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A Process for Selecting Ecological Indicators for Application in Monitoring Impacts to Air Quality Related Values (AQRVs) From Atmospheric Pollutants

Final Report

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EXECUTIVE SUMMARY

Section 160 of the Clean Air Act (CAA) calls for measures be taken "to preserve, protect, and enhance air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic, or historic value." Pursuant to this, stringent requirement have been established for "Class I" areas, which include most National Parks and Wilderness Areas. Federal Land Managers (FLMs) are charged with the task of carrying out these requirements through the identification of air quality related values (AQRVs) that are potentially at risk from atmospheric pollutants. This is a complex task, the success of which is dependent on the gathering of information on a wide variety of factors that contribute to the potential for impacting resources in Class I areas. Further complicating the issue is the diversity of ecological systems found in Class I areas.

There is a critical need for the development of monitoring programs to assess the status of AQRVs in Class I areas with respect to impacts caused by atmospheric pollutants. These monitoring programs must be based on the measurement of a carefully selected suite of key physical, chemical, and biological parameters that serve as indicators of the status of the ecosystems found in Class I areas. Such programs must be both scientifically-based and cost-effective, and must provide the data necessary for FLMs to make objective, defensible decisions.

This document summarizes a method for developing AQRV monitoring programs in Class I areas. A series of steps is suggested during which information is collected and applied regarding emission sources, pollutant transport and fate, ecological systems present at Class I areas, source/receptor relations, etc., *before* decisions are made regarding what resources are in need of monitoring. The need for each of these steps is described in various documents on wilderness monitoring published by the land management agencies. The objectives of a monitoring program can only be defined after this information has been gathered.

Once the objectives have been defined, indicators of AQRV status must be identified that will be capable of providing the data necessary to assess damage to AQRVs from atmospheric pollutants at the levels to which the area is exposed. *This selection of valid indicators provides the primary focus of this document.* Valid, defensible conclusions on the status of AQRVs must be based on quality-assured data generated in a scientific manner focusing on the testing of hypotheses relating the impacts from ambient levels of atmospheric pollutants on AQRV indicators.

Following an introductory section, Section 2 of this document provides an overview of the proposed process for determining which Class I areas are at risk from atmospheric pollutants, and which AQRVs and sensitive receptors provide the bases for this risk. The focus of this discussion is on the various types of information that should be considered before decisions regarding potential risk can be made. The selection of indicators of AQRV status for monitoring programs is discussed in Section 3. The process proposed for selecting indicators is based on the identification and ranking of indicator criteria - i.e., attributes that indicators must (or should) possess for it to effectively provide the information necessary to assess impacts from atmospheric pollutants. Section 4 provides a discussion of the importance of hypothesis testing in the implementation of AQRV monitoring programs. Common problems associated with sample design in monitoring programs are discussed. Conclusions and recommendations on the proposed process are provided in Section 5.

A summary of the history of the INEL/WEST program is provided in the Appendix to this document. Included in the Appendix are an overall summary of the project, including highlights of the workshops conducted as part of the program. Brief summaries of the documented processes that are currently being used by the land management agencies in assessing AQRV impacts, and accomplishments to date of the INEL/WEST program are also summarized in the Appendix. Finally, the Appendix contains recommendations regarding how INEL, WEST, and the land management agencies should proceed toward the goal of establishing a consistent, defensible process for assessing impacts to AQRVs in Class I attainment areas.

Establishment of a valid monitoring program to accurately assess AQRV status in Class I areas is an important issue to all parties involved, including land management and other federal and state agencies, industry, and private groups. Only by involving all interested parties throughout the design process can the right suite of parameters be selected for measurement at the right locations, at the right time and using the right methods.

It is out intent that this document provide a starting point for the development of a consistent, universally accepted process for addressing AQRV issues. For this reason, the document is intended to be dynamic in the sense that it will be revised periodically as additional information and contributions from other stakeholders become available. In this way, we hope that this document can help to foster collaboration between the various stakeholders in the AQRV issue.

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TERMS AND ACRONYMS

AQRV	Air quality related value -- any wild component of the wilderness such as flora, fauna, soil, water, visibility, and cultural objects, that can be modified by human-caused air pollution.
BACT	Best available control technology
BLM	Bureau of Land Management (Department of Interior)
CAA	Clean Air Act, as amended in 1990.
Class I area	Areas established by the Clean Air Act, including national parks over 6000 acres and wilderness areas over 5000 acres. Stringent requirements for protecting air quality related values in these Class I areas are established in the Clean Air Act.
Criteria Pollutants	Six pollutants (CO, SO_2, NO_2, O_3, PM_{10}, and Pb) identified by the EPA for which regulatory limits have been established.
EPA	U.S. Environmental Protection Agency
FLM	Federal land manager
HAP	Hazardous air pollutant, as defined in the CAA
Indicators	Any expression of the environment that provides an estimation of the condition of the sensitive receptor, the magnitude of stress acting on those receptors, the exposure of a biological component to stress, or the amount of change in a condition. These may include any parameter associated with the sensitive receptor that responds in some way to atmospheric pollution.
K-T Process	Kepner-Tregoe Process. A technique for providing quantitative decision analysis to reach consensus decisions.
LAC	Limits of acceptable change. A recognized level of change in a physical, chemical, and/or biological component of an ecosystem that is considered small enough to not cause deterioration of the Class I resource, but large enough to not prevent development.
NAAQS	National Ambient Air Quality Standards. Ambient concentrations of specific atmospheric pollutants which require the initiation of implementation of regulatory actions if exceeded.
NADP	National Atmospheric Deposition Program
NAPAP	National Acid Precipitation Assessment Program.

NPS	National Park Service (Department of Interior)
PAN	peroxyacetyl nitrate, a secondary pollutant formed in the atmosphere under the proper environmental conditions.
Priority Pollutants	Six atmospheric pollutants (SO_2, NO_2, O_3, PM_{10}, Pb, and CO_2) for which EPA has established NAAQS.
PSD	Prevention of significant deterioration (defined in the CAA)
Sensitive receptors	Specific objects, processes, attributes, or species that can provide a measure of whether AQRVs are being adversely impacted
Source term	Emission inventory from a point source. Includes identification of pollutants released, quantities released, and the time frame of the release.
USFS	U.S. Forest Service (Department of Agriculture)
USFWS	U.S. Fish and Wildlife Service (Department of Interior)

1. INTRODUCTION

In recent years, the importance of assessing the impacts to wilderness areas and other protected lands from atmospheric pollutants has become widely recognized by parties representing diverse interests. Substantial efforts are currently being devoted to the identification and development of indicators of environmental quality for use in monitoring and assessment programs (e.g. National Research Council, 1986; Noss, 1990; Messer et al., 1991; Bruns et al., 1991; 1997). These include regulatory and land management agencies of the state and federal government, electric utilities and other industrial groups, private interest groups, and the general public. However, although general consensus exists among these varying entities regarding the importance of maintaining wilderness systems in pristine condition, accurate assessment of impacts to these systems far removed from the pollutant sources has been hampered by a general lack of information in many key areas, or by the failure to collect and/or consider the information available.

Assessment of impacts to ecological systems in Class I areas is further complicated by the vast diversity in structure, extent, and composition of these ecosystems, and by the harsh environments and difficult access that may be associated with such sites. Because of the diversity of ecological systems in Class I areas, data collected in one area may not be applicable to other systems nearby. Furthermore, extensive physical, chemical, and biological monitoring at protected areas may be impractical due to the associated cost constraints and to the environmental degradation that could result from implementing such a monitoring program.

A consistent process is needed that can be applied to the design of AQRV monitoring programs on all federal lands to ensure the effectiveness of these programs. This process should provide detailed explanations of how the various decisions regarding AQRV monitoring are made, and what information is needed before making these decisions. Basic decisions within the overall process include:

1. Which Class I areas are at risk from pollutants generated at a new or existing facility?
2. What are the current and expected future pollutant inputs to these Class I areas?
3. Which AQRVs are potentially impacted at the Class I area?
4. Which pollutants are likely to be responsible for these impacts?
5. What are the sensitive receptors for these pollutants within each AQRV?
6. What indicators should be used to assess the impacts of the selected pollutants on the sensitive receptors?
7. At what specific locations(s) should the indicators be monitored?

All of these questions should be addressed within the context of sound science.

As will be discussed in more detail later, the selection of ecological indicators must consider the roles of these indicators in the dynamics of the system to be monitored, the degree to which these roles are understood, and the certainty associated with observed levels of the indicators. Candidate indicators should therefore represent measures that, based on expert knowledge and available literature, will provide information concerning the condition of the ecosystem being monitored.

Criteria must be established that can be used to assess the effectiveness of indicators to ensure that:

1. the resulting data will be sufficient to answer the pertinent questions regarding the status of the AQRV of interest;
2. the resulting data are of known quality; and
3. the monitoring program can be implemented in the most cost-effective manner.

These criteria should then be applied to the selection of indicators of the condition of the AQRVs identified by the FLM as being at risk. Monitoring programs based on the measurements of these indicators may then be designed in a manner that will provide cost-effective, scientifically-based assessment of the impacts to protected areas from atmospheric pollutants upon which management decisions may be objectively based. Without applying a consistent, scientific approach, it is difficult to predict which indicators will best reflect the potential effects due to specific air emission sources, or to select the most effective methods for monitoring these effects.

1.1 Objective and Scope

The federal land management agencies have begun to develop and document processes for establishing AQRV monitoring programs in Class I areas. Of these agencies, the U.S. Forest Service appears to have made the most progress (e.g. Adams et al., 1991; Schmoldt and Peterson, 1991; J. Peterson et al., 1992; D.L. Peterson et al., 1992; Peine et al., 1995). The documents cited provide adequate background information on the regulatory responsibilities of the FLMs and descriptions of the important AQRVs that the FLM should consider. They also effectively describe some of the difficulties encountered in making such assessments, such as the lack of adequate baseline information, etc. Finally, these existing documents allude to the a variety of potential pitfalls associated with several ecological indicators that are commonly used in monitoring programs.

An overall method for establishing AQRV monitoring programs is not yet complete, and lacks a generally-excepted process for the *a priori* evaluation of potential indicators of AQRV status. Furthermore, there remains a general lack of agreement between the various land management agencies regarding how AQRV issues should be addressed stemming at least in part from the fact that each agency has a somewhat unique mission. Development of a universally acceptable AQRV process requires the identification of specific criteria that can be applied in selecting and ranking candidate indicators. Input to the process should incorporated from regulatory agencies, FLMs, industry and other interested parties. Methods must be identified that will allow these indicators to be adequately measured, and decisions must be made regarding how the resulting data will be used.

Further complicating the development of a consistent process for AQRV evaluation is the fact that monitoring programs that use ecological indicators to assess AQRV status must be established on a site-by-site basis. This is important not only because each protected area is unique geologically, hydrologically, and ecologically, but also because each pollutant source is at least somewhat unique in terms of source-term (emissions inventories) and physical setting. Monitoring programs must be designed for each combination of source and protected area independently, as a program designed for one scenario will not necessarily be applicable to another.

The purpose of this document is to summarize a process that is being proposed for designing and implementing AQRV monitoring programs in Class I areas. This process builds largely on the previous efforts of the Forest Service and other organizations. The approach described in this document is intended to be generic in that it is applicable to virtually any combination of source and receptor of interest. However, the output must be considered site-specific at *both* ends of the source/receptor continuum. Section 2 of this document provides overview information on the series of steps involved in determining the receptors that should be monitored. Each step is provided with an objective or rationale, along with the approach taken for each step. Examples are also provided where necessary, as are the forms that may be used during each step. Ultimately, the process described should be useful in making decisions regarding the resources that are potentially at risk, the atmospheric pollutants responsible for this risk, and the specific locations at which impacts should be evaluated. These decisions will allow for monitoring programs to be established to adequately assess the status of these resources in a manner that will ensure that these resources are protected while not requiring unnecessary monitoring.

> ***The specific goal of this document is to take the process of developing AQRV monitoring programs one step further by proposing a method for determining the best suite of indicators with which to assess impacts to sensitive receptors.***

To accomplish this, a series of criteria is proposed by which potential indicators of pollutant impacts may be evaluated. These criteria are described in Section 3 of this document. By applying these criteria during the planning stage, it is anticipated that monitoring programs can be more readily developed to provide defensible, quality-assured data in the most cost-effective manner, and that are acceptable and useful to regulated industries, responsible federal land managers, regulatory agencies, and other interested parties. This may be accomplished by ensuring that a set of indicators is selected that best provides the FLM with information needed to assess impacts.

The general approach proposed here for developing an AQRV monitoring program is as follows:

1. Gather pertinent information on emissions, transport pathways, potentially-sensitive ecosystems or components of the ecosystem (receptors), dose/response, relationships, etc. that will help determine the specific approach to be taken in the monitoring program.

2. Develop a conceptual framework using this information to understand the dynamics of the system(s) of interest.

3. Establish and rank criteria for evaluating potential indicators of changes to AQRVs, and use these criteria to select the appropriate indicators for assessing changes in the status of AQRVs.

4. Develop hypotheses to be tested using the indicators selected.

The methodology described in this document is focused on AQRV issues relevant to the electric power industry (especially coal-fired power plants). The electric utility approach is being taken because this industry is currently being confronted with the AQRV issue in the western U.S. However, the general methods described are applicable to other industries as well. To date, the primary focus of AQRV issues as they relate to the electric power industry has been on visibility; however, this focus is becoming more broad, and will likely include various components of ecological systems that may be impacted by atmospheric pollutants. It is these ecological issues, rather than the more aesthetically-oriented ones, that provide the focus of this document. Continued revision is anticipated in the future, as additional information becomes available and further cooperation between stakeholders occurs.

The general intent of this document is therefore to help with the development of scientifically-defensible, cost-effective monitoring programs to assess the status of AQRVs in protected areas, as designated by FLMs. This document is intended as a working document, and has been revised following each workshop conducted to date, including those attended by members of the electric power generation industry and federal land management agencies.

1.2 Regulatory Background

The basic framework for controlling air pollutants in the United States is mandated by the Clean Air Act (CAA), as amended in 1977 and 1990, which was designed to "protect and enhance" air quality [42 U.S.C. § 7401(b)(1)]. The primary means by which this is to be accomplished is through implementation of National Ambient Air Quality Standards (NAAQS), ambient concentrations of specific atmospheric pollutants which, if exceeded, trigger the implementation of regulatory actions. At present, NAAQS have been established for only six atmospheric pollutants: sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), particulate matter less than 10 μm in diameter (PM_{10}), lead (Pb), and carbon monoxide (CO). These six pollutants are commonly referred to as the EPA Priority Pollutants.

Each of the NAAQS identified by EPA have been subdivided into primary and secondary standards. Primary standards are intended "to protect the public health...with an adequate margin of safety" [U.S.C. §7409(b)(1)], whereas secondary standards are designed to "protect the public welfare" [U.S.C. §7409(b)(2)]. If ambient air concentrations frequently exceeding a NAAQS for the pollutant measured, the area is designated nonattainment.

Included under the umbrella of "public welfare" are natural resources. Specifically, Section 160 of the CAA requires measures "to preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreation, scenic, or historic value." Stringent requirements are therefore established for areas designated as "Class I" attainment areas. Class I areas include Forest Service wilderness areas over 5,000 acres that were in existence before August 1977, and National Parks in excess of 6,000 acres. Designation as a Class I area allows only very small increments of new pollution above already existing air pollution levels within the area.

