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Environmental Monitoring and Assessment Program Assessment Framework

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Abstract

The assessment framework proposed in this report provides a common approach for planning and conducting a wide variety of ecological assessments within EMAP. The framework also demonstrates how EMAP complements EPA's assessment approach proposed in the Risk Assessment Forum's (RAF) *Framework for Ecological Risk Assessment* (RAF 1992). EMAP assessments can contribute directly to the problem formulation phase of the EPA-RAF *Framework* by identifying and quantifying factors that might contribute to the condition of ecological resources. EMAP assessments also will provide information needed to conduct ecological risk assessments that verify model predictions and the cumulative effectiveness of environmental protection and management decisions.

EMAP uses a retrospective or effects-oriented approach to assessment. There are three phases in EMAP assessments: problem formulation, analysis, and interpretation and communication. These three phases emphasize (1) formulating and refining assessment questions and issues with EMAP users, (2) identifying indicators of condition, (3) developing conceptual models, (4) analyzing data on ecological resources using weight of evidence and process of elimination approaches to infer factors contributing to observed trends in ecological effects, and (5) interpreting and effectively communicating assessment results in a policy-relevant context for users. There are five basic assessment products: quality-assured data, annual statistical summaries, ecological resource assessments, assessment tools, and guidance.

Because it will take a number of years before all resources in all regions of the country will be routinely monitored, the ability of the program to conduct ecological resource assessments will depend on implementing its research, monitoring, and assessment activities in planned phases. Initial assessments will focus on data to determine extent, geographic coverage, and condition for individual ecological resources. Single region, single resource assessments will be conducted before assessments encompass multiple regions or national levels. Assessments of multiple ecological resources in a single region will be conducted as other resources start monitoring in that region.

Key words:

USEPA-EMAP, ecology--decision making, ecology--risk assessment, ecology--measurement, environmental monitoring--risk assessment, environmental policy, environmental risk assessment, indicators (biology), landscape assessment, risk assessment, risk communication, risk management, statistics.

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Preface

Over the past several years, there has been an increased emphasis on comparative ecological risk assessment within the U.S. Environmental Protection Agency (EPA), other agencies, and the scientific community. Also, there have been questions raised on the role of the Environmental Monitoring and Assessment Program (EMAP) in comparative ecological risk assessment and its relationship with EPA's Risk Assessment Forum. This report describes a framework, and its basic elements, for conducting assessments within EMAP as well as the relation of EMAP assessments to EPA's Risk Assessment Forum. This document about EMAP's assessment framework is intended primarily for scientific administrators and managers who require assessment information for making decisions related to environmental protection and management; further, it provides a scientific explanation -- i.e., a "definition" -- of ecological assessment in the context of the EMAP program, and should not be interpreted as a strategic planning document, or any other form of planning or policy document.

Requests for additional information on EMAP should be directed to: EMAP Director, Office of Modeling, Monitoring Systems and Quality Assurance, Mail Code 8205, U.S. Environmental Protection Agency, 401 M Street, S.W., Washington, DC 20460.

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Contents

Figures

Tables

1 — Introduction

Purpose

This document presents a framework for conducting assessments in the Environmental Monitoring and Assessment Program (EMAP). The framework describes basic elements of the assessment process and provides a common foundation for conducting assessments within EMAP. Because of its general nature, the framework should be adaptable to a diverse set of assessment questions and needs. Consequently, this document is written to assist science administrators and resource managers in understanding the EMAP assessment process.

Assessment Defined

Assessment connotes different definitions and processes, depending on the discipline, agency, and audience (Table 1). Many Federal and State environmental assessments are based on legislative or regulatory requirements that dictate explicit purposes and approaches. In general, these assessments are site specific and range from addressing specific problems (e.g., the Comprehensive Environmental Responsibility, Compensation, and Liability Act [CERCLA] Natural Resources Damage Assessments) to broadly identifying or disclosing all potential environmental impacts (e.g., the

Table 1. Assessment definitions.

Source	Definition of Assessment
EMAP	**Assessment is the interpretation and evaluation of EMAP results for the purpose of answering policy-relevant questions about ecological resources including: (1) determination of the fraction of the population that meets a socially-defined value and/or (2) associations among indicators of ecological condition and stressors.**
NEPA (1969)	Assessment is the evaluation of the consequences of an action including short-term, long-term, direct, indirect, cumulative, and irreversible, irretrievable effects for the purposes of avoiding to the fullest extent practicable undesirable consequences for the environment.
Deuel and D'Aloia (1989)	Assessment is a comprehensive multifaceted investigation that includes data acquisition, evaluation, conclusions, and recommendations.
Streets (1989)	Assessment is the translation of scientific results into answers for policy-relevant questions and issues within a decision framework.
NAPAP (1991)	Assessment is an interdisciplinary activity wherein findings from diverse disciplines are coordinated to produce a better understanding of the cumulative impacts of a stressor (i.e., acidic deposition).
Webster (Ninth ed. 1991)	Assessment is the act of determining the importance, size and value of something.
Cowling (1992)	Assessment is a process by which scientific and technological evidence is marshalled for the purposes of predicting the outcomes of alternative courses of action.
Suter (1993)	Assessment is the combination of analysis with policy-related activities such as identification of issues and comparison of risks and benefits.

National Environmental Policy Act [NEPA] Environmental Assessments/Environmental Impact Statements). Just as users must understand the specific framework and elements of an environmental assessment, assessors must understand from the outset what the user needs from the assessment.

Regardless of the definition, requirements, or approaches of assessment, several features are common to almost every environmental assessment. First, there is a link with policy or regulatory questions and issues. Second, there is a value-added perspective to assessments, ranging from a formal, quantitative cost/benefit analysis of all alternatives to a qualitative improvement in our understanding of potential impacts or effects. Finally, assessments synthesize and interpret scientific information and present it in an understandable format for the intended audience. Over the past decade, environmental assessments have evolved from analyzing and comparing solely ecological effects from stressors to a wider consideration of the risks to human and ecological health associated with these stressors. A stressor is any physical, chemical, or biological entity or process that can induce adverse effects on individuals, populations, communities, or ecosystems (RAF 1992, xiv).

