitative information about source areas and transport patterns.

b. Trajectory Mass Balance – Regression of residence time of back trajectories in selected source areas against concentrations yielding quantitative source attributions.

Category 2. Analyses of Interspecies Relationships

a. Chemical Mass Balance (CMB) - Quantitative source attributions are obtained by a weighted regression of known source profiles against measured concentrations of several species.
b. UNMIX – By looking for "edges" in the relationships between species, UNMIX estimates both the source profiles and the quantitative source contributions from each source.
c. Positive Matrix Factorization (PMF) – PMF, like UNMIX, uses the relationships between species to estimate the number and composition of the sources and the quantitative source contributions.
d. Enrichment Factors (EF) – The "enrichment" of certain ratios of trace elements is used to qualitatively infer source types impacting a receptor.

Category 3. Analyses of Spatial and Temporal Patterns

a. Empirical Orthogonal Function Analysis (EOF) – Analysis of spatial and temporal patterns leading to qualitative information about locations of dominant source areas, frequency and timing of source impacts and meteorological conditions associated with them.
b. Receptor Model Applied to Patterns in Space (RMAPS) – With additional assumptions applied to EOFs, quantitative source attributions are estimated.

Category 4. Tracer Analyses

a. Tracer Mass Balance Regression (TMBR) – Tracer concentrations, possibly weighted by other factors, are regressed against concentrations of the species of interest to give a quantitative estimate of the contribution from the source that emitted the tracer.
b. Differential Mass Balance (DMB) - The differential ratios of tracer to pollutant between source and receptor are adjusted based on simple chemistry and meteorology to give an estimate of the contribution of the tracer source to the receptor.
c. Tracer-Aerosol Gradient Interpretive Technique (TAGIT) – By comparing the ratios of tracer to concentration of interest at "background" sites to the ratios at tracer-affected sites, a quantitative attribution of the tracer source to the receptor is estimated.

Following are brief descriptions of each of these models and a few references giving further details and examples of their use.

1a. Qualitative Back Trajectory Residence Time Analyses

There are several methods of statistically analyzing the relationships between where air masses arrived from and the concentrations measured at a receptor. These include, but are not limited to: 1) where was air most likely to arrive from when concentrations are high; 2) if air arrived from a given area, what is the probability that the concentration at the receptor was high when the air mass arrived there; 3) what is the mean (or median or maximum or distribution) of concentrations at the receptor when air masses arrived from a given area. Selected References: Ashbaugh et al. (1985), Gebhart et al. (2001), Poirot and Wishinski (1986).

Data Needed: A time series of concentrations of the species of interest. One or more back trajectories of three to five days duration corresponding to each concentration. Back trajectories can be calculated by any of several methods including ATAD, Hysplit, the CAPITA Monte Carlo Model, as well as others. Standard National Weather Service upper air data can be used as input, though more detailed meteorological data can be input if available. Dispersion can be included in some of these models.

Model Assumptions: Errors in trajectory placement are random and uncorrelated. Variations in deposition, chemistry, emissions, and so forth, have less influence on measured concentrations on average than variations in transport directions.

Biggest Potential Problems: Results of these types of analyses are qualitative rather than quantitative. Results are more statistically robust when averaged over long time periods, usually a minimum of one season and preferably several years. Nearby sources cannot be resolved. User judgment is required to choose trajectories of an appropriate type, height, and length and also to choose appropriate definitions of "high" concentrations. Some concentrations that vary seasonally may have all "high" concentrations in a single season, necessitating some compensation in the analysis. Model results are probably more appropriate for species such as particulate sulfate that are relatively uniform over large spatial scales, rather than, for example, particulate nitrate, which is more volatile and seems to be more related to local sources than long-range transport.

1b. TrMB (Trajectory Mass Balance)

This is a multiple linear regression of the frequency of occurrence of trajectory endpoints in each of several source areas against the corresponding concentrations at the receptor. The result is the average attribution of a single species among up to about 25 source areas over a long time, for example, one season or year, or several years. Selected references: Gebhart and Malm (1989), Stohl (1998).

Data Needed: Time series of concentrations of the pollutant of interest at a single site. One or more back trajectories associated with each concentration. Input data for these are upper air winds, temperatures, and moisture over a large area. Often data are obtained from the standard National Weather Service observations, but other data such as higher resolution wind fields, wind profiler data specific to a given study, can also be used if available. Emission data can be used if available, but must vary in time to be useful. Simple chemistry and/or deposition can be used if data are available. The user defines the size and locations of the source areas to be considered.

Model Assumptions: Average contributions of each source area can be written as a linear combination of the contributions from several source areas. Average chemistry and deposition are adequate to explain average source contributions. Errors in back trajectories are random and normally distributed.

Biggest Potential Problems: No attribution to single sources—only to source areas. Attributions must be averaged over long time periods. Nearby sources cannot be modeled accurately. Subjectivity in choosing source areas. Violation of assumptions of linear chemistry.

2a. Chemical Mass Balance (CMB)

CMB is a multiple linear regression of measured concentrations against known source profiles. It is used for the attribution of all measured chemical species among several sources for each concentration measurement period for a single monitoring site. Regressions are weighted by the uncertainties in both the source profiles and the concentrations. Selected References: Watson et al. (1984 and 2001).

Data Needed: Concentrations and measurement uncertainties of both the chemical species of interest and of as many trace elements as possible are necessary for each time period and location for which attributions are desired. IMPROVE data can be used. A source profile is needed for each source. These are the relative amounts of each emitted chemical species and the uncertainties in these values.