Another requirement of the CAA (as amended) is that new major stationary sources (i.e. those that will emit over 100 tons/yr of priority pollutants) or modifications of existing major stationary sources (250 tons/year) must first receive a "Prevention of Significant Deterioration" (PSD) permit from the appropriate air regulatory agency (typically either EPA or a designated state agency) before construction or modification of these sources can be accomplished. As such, the PSD program represents a pre-construction review and permitting process for major new or expanding sources of pollution. The PSD permitting program does not apply to existing facilities, unless a major modification of the facility that is proposed.

PSD provisions are aimed at protecting and enhancing the air quality in wilderness areas and other locations of special scenic, recreational, historical, or natural value. Applicants for PSD permits must demonstrate that the proposed facility (or modification) will achieve the following:

1. The facility will not violate state or national ambient air quality standards.

2. The facility will use the "Best Available Control Technology" (BACT), thereby assuring that the appropriate type and level of air pollution controls are applied. The application of suitable BACT requirements is evaluated on a case-by-case basis, taking economic impact into account as well as efficiency of pollution control, with the interpretation of what constitutes BACT varying among the states (Peine et al., 1995).

3. The facility must not violate either Class I or II increments for SO_x, NO_x, or particulate emissions [42 U.S.C.§7475(a)(1)(2)].

4. The facility must not cause *or contribute to* harmful effects on air quality related values (AQRVs) that have the potential to be changed by air pollution in any Class I area.

AQRVs have been broadly defined as "any wild component of the wilderness system that can be modified by human-caused air pollution". AQRVs therefore may include flora, fauna, soil, water, visibility, and cultural objects. However, AQRVs may also be less broadly defined to include anything inherent to the Class I area that could be impacted by air pollution in such a manner that the purpose for which the area was established (biological diversity, water quality, fish) would be adversely affected (Fox et al., 1989). Application of such a definition implies that virtually anything within the wilderness is related in some way to one or more AQRVs, and therefore must be protected from deterioration.

Class I designations for National Parks and Wilderness Areas provide special protection for these areas under the PSD program. Designation as a Class I area provides the Federal Land Manager (FLM) with the "affirmative responsibility to protect the air quality related values of [the Class I area] and to consider, in consultation with [EPA and/or state officials], whether a proposed major [stationary source] will have an adverse impact on such values" [42 U.S.C.§7475(d)(2)(B)]. The authority of the FLM is restricted to an advisory role of reviewing PSD permit applications for new (or modifications to existing) major pollution sources. However, FLMs are not involved in a similar manner with air quality management relating to mobile sources, existing point sources, or toxic emission sources. The PSD program is therefore inadequate as a regulatory mechanism for protection of AQRVs in Class I areas (Peine et al., 1995).

The definition of "adverse impact" is dependent on: (1) the specific components of the Class I area; (2) the degree to which these specific components should be protected; and (3) whether the proposed facility result in concentrations or deposition within the wilderness area that could cause established protection levels to be exceeded (Schmoldt and Peterson, 1991). The first two of these criteria are determined by the appropriate FLM *in consultation with the public sector*. The third is rendered much more difficult because accurate assessment of definitive causal relationships requires a thorough understanding of the pollutants and the ecosystems involved, and adequate information on ecological systems is typically lacking.

In general, any effects on resources in Class I areas caused by air pollution constitute an unacceptable, adverse impact (47 FR 30222) if they: (1) diminish the national significance of the area; (2) impair the structure and functioning of ecosystem, and/or; (3) impair the quality of visitor experience (Sigal and Suter, 1987). Determination of "adverse impacts" can be accomplished through a process of identifying receptors that are sensitive to, or modified by, anthropogenic air pollution. Receptors may represent objects, processes, attributes, or species that can provide a measure of change related to air pollution impacts. For example, lichens may be a sensitive receptor within the flora AQRV.

Sensitive receptors should have the following characteristics:

1. They must be sensitive and directly responsive to changing environmental conditions.

2. Changes in the receptor must be capable of being detected, measured, and monitored.

3. The response of the receptor to changes in pollutant input must be predictable and capable of being modeled.

The framework for determining what constitutes acceptable and appropriate conditions of AQRVs in protected areas is provided by **limits of acceptable change** (LACs). The LAC process requires FLMs to define desired wilderness conditions and to undertake actions to maintain or achieve these conditions (Stankey et al., 1985). LACs are defined relative to the attributes of sensitive receptors, and therefore provide a measure of changes in the physical, chemical, and/or biological components of the ecosystem due to anthropogenic factors that are deemed acceptable by the FLM. LACs should be small enough to avoid deterioration of the Class I wilderness resource, but at the same time should be large enough to not systematically prevent development from occurring. The LAC process consists of four major components (Stankey et al., 1985):

1. Specification of acceptable and achievable resource and social conditions, defined by a series of measurable parameters;

2. Analysis of the relationship between existing conditions and those judged acceptable;

3. Identification of management actions necessary to achieve these conditions; and

4. Development of monitoring programs to evaluate the effectiveness of the LAC.

Finally, **indicators** of AQRV status must be identified because AQRVs, and even sensitive receptors, cannot typically be measured directly. Indicators represent any parameter that provides a quantitative or qualitative expression of the condition of the sensitive receptor, the magnitude of stress acting on those receptors, the exposure of a biological component to stress, or the amount of change in a condition of the receptor. Indicators therefore provide the means by which the response of a sensitive receptor to atmospheric pollutants (or other stress agents) may be assessed, and whether the LAC is being compromised. Any measurable parameter that is associated with the sensitive receptor and that responds in some known and quantifiable way to atmospheric pollution may be considered an indicator. However, the selection of effective ecological indicators of AQRV status in Class I areas that are far removed from the pollutant source can be a daunting task, and the ultimate success of any AQRV monitoring program hinges on the successful selection of appropriate indicators.

1.3 BASIC CONCEPTS OF MONITORING PROGRAM DESIGN

Monitoring involves:

> *the continual systematic time series observation of an* <u>*appropriate*</u> *suite of pre-determined chemical, physical, and/or biological parameters within the* <u>*appropriate*</u> *components of the* <u>*appropriate*</u> *ecosystem, for an* <u>*appropriate*</u> *period of time that is sufficient to determine (1) existing conditions; (2) trends; and (3) natural variations of each component measured* (Segar, 1986).

To accomplish this, monitoring programs must be designed properly. The most important step in the design of any monitoring program is the definition of the objectives of the program. Only when specific objectives such as these have been established have been established can the scientific method of establishing and testing hypotheses be applied (Segar, 1986). These objectives must adequately define:

- the specific receptor to be evaluated;
- the specific effect to be monitored; and
- the level of effect that bounds acceptable versus unacceptable conditions (i.e. the LAC).

To effectively meet the objectives of an AQRV monitoring program, monitoring must be designed to detect changes in indicators that are both *measurable* and *significant*. It is not realistic to design a monitoring program to assess the concentration of *every* potential contaminant in *all* media at *all* locations that might be impacted, in order to detect *any* increase in the concentration of each contaminant. Similarly, ecological monitored cannot be conducted to identify *any* change in the abundance, health, growth rate, reproductive rate, etc. of *any* species or community which are caused by *any* contaminant that might reach the area (Segar, 1986). Such goals are neither realistic nor attainable.

2. SELECTION OF CLASS I AREAS, AQRVs, AND SENSITIVE RECEPTORS

Ideally, the development of AQRV monitoring programs should be a cooperative effort between regulated industries, federal land management agencies, federal and state regulatory agencies, and other stakeholders. Although many of the decisions involved in the AQRV process are the responsibility of the FLM, input from other interested parties should also be considered. Wherever feasible, efforts should be focused on the generation of consensus-based decisions regarding how the program should be designed and operated, and how the resulting data should be used. Although considerable disagreement may exist between interested parties in terms of implementing monitoring programs in Class I areas, there is also considerable common ground; all parties generally agree on the following key aspects:

1. Protection of the environment in Class I areas is the first and foremost concern;

2. All aspects of the monitoring program should be scientifically defensible; and

3. Monitoring programs should make the most effective use of available resources.

The sections below describe a general process for satisfying these goals. The overall process of developing an AQRV monitoring program involves a series of steps (see box). The initial steps involve the collection of the many different types of information that are needed before an AQRV monitoring program can be effectively established. A series of key questions is provided for most of these steps, to help the user determine the necessary information. Several of the steps also involve the evaluation of various options, to which there will not generally be agreement. The descriptions of these steps therefore also include methods for generating reasonable consensus opinions on the various options. Each of the general steps in the development of an AQRV monitoring program is described in detail below.

General Steps in Developing AQRV Monitoring Programs

1. Determine the applicable source term (i.e. what existing and planned facilities exist, where are they located, and what types and quantities of pollutants are discharged).

2. To the extent practicable, evaluate the transport and fate of the pollutants from each facility (i.e. how do the pollutants behave in the environment, or where do they go?).

3. Based partially on the information derived from 1 and 2, determine which Class I areas receive pollutants from the identified facilities.

4. Determine the AQRVs of concern for each Class I area identified, based on potential sensitivity and estimated pollutant load levels.

5. Develop an understanding of the potential relationships between pollutant exposures and effects to AQRVs (i.e. information on cause/effect relationships).

6. Examine existing information on:
   a. The Class I area(s) of concern; and

b. The species and/or systems found within the Class I area (information may be on the same or similar species/systems in other areas).

7. Determine the specific locations where assessments should be conducted.

8. Identify and weight criteria to be used to rank indicators of the status of AQRVs. Determine the suite of indicators that can best be integrated into a monitoring program for evaluating the status and trends in the condition of AQRVs.

9. Develop testable hypotheses for each indicator to be used in the evaluation of AQRV status.

2.1 Step 1: Examine Emissions Information

Objective: The goal of this step is to develop an understanding of the *source term*, or the emission inventory, for each point source. Information needed includes identification of all important pollutants released by the facility, the quantities of each pollutant released, and the time frame over which the releases occur. This can typically be accomplished using operational and monitoring data for existing facilities, and through modeling for planned sources.

Approach: Establishment of an AQRV monitoring program involves the elucidation of relationships between pollutant sources and receptors, or alternatively between cause and effect. In either case, accurate information (either measurements or estimates based on predictive modeling) regarding the pollutants emitted from a stationary source is needed before determining whether an AQRV monitoring program is necessary. This information can generally be obtained by answering the three related questions shown in the box below:

Questions Relating to Source Term

- **What are the pollutants of concern that are emitted from a source?**
- **What are the quantities of each pollutant emitted from the source?**
- **What are the quantities of each pollutant emitted regionally?**

Emission inventories are generally well known for existing facilities, and are estimated for planned facilities as part of the permitting process. Furthermore, permit requirements for stack monitoring provides accurate measurements of many of the more important constituents of the effluent stream, while calculations based on analyses of fuel and other factors can provide reasonable approximations for others. Emissions rates for proposed new facilities can be made based on the operations design specifications and estimated fuel content.

The third question is somewhat more difficult to address, and is intended to provide a comparison of the emissions from a particular facility with those of other sources anthropogenic and natural sources within the region. For new facilities, the degree to which the new facility will increase the loads of various pollutants should be determined. In effect, the degree to which a particular facility contributes (or will contribute) to the regional loads of each pollutant must be determined in order to assess the relative impact of the facility.

Example: An example of a regional inventory of NO_x and SO_2 emissions from point sources in western Wyoming is provided in Table 1. Similar inventories could be put together for other pollutants. This particular inventory was developed during the assessment of potential impacts to ecosystems from acidic deposition in the Wind River range downwind from these sources. This inventory, in the form of permitted SO_2 and NO_x levels, are provided in Table 1. It was also recognized that the Wind River area receives considerable atmospheric pollutant input from area sources along the Wasatch Front in northern Utah. Estimated 1983 SO_2 and NO_x inventories for the five counties in northern Utah with the largest contributions of these materials are provided in Table 2.

If we make the reasonable assumption that the majority of the regional loading of SO_2 and NO_x are derived from the 16 industrial facilities and the 5 northern Utah counties listed in Tables 1 and 2, then the additional loading from a new, proposed facility can be compared with existing emissions.

A form is also provided that will assist in the evaluation of emission data. Emission rates for various pollutants may be entered in the form for the facility in question and for other significant sources in the region. The relative fraction of the regional emissions for the facility may then be determined.

Table 1. Major stationary sources of SO_2 and NO_x in Southwestern Wyoming and their permitted emission levels (Benoit 1985, personal communication).

Allowable Emissions (tons/year) Source	SO_2	NO_x
Naughton Power Plant	25,820	21,980
Opal Gasoline Plant	0	779
Carter Creek Gas Treatment Plant	158	1,022
Whitney Canyon Gas Treatment Plant	13,650	70
Texas Gulf Trona	1,256	6,513
Tenneco Trona	990	3,460
FMC Coking	1,149	110
Allied Chemical Trona	7,432	4,622
FMC Trona	9,325	5,439
Stauffer Trona	5,885	515
Jim Bridger Power Plant	24,187	61,565
Sweetwater Resources	2,233	0
Chevron Phosphate Plant[a]	3,127	787
Brady Gas Plant	171	0
Mountain Fuels Butcher Knife Springs	767	0
Mountain Fuels Church Buttes	706	0
TOTALS	96,856	106,862

Table 2. Example regional emission inventories for SO_2 and NO_x for five counties along the Wasatch Front of northern Utah (Utah Bureau of Air Quality 1983).

COUNTY	Emissions (tons/yr) SO_2	Emissions (tons/yr) NO_x
Utah	5,733	20,988
Salt Lake	67,422	29,498
Davis	7,343	7,870
Weber	538	4,779
Cache	324	1,944
TOTALS	81,360	65,079

FACILITY AND REGIONAL AIR EMISSION INVENTORY FORM

	NO_2	SO_x	CO	Pb	PM_{10}		
PROPOSED FACILITY (OR EXISTING TARGET FACILITY)							
EXISTING REGIONAL FACILITIES (AND OTHER SIGNIFICANT REGIONAL SOURCES)							
TOTAL REGIONAL EMISSIONS							
FRACTION OF TOTAL							

2.2 Step 2: Evaluate Expected Pollutant Behavior (Environmental Fate)

Objective: The objective of Step 2 is to develop an understanding of the expected behavior of pollutants in the environment after they have been emitted from the facility.

Approach: A reasonable understanding of how the pollutants released from a facility behave in the outside environment is needed before an effective AQRV monitoring program can be designed. This information, coupled with the emission information gained in Step 1, provides the basis with which to determine which Class I areas might be at risk. Although these decisions are ultimately made by the FLM, an understanding of the expected behavior of pollutants is needed by other stakeholders as well.

Specifically, information is needed on the potential transport pathways by which pollutants move through the environment, the rates at which pollutants move along these pathways, and how various environmental factors influence these transport rates. An understanding of the chemical reactions that occur in the atmosphere involving these pollutants and the rates at which these reactions occur is also important.

Finally, an understanding of the ultimate fate of each material in the environment is needed.

To determine the environmental fate of these materials, the following questions should be addressed:

Pollutant Behavior Questions

- What are the key transport pathways for each pollutant of concern?
- What transformations do the pollutants undergo in the atmosphere?
- What secondary pollutants are formed in the atmosphere?
- What is the ultimate fate of both primary and secondary pollutants?
- What systems (or system components) serve as receptors?

Considerable information is available on the transport of gaseous and particulate pollutants in the atmosphere. Atmospheric transport models are available that can predict the movement of materials given the relevant site data (emission rates, release height, wind speed and direction, relative humidity, etc.). While in the atmosphere, many pollutants undergo chemical changes (e.g., $NO_2 \rightarrow NO_3^-$). Some of these reactions mav result in the production of important secondary pollutants such ozone, which is generated via a series of atmospheric reactions involving NO_x. These secondary pollutants may be generated at large distances from the source, and may pose a more severe threat to ecological systems than the primary pollutants that were originally discharged from the facility. At present, the specific relationships between NO_x emissions and formation of rural ozone are not well understood (Peine et al., 1995).