Risk assessment is defined as the process of assigning magnitudes and probabilities to the adverse effects of human activities or natural catastrophes (Suter 1993). Guidelines for conducting risk assessments on human health have been issued by the U.S. Environmental Protection Agency (EPA 1976, 1986) and are being revised continually. Ecological risk assessment, however, is just emerging as a process for comparing and evaluating the effects of multiple stressors on ecological resources.

EPA has embarked on a process to focus its efforts on the environmental problems that pose the greatest risks rather than those that receive the greatest public attention (Roberts 1990). This process involves conducting comparative ecological risk assessments so that the highest priority risks can be identified and addressed. The concept of comparative risk was initially proposed in *Unfinished Business: A Comparative Assessment of Environmental Problems* (EPA 1987), which indicated the greatest risks to the environment were not posed by site-specific problems such as toxic waste dump sites, but by regional and global scale problems (e.g., nonpoint source pollution, habitat alteration, loss of biodiversity, or global climate change). EPA's Science Advisory Board endorsed and expanded the call for comparative ecological risk assessment, recommending that EPA: 1) plan, implement, and sustain a long-term monitoring and research program; 2) report on the status and trends in environmental quality; 3) target its environmental protection efforts on the basis of opportunities for the greatest risk reduction; 4) improve the data and analytical methods that support the assessment, comparison, and reduction of different environmental risks; and 5) increase its efforts to integrate environmental considerations into broader aspects of public policy as fundamentally as economic considerations are included in policy analysis (SAB 1988, 1990). EPA has established a Risk Assessment Forum (EPA-RAF) that is charting a strategic direction and developing specific guidance for conducting ecological risk assessments. The *Framework for Ecological Risk Assessment* (RAF 1992) presents a basic structure and starting principles for conducting EPA's ecological risk assessments. The *Framework* initiates a process in which long-term guidelines for ecological risk assessment can be organized (RAF 1992).

Ecological Risk Assessment Framework

EPA defines ecological risk assessment as "the process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors" (RAF 1992, 37). A risk is not considered to exist unless (1) the identified stressor(s) has (have) the inherent ability to cause adverse ecological effect(s) and (2) the stressor co-occurs with or contacts an ecological component for a sufficient time and at sufficient intensity to elicit the identified effect(s). Ecological risk assessment may evaluate one or several stressors or ecological components.

In its *Framework*, EPA's Risk Assessment Forum describes a flexible structure for its ecological risk assessment with three sequential phases, namely, 1) **problem formulation**, 2) **analysis**, and 3) **risk characterization** (Figure 1).

> **Problem formulation** is a planning and scoping phase that links the regulatory or management goals to the risk assessment. It results in a conceptual model that identifies the environmental values to be protected (the assessment endpoints), the data needed, and the analyses to be used.
>
> The **Analysis** phase develops and links profiles of environmental exposure and profiles of ecological effects to stressors. "The exposure profile characterizes the ecosystems in which the stressor may occur as well as the biota that may be exposed. It also describes the magnitude and spatial/temporal pattern of exposure. The ecological effects profile summarizes data on the effects of the stressor and relates them to the assessment endpoints" (RAF 1992, xiv).
>
> "**Risk characterization** integrates the exposure and effects profiles" (RAF 1992, xiv). By comparing individual exposure and effects values, comparing the distributions of exposure and effects, or using simulation models, risks can be expressed either as qualitative or quantitative estimates. Results of risk characterization describe relations between the risks and social values or assessment endpoints; discuss ecological significance of the effects; estimate the overall confidence or uncertainty in the assessment; and suggest