Model Assumptions: Compositions of source emissions are constant over the period of ambient and source sampling. Chemical species do not react with each other, for example, they add linearly. All sources with a potential for significantly contributing to the receptor have been identified and have had their emissions characterized. The sources' compositions are linearly independent of each other. The number of sources or source categories is less than or equal to the number of chemical species. Measurement uncertainties are random, uncorrelated and normally distributed.

Biggest Potential Problems: The model cannot directly apportion secondary species such as sulfates, nitrates, and secondary organics. There are some workarounds for this. The usual tactic is to apportion these species between the known primary sources and a source designated as "secondary particles." It is also possible to use "fractionated" or "aged" source profiles where an attempt is made to pre-determine the chemical processes that occurred between source and receptor and then adjust the source profile accordingly. Obtaining all necessary source profiles can be difficult. In some studies, other receptor models have estimated source profiles.

2b. UNMIX

For a selection of measured species, UNMIX uses singular value decomposition with additional non-negativity constraints to estimate the number of sources, the source compositions, and the source contributions to each sample at a single monitoring site. UNMIX attempts to find the "edges" in the relationships between species and relates these to sources. Selected References: Henry (1997a, 1999), Lewis et al. (1998).

Data Needed: A time series of concentrations of several species measured at a single site. IMPROVE data can be used.

Model Assumptions: Concentrations are linear combinations of an unknown number of sources of unknown composition. Contributions from sources are positive. Source compositions are approximately constant in time. For each source there are some samples that contain little or no contribution from that source.

Biggest Potential Problems: A maximum of seven sources can be identified. There is some subjectivity in choosing fitting species, number of sources, how to deal with missing or below detection limit values, and which time periods and species should be analyzed together. Sources of secondary species will probably violate the assumption of constant source composition. This can cause multiple sources to be identified for a single physical source that impacts the receptor under differing conditions. Supplemental analysis may be required to deconvolute these.

2c. Positive Matrix Factorization (PMF)

PMF uses an iterative weighted least squares method to decompose a time-by-species matrix to estimate the number and composition of the sources and the contributions of each source to each measured species. It will also calculate error estimates for these values. Selected References: Paatero and Tapper (1994), Paatero (1997); Xie *et al.* (1999).

Data Needed: A time series of concentrations and their uncertainties for several species at a single monitoring location. IMPROVE data can be used.

Model Assumptions: Concentrations are linear combinations of an unknown number of sources of unknown composition. Contributions from sources are positive. Source compositions are approximately constant in time.

Biggest Potential Problems: Correlations in detection limits or uncertainties as well as in concentrations can influence the results. For example, PMF may detect positive correlations between species either due to source activity (desirable) or measurement protocol changes (undesirable).

2d. Enrichment Factors (EF)

The differences in ratios of elemental concentrations between a reference sample and a measured sample are used to determine how sources may have “enriched” the concentrations of certain species. Some examples include: high Al/Ca has been linked to Saharan dust, high Br/Pb may indicate lead is linked to autos rather than industry, high Se is linked to coal burning, heavy metals are linked to smelting, V and Ni are linked to residual oil combustion. Selected References: Lawson and Winchester (1979), Parekh et al. (1989), Perru (1997), Roshid and Griffiths (1993).

Data Needed: Time series of concentrations of trace elements and the species of interest. Some historical information about the “standard” crustal, sea salt, or other ratios for a region.

Model Assumptions: Elemental ratios depend mostly on enrichment of trace elements by a source and have less dependence on meteorology. The reference ratios are constant.

Biggest Potential Problems: Attributions are generally to source areas, not to single sources.

3a. Empirical Orthogonal Function Analysis (EOF)

A few (typically two to six) spatial patterns that explain most of the covariance in the spatial and temporal patterns of a measured species are obtained by singular value decomposition. Associations between the spatial patterns and source areas and/or transport of air pollutants into the study area can often be inferred, but are qualitative. The original data matrix can be approximately reconstructed by linearly recombining these few patterns. Selected References: Gebhart and Malm (1997), Henry et al. (1991), Malm et al. (1990), Malm and Gebhart (1997).

Data Needed: Measurements of a single air pollutant of interest at several sites for several time periods. Typically used are concentrations measured at fifteen to forty sites for thirty or more time periods. There must be more time periods than sites. Data from special studies are often analyzed in this way.

Model Assumptions: Only a few spatial patterns are required to explain a large majority of the covariance in the spatial and temporal patterns. These patterns have a physical meaning that can be inferred, such as transport of emissions from a source into the study area or local stagnation.

Biggest Potential Problems: Source attributions are qualitative, not quantitative and interpretation of the spatial patterns is subjective. The model requires a site by time matrix with no missing values, so some method of eliminating or filling in both missing and below detection limit values is necessary.

3b. Receptor Model Applied to Patterns in Space (RMAPS)

Determines the average attribution of a single species among a few source areas by decomposing the time by site matrix of concentrations into a source matrix and a time weighting matrix. Similar to UNMIX, the edges in the scatterplots between sources and non-negativity requirements are used to constrain the identification of sources. Selected References: Henry (1997 b, c, d), White (1999).

Data Needed: Time series of concentrations of the pollutant of interest at several sites within a region. The model previously has been used in special studies such as Project MOHAVE and PREVENT where there are fifteen to forty sites within a one or two state region collecting data daily for several weeks or months.

Model Assumptions: Average contributions of each source area can be written as a non-negative linear combination of the major principal components of the data. The spatial scale of the pollutant is large compared to the spacing of the sampling sites.

Biggest Potential Problems: If the second major assumption is violated, the concentrations of the pollutant at each site will have little correlation with the other sites; therefore the model would not apply because it relies on the common variations among sites.