The rates at which different reactions occur in the atmosphere is also important. If the reaction is very slow, the pollutants may be adequately diluted before the reaction occurs. Atmospheric conditions such as relative humidity and light may influence or control reaction rates. Seasonal variability may play an important role as well.

Considerable research has been conducted on the chemical interactions in the atmosphere, and some information is available through national programs such as the National Acid Deposition Program (NADP) regarding the distribution of regional air pollutants. However, less information is available regarding how pollutants interact with biota once they are deposited. Some materials may accumulate in particular components of the ecosystem. For example, metals may accumulate in litter and humus in terrestrial systems, or in sediment in aquatic systems. Once in the soil or sediment, some materials may remain indefinitely whereas others may undergo chemical degradation reactions or leach to groundwater quickly, thereby leaving the ecosystem. Upon reaching the surface of soils or sediment, contaminant pathways include retention (adsorption-desorption from the surface of soil colloids), microbial transformations chemical degradation, volatilization, overland flow, and leaching (Ghardiri et al., 1985). These processes are governed by many soil and environmental factors, including soil type, soil water content, pH, temperature, clay and organic matter content, microbial type, populations, and activities, and oxygen level (Craigmill and Winterlin, 1985; Racke et al., 1990).

Besides general information on pollutant behavior, information of a more regional or site-specific basis may be obtained from a variety of sources. These include federal, state and local government agencies, universities, industries, etc.

Example: In developing an understanding of pollutant behavior, it is usually beneficial to use a conceptual approach to help visualize the movement of materials through the environment. An example drawn from the Wind River monitoring program is provided below to illustrate how a conceptual approach can be applied during the development of an AQRV monitoring program.

Among the most useful tools that can be applied during the development of AQRV monitoring programs are simple conceptual models that illustrate the transport of materials throughout the environment from source to sink. One common form taken by these models are simple "box and arrow" diagrams such as that shown in Figure 1. In these diagrams, each "box" represents some component of the ecosystem. In the case of Figure 1, ecosystem components such as "surface water", "vegetation" etc. are identified, and these may reflect the candidate AQRVs to be evaluated. Connecting the boxes are arrows which represent the transport pathways into and out of the system and between the different components of the system. Such diagrams are intended to illustrate the structure and function of the ecological system so as to help visualize the dynamics of pollutants in the environment. Thus conceptualized, mathematical models may be applied using the conceptual model to quantify the rates at which materials are expected to move through the system. Such an approach allows for periodic reevaluation of data sets based on model calculations, which ultimately may allow for the modification of the monitoring system design in such a way as to improve cost-effectiveness.

Conceptual diagrams may be used as heuristic tools for establishing many of the key aspects of the monitoring program design, including:

1. Source-receptor relationships: How are pollutants transported once released from the source? What Class I areas potentially receive these materials? How do these materials enter the system?

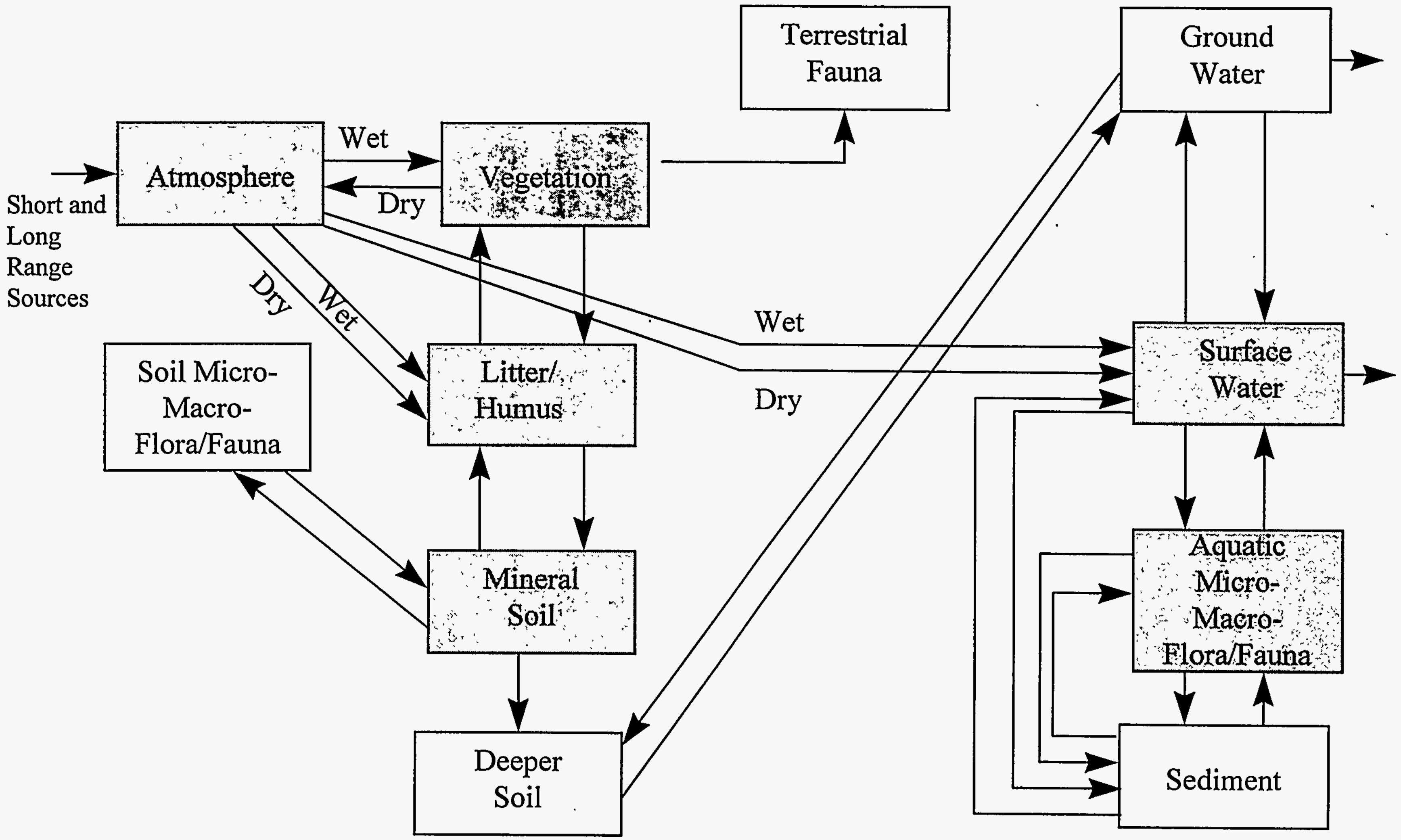

Figure 1. “Box and arrow: diagram used to conceptualize an ecological system during the development of an AQRV monitoring program. Shaded compartments indicate the portions of the ecosystem included in the Wind River monitoring program.

2. Contaminant pathways: How do pollutants move through the system (e.g., from atmosphere to biota, to litter, to soil, to groundwater, etc.)?

3. Critical receptors: What are the primary components of the ecosystem (e.g., vegetation, aquatic biota, etc.) that are at risk?

4. Environmental fate of the contaminants: Where and in what form do these materials accumulate? By what means are they broken down chemically? By what means do they exit the system? How rapid are each of these processes?

More detailed conceptual models such as that shown in Figure 2 can be used to show how selected ecosystem indicator categories might be linked together. Use of conceptual models such as that shown in Figures 1 and 2 help to illustrate important linkages between pollutants, critical receptors, and indicators used to assess AQRV status. This is conducive to an ecosystem approach to environmental monitoring whereby interrelationships between different components of the system are considered, recognizing that alterations to one component of the system may affect other components. Such an ecosystem approach is explained in further detail in Step 8, and enables pollutant impacts to be assessed in an integrated manner, rather than as isolated, independent assessments.

By helping to describe the movement of pollutants through the system, conceptual models help to provide information that may be used to help determine which Class I areas are at risk, which AQRVs are important, and what indicators should be used to quantitatively link the source to a critical receptor. This approach provides for the effective integration of various indicators of change that will enable the evaluation of the system as a whole. Models can also help to identify gaps in the existing data.

2.3. Step 3: Identify Class I Areas at Risk

Objective: The objective of Step 3 is to identify all Class I areas that have a reasonable potential for being impacted by emissions from a major stationary source.

Approach: The identification of potentially-impacted Class I areas is the responsibility of the FLM. However, consideration should be given to input from other interested parties. These decisions should be based on information gathered during Steps 1 and 2, as well as on the relative sensitivities of the Class I areas under consideration, and should be done in conjunction with the conceptual model developed in Step 2.

In identifying potentially impacted Class I areas, consideration should be given to:

1. Proximity of the Class I area to the source
2. Emissions inventory of the source
3. Pollutant transport phenomena
4. Relative sensitivity of the systems, as based on available information
5. Human perception.

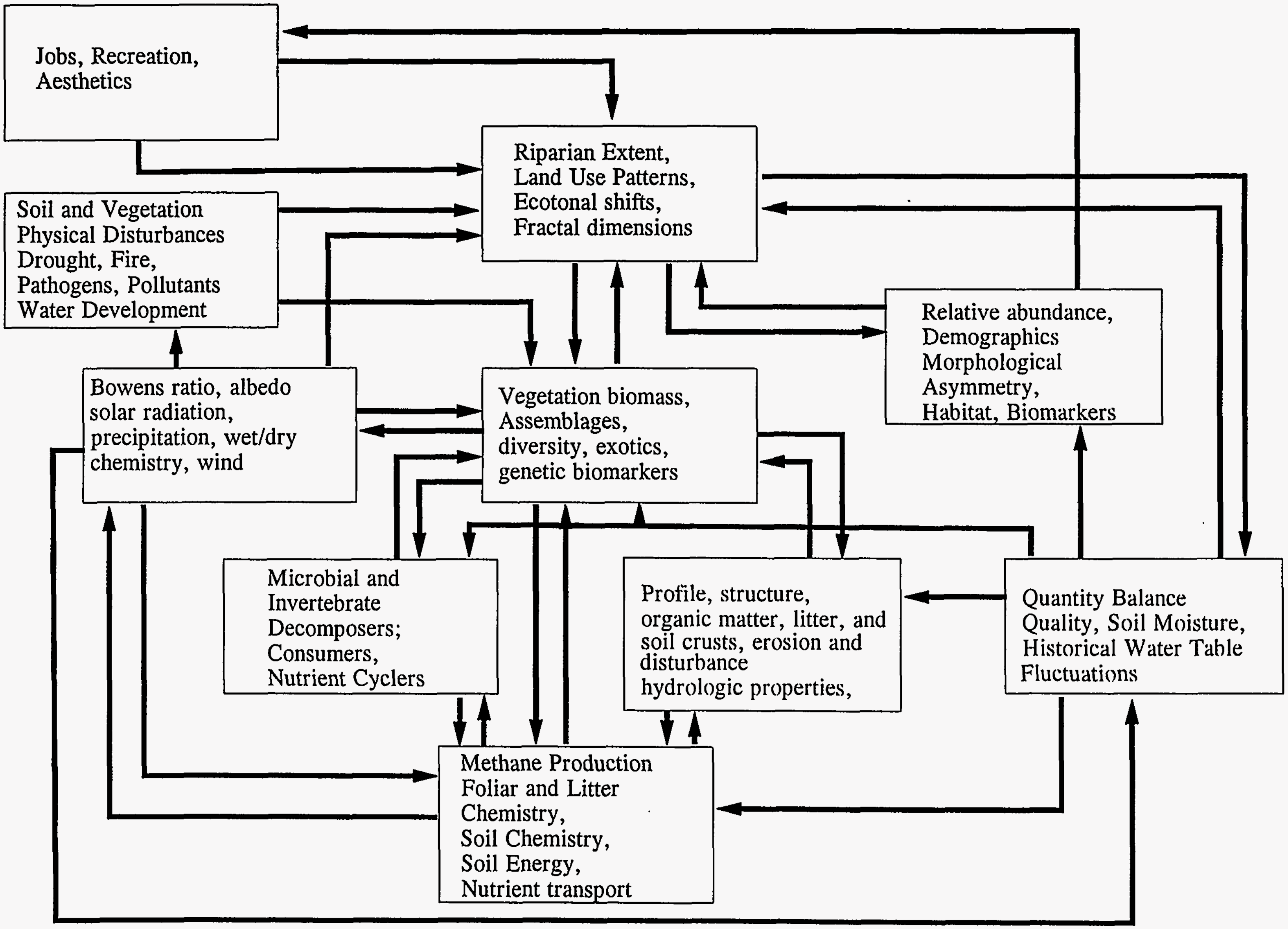

Figure 2. More detailed conceptual diagram of an ecosystem monitoring program (from the EMAP Rangeland Health Group).

2.4 Step 4: Determine Air quality Related Values for Each Class I Area

Objective: The objective of Step 4 in the development of an AQRV monitoring program is to identify which AQRVs are most likely to be impacted for each Class I area of concern.

Approach: As with Step 3, the responsibility for designating AQRVs for each Class I area lies exclusively with the FLM. AQRVs are defined broadly as "any wild component (features or properties) of the wilderness that can be modified by human-caused air pollution", implying that the potential number of AQRVs are somewhat limited to general components of the system such as flora, fauna, soil, water, visibility, and/or cultural objects. From a practical standpoint, however, AQRVs may be considered to include anything inherent to the Class I area that could be impacted by air pollution in such a manner that the purpose for which the area was established (biological diversity, water quality, fish) would be adversely affected (Fox et al., 1989). Therefore, "lichens" or "quaking aspen" or "benthic macroinvertebrates" could be considered as AQRVs.

Conceptual models similar to that described in Step 2 represent useful tools that the FLM could use to determine what AQRVs should be monitored. In this manner, data on emission levels and pollutant behavior are considered in making these determinations.

2.5 Step 5: Identify Cause and Effect Information on Contaminants and AQRVs

Objective: The objective of Step 5 is to identify information that relates contaminants emitted from the proposed source and the AQRVs selected in Step 4.

Approach: Once AQRVs are identified, it is important to narrow the focus of the potential relationship between source and receptor. It is not enough to determine that the deposition of atmospheric pollutants *may* cause impacts to the flora in a Class I area. Rather, information is needed on the species or communities of plants that may be at risk, the anticipated response(s) of these species or communities, and the exposures necessary to elicit these responses. The questions listed in the box below, in combination with the information gained in the previous Steps can be useful in the establishment of potential source/receptor relations.

Questions on Potential Source/Receptor Relationships

- **What are the effect(s) of the identified pollutants on ecosystems?**
- **At what level of biological organization do the effects operate?**
- **Which pollutant(s) are responsible for these changes?**
- **What is the mode of action by which the effect occurs?**
- **What characteristics (e.g., temporal component, etc.) Of the event control the effect?**
- **What characteristics of the site are involved?**
- **To what degree can laboratory data be extrapolated to the field?**

Effects of pollutants on ecological systems are extremely complex and diverse, and may be classified variously as direct versus indirect, acute versus chronic, lethal versus sublethal, biotic versus abiotic, visible versus microscopic, positive versus negative, etc. Furthermore, it is important that effects be considered for all levels of biological organization. Not only may effects be observed at the ecosystem, community, population, or individual levels of biological organization, but at the other extreme, effects may also be observed at the cellular level, biochemical level, or genetic levels. Potential effects on AQRVs due to atmospheric pollutants must be identified, even if there is no obvious evidence that this damage is occurring.

The specific pollutants potentially responsible for each effect must also be determined, integrating dose/response information wherever possible. To complicate matters further, the possibility of synergistic effects brought about by a combination of pollutants must also be considered. Other potential causal or contributing factors should also be identified. These could represent additional independent stress factors (e.g., drought, pathogens, insect pests), or factors associated with the environment (e.g., soil pH, temperature, etc.) or with the organism itself (e.g., physiological, morphological, and other features of the organism that renders it susceptible).