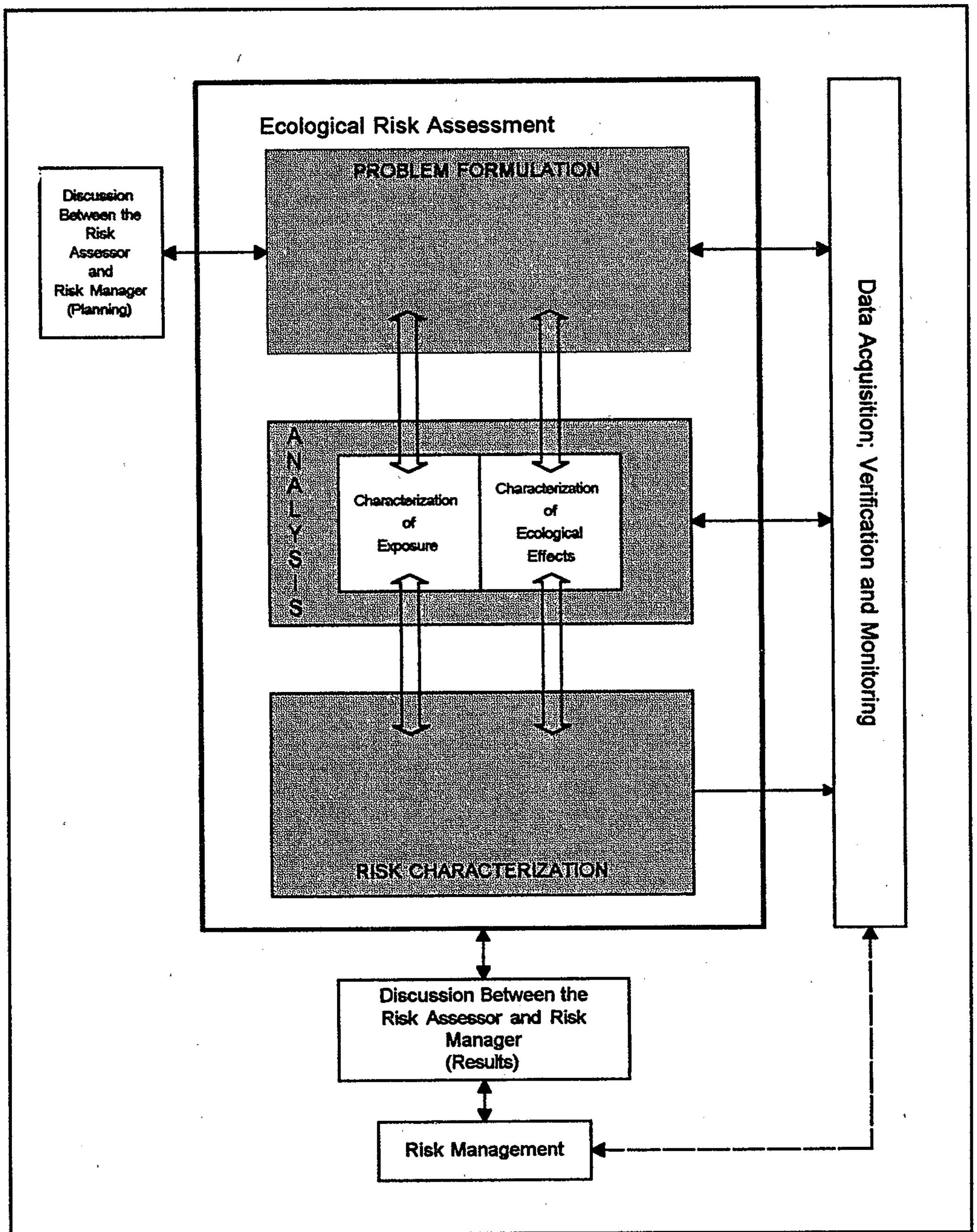


Figure 1. Framework for ecological risk assessment (RAF 1992, 4).

effective approaches for communicating these risks to the user and the risk manager.

EPA-RAF's *Framework* "also recognizes several additional activities that are integral to, but separate from, the risk assessment process" (RAF 1992, xv). First, early discussions between the risk assessor and the risk manager ensure that the assessment will provide information relevant to the decision making process, that the assessment addresses all relevant ecological concerns, and that the manager has a full and complete understanding of the conclusions, assumptions, limitations, and uncertainties associated with the assessment. Next, data acquisition, verification, and monitoring studies provide the information required for analysis, for validation of the results of a specific assessment and the overall *Framework* approach, and for improving the assessment process.

The general risk assessment paradigm (NRC 1983), the ecological risk assessment *Framework* (RAF 1992), and most of the procedures and tools developed for risk assessment are applicable for both retrospective and predictive assessments, but have been used primarily for predictive assessments (Suter 1993). Predictive assessments usually are stress-oriented, focusing on a particular stressor and then estimating future risks to the assessment endpoints (formal expressions of EMAP's condition indicators) from this stressor.

Other assessment approaches, such as epidemiological or effects-oriented assessments, begin with an observed effect and subsequently identify stressors that might have contributed to this effect; EMAP's assessment strategy follows this effects-oriented approach. EMAP's strategy complements the EPA-RAF *Framework* by contributing to problem formulation and providing corroborative information to the analysis and risk characterization phases.

Effects-Oriented Risk Assessment

The *Framework for Ecological Risk Assessment* (RAF 1992) discusses a broad approach for conducting ecological risk assessments, and it starts with a characterization of the stressor, then describes exposure pathways from the sources of the stressor to the associated ecological effects (Figure 2). While this approach is equally applicable for both predictive and retrospective analyses, it typically emphasizes prospective analyses using simulation models to predict exposure and stressor-effects profiles. Such predictive approaches are dependent upon cause-effect relationships between stressors and ecological effects.

A complementary approach to conducting ecological assessments is the strategy being developed in EMAP, a retrospective approach like that used in environmental epidemiology (NRC 1991) and the emerging area of ecosystem health (Costanza et al. 1992, Rapport 1992). Effects are observed rather than the stressors (Figure 2). Effects-oriented approaches emphasize association, weight of evidence, and process of elimination analyses to identify possible factors contributing to the observed ecological effects. Although epidemiologic methods can include predictive analyses, its initial emphasis—as well as EMAP's strategy—are based on retrospective analyses. Both these approaches—retrospective and predictive—were used in assessing the effects of acidic deposition on aquatic ecosystems in the National Acid Precipitation Program (NAPAP 1991), illustrating how these two approaches complement each other (Thornton 1993). Both approaches represent scientifically valid approaches for assessing ecological effects. In general, the predictive stress-oriented approach is used—and better understood—than the retrospective effects-oriented approach in conducting environmental assessments (Suter 1993). Effects-oriented strategies, however, will become increasingly important as