4a. Tracer Mass Balance Regression (TMBR) also called Multiple Linear Regression (MLR) on Marker Species

Estimates the attribution of the aerosol species of interest by a source or source type, which emitted or emits a unique tracer. Uncertainty estimates are also generated if included in the regression. The model is a regression of the tracer, possibly weighted by other factors against the species of interest. Selected References: Malm et al. (1989 a, b, c).

Data Needed: Time series of ambient concentrations and their uncertainties for the aerosol species being apportioned and also the tracer species.

Model Assumptions: The tracer(s) are uniquely emitted by non-overlapping groups of sources. Source emissions are constant over the period of ambient sampling. Deposition and conversion are constant for all sampling periods and can be estimated by first-order approximations. In the WHITEX application, sulfate oxidation rates were assumed to be related to RH, where RH was a surrogate for time the air mass spent in clouds. Measurement errors are random, uncorrelated, and normally distributed.

Biggest Potential Problems: Tracer concentrations are not often available. Source profiles, deposition, and conversion all vary in time and space.

4b. Differential Mass Balance (DMB)

DMB estimates the fraction of a species of interest attributable to a single source that can be tagged with a unique tracer. The ratio of measured tracer to measured sulfate or nitrate is assumed to be related to the fractional contribution of the traced source. The ratio is adjusted based on the estimated difference between the ratio at the source to the ratio at the receptor. Travel times between the source and receptor are estimated based on winds, and then by using simple estimates of dispersion, deposition and oxidation, the tracer to secondary species ratio is adjusted. Selected References: Malm (1989b, c).

Data Needed: Time series of tracer concentrations and concentrations and emission rates of the species of interest and its precursors, for example, sulfur dioxide and sulfate. Estimates of wind speed and direction, mixing heights, deposition and oxidation rates.

Model Assumptions: Wind direction does not change during transport time. The rates for deposition and conversion are first-order and invariant in space and time along the transport path between the source and the receptor. The ratio of the emission rates for the species of interest or its parent species and the tracer is known.

Biggest Potential Problems: Simple chemistry and meteorology may not be adequate, especially for long transport times, complex terrain, and/or changing chemical regimes. Tracer concentrations unique to a single source are often not available. The fraction of attributable concentration may only be calculable to within a range based on the reasonable ranges of rate coefficients.

4c. Tracer-Aerosol Gradient Interpretive Technique (TAGIT)

Results are the attribution of primary or secondary species associated with the source "tagged" by a tracer release. TAGIT computes attributions on a sample period-by-sample period basis. For each sample period, background concentration of the species of interest is determined by averaging the concentrations of the species at nearby sites that do not have tracer concentrations and are significantly above background. These sites are presumed to be unaffected by the tracer-tagged source and thus represent the average background. This background for each sample period is then subtracted from the concentration of the species of interest at impacted receptor sites for corresponding sample periods. The difference is the concentration attributable to the tagged source. Green (2001), Kuhns et al. (1999), Pitchford et al. (2000).

Data Needed: Concentrations of a unique tracer from a source of interest and simultaneous concentrations of a pollutant of interest at several sites in a region.

Model Assumptions: There is no impact from the tagged source if the tracer concentration is less than the level considered to be "significantly" above its' background. Background concentrations of the species of interest do not vary systematically in space.

Biggest Potential Problems: Assuming no impact from the tagged source when tracer is not statistically above background can lead to an underestimation of attribution. Measured tracer concentrations often have large uncertainties. Some sampling periods will have a negative concentration attributed to the tagged source.

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Table 5. Observational Modeling Techniques

	Analyses of Back Trajectories					
Criteria	**Residence Time & Source Contribution Function**	**Conditional Probability**	**Concentration Statistics by Air Mass History (Mean, Max, Median)**	**Cluster Analysis**	**Hit – No Hit**	**Trajectory Mass Balance**
Quantitative Source Attribution?	No	No	No	No	No	Yes
Number of sources that can be distinguished?	Typically only about 10 or fewer transport patterns are distinguishable	Maximum of 10-15	1/grid cell, typically 50x50 (2500), though usually only about 5-20 transport patterns are distinguishable	2-15	1	20-30 max
Averaging Time of Result?	Weeks to years	Weeks to years	Weeks to years	Weeks to years	Daily, possibly hourly	Months to years
Previous use at Class I Areas? (See Text for References)	Yes	Yes	Yes	Yes	Yes	Yes
Magnitude of impacts?	No	No	Yes	No	No	Yes
Frequency of impacts?	Yes	No	No	Yes	Yes	Yes
Duration of impacts?	Yes	No	No	Yes	Yes	Yes
Time of Day of impacts?	Depends on particle data	Depends on particle data	Depends on particle data	Depends on particle data	Yes	Depends on particle data
Time of Year of impacts?	Yes	Yes	Yes	Yes	Yes	Yes
Appropriate for what source-receptor distances?	Regional Scale	Regional Scale	Regional Scale	Regional Scale	Regional Scale	Regional Scale
Attribution of Secondary Species?	Yes	Yes	Yes	Yes	Yes	Yes
Cost to run?	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal
Code Available?	No	No	No	No	No	No
Equations and/or algorithms available?	Yes	Yes	Yes	Yes	None needed	Yes
Computer Hardware Needed	PC	PC	PC	PC	PC	PC
Additional software necessary?	Any programming language or statistical package and graphics and/or mapping software that allows overlay of data on a map	Any programming language or statistical package and graphics and/or mapping software that allows overlay of data on a map	Any programming language or statistical package and graphics and/or mapping software that allows overlay of data on a map	Any programming language or statistical package and graphics and/or mapping software that allows overlay of data on a map	Graphing or mapping software that allows overlay of data on a map	Any programming language or statistical package and graphics and/or mapping software that allows overlay of data on a map
EPA Approved Model?	No	No	No	No	No	No