The response of organisms to atmospheric pollutants may vary substantially between sites, even if exposures are the same. This may be due to differences in receptor species (species composition and density, age class distribution, genetic pools) or by differences in the site (e.g., elevation, slope, aspect, solar incidence, precipitation, etc.). Soil characteristics (e.g., pH, percent organic matter, cation exchange capacity, percent base saturation, depth, sulfate adsorption capacity, fertility, buffering capacity, etc.) may be especially important.

Once the source/receptor relationships have been determined, the mode of action by which the effect occurs must be assessed. This requires an understanding of the mechanism of action involved with the interaction between pollutant and receptor. How is exposure duration (both instantaneous and chronic) and/or frequency involved in the manifestation of effects? Considerable information exists on the effects from short-term pollutant exposures for many plant species. However, there is little data available on the effects from long-term or chronic exposures.

Organisms, not ecosystems, respond directly to pollutants, and much of the information available on the impacts of atmospheric pollutants on biological systems in remote locations therefore is based on observation of responses of individual organisms. Higher levels of biological organizations in turn integrate the responses of the various individuals through various trophic and competitive interactions, before an ecosystem-level response can be observed (Sigal and Suter, 1987) without a prior organism response. Responses of organism therefore precede those of ecosystems and in the process of monitoring the parameters of entire ecosystems, the responses of sensitive individuals and populations tend to be masked or averaged out. Observations of impacts at the organism level biological organization are relatively easy and inexpensive to measure (Sigal and Suter, 1987). Information linking these organism-based parameters to adverse impacts on higher levels of biological organization (i.e. populations, communities, or ecosystems) are generally lacking, and are confounded by natural variability, extended response times, variability of climatic conditions, influences of pathogens and insect pests, and other factors (Sigal and Suter, 1987).

Example: Methods for determining adverse impacts of air pollutants on four levels of biological organization of terrestrial ecosystems in Class I areas were evaluated by Sigal and Suter (1987), focussing on SO_2 and O_3. The four levels of organization examined were: *individual* (visible injury, biomass, S uptake), *population* (mortality, natality), *community* (diversity), and *ecosystem* (biogeochemical cycling).

2.6 Step 6: Identify and Examine Existing Site - and AQRV-Specific Information

Objective: The objective of Step 6 is to collect and incorporate into the process all relevant information that is available on both the Class I area(s) of concern identified by the FLM and the AQRV(s) identified for each Class I area.

Approach: Information on the Class I areas is necessary because all Class I areas are at least to some extent unique. Depending on the AQRVs identified by the FLM, information may be needed on a wide variety of topics. If vegetation is identified as an AQRV, then the distribution of various species and communities are needed. Data on soil development, soil chemistry, insect and disease history, meteorological parameters, and physical parameters (e.g., slope, aspect, elevation) may also be helpful. In the case of fisheries, data on historical populations of fish species (e.g., through catch records), water chemistry, atmospheric deposition, are among the data types that may be useful.

Collection of these types of information will help in the subsequent steps in the development of an approach for monitoring the status of specific AQRVs at identified Class I areas. Much of this information should be available through the FLM responsible for each Class I area.

- **What information is available for the class I area of concern?**
- **What information is available for the receptor(s) of concern?**
- **What information is available relating air pollutant damage to the plant and animal species present in the class I area of concern?**
- **What information is available from other areas sharing similar geography, geology, and/or ecology?**

2.7 Step 7: Identify Specific Locations Where AQRVS Should be Assessed

Objective: The objective of Step 7 is to identify the specific locations within each Class I area at which AQRV status should be monitored.

Approach: Using the information generated in Step 6, candidate locations should be identified to conduct monitoring. Criteria should be established with which to evaluate candidate sites, and then these sites should be ranked using these criteria. Monitoring locations selected may not be the same for each AQRV, nor for each parameter or indicator measured for a given AQRV, but should be based on where the best information can be obtained in the most cost-effective manner.

The design of a monitoring program to evaluate the status of AQRVs in a wilderness setting will typically involve two separate actions: a synoptic survey and a long-term monitoring program. Synoptic surveys involve the identification of sensitive aquatic and terrestrial ecosystems, making optimum use of the information obtained in Step 6. Candidate sites should be visited to confirm their potential utility, and where possible, their vulnerability should be related to geologic, hydrologic, and other characteristics of the system. Information collected in this manner is then used to select the most sensitive systems within the Class I area for use in predicting, modeling, and monitoring the status of the AQRVs identified by the FLM. In effect, the synoptic survey is performed to identify the systems in which the long-term monitoring should be conducted.

Once a list of candidate monitoring sites are selected, they must be ranked such that the "best" subset of sites is selected for monitoring AQRV status. The ranking of candidate sites should be accomplished in a manner that makes use of input from all interested parties. Although many different sites may meet the basic requirements for a monitoring location, it is desirable to select the optimum site (or sites) for each AQRV to be assessed. However, opinions on which site is the best at which to derive the desired information can be highly variable. For this reason, a decision analysis technique may be very useful, and should be implemented during this Step.

3. SELECTION OF INDICATORS OF AQRV STATUS

Up to this point, the focus of the process for developing an AQRV monitoring program has been on "what" and "where":

What are the relevant pollutant sources?
What pollutants do they discharge?
What quantities are discharged?
Where do the pollutants go?
What Class I areas receive these pollutants?
What AQRVs might be of concern in these Class I areas?
Where are these AQRVs located?
What sensitive receptors can be identified for each AQRV?
Where are these receptors located?

The emphasis of this section changes to "how". Specifically, how can impacts to sensitive receptors best be assessed? Methods must be identified or developed with which to assess the condition of these receptors. For example, if aspen are identified as potentially sensitive receptors for SO_2 in a particular location, methods must be applied that will allow for the assessment of the status of the aspen at the selected location. Indicators must be identified that will allow impacts to aspen from SO_2 to be quantified. These indicators may be chemical, physical, or biological (ecological) measurements that individually or collectively will allow for the evaluation of the status of critical receptors. The method proposed here for assessing the status of sensitive receptors involves the evaluation of one or more indicators to provide the means for quantifying the condition of a receptor or a group of receptors. Careful selection and implementation of these indicators will provide the most effective means for assessing AQRV status.

A method is proposed below for selecting the most effective suite of ecological indicators for assessing the status of a particular sensitive receptor or group of receptors within a given geographic area. The process involves development of a list of criteria for selecting these indicators. Once the criteria list is established, the criteria are ranked in terms of their relative importance to the success of the monitoring program. This identification and ranking of criteria is done largely from a scientific basis, and is performed *before* actual indicators are considered: only after criteria are established are potential indicators evaluated against one another. By applying these criteria to indicator selection during the planning stage, monitoring programs can be developed to better provide defensible, quality-assured data in a cost-effective manner. Establishing selection criteria early in the overall process helps to assure that the monitoring program will adequately provide the necessary answers to questions regarding the status of the AQRVs. Consistent application of this process will help ensure the effectiveness of the resulting monitoring programs. Furthermore, the results generated by the monitoring program will be more generally accepted by all interested parties if a consistent, scientifically-based process such as that proposed here is implemented.

Objective: The objective of this step in the development of AQRV monitoring programs is to use the information gained in Steps 1 through 7 to identify and rank the potential indicators that can be used to evaluate the status of each AQRV at each Class I area. The outcome is a consensus-based method for determining the best suite of indicators with which to assess impacts to sensitive receptors. This is done by developing and implementing a series of scientifically-based criteria by which potential indicators of pollutant impacts may be evaluated.

3.1 Selection of Criteria for Indicators

The purpose of establishing criteria with which to evaluate potential indicators of AQRV status is to define *a priori* the characteristic properties that an indicator or indicators should possess in order to be effective. This approach is recommended to avoid some of the problems common to many existing monitoring programs whereby ecological indicators fail to provide the information necessary to evaluate the condition of the resource being monitored (D.L. Peterson et al., 1992; J. Peterson et al., 1992). The criteria developed should be used to bound potential ecological indicators in a manner that will better ensure that the data produced is of known quality and is collected in the most cost-effective manner.

AQRV monitoring programs must be designed for each combination of source and protected area independently. This is because each stationary source is at least somewhat unique with respect to both source term (emissions inventories) and physical setting. Furthermore, every protected area potentially impacted by emissions from a proposed source is also unique in terms of geology, hydrology, and ecology. A monitoring program designed for one scenario will not necessarily be applicable to another, and the monitoring design must therefore be established on a site-by-site basis.

3.2 Suggested Criteria for Selecting AQRV Indicators

A series of suggested criteria for evaluating the effectiveness of indicators in assessing AQRV status are described in this section. These criteria are of varying importance, and reaching consensus opinions regarding the relative importance of each criterion may be difficult. Furthermore, the relative importance of each may vary between sites. The goal is to apply these and/or other alternative criteria to provide a consistent, generic approach to the selection of AQRV indicators. This approach can be applied in virtually any situation (i.e. any combination of source and receptor of interest), but the output must be considered site-specific. A process for ranking the criteria is also described below in Section 3.3.

3.2.1 Criterion 1: Ecosystem Conceptual Approach

The ecosystem approach to environmental monitoring considers many features of ecosystem simultaneously, rather than focusing on single, isolated features of the environment. To satisfy the ecosystem conceptual approach criterion, indicator parameters must relate in a known way to the structure or function of the ecological system to be monitored so that the information obtained provides a "piece of the overall puzzle". Individual parameters should directly or indirectly involve some physical, chemical, or biological process (or processes) associated with the atmospheric, terrestrial, and/or aquatic portions of the system.

Many different approaches can be applied to AQRV monitoring, and each may be classified as either reductionist or synthesist in terms of the general strategy employed. A reductionist approach to monitoring assesses each parameter independently, whereas a synthesist strategy incorporates a more holistic approach that addresses the interrelationships between different components of the system. The reductionist approach therefore recognizes that if one component of the system is altered or stressed in some way, there will be direct and/or indirect consequences to other components as well, and that each of these, in turn, will cause further changes to occur. For most aspects of AQRV monitoring programs in Class I areas, it is recommended that a synthesist or "ecosystem approach" be taken, similar to that described in Step 2 during the evaluation of expected pollutant behavior. This will better enable overall impacts to be assessed in an integrated manner rather than as isolated, independent events.

The ecosystem conceptual approach criterion must be addressed at two levels. First, the approach should be applied to the overall monitoring program through the application of the systems conceptual models designed during the assessment of pollutant behavior in Step 2 (Figure 1). These models help the user visualize relationships between pollutant sources and the receptors of the material within the ecosystem, as well as the various contaminant pathways within the ecosystem, and may therefore be used to help identify indicators of AQRV status.

At the second level, each individual component of the monitoring program should be evaluated to see how well it fits into the ecosystem approach to monitoring. With regard to a particular indicator, the basic questions asked relating to the ecosystem conceptual approach include the following:

Questions Relating to the Ecosystem Conceptual Approach

1. Is application of the particular indicator (or set of indicators) consistent with current concepts of ecosystem theory?
2. Does the indicator relate to some process or processes associated with the structure and/or function of the ecological system?
3. Do the procedures to be used for measuring the indicator adequately document how that particular indicator (or set of indicators) fits within an ecosystem context?
4. Will the resulting data be useful in providing an adequate understanding of the system to be monitored?
5. If a particular indicator does not adequately satisfy the above, what alternative indicators may be recommended to meet such a requirement?

There are many good examples of indicators of ecosystem stress that meet the ecosystem conceptual approach to environmental monitoring. For example, litter decomposition and multimedia elemental analysis both provide information on the nutrient dynamics of the system. Vegetation surveys in the terrestrial system and analysis of functional feeding groups in aquatic systems can provide information on the structure of the ecosystem.

Conversely, although parameters associated with visibility may represent important measurements, these do not fit well into the ecosystem conceptual approach because visibility is primarily an aesthetic issue rather than an ecological one. Visibility is therefore more effectively treated individually.

3.2.2 Criterion 2: Useability

The useability criterion relates to the level of documentation available for each indicator measurement: the relative completeness and thoroughness of the procedures for measuring indicator parameter provide the best indication of the useability of that indicator. The useability criterion is therefore satisfied for indicators for which the level of supporting documentation is complete.

Ideally, detailed standard operating procedures (SOPs) should be available for each parameter measured as part of the AQRV monitoring program, and these SOPs should represent generally accepted, standardized methods. If the methods used are not well established, then supporting documents describing earlier applications of the method should be available. Any supporting documents used to justify the choice of indicator measurements or necessary to implement the measurements should be identified and referenced within the SOPs for each parameter measured. Information on previous field testing of the SOPs and supporting documents should be available as well.

Good examples of indicator parameters that satisfy the useability criterion include the widely used methods for measuring wet deposition, water chemistry, and soil chemistry. Established procedures for monitoring wet deposition are available and have been used for over a decade as part of the National Acid Deposition Program (NADP). Procedures for analyzing the chemical properties of water and soil are also well established. These procedures have long histories of field use, and generally satisfy the useability criterion.

In contrast, however, measurements of many ecological indicators are made using variable techniques, with little or no consensus regarding the best methodology available.

3.2.3 Criterion 3: Cost Effectiveness

This criterion can be evaluated on a relative basis based on the answer to a single question:. "Is the incremental cost associated with the measurement low relative to the information obtained?".

In determining cost-effectiveness, consideration should be given to the time necessary for the preparation of sampling activities, collection of the samples, analysis of the samples (where applicable), and analysis and interpretation of the resulting data. The cost of field or laboratory equipment must also be considered. Where possible, measurements that may be performed using synoptic monitoring techniques are more cost-effective, although there are some cost-effective automated monitoring that may be applied in some circumstances.

Aquatic chemistry parameters and litter decomposition rates are among the many examples of indicators that are relatively cost-effective. Remote sensing technologies offer promise for a variety of indicators in that they may reduce the expense associated with sending personnel to remote field sites to collect samples or to conduct measurements.

Any parameter with high equipment or analytical expenses, or which necessitate large time commitments in the field or laboratory may not satisfy the cost effectiveness criterion. Atmospheric pollutant measurements, for example, are typically expensive to purchase and operate, and may not be justified based on the amount of information obtained, especially if reasonable estimations of atmospheric input can be obtained via other means (i.e. from a nearby monitoring station, or by modeling). Other parameters such as relative sensitivity tables for plants and other organisms may be very useful, but may be very costly to produce for a specific site, unless the information happens to be available elsewhere for the species at the site of interest.

3.2.4 Criterion 4: Cause/Effect

This criterion can only be met if there is a clear understanding of the relationship between pollutant concentration or input and the receptor such that the indicator used will exhibit a clear response (effect) to a measurable increase in the level of the pollutant (cause).

To evaluate this relationship between cause and effect, the following questions should be considered:

Questions Relating to Cause and Effect Relationships

1. Does the indicator respond in a known, quantifiable, and unambiguous manner to the atmospheric pollutant(s) in question?
2. Is there dose/response information available for the indicator and the pollutant(s) of concern?
3. Are exposure thresholds or trends known for the indicator?
4. Will the indicator provide similar information for most potential sampling areas within a wide geographic region?

The primary difficulty with establishing causal effects in ecological settings that are relatively far removed from pollutant sources is that often the early symptoms of pollutant damage are indistinguishable from those caused by other stress agents. In fact, with the exception of areas where pollutant damage is severe, recognition of pollutant damage is likely to be very difficult, and will take the form of general stress potentially attributable to many different factors or a combination of factors.