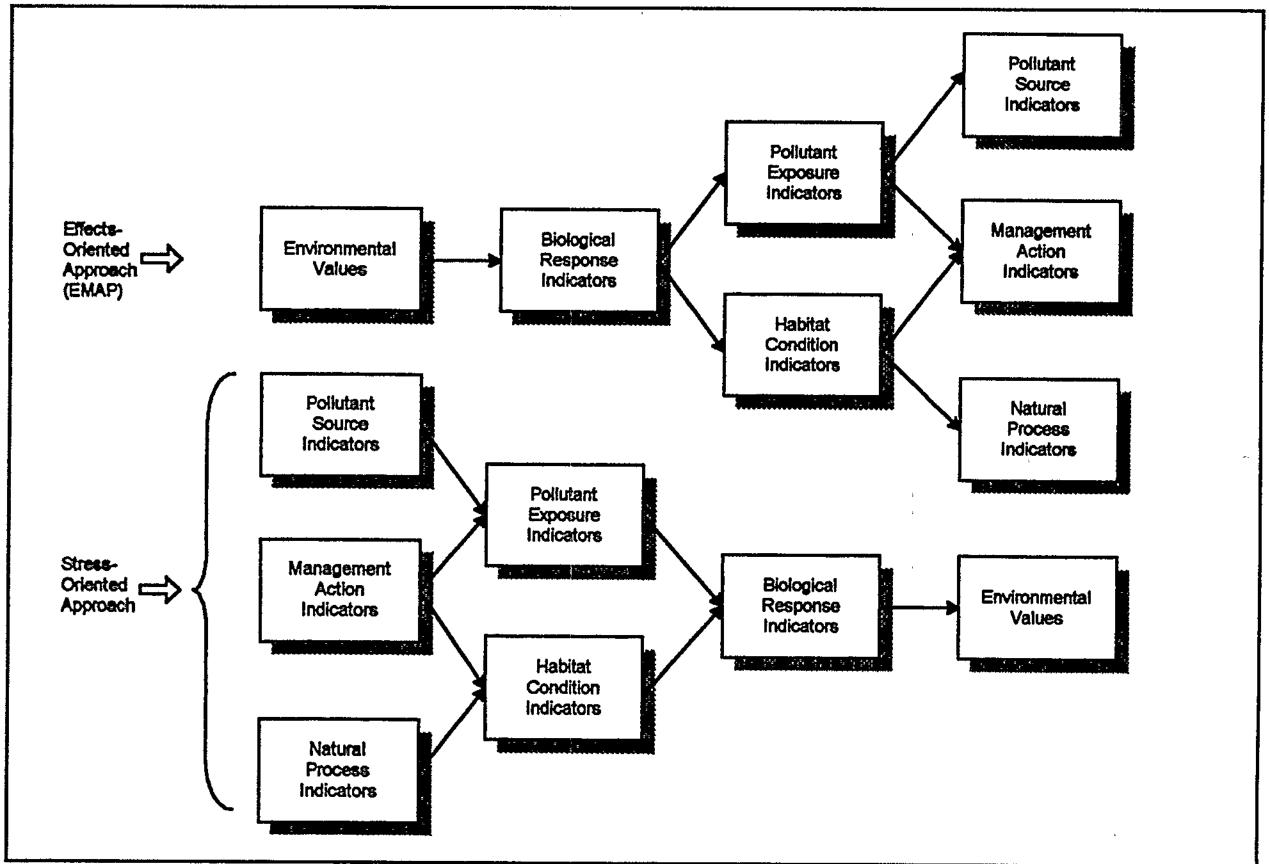


Figure 2. EMAP's effects-oriented strategy compared to a stressor-oriented approach for ecological assessments.

assessments of larger scale problems are conducted because it will become increasingly more difficult to establish specific cause-effect relationships between a stressor and an effect. Effects-oriented approaches can help eliminate possible stressors and pathways, and assist in identifying probable sources of stress and pathways for predictive ecological risk assessments. Comparing the characteristics of these two assessment approaches, a user can better understand how information from each approach contributes to ecological assessment (Table 2).

This document, EMAP's *Assessment Framework*, provides a broad outline of how EMAP contributes to ecological assessment and how it builds on the interrelationships of assessment, monitoring, and research studies being conducted in EMAP. The results of EMAP's assessment framework will complement studies being conducted in EPA's Risk Assessment Forum and elsewhere.

Table 2. Comparison of stress-oriented and effects-oriented risk assessment approaches.

Predictive, Stress-Oriented	Retrospective, Effects-Oriented
• Critical Questions	• Critical Questions
• Stressor/Problem Oriented	• Effects Oriented
• Individual Sites/Systems	• Target Populations
• Link Stressor to Possible Responses	• Link Condition to Possible Stressors
• Exposure Characterization	• Effect/Exposure Associations
• Stressor-Effect Characterization	• Effect/Stressor Associations
• *Prospective*/Retrospective	• *Retrospective*/Prospective
• Simulation Models/Causal Relationships	• Weight of Evidence/Process of Elimination
• Cause-Effect	• Association

Assessment Summary

Ecological risk assessment, clearly, is in its infancy. Currently, we do not have effective methods and programs, at regional and national scales, to monitor ecological conditions, measure and detect ecological trends, perform comparative ecological risk assessments, and effectively communicate the results to decision makers. EMAP is designed to contribute to the research and assessment activities of EPA's Risk Assessment Forum and provide essential monitoring information for comparative ecological risk assessments (Figure 3).

For example, EMAP assessments will contribute directly to the Problem Formulation phase of ecological risk assessment through activities focused on question formulation, resource characterization, and conceptual model development. In addition, EMAP can contribute to the Analysis and Risk Characterization phases by providing information which characterizes resource condition; analyses which examine associations among indicators of condition and stressors; data sets for model development, data verification or confirmation, and estimates of uncertainty. Because data acquisition and monitoring of the Nation's ecological resources is an integral part of EMAP, the Program serves a separate but extremely important role for EPA-RAF's ecological risk assessment program by providing quality assured data for performing large-scale risk assessments.

Document Organization

EMAP's *Assessment Framework*, describes the structure and strategy EMAP will use in ecological assessments.

The information in section **2 — Environmental Monitoring and Assessment Program** explains the rationale for EMAP, its goal and objectives, program structure, and assessment products. Because EMAP's assessment framework is part of the process for achieving EMAP's goal and objectives, it is important for users of program information to understand what the program aims to accomplish and why.

Section **3 — the Assessment Framework** explains the three phases for conducting assessments in EMAP: problem formulation, data analysis, and interpretation and communication. These phases emphasize (1) formulating and refining assessment questions and issues with EMAP users, (2) identifying indicators of condition, (3) developing conceptual models, (4) analyzing ecological resources data using effects-oriented strategies to answer the questions, and (5) interpreting and effectively communicating assessment results in a policy-relevant context for clients and other users.

The concluding section **4 — Evolving Program and Process** discusses the implementation of EMAP and the evolving assessment process.

A list of references and glossary of terms complete EMAP's *Assessment Framework.*