Observational Modeling Techniques(continued)

	Analyses of inter-species relationships				**Analyses of Spatial and Temporal Patterns**	
Criteria	**CMB**	**PMF**	**UNMIX**	**Factor Analysis**	**EOF**	**RMAPS**
Quantitative Source Attribution?	Yes	Yes	Yes	No	No	Yes
Number of sources that can be distinguished?	Usually < 10	Usually < 10	7	< Number of species analyzed	Usually 4-8 transport patterns	Usually 4-8 transport patterns
Averaging Time of Result?	Same as monitoring data	Same as monitoring data	Same as monitoring data		Same as monitoring data	Same as monitoring data
Previous use at Class I Areas? (See Text for References)	Yes	No?	No?	Yes	Yes	Yes
Magnitude of impacts?	Yes	Yes	Yes	No	No	Yes
Frequency of impacts?	Yes	Yes	Yes	Yes	Yes	Yes
Duration of impacts?	Yes	Yes	Yes	No	Yes	Yes
Time of Day of impacts?	Depends on input data	Depends on input data	Depends on input data	Depends on input data	Depends on input data	Depends on input data
Time of Year of impacts?	Yes	Yes	Yes	Yes	Yes	Yes
Appropriate for what source-receptor distances?	Urban to regional scales	Urban to regional scales	Urban to regional scales	Urban to regional scales	Regional Scale	Regional Scale
Attribution of Secondary Species?	With additional information	With additional information	With additional information	Yes	Yes	Yes
Cost to run?	Free to purchase, minimal to run	$700 to purchase, minimal to run	Currently free to purchase, minimal to run, $100 (student)-1500 (full) for MATLAB	Minimal	Minimal	Minimal
Code Available?	Yes	Yes	Yes	No	No	No
Equations and/or algorithms available?	Yes	Yes	Yes	Yes	Yes	Yes
Computer Hardware Needed	PC	PC	PC	PC	PC	PC
Additional software necessary?	No	No	MATLAB with optimization toolbox	Any statistics package	Any statistics package with ability to do singular value decompositions	Any statistics package with ability to do singular value decompositions
EPA Model?	Yes	No?	Yes?	No	No	No

Observational Modeling Techniques (continued)

	Analyses of Unique Tracer Data		
Criteria	**TMBR**	**DMB**	**TAGIT**
Quantitative Source Attribution?	Yes	Yes	Yes
Number of sources that can be distinguished?	1-3	1-3	1/tracer
Averaging Time of Result?		Same as particulate data	Same as particulate data
Previous use at Class I Areas? (See Text for References)	Yes	Yes	Yes
Magnitude of impacts?	Yes	Yes	Yes
Frequency of impacts?	Yes	Yes	Yes
Duration of impacts?	Yes	Yes	Yes
Time of Day of impacts?	Depends on particulate data	Depends on particulate data	Depends on particulate data
Time of Year of impacts?	Yes	Yes	Yes
Appropriate for what source-receptor distances?	Urban to Regional Scale	Urban to Regional Scale	Regional Scale
Attribution of Secondary Species?	Yes	Yes	Yes
Cost to run?	Minimal	Minimal	Minimal
Code Available?	No	No	No
Equations and/or algorithms available?	Yes	Yes	Yes
Computer Hardware Needed	PC	PC	PC
Additional software necessary?	Any programming language, spreadsheet, or statistical package	Any programming language, spreadsheet, or statistical package	Any programming language, spreadsheet, or statistical package
EPA Model?	No	No	No

Appendix A: **RA BART Rule** (40 CFR 51.300-306)

Sec. 51.300 Purpose and applicability.

Authority: Secs. 110, 114, 121, 160-169, 169A, and 301 of the Clean Air Act, (42 U.S.C. 7410, 7414, 7421, 7470-7479, and 7601).

Source: 45 FR 80089, Dec. 2, 1980, unless otherwise noted.

(a) Purpose. The primary purposes of this subpart are to require States to develop programs to assure reasonable progress toward meeting the national goal of preventing any future, and remedying any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from manmade air pollution; and to establish necessary additional procedures for new source permit applicants, States and Federal Land Managers to use in conducting the visibility impact analysis required for new sources under Sec. 51.166. This subpart sets forth requirements addressing visibility impairment in its two principal forms: ``reasonably attributable'' impairment (i.e., impairment attributable to a single source/small group of sources) and regional haze (i.e., widespread haze from a multitude of sources which impairs visibility in every direction over a large area).

(b) Applicability. (1) General Applicability. The provisions of this subpart pertaining to implementation plan requirements for assuring reasonable progress in preventing any future and remedying any existing visibility impairment are applicable to:

(i) Each State which has a mandatory Class I Federal area identified in part 81, subpart D, of this title, and Each State in which there is any source the emissions from which may reasonably be anticipated to cause or contribute to any impairment of visibility in any such area.

(ii)The provisions of this subpart pertaining to implementation plans to address reasonably attributable visibility impairment are applicable to the following States: Alabama, Alaska, Arizona, Arkansas, California, Colorado, Florida, Georgia, Hawaii, Idaho, Kentucky, Louisiana, Maine, Michigan, Minnesota, Missouri, Montana, Nevada, New Hampshire, New Jersey, New Mexico, North Carolina, North Dakota, Oklahoma, Oregon, South Carolina, South Dakota, Tennessee, Texas, Utah, Vermont, Virginia, Virgin Islands, Washington, West Virginia, Wyoming.