Odum (1985) defined stress as "a detrimental or disorganizing influence", and categorized the manifestation of stress in ecological systems as changes in (1) energetics; (2) nutrient cycling; and (3) community structure and function, as summarized in Table 3. For example, visible symptoms of chronic air pollution toxicity in trees and other plants are not highly specific, and in natural environments these symptoms can easily be confused with symptoms of other, unrelated stress factors including extreme climate conditions, nutrient deficiencies, and insect and disease disorders (Sigal and Suter, 1987). Climatic conditions (present and past) to which the plant is exposed, soil factors (i.e. nutrient availability), time of the year and time of the day that the plant is sampled, position within the plant and within the canopy that the plant is sampled, tissue age, genetic factors, presence of disease organisms or insect pests, etc. all present confounding variables.

Margalef (1981) stated that "stress is something that puts into action the mechanism of homeostasis". Early warning of stress will be more easily seen at the species level, although shifts here should be accompanied by changes in the rate of respiration and/or decomposition, which are more difficult to detect in large systems. When stress is detectable at the ecosystem level, there is real cause for alarm, for it may signal a breakdown in homeostasis (Odum, 1985).

There is substantial information available on the effects of various pollutants on plants and some aquatic animals, with somewhat less information available for other organisms. Much of this information

Table 3. Structural and functional Components susceptible to air pollutants for four levels of biological organization (from Sigal and Suter, 1987).

LEVEL OF ORGANIZATION	STRUCTURE	FUNCTION
Individual	Injury Biomass	Cell Death Metabolic processes (respiration, photosynthesis)
Population	Age structure, density Biomass Benthic composition Dispersion (pattern)	Natality Mortality Productivity Patterning of natality, mortality
Community	Diversity: (species richness, eveness) Physical structure (leaf area index) Trophic structure (trophic levels, food webs)	Succession (the integration of all interspecies processes such as competition, predation)
Ecosystem	Biomass Element pools	Energy flow Biogeochemical cycling

has been based on laboratory and/or greenhouse studies, and should only be extrapolated to field conditions with caution. Furthermore, little dose/response information is available for mixtures of pollutants, or for pollutants in plants simultaneously subject to additional stress factors.

Most studies of effects of air pollutants conducted to date have focused on responses of individual organisms rather than on the higher levels of biological organization. For example, visible injury to plants and reductions in biomass accumulation rates have often been cited as responses to atmospheric pollutants. However, linkages of these parameters to adverse impacts on populations and communities are lacking. Disturbance that is detrimental at one level of biological organization may actually be beneficial at another. Similarly, a disturbance may be detrimental over the short term, but beneficial over the long term. For example, Odum (1985) indicated that periodic fire in fire-adapted systems such as chaparral may cause stress to individual plants resulting in injury or mortality, but the absence or exclusion of fire would represent the stress at the ecosystem level.

The ability to accurately quantify a response may be rendered useless if the relationship between cause and effect is ambiguous. For example, although there is a large volume of documented evidence that indicates that exposure of many species of deciduous and evergreen trees to a variety of atmospheric pollutants will result in the development of symptoms of foliar chlorosis, this represents a typical response of green plants to stress in general. True assessment of damage from atmospheric pollutants may therefore be complicated by other stress factors, including physical damage, low soil nitrogen concentrations, root fungi, bark beetles, leaf-feeding insects, drought, etc.

Table 4. Trends expected in stressed ecosystems (from Odum, 1985).

A. Energetics:

1. Increased community respiration: This may represent an early-warning sign of ecosystem stress, due to the acceleration of repair processes in response to damage caused by the disturbance. This requires diverting energy otherwise available for growth and production to maintenance.
2. Unbalanced ratio of production to respiration: This may be either greater than or less than 1.
3. Ratios of production to biomass (P/B) and respiration to biomass (R/B) tend to increase: The increased R/B occurs as organisms respond to the disorder created by disturbance.
4. Auxiliary energy increases in importance.
5. The fraction of primary production that is unused increases.

B. Nutrient Cycling:

1. Nutrient turnover rates increase.
2. Horizontal transport increases and vertical cycling of nutrients decreases (cycling index decreases).
3. Nutrient loss increases (System becomes more "leaky").

C. Community Structure:

1. Proportion of r-strategists (versus K-strategists) increases.
2. Size of organisms decrease.
3. Lifespans of organisms or parts of organisms (e.g. leaves) decrease.
4. Food chains become shorter due to reduced energy flow at higher trophic levels and/or the greater sensitivity of predators to stress.
5. Species diversity decreases and dominance increases; if pre-stress diversity is low, the reverse may occur; at the ecosystem level, redundancy of parallel processes theoretically decline.

D. General System-Level Trends:

1. The ecosystem becomes more open (i.e. input and output environments become more important as internal cycling is reduced).
2. Autogenic successional trends reverse (succession reverts to earlier stages).
3. Efficiency of resource use decreases.
4. Parasitism and other negative interactions increase, and mutualism and other positive interactions decrease.
5. Functional properties (such as community metabolism) are more robust (homeostatic-resistant to stressors) than are species composition and other structural properties.

Similarly, tree mortality has been shown to result from acute exposures of several different pollutants. In areas further removed from the pollutant sources, however, atmospheric pollutants more often represents a contributing factor to the mortality, and determining the influence of pollutants relative to other proximate stress factors is virtually impossible.

Because of difficulties in proving that an observed change is due to pollutant exposures, responses that are diagnostic of the pollutant should constitute key components of monitoring programs. Examples include accumulation of the pollutant and characteristic gross and histological injuries (Sigal and Suter, 1987).

3.2.5 Criterion 5: Signal/Noise Ratio

This relates somewhat to the previous criterion, but refers more specifically to the relative ease with which changes in the indicator caused by the pollutant may be distinguished from changes due to natural variability. For indicators to satisfy this criterion, separation from pollutant-induced changes from changes due to other factors must be relatively easy.

The signal-to-noise ratio in ecological parameters is a function of the degree of variability exhibited by the parameter in the absence of the pollutant (or other stress factor) being evaluated. To evaluate indicators in terms of this criterion, the following questions should be asked:

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1. What is the natural *spatial* variability associated with the parameter to be measured?
2. What is the natural *temporal* variability associated with the parameter to be measured?
3. Are there predictable patterns in the spatial (e.g., slope, aspect, soil association, moisture) or temporal (e.g., seasonal) variability of the indicator?
4. Does the indicator possess sufficiently high signal strength, in comparison to natural variability, to allow detection of statistically significant changes within a reasonable time frame?

The successful separation of anthropogenic "signal" from the background "noise" is generally complicated by natural variability caused by season, climate, natural succession, natural disturbance, microclimate, etc. Often, the temporal and spatial variability within the ecosystem will be substantially greater than the variability the monitoring method is designed to detect. When this is the case, assessment of the spatial and/or temporal variability necessitates enormous data bases that is not available in most instances. Such monitoring methods may work well in areas of high pollutant input, close to industrial areas, or in laboratory experiments, but may be inappropriate for wilderness systems where pollutant input patterns may be seasonal, tied to snow melt or other variables.
Variability is important on a variety of spatial and temporal scales. Temporally, ecological parameters may vary on sporadic, seasonal, and/or annual basis. Some water quality parameters, for example, exhibit a short-term "pulse".

The results of water quality sampling may be substantially different depending on whether sampling occurred during the pulse.

Many ecological parameters vary on a seasonal basis. For example, nutrient concentrations in tree foliage may change dramatically during the growing season, especially for hardwood species. Nitrogen concentrations generally increase rapidly in the spring, undergo slight declines during the growing season, and decrease rapidly at the beginning of fall senescence as the tree resorbs this element. Conversely, concentrations of boron, calcium and some non-nutrients including aluminum and heavy metals tend to increase steadily throughout the life of the leaf. Concentrations of potassium are more difficult to predict, due to factors such as foliar leaching. These types of within-year temporal patterns must be understood.

Knowledge of between-year variability is also important, as annual sampling or measurements must take into consideration the differences that occur between years. For many ecological parameters, collection and analysis data from a period of at least five consecutive years is necessary to minimally attempt to assess temporal variability of many ecosystem parameters. In some cases, a five year data base may not be sufficient to assess interannual variation. For example, tree ring width can be highly variable from year to year (and between sites) due to a wide variety of factors, including annual and seasonal moisture and temperature regimes and organism age. Detection of subtle reductions (or increases) in tree ring growth resulting from air pollutants emitted upwind is very difficult. Long-term data is generally not available except in isolated, existing long-term monitoring sites.

Spatial variability of ecological parameters may often exceed the range of temporal variability (Podlesakova and Nemecek, 1995). On a small scale, spatial differences may be attributable to the characteristics of the microsite, whereas factors such as slope, aspect, and elevation may be important on a larger scale.

Potential indicators of AQRV status must be evaluated in terms of both their natural and pollution-related fluctuations and trends. An ideal indicator will exhibit relatively low natural variability both spatially and temporally when compared to the changes resulting from the pollutant at the levels of interest (Hinds, 1984). Unfortunately, low degrees of spatial and temporal variability are typically very difficult to attain in ecological systems.

The ability to adequately define and quantify natural variability is a critical feature of the design of a monitoring program. In general, the monitoring of ecological effects of air pollutants should be viewed as an experiment in testing the null hypothesis that the pollution has no adverse effect on the receiving biological system. To accomplish this, the spatial and temporal variability due to factors other than the pollutants of concern must be assessed.

Many past and current remote site monitoring programs have suffered from design problems that resulted in the inability to accurately determine signal to noise ratios in many of the parameters measured. These problems were caused by one or more of the factors listed below (Segar, 1986).

1. The species and sites used were selected according to their relative ease of sampling rather than from a scientific standpoint that would provide the most useful information.

2. Individuals (or individual samples) from a sampling site are pooled for analysis, thereby artificially reducing the spatial variability associated with the results.

3. Composite samples are used to reduce analytical costs, which also results in a reduction of spatial variability.

4. Variance estimates reported for a site are often based on analytical replicate variance only, without consideration for spatial variability. This results in the determination of statistical significance between two mean concentrations on the basis of analytical variance alone.

5. Within-year temporal variability is not considered, and/or sampling is not performed at a consistent or critical time (e.g., during spring runoff or at a critical stage of the life-cycle).

Upon analysis of the data, failure to effectively consider natural spatial and temporal variability can easily lead to the wrong conclusion regarding ecological impacts. To avoid these problems, a properly designed AQRV monitoring program should have the following characteristics (Segar, 1986):

1. The general objectives of the program should be clearly established (i.e. what are the AQRVs that need to be monitored).

2. The specific objectives of the monitoring program should be clearly established (i.e. what parameters will be measured to meet the general objective of the program).

3. The limit of acceptable change (LAC) for each measured parameter should be specified and detectable.

4. Alternative null hypotheses should be established for each specific objective, stipulating the required resolution level.

5. The design of a sampling and analysis program should be established for each null hypothesis.

6. A specific null hypotheses should be selected to be tested for each specific objective. The spatial and temporal scale of the hypothesized effect that must be observed must be determined, and the magnitude of smallest change or difference in mean value of monitored parameter that must be observed and statistically verified on the specified spatial and temporal scales if the null hypothesis is to be disproved. When properly specified, these elements constitute the required *resolution*.

7. Establish and evaluate new null hypothesis if it is determined that all originally selected null hypotheses for a specific objective cannot be tested.

3.6 Criterion 6: Alternative Approaches

This criterion is satisfied if it can be concluded that no other approaches for measuring AQRV status are available that would increase the quantity or quality of information obtained.

In effect, the alternative approaches criterion provides for a reevaluation of the selection process, whereby alternative indicators and/or methods are assessed for their potential for providing better information than those selected. The purpose of the alternative approaches criterion is therefore to assess whether there are methods, procedures, equipment, or ecosystem parameters available other than those being considered that could be better suited for remote site monitoring.

3.2.7 Criterion 7: Quality Assurance

The criterion is satisfied if the quality of the resulting data can be reasonably assessed from a statistical and procedural standpoint.

Ideally, quality assurance/quality control (QA/QC) procedures should be available for any parameter to be measured, and these procedures should be adequately referenced and outlined within the procedures used to collect the data. If no established QA/QC procedures are available, this criterion may still be satisfied if the technique lends itself to the development and application of effective QA/QC procedures.

Some parameters commonly associated with environmental monitoring programs are associated with long-established and well-accepted QA/QC procedures. For example, the wet deposition measurements collected as part of the NADP have utilized established, time-tested procedures. Similarly, many of the water chemistry procedures have good QA/QC procedures. However, many ecological parameters do not lend themselves well to effective QA/QC procedures. For example, the determination of fish age class based on the counting of scales is not generally well replicated.

3.2.8 Criterion 8: Anticipatory

Ideally, an indicator applied to an AQRV monitoring program in a Class I area should be designed to provide an early warning of widespread changes in ecological condition or processes. Measurable changes in many parameters currently being used in wilderness monitoring programs would not likely be observed until substantial damage has already occurred. For example, some programs estimate fluctuations in the populations of certain organisms. Should natural populations fluctuate measurably (i.e. to be able to distinguish from natural variability), it is likely that ecological damage has already occurred.

3.2.8 Criterion 9: Historical Record

In some cases, historical data can be obtained for a parameter of interest from archived data bases. Such data can be extremely valuable for establishing natural baseline conditions and the degree of natural variability associated with the parameter. For example, the U.S. Forest Service has long-term timber survey plots in many areas. In some cases, the data collected at these sites were related to timber production data only (i.e. tree species, diameter, height, crown class, etc.). In other instances, however, additional information may be available, such as the distribution of non-woody plant species, wildlife, the presence of threatened or endangered species, etc. Similarly, many state fish and game agencies maintain substantial long-term data bases on fishery status. Some lake chemistry data may also be available for many areas. Conversely, little information is generally available on parameters such as functional feeding groups in aquatic systems or other ecological parameters.

3.2.10 Criterion 10: Retrospective

Some parameters allow for retrospective analysis, in that *new* data may be generated that provide information on *past* conditions. For example, tree rings provide growth indices for each year of the life of the tree. Other parameters, such as metal concentrations in litter, tend to accumulate over time, such that sampling this medium provides data that are integrated over time. Most other parameters, including such as ambient atmospheric monitoring allow only for a "snapshot in time".

3.2.11 Criterion 11: New Information

All parameters applied to an AQRV monitoring program should provide new information, rather than simply replicate data already collected. For example, a vegetation survey to determine the range of major plant communities in areas where the Forest Service already maintains such data would not be useful, as any observed change would invariably represent a substantial degree of impact.

3.2.12 Criterion 12: Minimal Environmental Impact

Any procedure applied should result in minimal environmental impact to the Class I area. Application of any indicator of damage to sensitive receptors should not in itself result in more environmental impact than the air pollution. Wherever possible, non-destructive biological surveys should be used rather than those which rely on destructive sampling techniques. Measurements that require considerable destructive sampling may not be acceptable within National Parks or wilderness areas, and should therefore be avoided. For example, tree ring chronologies and sapwood volumes are often determined from "cookies", or cross-sections of trees that are collected from a tree that must first be cut down. Such destructive sampling should not be performed unless the information generated from the sampling justifies the loss of the organisms being sampled.

Additionally, measurements that require large equipment should be avoided wherever possible. For example, most methods for measuring concentrations in ambient air involve the use of elaborate equipment housed in an instrument shelter. Although use of such equipment in some locations may feasible, application of such techniques within most wilderness areas are not practical. Furthermore, since this equipment requires electrical power, this severely restricts the locations in which the equipment may be installed, and potentially exposes the equipment to roadway pollutants.

3.3 Ranking of Criteria

Once the relevant criteria are established for a given scenario, they must then be ranked. It is proposed that this ranking be performed in two steps:

Step 1: Separate the established criteria into two groups; "*must*" criteria and "*want*" criteria. "Must" criteria represent absolute requirements in that an ecological indicator that does not satisfy all of the "must" criteria is automatically eliminated from consideration during the selection process. In contrast, "want" criteria represent those attributes which are desirable but cannot be viewed as absolutely necessary to the success of the indicator.