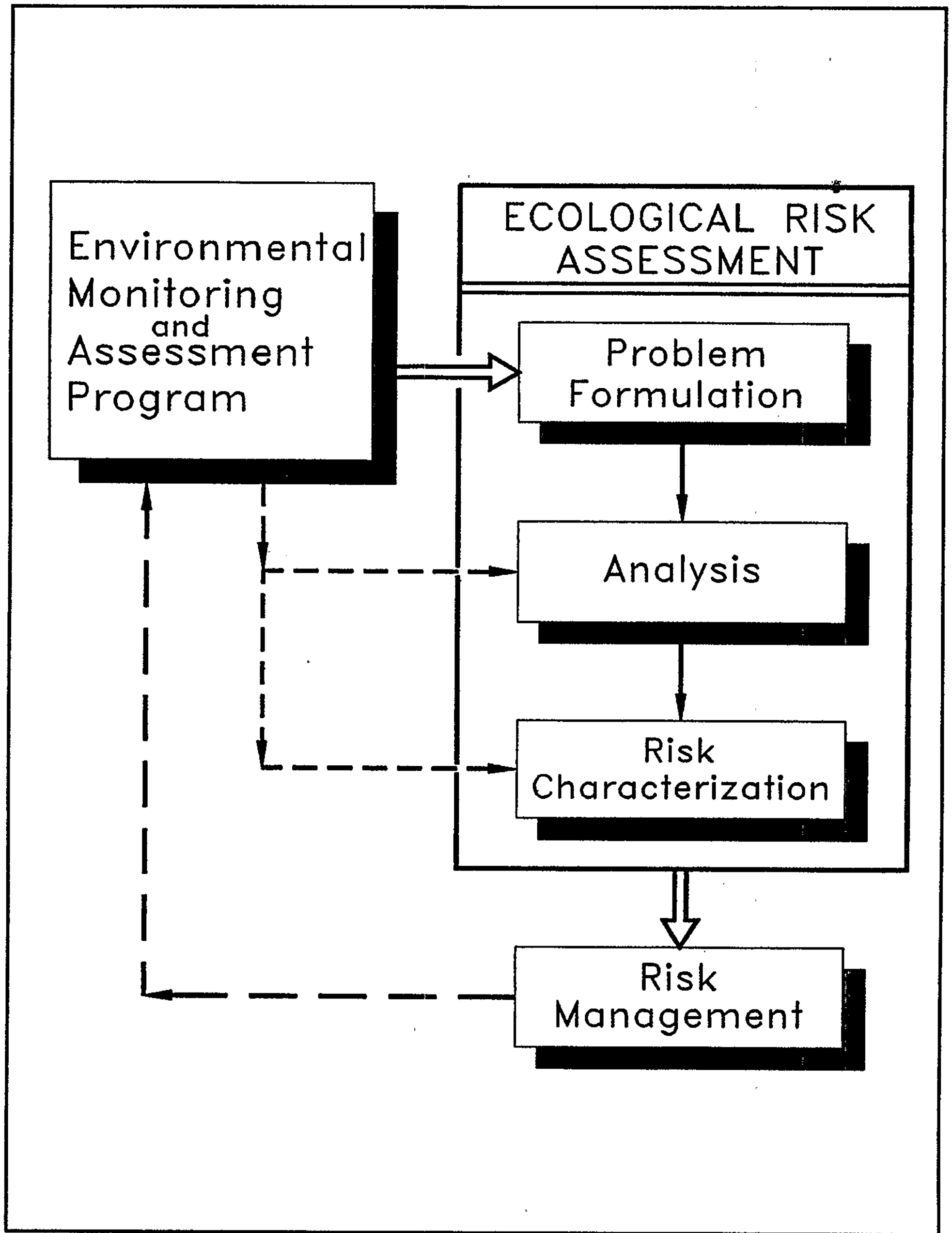


Figure 3. Relations of EMAP assessment to RAF's risk assessment framework. EMAP assessments contribute primarily to problem formulation, with more limited contributions to other phases.

2 — Environmental Monitoring and Assessment Program

This section presents the rationale for EMAP, the Program's goal and objectives, a brief description of EMAP's structure, and approaches for keeping EMAP assessments relevant. Additional information on EMAP can be obtained by writing to the address listed in the Preface.

Rationale

EMAP evolved from discussions about the basic elements needed in a Federal monitoring and assessment program to contribute to decision making on environmental protection and management. Seven elements summarized these discussions:

1) A focus on social values and policy-relevant questions;
2) Approaches that assess and translate scientific results into information useful for decision makers and the public;
3) Ecological indicators of condition for monitoring key ecological resources rather than individual pollutants or stressors;
4) Periodic estimates, with known confidence, of the status and trends in indicators of ecological condition;
5) An integrated approach to monitoring that includes all ecological resources;
6) National implementation with regional scales of resolution, rather than an individual site or local area orientation; and
7) An interagency, interdisciplinary program in which all participating agencies are cooperative partners in the research, monitoring, and assessment efforts.

Decisions on environmental protection and management require that the important societal values associated with our ecological resources and the related policy questions be identified and clearly stated.

The possible uses of the data to support decisions must be considered throughout the assessment process, not only after the data are collected but also initially to determine what information is needed. Then, through the design of a scientifically rigorous monitoring network, appropriate indicators are selected and monitored to provide the types of information required to address these questions. Measuring these indicators within a network of probability samples, rather than from sites selected using subjective criteria, permits estimates of the status and trends in ecological indicators of condition on a regional and national basis with known confidence. Existing State and Federal monitoring networks typically focus on a specific resource or medium, which often results in "question-specific" designs. Aggregating data from these designs to address regional, multi-resource issues is difficult, if not impossible; therefore, a critical need exists for a complementary, integrated program that monitors all ecological resources. Emerging regional and national environmental problems require monitoring networks designed to provide information at these scales. Finally, cooperative and collaborative interagency, interdisciplinary programs are required to address these complex issues.

The technology and methods required to design a cost-effective, nationwide monitoring program of the scope of EMAP are available, but they have never been fully tested. Existing programs provide valuable information, but many were designed for other purposes such as compliance monitoring, single-resource management, or problem-specific monitoring. Although many monitoring programs measure specific elements of environmental quality, reviews have repeatedly found these programs to be inadequate (GAO 1988, NRC 1990). By designing and implementing EMAP, EPA has set in motion an ecological research, monitoring, and assessment program with a regional and national scope. These basic programmatic elements are reflected in EMAP's goal and objectives.