(3) The provisions of this subpart pertaining to implementation plans to address regional haze visibility impairment are applicable to all States as defined in section 302(d) of the Clean Air Act (CAA) except Guam, Puerto Rico, American Samoa, and the Northern Mariana Islands.

[45 FR 80089, Dec. 2, 1980, as amended at 64 FR 35763, July 1, 1999]

Sec. 51.301 Definitions.

For purposes of this subpart:

Adverse impact on visibility means, for purposes of section 307, visibility impairment which interferes with the management, protection, preservation, or enjoyment of the visitor's visual experience of the Federal Class I area. This determination must be made on a case-by-case basis taking into account the geographic extent, intensity, duration, frequency and time of visibility impairments, and how these factors correlate with (1) times of visitor use of the Federal Class I area, and (2) the frequency and timing of natural conditions that reduce visibility. This term does not include effects on integral vistas.

Agency means the U.S. Environmental Protection Agency.

BART-eligible source means an existing stationary facility as defined in this section. Best Available Retrofit Technology (BART) means an emission limitation based on the degree of reduction achievable through the application of the best system of continuous emission reduction for each pollutant which is emitted by an existing stationary facility. The emission limitation must be established, on a case-by-case basis, taking into consideration the technology available, the costs of compliance, the energy and nonair quality environmental impacts of compliance, any pollution control equipment in use or in existence at the source, the remaining useful life of the source, and the degree of improvement in visibility which may reasonably be anticipated to result from the use of such technology.

Building, structure, or facility means all of the pollutant-emitting activities which belong to the same industrial grouping, are located on one or more contiguous or adjacent properties, and are under the control of the same person (or persons under common control). Pollutant-emitting activities must be considered as part of the same industrial grouping if they belong to the same Major Group (i.e., which have the same two-digit code) as described in the Standard Industrial Classification Manual, 1972 as amended by the 1977 Supplement (U.S. Government Printing Office stock numbers 4101-0066 and 003-005-00176-0 respectively).

Deciview means a measurement of visibility impairment. A deciview is a haze index derived from calculated light extinction, such that uniform changes in haziness correspond to uniform incremental changes in perception across the entire range of conditions, from pristine to highly impaired. The deciview haze index is calculated based on the following equation (for the purposes of calculating deciview, the atmospheric light extinction coefficient must be calculated from aerosol measurements):

Deciview haze index = $10 \ln_e (b_{ext}/10\text{Mm}^{-1})$ Where b_{ext} = the atmospheric light extinction coefficient, expressed in inverse megameters (Mm^{-1}).

Existing stationary facility means any of the following stationary sources of air pollutants, including any reconstructed source, which was not in operation prior to August 7, 1962, and was in existence on August 7, 1977, and has the potential to emit 250 tons per year or more of any air pollutant. In determining potential to emit, fugitive emissions, to the extent quantifiable, must be counted.

Fossil-fuel fired steam electric plants of more than 250 million British thermal units per hour heat input,

Coal cleaning plants (thermal dryers),

Kraft pulp mills,

Portland cement plants,

Primary zinc smelters,

Iron and steel mill plants,

Primary aluminum ore reduction plants,

Primary copper smelters,

Municipal incinerators capable of charging more than 250 tons of refuse per day,

Hydrofluoric, sulfuric, and nitric acid plants,

Petroleum refineries,

Lime plants,

Phosphate rock processing plants,

Coke oven batteries,
Sulfur recovery plants,
Carbon black plants (furnace process),
Primary lead smelters,
Fuel conversion plants,
Sintering plants,
Secondary metal production facilities,
Chemical process plants,
Fossil-fuel boilers of more than 250 million British thermal units per hour heat input,
Petroleum storage and transfer facilities with a capacity exceeding 300,000 barrels,
Taconite ore processing facilities,
Glass fiber processing plants, and
Charcoal production facilities.

Federal Class I area means any Federal land that is classified or reclassified Class I.

Federal Land Manager means the Secretary of the department with authority over the Federal Class I area (or the Secretary's designee) or, with respect to Roosevelt-Campobello International Park, the Chairman of the Roosevelt-Campobello International Park Commission.

Federally enforceable means all limitations and conditions which are enforceable by the Administrator under the Clean Air Act including those requirements developed pursuant to parts 60 and 61 of this title, requirements within any applicable State Implementation Plan, and any permit requirements established pursuant to Sec. 52.21 of this chapter or under regulations approved pursuant to part 51, 52, or 60 of this title.

Fixed capital cost means the capital needed to provide all of the depreciable components.

Fugitive Emissions means those emissions which could not reasonably pass through a stack, chimney, vent, or other functionally equivalent opening.

Geographic enhancement for the purpose of Sec. 51.308 means a method, procedure, or process to allow a broad regional strategy, such as an emissions trading program designed to achieve greater reasonable progress than BART for regional haze, to accommodate BART for reasonably attributable impairment.

Implementation plan means, for the purposes of this part, any State Implementation Plan, Federal Implementation Plan, or Tribal Implementation Plan.

Indian tribe or *tribe* means any Indian tribe, band, nation, or other organized group or community, including any Alaska Native village, which is federally recognized as eligible for the special programs and services provided by the United States to Indians because of their status as Indians.

In existence means that the owner or operator has obtained all necessary preconstruction approvals or permits required by Federal, State, or local air pollution emissions and air quality laws or regulations and either has (1) begun, or caused to begin, a continuous program of physical on-site construction of the facility or (2) entered into binding agreements or contractual obligations, which cannot be cancelled or modified without substantial loss to the owner or operator, to undertake a program of construction of the facility to be completed in a reasonable time.