Step 2: Rank the "want" criteria. Whereas the "must" criteria represent absolute requirements, "want" criteria represent desirable attributes, and some of these attributes may be more desirable than others. For this reason, the "want" criteria should be ranked in terms of their relative importance, considering the specific scenario of interest.

Both of these steps involve subjective decisions; opinions will vary with respect to which criteria should be designated as "must", and the "want" criteria should be ranked. It is recommended that both steps involve input from varying interested parties, and that some established consensus-building methods such as the K-T process (Kepner and Tregoe, 1981) be applied during the decision making.

It should also be remembered that every situation (i.e. every combination of different AQRVs and different Class I areas) will be different, and therefore there can be no generic set of criteria that will be applicable to all situations.

4. HYPOTHESIS TESTING

Hypothesis testing is an integral part of any monitoring program, and the design of the program must allow for the data generated to be used to test predetermined hypotheses regarding the response of the indicator to pollutant inputs. Only through the statistical testing of hypotheses can valid conclusions be derived from monitoring data, and this development of adequate, testable hypotheses can be a difficult task.

A general outline of the steps that should be taken in the design of a statistical monitoring program are provided in the box below.

STATISTICAL MONITORING PROGRAM DESIGN

1. Establish null hypothesis for each parameter (indicator) to be measured.
2. Measure the variance associated with the analytical procedure used for each parameter.
3. Measure the natural spatial variance associated with each parameter measured.
4. Measure the natural temporal variance associated with each parameter measured.
5. Design the sampling program considering:
    - The effect of sample replication and pooling designed to reduce analytical and temporal variance.
    - Statistical power required to detect different levels of deviation in the mean between sampling periods or geographic areas.
    - Estimated potential maximum deviation from the mean due to anthropogenic input (mass balance calculations, etc.).
6. Determine whether potential maximum deviation of the mean could be detected by practical monitoring program.
7. Establish the level of deviation of the mean required to disprove null hypothesis (this must be a level of deviation detectable with reasonable statistical power).

Null hypotheses generated for environmental monitoring parameters typically take one of the following general forms:

1. To assess the status of a parameter, the form is "the mean concentration of contaminant X in bioindicator Y at potentially contaminated site A does not exceed the mean concentration of contaminant X in bioindicator Y at uncontaminated reference sites by more than Z%.

2. To assess trends in the status of a parameter at a given site, the form is one of the following (Segar et al., 1987):

   - The mean concentration of contaminant X in bioindicator Y within the defined area A at time T_2 has not increased by more than Z% since time T_1; or

   - The mean concentration of contaminant X in bioindicator Y within the defined area A has not increased at a rate exceeding Z% per annum since a reference time T_1.

The first type of hypothesis is tested once at a specified time after the baseline is established, and may then be retested at subsequent regular or irregular intervals (Segar et al, 1987). This requires only relatively simple statistical approaches, and can satisfy most management needs. The second type is more difficult to test since complex statistical "trend" analysis is necessary. However, if the second type of hypothesis is tested with a properly designed program, the sensitivity of the program for early detection of progressive long-term contaminant accumulation should be substantially enhanced.

Some of the more common problems associated with developing and testing hypotheses in ecological systems are described below. Most of these problems are due to poor sample design. Each parameter included in an AQRV monitoring program must be measured with sufficient frequency in time and/or space allow for the identification of statistically-significant changes. Otherwise, interpretation of the resulting data and the identification of trends will be impossible.

The amount of change which is considered significant must be predetermined, because with any data set the possibility that some extremely small change may have occurred that is below the resolution of the measurement system employed will be possible (Segar, 1986). *It is never possible to prove that* *no change has occurred.* Rather, some attainable and measurable bounds must be established.

The three essential elements of hypothesis testing are:

1. the spatial scale on which the observation is to be based;
2. the temporal scale on which the observation is to be based; and
3. the magnitude of the smallest change or difference that the program must observe and statistically verify (i.e. the required "resolution").

While monitoring programs often fail to adequately define the spacial and temporal scales to be addressed, the required resolution is almost invariably ignored until sampling and analysis are completed and the data are to be analyzed. This results in wasted resources, either:

1. because the sampling program was inadequate and did not provide the resolution required (i.e. the data show change was not observed or verified, although the minimum observable change was so high that a change whose magnitude exceeds the LAC might have existed); or
2. because the sampling program was intensive and identified a change or difference that was so small as to be of no environmental significance.

The primary factors influencing the resolution attainable in monitoring programs using bioindicators are:

1. Individual variability within sampled populations;

2. Spatial variability on spatial scales smaller than those of interest (e.g., effects of microhabitat);

3. Temporal variability on time scales shorter than those of interest (e.g., seasonal effects from run-off, or short term fluctuations in emission rate);

4. Sample handling and preparation variability; and

5. Analytical variability.

The resolution selected must be both scientifically attainable with available resources, and environmentally significant. The selected resolution is not environmentally significant if it is (Segar, 1986):

1. so small that there is no potential threat of environmental damage (i.e. so much smaller than the LAC as to be insignificant);

2. so large that there is no credible scenario in which it would occur; or

3. so large that, once observed, substantial environmental damage would already have occurred (i.e. greater than the LAC).

In many cases, the design of the study will result in a conclusion that technical limitation (e.g., extreme spatial and/or temporal environmental variability) and/or resource limitations that prohibit sufficiently intensive sampling and analysis dictate that an environmentally-significant resolution cannot be achieved.

Once the objectives of the sampling program and null hypotheses are defined, other program details such as the number and location of sampling sites, number of samples per site, frequency of sampling, number of replicate analyses per sample, and whether to composite samples, etc., must be determined. Sampling designs that use bioindicators require particular attention, as substantial variance among organisms of the same species may occur due to differences in size, age, sex, and habitat. The optimum sampling and analysis plan must select the age, size range, and number of individuals per sample, the number of samples per site, the number of replicate analyses per sample, and other factors based on the known sources of variance in the environment, sampling population, and analysis procedure (Segar et al., 1987). Improperly designed monitoring programs are incapable of producing data sets that can adequately verify statistical differences between sites or with time (Phillips and Segar, 1986).

Another problem common to many monitoring programs is the lack of adequate replicates (Sigal and Suter, 1987). Ideally, there should be random assignment of replicate biological components to experimental and control treatments. Replicate treatments may be possible within a Class I area if pollutant dispersal results in no significant differences in input within the Class I area. If this is the case, monitoring must compare baseline and treatment measurements of the same organism or plot. Interpretation of data resulting from this type of experimental can be difficult because natural temporal trends must be distinguished from those induced by pollution. Within a given site, there may be adequate replicate organisms. However, it is virtually impossible to identify replicate ecosystems, as no two ecological systems can be considered identical.

Lack of true control locations also a common problem with monitoring in Class I areas. This is largely inevitable, and "ecologically analogous sites" are generally sought *in lieu* of true controls. Legge et al. (1976) and others have emphasized the importance of exercising caution when selecting such sites. Collectively, these problems of incorporating adequate replication and control sites into the design of a monitoring program can create substantial problems for statistical hypothesis testing (Eberhardt, 1976; Green 1979; Hurlbert, 1984).

Another common problem associated with the design of monitoring programs occurs when the sampling design provides insufficient statistical power to distinguish ecologically significant effect levels. Whereas experiments may often be repeated if the power of the test is too low, monitoring programs are generally not repeatable.

5. CONCLUSIONS

This document provides an overview of a process proposed for developing AQRV monitoring programs, and a more detailed description of how ecological indicators should be selected for application to these programs. Throughout the document we have emphasized the following three key components of the overall process:

1. *Consistency:* A consistent process should be applied to the overall development of AQRV monitoring programs, including the selection of ecological indicators of AQRV status that will be applied to such programs. Ideally, the process should be applicable to Class I areas throughout the U.S., and by *all* land management agencies. This consistency will help to ensure the credibility of the resulting programs.

2. *Scientific basis:* This process must be based on sound science - i.e. monitoring activities should only be conducted if they have a sound scientific basis, and if there is a reasonable probability that the resulting data will enable the status of the AQRV to be assessed. This dictates that hypothesis testing must be an integral part of any monitoring effort, and that indicators applied to the program must meet certain predetermined criteria. Basing monitoring programs on sound scientific principals will ensure that the resulting programs are both credible and defensible.

3. *Stakeholder involvement:* All interested parties, including federal land management agencies, regulatory agencies, industry, and the public, should be involved in the design of AQRV monitoring programs. This is *not* intended to usurp the authority of the FLM in any way - several key decisions are solely the responsibility of the FLM. However, input to these decisions should also be solicited by the FLM. *Open involvement of all stakeholders throughout the development of an AQRV monitoring program will greatly enhance the acceptance of the program by all interested parties, which in turn will help ensure the success of the program in meeting its goals.*

The selection of ecological indicators according to a predetermined set of criteria relates to each of these components: it provides a consistent, scientifically-based process for selecting indicators, and it provides an opportunity for all stakeholders to become involved. Furthermore, the criteria list and ranking can be modified on a site-by-site basis to allow for the process to be applied to any Class I area or to any AQRV within a Class I area. Finally, as scientific knowledge progresses, the criteria may be applied to newly developed indicators, or to existing indicators for which new information exists.

As described above, the selection of ecological indicators should be based on pre-established criteria. Some of these criteria are "must" criteria because indicators that do not meet these criteria cannot adequately provide the information for which they are designed. Other, less restrictive or "want" criteria are those that are desirable, but not necessarily crucial to the effectiveness of the indicator. Unlike the "must" criteria, the "want" criteria are not equally important and may therefore be ranked in terms of their relative importance.

Below is a listing of "must" and "want" criteria proposed by the INEL for the selection of ecological indicators. Suggested ranking of the "want" criteria is also provided. Is must be kept in mind that the separation of "must" from "want" criteria and the ranking of "want" criteria is at least to some degree subjective. It is further recognized that additional criteria not listed here may be important on a site-specific basis. Still, we feel that this represents the best combination of criteria for selecting ecological indicators that will ensure that the indicators selected will provide the information necessary to make decisions.

"MUST" CRITERIA: Four "must" criteria were identified.

ECOSYSTEM CONCEPTUAL APPROACH -- Because our focus is on ecological indicators, any indicator selected must be related in some known way to the structure or function of the ecosystem under consideration. This criterion in not restrictive; it can be satisfied by virtually any chemical, physical, or biological parameter can satisfy. However, there should be a clear understanding of the relationship between the measurement and the structure and/or function of the ecological system. For example, streamwater pH may be an effective indicator if it is understood that decreased pH alters the structure of the benthic invertebrate community.

CAUSE/EFFECT -- There must be a clearly-understood relationship between pollutant concentrations or input rates (cause) and changes in the parameter measured (effect). This generally includes dose-response relationships.

SIGNAL/NOISE RATIO -- Ideally, the natural variability (spatial and temporal) observed in the parameter should be relatively small in comparison to changes due to pollutant inputs. In this way, the signal to noise ratio is such that effects due to the pollutant(s) of interest are readily distinguishable from natural variability.

QUALITY ASSURANCE -- The quality of the resulting data should be reasonably well-assured from a statistical and procedural standpoint. Data generated without adequate quality assurance are not defensible scientifically.

"WANT" CRITERIA (RANKED):

1. **USEABILITY** -- Procedures should be complete and thorough. Ideally, should use detailed and established SOPs based on standardized methods.

2. **ANTICIPATORY** -- Indicators should provide an early warning of widespread changes in ecological condition *before* substantial damage occurs.

3. **RESULT IN MINIMAL ENVIRONMENTAL IMPACT** -- Non- or minimally-destructive sampling techniques should be used, and measurements that require large equipment deployed over long periods of time should be avoided.

4. **COST EFFECTIVENESS** -- The incremental cost associated with measuring a parameter should be low relative to the information obtained.

5. **ALTERNATIVE APPROACHES** -- There should be no other approaches available for determining impacts to the sensitive receptor(s) of interest that would improve the quantity or quality of information obtained.

6. **HISTORICAL RECORD AVAILABLE** -- Information gained may be strengthened if a quality-assured historical data base is available to provide historical time-series data.

7. **PROVIDE RETROSPECTIVE INFORMATION** -- Application of some parameters will provide information on past conditions in addition to present conditions.

REFERENCES

Adams, M.B., D.S. Nichols, C.A. Federer, K.F. Jensen, and H. Parrott. 1991. Screening procedure to evaluate effects of air pollution on Eastern Region Wildernesses cited as Class I Air Quality Areas. USDA Forest Service, Northeastern Forest Experiment Station, General Technical Report NE-151.

Benoit, C. 1985. Personal communication.

Bingham, G.E. and P.I. Coyne. 1980. Photosynthesis and stomatal response to light and temperature in ponderosa pine exposed to long-term oxidant stress. p. 228 in: Proceedings Symposium on effects of air pollutants on mediterranean and temperate forest ecosystems. USDA Forest Service General Technical Report PSW-43.

Breckenridge, R.P., W.G. Kepner, and D.A. Mouat. 1995. A Process for selecting indicators for monitoring conditions of rangeland health. Environmental Monitoring and Assessment 78:1-16.

Bruns, D.A., G.B. Wiersma, and G.J. White. 1997. Testing and application of ecosystem monitoring parameters. Toxicological and Environmental Chemistry. *In Press*.

Bruns, D.A., G.B. Wiersma, & E.J. Rykiel, Jr. 1991. Ecosystem monitoring at global baseline sites. Environmental Monitoring and Assessment 17:3-31.

Craigmill, A.L. and W.L. Winterlin. 1985. Pesticide wastewater disposal: Biological methods. pp. 54-59 in: Proceedings of the National Workshop on Pesticide Waste Disposal. U.S. Environmental Protection Agency. EPA/600/9-85/030.

Eberhardt, L.L. 1976. Quantitative ecology and impact assessment. J. of Environmental Management 4:27-70.

Fox, D.G., A.M. Bartuska, J.G. Byrne, E. Cowling, R. Fisher, G.E. Likens, S.E. Lindberg, R.A. Linthurst, J. Messer, and D.S. Nichols. 1989. A Screening Procedure to Evaluate Air Pollution Effects on Class I Areas. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-168.

Fritts, H.C. 1971. Tree rings and climate. Academic Press, London, 567 pp.

Ghardiri, H., C.W. Rose, and D.W. Connell. 1995. Degradation of organochlorine pesticides in soils under controlled environment and outdoor conditions. Journal of Environmental Management 43:141-151.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. John Wiley & Sons, New York. 257 pp.

Heck, W.W., S.V. Krupa, and S.N. Linzon (eds.) 1979. Handbook of methodology for the assessment of air pollution effects on vegetation. Air Pollution Control Association, Pittsburgh, PA.

Hinds, W.T. 1984. Towards monitoring of long-term trends in terrestrial ecosystems. Environmental Conservation 11:11-18.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54:187-211.

Husch, G., C.I. Miller, and T.W. Beers. 1972. Forest Mensuration. Ronald Press Co., New York. 410 pp.

Johnson, D.W., J. Turner, and J.M. Kelly. 1982. The effects of acid rain on forest nutrient status. Water Resources Research 18:449-461.

Kepner, C.H. and B.B. Tregoe. 1981. The New Rational Manager. Princeton Research Press, Princeton, NJ. pp. 90-102.

Legge, A.H., G.W. Harvey, P.F. Lester, D.R. Jaques, H.R. Krouse, J. Mayo, A.P. Hartgerink, R.G. Amundson, and R.B. Walker. 1976. Quantitative assessment of the impact of sulfur gas emissions on a forest ecosystem. Kananaskis Centre for Environmental Research, University of Calgary, Alberta, Canada.