Goal and Objectives

EMAP's goal is to monitor and assess the condition of the Nation's ecological resources to contribute to decisions on environmental protection and management. To accomplish this goal, EMAP works to attain four objectives:

1) ***Estimate the current status, trends, and changes in selected indicators of the condition of the Nation's ecological resources on a regional basis with known confidence.***
EMAP will use selected indicators to monitor and assess the condition of the Nation's ecological resources. Indicators are characteristics of the environment, both biotic (biological) and abiotic (non-living), that can provide quantitative information on the condition of ecological resources. EMAP emphasizes biological indicators in contrast to the traditional approach of

monitoring chemical and physical indicators. Currently, the Nation's ecological resources are grouped by EMAP into the following categories: agroecosystems, arid ecosystems, estuaries, forests, the Great Lakes, surface waters (both lakes and streams), and wetlands. EMAP will monitor and assess these resources at the scale of the landscape, so landscape indicators also are important. Status of each resource will be described through the distribution of scores for condition indicators for a specified time with relation to the reference condition associated with specific social values or desired uses. Trends will be described by the changes in the distribution of scores for indicators of condition over multiple time periods. Change is the difference in the distribution of measurements of condition indicators between two time periods. Because the design has an underlying statistical basis, the proportion of resources in a given condition—for instance, the proportion of lakes that are eutrophic—can be estimated with known confidence.

2) ***Estimate the geographic coverage and extent of the Nation's ecological resources with known confidence.*** Determining the national geographic coverage of multiple ecological resources has been a high priority among agencies and within scientific communities for several years. In conjunction with other agencies, EMAP will provide information on geographic coverage for the Nation's ecological resources as spatial displays at specific scales of resolution, for example, at the scale of satellite Thematic Mapper images with 30 m resolution. EMAP will estimate the extent or amount of a resource, for example, the acres of forest, miles of streams, or numbers of lakes. Each of these estimates will be presented with known confidence. Also, EMAP will monitor and assess changes and trends in geographic coverage and extent.

3) ***Seek associations among selected indicators of natural and anthropogenic stresses and indicators of condition of ecological resources.*** EMAP will seek associations or relationships among selected indicators of natural and anthropogenic (human-induced) stresses and ecological condition to identify factors that might be contributing to the condition which the ecological indicators express. Any stressors proposed for EMAP are selected to aid in interpreting the indicators of ecological condition. When monitoring a stressor, EMAP requires that an explicit relationship exist between the selected indicator of stress and the indicator of condition or that there be a testable hypothesis regarding this relationship.

4) ***Provide annual statistical summaries and periodic assessments of the Nation's ecological resources.*** EMAP information will be made readily available to all individuals, organizations, and agencies that are interested in the condition of our ecological resources. Annual statistical summaries will be prepared for each ecological resource and distributed in a timely fashion. EMAP results will be interpreted or translated into answers for specific questions from users and decision makers. These assessments will be conducted on both a periodic and ad hoc basis, as described in the remainder of this document.

These objectives support EMAP's goal and seek to provide scientific information useful to decision makers.

Program Structure

To achieve its programmatic objectives, EMAP has developed an organizational structure in which research, monitoring, and assessment activities are coordinated and integrated throughout the Program (Figure 4).

EMAP will monitor all of the aforementioned major categories of ecological resources and determine the patterns of these ecological resources on the landscape. An interagency resource group is responsible for each ecological resource as well as one for landscapes. For these eight resource categories (including landscapes), EMAP will monitor selected indicators of ecological condition and will collect and compile data on selected stressor indicators (including atmospheric deposition). The program will integrate its monitoring of indicators within and across resources, such as forests, surface waters, and wetlands, so that changes in indicators of ecological condition and landscape patterns can be detected over time. This large-scale integration represents one of the greatest technical challenges to the program.

The scope and complexity of EMAP require extensive coordination if the Program is to be successful and fully integrate data into its assessments. Consequently, EMAP places a high priority on coordination at both the technical and administrative levels. Cross-cutting groups (Figure 4) are responsible for ensuring there is consistent, compatible and comparable approaches among resource groups for design and statistical analyses, indicator development, information management, assessment and reporting, landscape characterization, development of methods, logistics, and quality assurance. Also, EMAP coordinates its research, monitoring, and assessment activities among a variety of other agencies and programs.

The concept of assessing monitoring information in a policy-relevant context represents a central theme underlying all EMAP activities. Assessment in EMAP is the process of interpreting and evaluating EMAP results for the purpose of answering policy-relevant questions about ecological resources including determination of the fraction of the resource population that meets socially-defined values and associations among indicators of ecological condition and selected stressors. In turn, assessment results can describe where refinements in monitoring are required. One of the primary lessons learned from the 10-year National Acid Precipitation Assessment