In operation means engaged in activity related to the primary design function of the source.

Installation means an identifiable piece of process equipment.

Integral vista means a view perceived from within the mandatory Class I Federal area of a specific landmark or panorama located outside the boundary of the mandatory Class I Federal area.

Least impaired days means the average visibility impairment (measured in deciviews) for the twenty percent of monitored days in a calendar year with the lowest amount of visibility impairment.

Major stationary source and major modification mean major stationary source and major modification, respectively, as defined in Sec. 51.166.

Mandatory Class I Federal Area means any area identified in part 81, subpart D of this title.

Most impaired days means the average visibility impairment (measured in deciviews) for the twenty percent of monitored days in a calendar year with the highest amount of visibility impairment.

Natural conditions includes naturally occurring phenomena that reduce visibility as measured in terms of light extinction, visual range, contrast, or coloration.

Potential to emit means the maximum capacity of a stationary source to emit a pollutant under its physical and operational design. Any physical or operational limitation on the capacity of the source to emit a pollutant including air pollution control equipment and restrictions on hours of operation or on the type or amount of material combusted, stored, or processed, shall be treated as part of its design if the limitation or the effect it would have on emissions is federally enforceable.

Secondary emissions do not count in determining the potential to emit of a stationary source.

Reasonably attributable means attributable by visual observation or any other technique the State deems appropriate. Reasonably attributable visibility impairment means visibility impairment that is caused by the emission of air pollutants from one, or a small number of sources.

Reconstruction will be presumed to have taken place where the fixed capital cost of the new component exceeds 50 percent of the fixed capital cost of a comparable entirely new source. Any final decision as to whether reconstruction has occurred must be made in accordance with the provisions of Sec. 60.15 (f) (1) through (3) of this title.

Regional haze means visibility impairment that is caused by the emission of air pollutants from numerous sources located over a wide geographic area. Such sources include, but are not limited to, major and minor stationary sources, mobile sources, and area sources.

Secondary emissions means emissions which occur as a result of the construction or operation of an existing stationary facility but do not come from the existing stationary facility. Secondary emissions may include, but are not limited to, emissions from ships or trains coming to or from the existing stationary facility.

Significant impairment means, for purposes of Sec. 51.303, visibility impairment which, in the judgment of the Administrator, interferes with the management, protection, preservation, or enjoyment of the visitor's visual experience of the mandatory Class I Federal area. This determination must be made on a case-by-case basis taking into account the geographic extent, intensity, duration, frequency and time of the visibility impairment, and how these factors correlate with (1) times of visitor use of the mandatory Class I Federal area, and (2) the frequency and timing of natural conditions that reduce visibility.

State means ``State'' as defined in section 302(d) of the CAA.

Stationary Source means any building, structure, facility, or installation which emits or may emit any air pollutant.

Visibility impairment means any humanly perceptible change in visibility (light extinction, visual range, contrast, coloration) from that which would have existed under natural conditions.

Visibility in any mandatory Class I Federal area includes any integral vista associated with that area.

[45 FR 80089, Dec. 2, 1980, as amended at 64 FR 35763, 35774, July 1, 1999]

Sec. 51.302 Implementation control strategies for reasonably attributable visibility impairment.

(a) Plan Revision Procedures. (1) Each State identified in Sec. 51.300(b)(2) must have submitted, not later than September 2, 1981, an implementation plan meeting the requirements of this subpart pertaining to reasonably attributable visibility impairment.

(2)(i) The State, prior to adoption of any implementation plan to address reasonably attributable visibility impairment required by this subpart, must conduct one or more public hearings on such plan in accordance with Sec. 51.102.

(ii) In addition to the requirements in Sec. 51.102, the State must provide written notification of such hearings to each affected Federal Land Manager, and other affected States, and must state where the public can inspect a summary prepared by the Federal Land Managers of their conclusions and recommendations, if any, on the proposed plan revision.

(3) Submission of plans as required by this subpart must be conducted in accordance with the procedures in Sec. 51.103.

(b) State and Federal Land Manager Coordination. (1) The State must identify to the Federal Land Managers, in writing and within 30 days of the date of promulgation of these regulations, the title of the official to which the Federal Land Manager of any mandatory Class I Federal area can submit a recommendation on the implementation of this subpart including, but not limited to:

(i) A list of integral vistas that are to be listed by the State for the purpose of implementing section 304,

(ii) Identification of impairment of visibility in any mandatory Class I Federal area(s), and

(iii) Identification of elements for inclusion in the visibility monitoring strategy required by section 305.

(2) The State must provide opportunity for consultation, in person and at least 60 days prior to holding any public hearing on the plan, with the Federal Land Manager on the proposed SIP revision required by this subpart. This consultation must include the opportunity for the affected Federal Land Managers to discuss their:

(i) Assessment of impairment of visibility in any mandatory Class I Federal area, and

(ii) Recommendations on the development of the long-term strategy.

(3) The plan must provide procedures for continuing consultation between the State and Federal Land Manager on the implementation of the visibility protection program required by this subpart.

(c) General plan requirements for reasonably attributable visibility impairment. (1) The affected Federal Land Manager may certify to the State, at any time, that there exists reasonably attributable impairment of visibility in any mandatory Class I Federal area.

(2) The plan must contain the following to address reasonably attributable impairment:

(i) A long-term (10-15 years) strategy, as specified in Sec. 51.305 and Sec. 51.306, including such emission limitations, schedules of compliance, and such other measures including schedules for the implementation of the elements of the long-term strategy as may be necessary to make reasonable progress toward the national goal specified in Sec. 51.300(a).