Legge, A.H. 1980. Primary productivity, sulfur dioxide, and the forest ecosystem: an overview of a case study. pp. 51-62 in: Proceedings symposium on effects of air pollutants on mediterranean and temperate forest ecosystems. USDA Forest Service General Technical Report PSW-43.

Margalef, R. 1981. Human impact on transportation and diversity in ecosystems. How far is extrapolation valid? pp. 237-241 in: Proceedings of the First International Congress of Ecology. Centre of Agricultural publishing and Documentation, Wageningen, Netherlands.

McLaughlin, S.B. and O.V. Braker. 1985. Methods for evaluating and predicting forest growth responses to air pollution. Experientia 41:310-319.

Messer, J.J., R.A. Linthurst, & W.S. Overton. 1991. An EPA program for monitoring ecological status and trends. Environmental Monitoring and Assessment 17:67-78.

Mudd, J.B. and T.T. Kozlowski (eds.) 1975. Responses of plants to air pollution. Academic Press, New York. 383 pp.

Murtaugh, P.A. 1996. The statistical evaluation of ecological indicators. *Ecological Applications* 6:132-139.

National Research Council. 1986. Indicator species and biological monitoring. pp. 81-87 *in*: Ecological knowledge and environmental problem-solving: concepts and case studies. National Academy Press, Washington, DC.

Newbould, P.J. 1967. Methods for estimating the primary production of forests. IBP Handbook no. 2, Blackwell Scientific Publications, Oxford. 62 pp.

Noss, R.F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. Conservation Biology 4:355-364.

Odum, E.P. 1985. Trends expected in stressed ecosystems. BioScience 35:419-422.

O'Neill R.V., B.S. Ausmus, D.R. Jackson, R.I. Van Hook, P. Van Voris, C. Washburne, and A.P. Watson. 1977. Monitoring terrestrial ecosystems by analysis of nutrient export. Water, Air, and Soil Pollution 8:271-277.

Peine, J.D., J.C. Randolph, and J.J. Presswood, Jr. 1995. Evaluating the effectiveness of air quality management within the Class I Area of Great Smoky Mountains National Park. Environmental Management 19:515-526.

Peterson, D.L. J.M. Eilers, R.W. Fisher, and R.D. Doty. 1992. Guidelines for evaluating air pollution impacts on Class I wilderness areas in California. USDA Forest Service Pacific Southwest Research Station General Technical Report PSW-GTR-136.

Peterson, J., D.L. Schmoldt, D.L. Peterson, J.M. Eilers, R.W. Fisher, and R. Bachman. 1992. Guidelines for evaluating air pollution impacts on Class I wilderness areas in the Pacific Northwest. USDA Forest Service Pacific Northwest Research Station, General Technical Report PNW-299.

Phillips, D.J.H. and D.A. Segar. 1986. Use of bio-indicators in monitoring conservative contaminants: Programme design imperatives. Marine Pollution Bulletin 17:10-17.

Podlesakova, E. and J. Nemecek. 1995. Retrospective monitoring and inventory of soil contamination in relation to systematic monitoring. Environmental Monitoring and Assessment 34:121-125.

Racke, K.D., D.A. Laskowski, and M.R. Schulz. 1990. Resistance of chlorpyrifos to enhanced biodegradation in soil. Journal of Agriculture and Food Chemistry 38:1430-1436.

Sanders, F.S., S.M. Adams, L.W. Barnthouse, J.M. Giddings, E.E. Huber, K.D. Dumer, D. Lee, B. Murphy, G.W. Suter, and W. Van Winkle. 1980. Strategies for ecological effects assessment of DOE energy activity sites. ORNL/TM-6783. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Schmoldt, D.L. and D.L. Peterson. 1991. Applying knowledge-based methods to design and implement an air quality workshop. Environmental Management 15:623-634.

Segar, D.A., D.J.H. Phillips, and E. Stamman. 1987. Strategies for long-term pollution monitoring of the coastal oceans. pp. 12-27 in: T.P. Boyle (ed.), New Approaches to Monitoring Aquatic Ecosystems. ASTM STP 940, American Society for Testing and Materials. Philadelphia.

Segar, D.A. 1986. Design of monitoring studies to assess waste disposal effects on regional to site specific scales. pp. 189-206 in: K.D. Stolzenbach, J.T Kildow, and E.T. Harding (eds.), Public Waste Management and the Ocean Choice. MIT Sea Grant College Program, Cambridge, MA.

Sigal, L.L. and G.W. Suter II. 1987. Evaluation of methods for determining adverse impacts of air pollution on terrestrial ecosystems. Environmental Management 11:675-694.

Sisler, J.F., D. Huffman, and D.A. Latimer. 1993. Spatial and temporal patterns and the chemical composition of the haze in the United States: An analysis of data from the IMPROVE network, 1988-1991. Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO. ISSN No. 0737-5352-26.

Smith, W.H. 1981. Air pollution and forests. Springer-Verlag, New York. 379 pp.

Stankey, G.H., D.N. Cole, R.C. Lucas, M.E. Petersen, and S.S. Frissell. 1985. The limits of acceptable change (LAC) system for wilderness planning. U.S.D.A. Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report INT-176.

States, J.B., P.T. Haug, T.G. Shoemaker, L.W. Reed, and E.B. Reed. 1978. A systems approach to ecological baseline studies. FWS/OBS-78/21.U.S. Fish and Wildlife Service, Office of Biological Services, Fort Collins, Colorado.

Tamm, C.O. and C. Wiklander. 1980. Effects of artificial acidification with sulphuric acid on the growth in scots pine forest. pp. 188-189 in: D. Drablos and A. Tollan (eds.) Ecological impact of acid precipitation. Proceedings international conference. SNSF Project, Oslo, Norway.

Tveite, B. and G. Abrahamsen. 1980. Effects of artificial acid rain on the growth and nutrient status of trees. pp. 305-318 in: T.C. Hutchinson and M. Havas (eds.), Effects of acid precipitation on terrestrial ecosystems Plenum, New York.

Ulrich, B., R. Mayer, and P.K. Khanna. 1980. Chemical changes due to acid precipitation in a loess-derived soil in central Europe. Soil Science 130:193-199.

USFS. 1991. Weminuche Wilderness Monitoring Plan for Air Quality Related Values. USDA Forest Service, Rocky Mountain Region.

Utah Bureau of Air Quality. 1983. Utah air emissions inventory. Utah Department of Health, Salt Lake City.

Wood, T. and F.H. Bormann. 1976. Short-term effects of a simulated acid rain upon the growth and nutrient relations of *Pinus strobus* L. USDA Forest Service General Technical Report NE-23.

APPENDIX

HISTORY OF THE INEL/WEST PROGRAM

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This appendix provides a summary of the history of the INEL/WEST program. It includes an overall summary of the project including highlights of the workshops conducted as part of the program. Brief synopses are also provided of the *documented* processes that are currently being used by the land management agencies in assessing AQRV impacts. Accomplishments to date of the INEL/WEST program as well as recommendations regarding how INEL, WEST, and the land management agencies should proceed toward the goal of establishing a consistent, defensible process for assessing impacts to AQRVs in Class I attainment areas are also provided.

Project Summary

The original scope of the INEL/WEST program was twofold. First, a method was developed for identifying, evaluating, and selecting AQRVs and associated ecological indicators to be applied to the assessment of impacts due to air emissions on wilderness resources. This methodology was developed using primarily INEL funding. The second portion of the program involved conducting a series of workshops designed to provide a forum for stakeholders to discuss the issues related to AQRVs in Class I areas. This was accomplished with funds provided by WEST/PacifiCorp. The purpose of these workshops was to help focus the INEL document by providing input from federal agencies, industry, and the public regarding the identification of ecological indicators of AQRV status, identification of specific methods for measuring these indicators, and determining how the resulting data should be used. The ultimate goal of the program was to develop a consensus regarding how AQRV assessment programs should be conducted, and to identify a location or locations for conducting a pilot test of the INEL process described above.

By involving a wide variety of stakeholders, it was hoped that a consensus could be reached regarding how AQRV status should be evaluated. It is generally agreed that to be technically defensible, any process adapted by the land management agencies should be based on sound science. To reach consensus, input was sought from scientists, environmental organizations, regulatory agencies, and land managers regarding evaluation and selection of AQRV indicators for assessing potential environmental effects from air emission sources in Class I areas. Participants provided input regarding the information that is necessary before PSD recommendations can be made, and discussed the criteria for selecting ecological indicators. Issues relating to temporal and spatial variability of indicator measurements were discussed.

Brief summaries of the workshops are provided below.

Workshop 1: The first workshop was conducted in July 1995 in Sun Valley, Idaho, and was attended by approximately 20 members of the WEST Environmental Subcommittee. The focus of this workshop was to introduce WEST to the draft "Methodology for Developing and Implementing an AQRV Monitoring Program to Assess the Impacts from an Electric Power Generating Facility". An overview and discussion of the technical approach to AQRV monitoring was provided during the morning session. The afternoon was dedicated to establishing criteria for selecting ecological indicators of AQRV status. The session concluded with an exercise in applying the K-T Process, a consensus-building process, to the these criteria - i.e. ranking the criteria in terms of their relative importance. Additional criteria were suggested by WEST representatives.

As a result of suggestions subsequent to the Sun Valley AQRV workshop, several modifications to the project were proposed. These modifications represented clarifications rather that a changes in direction for the program, and thus could be accomplished under the existing Statement of Work (SOW). The intent was to help focus the objectives of the program. Effectively, the objective of the project changed from a process for selecting indicators to the development of a list of criteria to use when selecting indicators.

The following specific modifications were suggested:

1. **Elaborate on the site-specific nature of AQRV indicators:** The ultimate goal of the AQRV program is to provide a means by which indicators of AQRV status may be evaluated. In some cases, indicators may be applicable universally. However, it is much more likely that indicators of AQRV status will have to be evaluated on a case-by-case basis. Selection of the appropriate indicators will therefore be dependent on (1) the AQRV(s) selected by the FLM; (2) the sensitive receptor(s) identified by the FLM; (3) the specific pollutant(s) involved in the FLM's decision; (4) the expected behavior of these pollutants; and (5) the attributes of the ecosystems within the Class I area. A set of indicators in one system may not be appropriate for another system, even if the AQRV and the pollutants involved are the same. The process developed should allow for the selection of the optimum set of indicators for the specific set of circumstances, and should also help to identify research needed to determine the potential effectiveness of specific potentially-useful indicators.

2. **Focus on Criteria for Selecting Indicators:** The version of the AQRV document that we provided prior to the first workshop described a suggested procedure for the entire AQRV process, including evaluation of emissions, pollutant behavior, potentially susceptible ecological systems, selection of Class I areas and AQRVs, etc. Although inclusion of this information may be useful, most of these initial steps of the overall process are the responsibility of the land management agency. While some mention of the different types of information that the FLM should use in determining monitoring needs should be included in the document, the focus should be on the criteria for determining what constitutes a "good" indicator for measuring AQRV status. To accomplish this, the material in Steps 1 through 7 of the AQRV process was reduced, and added focus was placed on the identification and weighting of criteria for ranking indicators (Section 3) and the development of testable hypotheses (Section 4).

   There are a number reasons for these changes, including:

   - The first seven steps described in the draft document are the sole responsibility of the FLM, and the purpose of this document is not to usurp their authority. Some general information on these steps remains in the document, but more so that other stakeholders are aware of what types of information *should* go into the decisions made by the FLM. Furthermore, industry will be involved in providing information for several of the steps.

   - Much of this information is already available in various regional Forest Service documents (e.g., D.L. Peterson et al., 1992 for the Pacific Southwest, J. Peterson et al., 1992 for the Pacific Northwest, and Adams et al., 1991 for the Northeast Regions of the Forest Service). These documents were prepared with input from the National Park

Service, and are discussed in greater detail in Section 7 below. In these documents, the authors have described many of the problems discussed at the Sun Valley workshop, notably those associated with the signal-to-noise ratio and the relationships between cause and effect.

- There remains a need for a process that will allow for the evaluation of new information on potential indicators of pollutant damage, and to develop a list of criteria with which to assess the utility of existing as well as new indicators. Selection criteria must be applied on a case-by-case basis. Application of selection criteria should ensure that data collected is defensible and of known quality-assured manner.

3. **Reduce the emphasis on the K-T Process:** Following the Sun Valley workshop, it was determined that the K-T process should not be used to the degree originally proposed. Other potentially more useful decision analysis tools will be evaluated.

Several problems were identified with respect to the proposed application of the K-T process:

- Since the selection of Class I areas, AQRVs and even the specific locations at which to conduct monitoring is the responsibility of the FLM, a "consensus-building" approach such as is offered by the K-T process is not appropriate.

- The regulatory aspect of the AQRV issue makes the outcome more critical: a consensus-driven choice of indicators may not be satisfactory to the regulatory agencies. Furthermore, several federal documents state specifically that selection of AQRVs may be based on political and/or social factors, rather than on science

- Although the K-T process may work under the right circumstances for ranking indicators against one another on an individual basis, it will not help determine the most effective *suite* of indicators.

In its present form, the document is now focused more substantively on the selection of indicators of AQRV status and the criteria to be applied during the selection process. An outline of the basic steps of the overall process of determining AQRV impacts is still provided in Section 2, emphasizing the types of information that should be considered by the FLM. The utility of this portion of the document is that it will help the other stakeholders identify questions regarding how the decisions were made by the FLM.

Section 3 provides a more detailed description of the process to be used in selecting useful indicators to monitor AQRV status. This will expand on the information provided in the Forest Service document to allow for the consideration of additional indicators not described in these documents. In this way not only can the Forest Service work be built upon, but the likelihood that the agency will buy in to the process can be increased.

Workshop 2, December, 1995, Tucson, Arizona: At the request of WEST, representatives of the INEL attended and participated in a multiple-agency land-use workshop in Tucson *in lieu* of the second planned AQRV workshop. The title of the workshop was "Toward a Scientific and Social Framework for Ecologically Based Stewardship of Federal Lands and Waters", the goal of the workshop was stated as follows:

> "Engage the scientific and management communities in the development of a detailed framework that addresses options for implementing an ecologically based approach to stewardship of Federal lands and waters and documents the scientific foundation for those options. The framework will integrate technical, social and economic considerations to form the basis for how we will use and sustain natural resources both nationally and globally. It will require: (1) a clear description of an ecological approach for management; (2) an understanding of the relationship between an ecologically based approach to stewardship and how sustainability can be understood and addressed; (3) a scientific consensus regarding the components of an ecological approach to management; and (4) accommodating people and their needs within ecosystem."

The anticipated final product of the workshop is a "clear scientific framework for ecologically based stewardship approaches...to be published in book form as a compendium of papers that synthesize the available scientific basis and that develop the management options and alternatives for implementing an ecologically based approach to stewardship in the field." The compendium is still under revision at this time (November, 1996). Attendees split up into various working groups, each of which was responsible for producing a paper for the compendium. Once at the workshop, the INEL chose to participate in the "Monitoring and Evaluation" group because of the relevance to the AQRV project. Although not focused specifically on air quality issues, most of the criteria for selecting ecological indicators were incorporated into the paper. The INEL is continuing their participation in the revision of the "Monitoring and Evaluation" paper.

Workshop 3: The third workshop was held in March 1996 at the office of the U.S. Geological Survey Water Resources Division in Denver. The purpose of this workshop was to introduce representatives of federal land management agencies with a process developed by the INEL for selecting ecological indicators to be applied to AQRV monitoring programs in Class I attainment areas. This process was developed in an effort to implement consistent, scientifically-based approach to AQRV monitoring. This workshop was postponed several times due primarily to the government shut-down in late 1995.