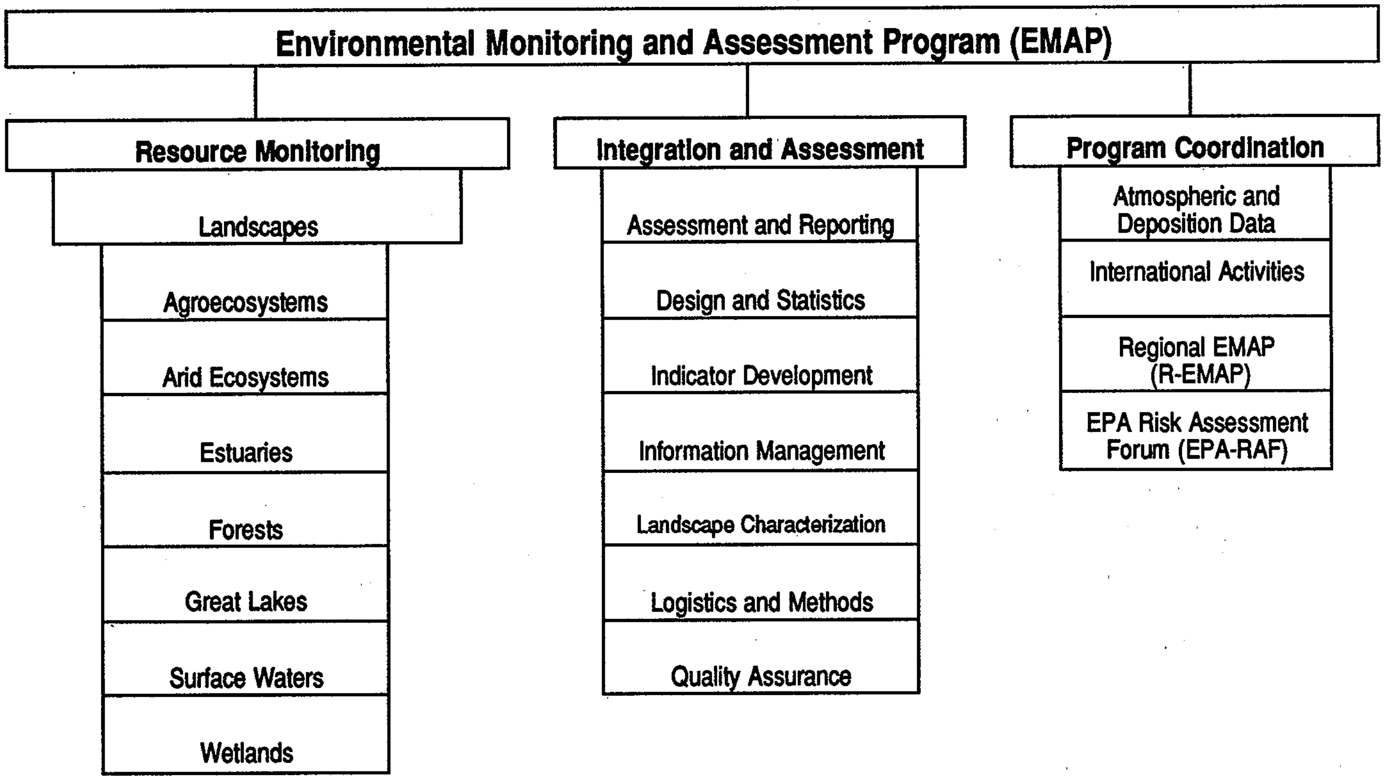


Figure 4. EMAP structure.

Program (NAPAP) was that monitoring and research require a continuous emphasis on assessment (ORB 1991). This emphasis on assessment is reflected in the development of this EMAP assessment framework.

Assessment Products

EMAP activities will produce verified, aggregated resource data; annual statistical summaries; assessments; and assessment tools. EMAP will produce two basic types of ecological assessment reports: pre-planned, periodic *Status of the Ecological Resource* reports and special topic assessments. The principal differences between these two assessments is that assessments for a *Status of the Ecological Resource* report have been planned as part of the programmatic design, based primarily on information being collected in EMAP, and scheduled for periodic production. This assessment focus has ensured that monitoring information will be available *a priori* to address identified assessment questions. Special topic assessments will likely address a specific environmental issue or set of specific policy-relevant questions that are not planned into the program design and that make greater use of auxiliary data. Either of these assessments can be done at any of four levels—single resource, single region; single resource, multiple regions; multiple resources, single region; and multiple resources, multiple regions. Assessment reports will be produced as collaborative efforts with partner agencies, by other agencies using EMAP data, by EMAP resource groups and by EMAP's Assessment and Reporting cross-cutting group. These reports will evaluate the status and trends in the ecological condition of resources and will suggest possible factors contributing to this condition.

EMAP can contribute to formulating hypotheses about the causes of ecological resource condition for investigation by other programs conducting cause-effect studies (Figure 3). Also, EMAP's assessment activities will contribute information to support the efforts of other offices and agencies: assisting development of biocriteria by EPA's Office of Water, developing ecological indicators to assist resource management agencies, evaluating environmental and spatial statistical methods in the scientific community, and providing other assessment tools, particularly regional assessment tools, as the process evolves. Because the diversity of potential assessments that may be conducted within EMAP is large, EMAP's *Assessment Framework* emphasizes the entire assessment process.

Evolving Process

The EMAP assessment process is evolving; it will provide policy-relevant information on important environmental issues, will stimulate new ideas and raise new questions about the status of and trends in conditions of the Nation's ecological resources, and will identify by association factors that might be contributing to these conditions. The lessons learned conducting assessments, not only in EMAP but also in other programs, will provide new ideas and new approaches. Based on a review of other national programs, e.g., National Acid Precipitation Assessment Program (Cowling 1992, NAPAP 1991, ORB 1991, NRC 1986) and the Global Climate Change Program (SPA 1992), several elements were identified that can improve the EMAP assessment process and its probability of success:

- ♦ **Open process.** An open and inclusive process must be followed in conducting large-scale assessments for subsequent decisions to be accepted by primary users, interested parties and the public. The concerns and issues of all parties must be heard and addressed, even if their suggestions and recommendations are not included in the assessment.

- ♦ **Review and oversight.** Both scientific and policy reviews are critical to ensure each assessment is based not only on sound, scientifically defensible approaches and information but also addresses important policy-relevant questions and issues.

- ♦ **Social, economic and policy perspectives and values.** Decisions typically are made on socioeconomic or policy values, rather than scientific values or ecological indicators. Ecological indicators must be linked or related to the values or variables on which decisions will be made.

- ♦ **Interagency cooperation and collaboration.** To address large-scale environmental issues in an effective and economical manner, collaborative interagency studies should be conducted. Each agency can contribute critical information to addressing questions and issues related to different social perspectives.

- ♦ **Interdisciplinary teams.** Interdisciplinary teams for assessments must include contributions from social scientists, economists, policy analysts, and administrators in addition to natural scientists and engineers. Scientists, professional communicators, policy analysts, and decision makers each play a key role in the assessment process, particularly for large-scale environmental problems and issues (Cowling 1992).

- ♦ **Multiple methods.** Weight of evidence methods and explicit uncertainty analyses are an integral part of the assessment process. Multiple methods, models, and technologies must be used in order to corroborate findings. Research should reduce those uncertainties that contribute to answering policy-relevant questions.

- ♦ **Conflict resolution procedures.** Different perspectives among natural, social and behavioral scientists, agencies, and societal groups will result in conflicts over the interpretation, certainty and translation of scientific and technological information for decision makers. Conflict resolution procedures need to be established before conflicts arise. These procedures might include minority reports, arbitration, or similar strategies.

Each of these elements is being evaluated to determine how to appropriately include them in the EMAP assessment process. Many of these elements were incorporated in the initial Program design, for example, interagency collaboration, and interdisciplinary teams. These evaluations are part of the iterative and evolving assessment process.

3 — Assessment Framework

There are three phases and two direct outputs from the EMAP assessment process (Figure 5). **Assessment questions, data analysis,** and **interpretation and communication** constitute the phases of EMAP's assessment framework. The outputs include **policy relevant information** and **research and development** tools and results.