(ii) An assessment of visibility impairment and a discussion of how each element of the plan relates to the preventing of future or remedying of existing impairment of visibility in any mandatory Class I Federal area within the State.

(iii) Emission limitations representing BART and schedules for compliance with BART for each existing stationary facility identified according to paragraph (c)(4) of this section.

(3) The plan must require each source to maintain control equipment required by this subpart and establish procedures to ensure such control equipment is properly operated and maintained.

(4) For any existing reasonably attributable visibility impairment the Federal Land Manager certifies to the State under paragraph (c)(1) of this section, at least 6 months prior to plan submission or revision:

(i) The State must identify and analyze for BART each existing stationary facility which may reasonably be anticipated to cause or contribute to impairment of visibility in any mandatory Class I Federal area where the impairment in the mandatory Class I Federal area is reasonably attributable to that existing stationary facility. The State need not consider any integral vista the Federal Land Manager did not identify pursuant to Sec. 51.304(b) at least 6 months before plan submission.

(ii) If the State determines that technologicial or economic limitations on the applicability of measurement methodology to a particular existing stationary facility would make the imposition of an emission standard infeasible it may instead prescribe a design, equipment, work practice, or other operational standard, or combination thereof, to require the application of BART. Such standard, to the degree possible, is to set forth the emission reduction to be achieved by implementation of such design, equipment, work practice or operation, and must provide for compliance by means which achieve equivalent results.

(iii) BART must be determined for fossil-fuel fired generating plants having a total generating capacity in excess of 750 megawatts pursuant to ``Guidelines for Determining Best Available Retrofit Technology for Coal-fired Power Plants and Other Existing Stationary Facilities'' (1980), which is incorporated by reference, exclusive of appendix E, which was published in the Federal Register on February 6, 1980 (45 FR 8210). It is EPA publication No. 450/3-80-009b and is for sale from the U.S. Department of Commerce, National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. It is also available for inspection at the Office of the Federal Register Information Center, 800 North Capitol NW., suite 700, Washington, DC.

(iv) The plan must require that each existing stationary facility required to install and operate BART do so as expeditiously as practicable but in no case later than five years after plan approval.

(v) The plan must provide for a BART analysis of any existing stationary facility that might cause or contribute to impairment of visibility in any mandatory Class I Federal area identified under this paragraph (c)(4) at such times, as determined by the Administrator, as new technology for control of the pollutant becomes reasonably available if:

(A) The pollutant is emitted by that existing stationary facility,

(B) Controls representing BART for the pollutant have not previously been required under this subpart, and

(C) The impairment of visibility in any mandatory Class I Federal area is reasonably attributable to the emissions of that pollutant.

[45 FR 80089, Dec. 2, 1980, as amended at 57 FR 40042, Sept. 1, 1992; 64 FR 35764, 35774, July 1, 1999]

Sec. 51.303 Exemptions from control.

(a)(1) Any existing stationary facility subject to the requirement under Sec. 51.302 to install, operate, and maintain BART may apply to the Administrator for an exemption from that requirement.

(2) An application under this section must include all available documentation relevant to the impact of the source's emissions on visibility in any mandatory Class I Federal area and a demonstration by the existing stationary facility that it does not or will not, by itself or in combination with other sources, emit any air pollutant which may be reasonably anticipated to cause or contribute to a significant impairment of visibility in any mandatory Class I Federal area.

(b) Any fossil-fuel fired power plant with a total generating capacity of 750 megawatts or more may receive an exemption from BART only if the owner or operator of such power plant demonstrates to the satisfaction of the Administrator that such power plant is located at such a distance from all mandatory Class I Federal areas that such power plant does not or will not, by itself or in combination with other sources, emit any air pollutant which may reasonably be anticipated to cause or contribute to significant impairment of visibility in any such mandatory Class I Federal area.

(c) Application under this Sec. 51.303 must be accompanied by a written concurrence from the State with regulatory authority over the source.

(d) The existing stationary facility must give prior written notice to all affected Federal Land Managers of any application for exemption under this Sec. 51.303.

(e) The Federal Land Manager may provide an initial recommendation or comment on the disposition of such application. Such recommendation, where provided, must be part of the exemption application. This recommendation is not to be construed as the concurrence required under paragraph (h) of this section.

(f) The Administrator, within 90 days of receipt of an application for exemption from control, will provide notice of receipt of an exemption application and notice of opportunity for public hearing on the application.

(g) After notice and opportunity for public hearing, the Administrator may grant or deny the exemption. For purposes of judicial review, final EPA action on an application for an exemption under this Sec. 51.303 will not occur until EPA approves or disapproves the State Implementation Plan revision.

(h) An exemption granted by the Administrator under this Sec. 51.303 will be effective only upon concurrence by all affected Federal Land Managers with the Administrator's determination.

[45 FR 80089, Dec. 2, 1980, as amended by 64 FR 35774, July 1, 1999]

Sec. 51.304 Identification of integral vistas.

(a) On or before December 31, 1985 the Federal Land Manager may identify any integral vista. The integral vista must be identified according to criteria the Federal Land Manager develops. These criteria must include, but are not limited to, whether the integral vista is important to the visitor's visual experience of the mandatory Class I Federal area. Adoption of criteria must be preceded by reasonable notice and opportunity for public comment on the proposed criteria.

(b) The Federal Land Manager must notify the State of any integral vistas identified under paragraph (a) of this section, and the reasons therefor.

(c) The State must list in its implementation plan any integral vista the Federal Land Manager identifies at least six months prior to plan submission, and must list in its implementation plan at its earliest opportunity, and in no case later than at the time of the periodic review of the SIP required by Sec. 51.306(c), any integral vista the Federal Land Manager identifies after that time.