The specific goals of the third workshop were:

1. To solicit input from the federal agencies on the current status of AQRV-related issues.

   Where do they stand at present?

   Is there new information available?

   What potential changes are in the works within the government that could influence how the project should proceed?

2. To solicit comments from the federal agencies on our proposed list of criteria for selecting ecological indicators, and of the proposed ranking of these criteria.

   Are there important criteria missing, or are there extraneous ones on the list?

   Would they rank the criteria differently?

3. To solicit feedback on our general approach to the AQRV issue, including the core document.

Do the processes the FLMs have in place clearly address the AQRV issue?

Are there *a priori* criteria established within these processes for selection of ecological indicators?

To what degree can consensus be reached on selecting a process for indicator selection among FLMs, industry, regulators, and states?

Is the process proposed by the INEL useable?

What needs to be improved so that the best available indicators can be selected?

This workshop was attended by representatives of the U.S. Forest Service, National Park Service, Fish and Wildlife Service, and the U.S. Geological Survey. Invited representatives from the Bureau of Land Management were not able to attend. It began with an overview of the INEL project and its relevance to the electric power industry. John Fooks of WEST then discussed the industry point of view with respect to AQRVs and what the INEL was attempting to accomplish. He indicated that industry does not understand how the process works, and that WEST would prefer one clearly articulated process across all agencies. A scientifically palatable process is needed - lined out clearly. INEL personnel then discussed the current status of the project, and the rationale for applying this procedure to the selection of ecological indicators. An open, round-table discussion followed.

Comments/questions that came out of this workshop from the federal agency people included:

- A standardized process applicable everywhere would result in guidelines too nebulous to be useful. This is in contrast to statements made in some agency publications.
- The Forest Service screening process currently is use is essentially a triage process, recognizing there is not much information available on their 88 Class I areas. There is not enough information available to come up with a good screening process, but a process is necessary, so the FS has done their best to come up with their current process. They use a process similar to the EPA approach (i.e., select the best model available, use available information, then use the results as the basis for making a recommendation). This can be frustrating because the screening process lacks specific detail (this problem is universally accepted), and more science is needed. All attending the workshop agreed with this.
- All questioned whether the utilities were aware of what the cost for the proposed effort would be.
- You must select an indicator that you know something about and this is a small number of indicators.
- Information that is available now needs to be brought together to do an analysis of the uncertainty. Data that is available now can be used to look at what the real magnitude of addressing the uncertainty will be - data is available with long-term variability.
- The overall problem is really three related problems - 1. Science problem; 2. Administrative process problem, and 3. Politics problem.

- To declare an adverse impact requires the FLM to have a very good case. Often it is necessary to make a decision based on inadequate data. As a result, very few applications are turned down.
- As written, the INEL/WEST process is too restrictive and would require collection of so much baseline data that they would never get to work on permits.
- Processes are in place, funding to work on and refine them would be welcome.

Finally, it appeared that everyone was in agreement at the end of the session that a useful direction for this effort would be to prepare a document that is a summary/guideline for the existing process(es). Industry would then be able to determine what to expect, what preparations would need to be made to address the process. This would include a summary of the current processes used by the agencies, a flowchart, and a decision tree or checklist. The agency representatives at the workshop initially offered to cooperate by providing the information necessary to accomplish this.

Workshop 4: The final workshop was a presentation by Bob Breckenridge of the INEL at the annual meeting of the environmental subcommittee of WEST, in Tempe, Arizona, April 1996. The findings of the first three workshops was presented along with options on how, when, and where a pilot test of a promising set of AQRV indicators could be conducted.

Summary of Documented Agency Processes

The following is a brief summary of the processes used by the federal agencies to determine AQRV impacts. The information described has been taken from available documents published over the past few years by the agencies. Although this summary has not been reviewed by the agencies, we believe that it represents a reasonable overview of the processes in place with the federal agencies.

U.S. Forest Service: The U.S. Forest Service uses a screening model to evaluate air pollution effects on Class I areas. This model was developed to help wilderness managers conduct adverse impact determination as part of the review process for PSD permit applications, and is described in the document "A Screening Procedure to Evaluate Air Pollution Effects on Class I Areas" (Fox et al., 1989). The screening model is based on the characterization of pollutant levels as acceptable (Green), intermediate (Yellow), and unacceptable (Red) for each parameter or indicator assessed. The basic idea is that if pollutant levels (N, S, and/or O_3) fall below the "green line", AQRVs are not expected to be adversely impacted, whereas impacts are expected if the levels exceed the "red line". The "yellow zone" represents the area of uncertainty lying between the green and red lines. These lines are ecosystem-specific. Doses above the red line value "are likely to cause at least one AQRV to be adversely affected...and would result in a recommendation for denial (of the permit application) unless additional site-specific data are provided to prove that the identified AQRV of the Class I area would not be adversely affected." Specifically, the green line denotes a total pollutant loading including both current deposition plus predicted additional deposition from the new source "*with a high degree of certainty*".

Although the model used by the Forest Service probably represents the best model available at present, the document states that "the magnitude of these screening values are subject to change based on better site specific information". In most cases, it is questionable whether the information required as input to the model is available on a site-specific level. Furthermore, as indicated in the document, the model described will help in the PSD review only if the assumptions, logic, and limitations involved, which are substantial, are fully understood by the FLM. For the model to be applied, the FLM must:

> "...have AQRVs clearly identified, their current status monitored, and specific limits of impact defined. ... (S)uch information must be based upon or include multiyear data, and scientific peer review. Use of these screening techniques is also based on the availability of accurate deposition and concentration data at or near the Class I areas. These data also should be quality assured."

Specific information needs described in the document include:

1. Deposition and air concentrations to estimate current loadings.
2. Expected deposition and air concentrations due to the proposed source.
3. Inventory of biological resources associated with the identified AQRVs of the Class I area.
4. Species response/biological effects data.
5. Snowpack chemistry and hydrologic characteristics of the area.

The Forest Service has also issued a series of guideline documents based on the results of regional workshops of technical experts and FLMs. These workshops were divided into groups for terrestrial effects, aquatic effects, and visibility effects. The purpose of the resulting documents was to provide "guidelines to assist FLMs in determining the potential effects of future increases in air pollutants on...(AQRVs)." To date, the INEL has reviewed documents from the Pacific Southwest (D.L. Peterson et al., 1992), the Pacific Northwest (J. Peterson et al., 1992), and the Northeast (Adams et al., 1991) Regions of the Forest Service.

These documents indicate that the information needed by the FLM to base his recommendation on include:

1. Components, or sensitive receptors of AQRVs in each Class I area that are most vulnerable to air pollution;
2. Acceptable limits of air pollution-caused changes (LACs) for each receptor (*erring on the side of protecting the resource*);
3. Quantities of and conditions under which the various pollutants will likely cause LACs to be exceeded for each sensitive receptor;
4. Current levels of air pollution impacts within the wilderness for each receptor.
5. Emissions expected from the proposed facility (specifically S and N);
6. Atmospheric transport, dispersion, and chemical transformation phenomena; and
7. Relevant deposition processes.

Although many of these can be based on statistical techniques or on atmospheric modeling, in most cases the information available is inadequate, at least on a site-specific basis.

Terrestrial Indicators: As noted in the Northwest Region document, "It is difficult to set condition classes for Pacific Northwest plant species based on so few data. Only general guidelines therefore are suggested." With respect to terrestrial systems, the Forest Service guideline documents provide substantial potentially useful information on ecosystems and species that may be relatively sensitive to pollutants. However, little useful information is provided regarding how to assess these receptors, and no definitive list of parameters is provided for terrestrial systems. Furthermore, virtually all of the terrestrial parameters described (e.g. foliar injury, decreased leaf longevity, reduced carbon gain, reduced plant growth) have very high natural variability associated with them. Also, whereas the documents discuss at length the possibility of using lichens, they effectively conclude that not enough is known about them to make them useful.

Aquatic Indicators: Much of the information provided in the Forest Service guideline documents regarding potential groups of aquatic organisms for use as indicators was based on information from Europe and elsewhere. In the case of the western regions, little regional information was available. This led to the conclusion that with respect to aquatic systems, "most criteria for screening sensitive waters ... are based on water chemistry (rather than aquatic biota)". Advantages of using water chemistry instead of aquatic biota as indicators involves both (1) the relative ease and precision of working with chemistry compared to aquatic organisms; and (2) the poor state of knowledge of aquatic communities in western systems, both in terms of species present and response to changes in water quality. Water quality parameters listed in the Forest Service guideline documents included ANC, pH, SO_4^{-2}, NO_3^-, NH_4, total P, DO, conductivity, transparency, and Al_i.

Among the conclusions discussed in these Forest Service guideline documents were the following:

- "To effectively participate in the PSD process, (FLMs) must:

    1. make decisions on which components of the wilderness resource should be protected from air pollution impacts and to what degree; and

    2. provide *high-quality information* on the existing condition of AQRVs, atmospheric deposition, and air chemistry in wilderness".

- "Forest Service recommendations must be (1) *scientifically sound*, (2) legally acceptable, and (3) philosophically justified". However, it was also stated that Class I areas "should be maintained in as pristine a condition as possible within *legal and political* constraints".

- "Research on basic ecological relationships is clearly needed to quantify air pollution effects that can be observed in the field".

As with the "Screening Procedure" document (Fox et al., 1989), these guideline documents cite the need for considerable additional information. Specifically, all Class I areas should have "*a complete inventory of sensitive receptors within each AQRV*". The guideline document from the Southwest region also mentioned the importance of considering various types of interactions (pollutant-pollutant, pollutant-natural stress, and pollutant-genotype, and area for which very little research has been conducted.

It is noteworthy that the Forest Service is emphasizing the need for science to drive the AQRV process, and that they recognize that the remaining information needs are substantial. This fits in well with our philosophy that a consistent and scientifically-based means for evaluating how information should be applied to wilderness monitoring programs is needed.

In addition to these regional guidance documents, the Forest Service has released a number of wilderness-specific monitoring plans for AQRVs (e.g. USFS, 1991).

National Park Service/U.S. Fish and Wildlife Service: The process(es) used to assess impacts to AQRVs by Park Service and Fish and Wildlife Service are not as well documented as those of the Forest Service.

In a recent publication on the effectiveness of air quality management within Class I areas in Great Smoky Mountains National Park, Peine et al. (1995) made the following observations:

1. It remains difficult to access air quality and emissions data for many locations because data bases are often out of date or incomplete, and substantial uncertainty exists regarding the relative contributions of various sources.

2. There remains a distinct need to establish a comprehensive research program to define thresholds of pollution deposition over the long term, which would result, and in some cases already has resulted, in irreversible adverse changes.

3. A series of models is needed to predict long-term pollutant loading and the resulting adverse effects in soils, water, and organisms.

4. The NPS is faced with the responsibility to establish credibility for its "declaration of adverse impact", and the best way to accomplish this is to build a broad-based consensus among scientists, the regulatory community, and the general public.

In summary, documents describing the U.S. Forest Service and National Park Service processes for assessing impacts to AQRVs provide information regarding *what* must be done, but little if any guidance is provided regarding *how* this is to be done. The INEL/WEST process could be used as a starting point to develop this.

Accomplishments to Date

A process has been developed to apply a consistent, scientifically-based method to the assessment of AQRV status in Class I wilderness areas. This process could be applied to any Class I area managed by any land management agency, and with respect to any AQRV of interest. Endorsement of the process by the land management agencies has been sought. Agency representatives have recognized the utility of portions of the process, they have not yet endorsed the entire process.

A series of workshops has been held to describe the INEL/WEST process. These workshops have been attended by representatives of industry and the land management agencies. Input from these workshops has been used to help develop and refine the process document. Although the agency representatives involved indicated that the current process described in this document is overly restrictive (if applied in such a manner), they agreed that the criteria for selecting ecological indicators represent a good goal. INEL representatives also attended a federal interagency workshop on land stewardship, and are contributing to two chapters of a document to be used to improve the management of ecological resources on federal lands. The first chapter is on the "Monitoring and Evaluation" of the status of federal lands. The second is on "Indicators of Ecological Condition". These chapters are currently under review.

The workshops have helped facilitate understanding among various agencies of the potential benefits of applying a consistent approach used by all land management agencies in the assessment of AQRVs. Furthermore, the agencies have acknowledged that the process should be science-driven *where possible*.

Recommendations - The Path Forward

Ultimately, a full-scale pilot study of the overall process described in this document should be conducted. Such a pilot study would include the following steps:

1. Identify a candidate Class I site or sites. These sites should be data rich and/or should have considerable information available on the condition of the system and on pollutant inputs.

2. Identify AQRVs at risk within each Class I site to be tested. Again, situations where considerable information is available should receive top priority.

3. Identify sensitive receptors for each AQRV identified as being at risk.

4. Application of the indicator selection criteria to determine the best group of indicators for determining impacts.

5. Conduct field tests to generate the monitoring data required for each scenario.

6. Evaluate the resulting data to assess the effectiveness of the overall process.

This pilot test or tests should be conducted in collaboration with the land management agencies and other interested parties. At present, however, a full-scale test of the process may be premature.

One suggestion that came from the Denver workshop was that we reduce the scope of a follow-up effort to focus on a more specific, scientific need. In particular, the agency representatives cited the "signal to noise ratio" criterion for selecting ecological indicators. As discussed above, one of the most substantial problems with the application of ecological indicators in monitoring programs is that most potentially useful ecological indicators exhibit significant natural variability both spatially and temporally. Furthermore, the inherent variability of many existing databases has never been evaluated. These readily available databases could be evaluated statistically using techniques such as those described in Murtaugh (1996), which evaluate both the sensitivity and the specificity of the parameter of interest, given the data available. The sensitivity and specificity of the parameter may be used to rank various parameters. In this manner, their effectiveness as indicators of ecosystem condition can be evaluated by assessing their ability to detect subtle, pollutant-caused changes within the field of normal spatial and temporal variability.

The goal of the proposed research is to develop a better, more cost-effective method for selecting indicators of ecosystem health that can be used to more accurately assess the condition of ecological resources in wilderness areas and other remote sites. Extensive ecological indicator data bases are available from several Class I areas in the western United States. A representative set of these data bases will be examined, and a suite of indicators will be selected for evaluation. These indicators will include a variety of physical, chemical, and biological parameters that relate to ecosystem structure and function. The data sets for these indicators will then be examined for their ability to detect anthropogenic signals from natural variability, and therefore for their effectiveness as assessment tools.

To accomplish this, the spatial and temporal variability associated with each data set may be evaluated statistically over various scales. The predictive capability of these parameters can then be assessed using techniques such as those described by Murtaugh (1996). This technique quantifies the relative sensitivity and specificity of the parameter, based on the available data. Sensitivity, as defined by Murtaugh, is the probability of a positive indicator given that the true response is positive, whereas specificity is the probability of a negative indicator given that the true response is negative. These two properties, together with the prevalence of the response within the population of the data set being examined, determines the predictive value of the indicator.

Among the candidate locations are (1) the Bridger-Teton Wilderness Area in Wyoming; (2) the Flat Top Wilderness in Colorado; and (3) Mount Rainier National Park and adjacent Forest Service wilderness areas in Washington. Much of the Bridger-Teton data was generated during the 1980s by the INEL, is readily available. Additional data is available from the Forest Service. Data sets from the Flat Top and Mount Rainier areas are available from the National Park Service, the U.S. Forest Service, and the U.S. Geological Survey. The proposed work will be done in collaboration with the agencies furnishing the data sets.

We anticipate the opportunity for further cooperative efforts with the land management agencies and other stakeholders in this area. Because this work would benefit all stakeholders, cooperative or in-kind funding will be sought from various sources.