(d) The State need not in its implementation plan list any integral vista the identification of which was not made in accordance with the criteria in paragraph (a) of this section. In making this finding, the State must carefully consider the expertise of the Federal Land Manager in making the judgments called for by the criteria for identification. Where the State and the Federal Land Manager disagree on the identification of any integral vista, the State must give the Federal Land Manager an opportunity to consult with the Governor of the State.

[45 FR 80089, Dec. 2, 1980, as amended by 64 FR 35774, July 1, 1999]

Sec. 51.305 Monitoring for reasonably attributable visibility impairment.

(a) For the purposes of addressing reasonably attributable visibility impairment, each State containing a mandatory Class I Federal area must include in the plan a strategy for evaluating reasonably attributable visibility impairment in any mandatory Class I Federal area by visual observation or other appropriate monitoring techniques. Such strategy must take into account current and anticipated visibility monitoring research, the availability of appropriate monitoring techniques, and such guidance as is provided by the Agency.

(b) The plan must provide for the consideration of available visibility data and must provide a mechanism for its use in decisions required by this subpart.

[45 FR 80089, Dec. 2, 1980, as amended at 64 FR 35764, July 1, 1999]

Sec. 51.306 Long-term strategy requirements for reasonably attributable visibility impairment.

(a)(1) For the purposes of addressing reasonably attributable visibility impairment, each plan must include a long-term (10-15 years) strategy for making reasonable progress toward the national goal specified in Sec. 51.300(a). This strategy must cover any existing impairment the Federal Land Manager certifies to the State at least 6 months prior to plan submission, and any integral vista of which the Federal Land Manager notifies the State at least 6 months prior to plan submission.

(2) A long-term strategy must be developed for each mandatory Class I Federal area located within the State and each mandatory Class I Federal area located outside the State which may be affected by sources within the State. This does not preclude the development of a single comprehensive plan for all such areas.

(3) The plan must set forth with reasonable specificity why the long-term strategy is adequate for making reasonable progress toward the national visibility goal, including remedying existing and preventing future impairment.

(b) The State must coordinate its long-term strategy for an area with existing plans and goals, including those provided by the affected Federal Land Managers, that may affect impairment of visibility in any mandatory Class I Federal area.

(c) The plan must provide for periodic review and revision, as appropriate, of the long-term strategy for addressing reasonably attributable visibility impairment. The plan must provide for such periodic review and revision not less frequently than every 3 years until the date of submission of the State's first plan addressing regional haze visibility impairment in accordance with Sec. 51.308(b) and (c). On or before this date, the State must revise its plan to provide for review and revision of a coordinated long-term strategy for addressing reasonably attributable and regional haze visibility impairment, and the State must submit the first such coordinated long-term strategy. Future coordinated long-term strategies must be submitted consistent with the schedule for periodic progress reports set forth in Sec. 51.308(g). Until the State revises its plan to meet this requirement, the State must continue to comply with existing requirements for plan review and revision, and with all emission management requirements in the plan to address reasonably attributable impairment. This requirement does not affect any preexisting deadlines for State submittal of a long-term strategy review (or element thereof) between August 30, 1999, and the date required for submission of the State's first regional haze plan. In addition, the plan must provide for review of the long-term strategy as it applies to reasonably attributable impairment, and revision as appropriate, within 3 years of State receipt of any certification of reasonably attributable impairment from a Federal Land Manager. The review process must include consultation with the appropriate Federal Land Managers, and the State must provide a report to the public and the Administrator on progress toward the national goal. This report must include an assessment of:

(1) The progress achieved in remedying existing impairment of visibility in any mandatory Class I Federal area;

(2) The ability of the long-term strategy to prevent future impairment of visibility in any mandatory Class I Federal area;

(3) Any change in visibility since the last such report, or, in the case of the first report, since plan approval;

(4) Additional measures, including the need for SIP revisions, that may be necessary to assure reasonable progress toward the national visibility goal;

(5) The progress achieved in implementing BART and meeting other schedules set forth in the long-term strategy;

(6) The impact of any exemption granted under Sec. 51.303;

(7) The need for BART to remedy existing visibility impairment of any integral vista listed in the plan since the last such report, or, in the case of the first report, since plan approval.

(d) The long-term strategy must provide for review of the impacts from any new major stationary source or major modifications on visibility in any mandatory Class I Federal area. This review of major stationary sources or major modifications must be in accordance with Sec. 51.307, Sec. 51.166, Sec. 51.160, and any other binding guidance provided by the Agency insofar as these provisions pertain to protection of visibility in any mandatory Class I Federal areas.

(e) The State must consider, at a minimum, the following factors during the development of its long-term strategy:

(1) Emission reductions due to ongoing air pollution control programs,

(2) Additional emission limitations and schedules for compliance,

(3) Measures to mitigate the impacts of construction activities,

(4) Source retirement and replacement schedules,

(5) Smoke management techniques for agricultural and forestry management purposes including such plans as currently exist within the State for these purposes, and

(6) Enforceability of emission limitations and control measures.

(f) The plan must discuss the reasons why the above and other reasonable measures considered in the development of the long-term strategy were or were not adopted as part of the long-term strategy.

(g) The State, in developing the long-term strategy, must take into account the effect of new sources, and the costs of compliance, the time necessary for compliance, the energy and nonair quality environmental impacts of compliance, and the remaining useful life of any affected existing source and equipment therein.

[45 FR 80089, Dec. 2, 1980, as amended at 64 FR 35764, 35774, July 1, 1999]