In the **assessment questions** phase, the users' assessment questions and issues are identified and validated, appropriate indicators of condition (i.e., assessment endpoints) are selected, links among indicators of condition and potential stressors are conceptualized, and data needs are determined. In **data analysis**, the relevant data needed for the assessment are acquired, summarized, integrated, and analyzed using association analyses, weight of evidence, and process of elimination methods. During **interpretation and communication**, results from the data analysis phase are interpreted in the context of the users' values and perspectives, then policy relevant information is communicated in a format that is understandable and that addresses the assessment questions. In addition, lessons learned from conducting the assessment can be incorporated in the Program to help EMAP maintain its policy relevance and responsiveness. These lessons or new tools might include revised analytical approaches or procedures, new indicators, new linkages in conceptual models, or possible modifications to the monitoring design (**Research and Development** in Figure 5).

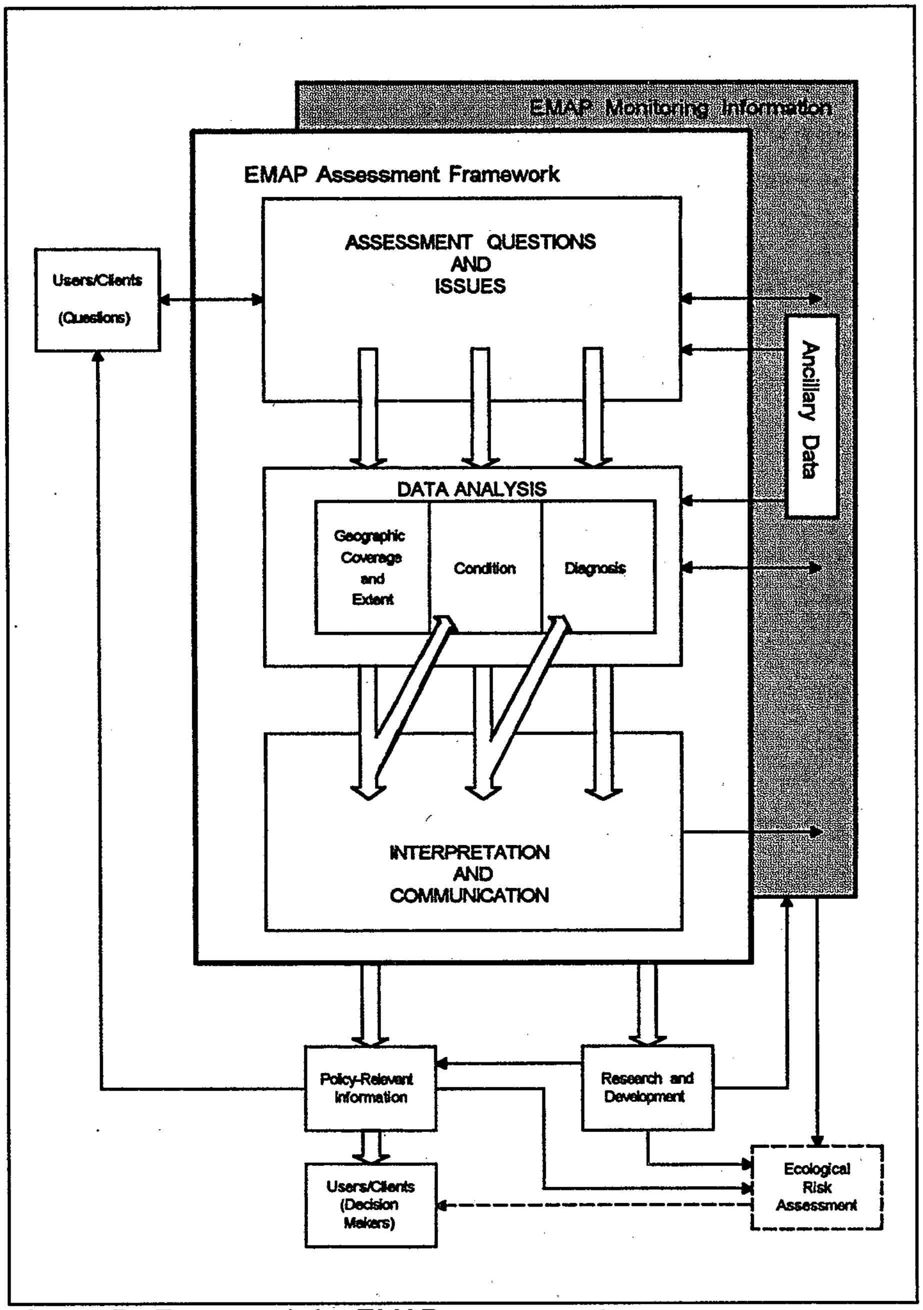


Figure 5. Framework for EMAP assessments.

One of EMAP's unique attributes is that the assessment process is inexorably coupled with monitoring information. This assessment focus ensures that monitoring information will be available *a priori* to address identified assessment questions.

Assessment Questions

The most important phase of the assessment process is identifying the client's questions and determining what information is needed to make informed decisions about environmental protection and management (Figure 6).

EMAP Users and Their Assessment Perspectives

Addressing environmental issues involves more than finding purely technical solutions (Bardwell 1991). Environmental questions and issues reflect political, societal, regulatory, and management values and expectations as much as, if not more than, scientific and technical information (Ehrlich 1980, Sampson and Hair 1990, Schnaiberg 1980, Waide et al. 1992). Contributing to decision-making processes requires that assessment information addresses questions based on these underlying expectations and perspectives.

EMAP users bring a variety of perspectives to ecological assessments ranging from:

- ♦ **Social** perspectives, which incorporate the broadest spectrum of environmental goals and values desired by contemporary society and expressed through the legislative process.

- ♦ **Administrative** perspectives, which include manage-ment and regulatory agencies and their legislative mandates to protect and manage both specific ecological resources and the total environment.

- ♦ **Scientific** perspectives, which include basic scientific principles and knowledge of ecological structure and function as well as causal understanding of ecological responses to human disturbances and natural variability (Figure 6).

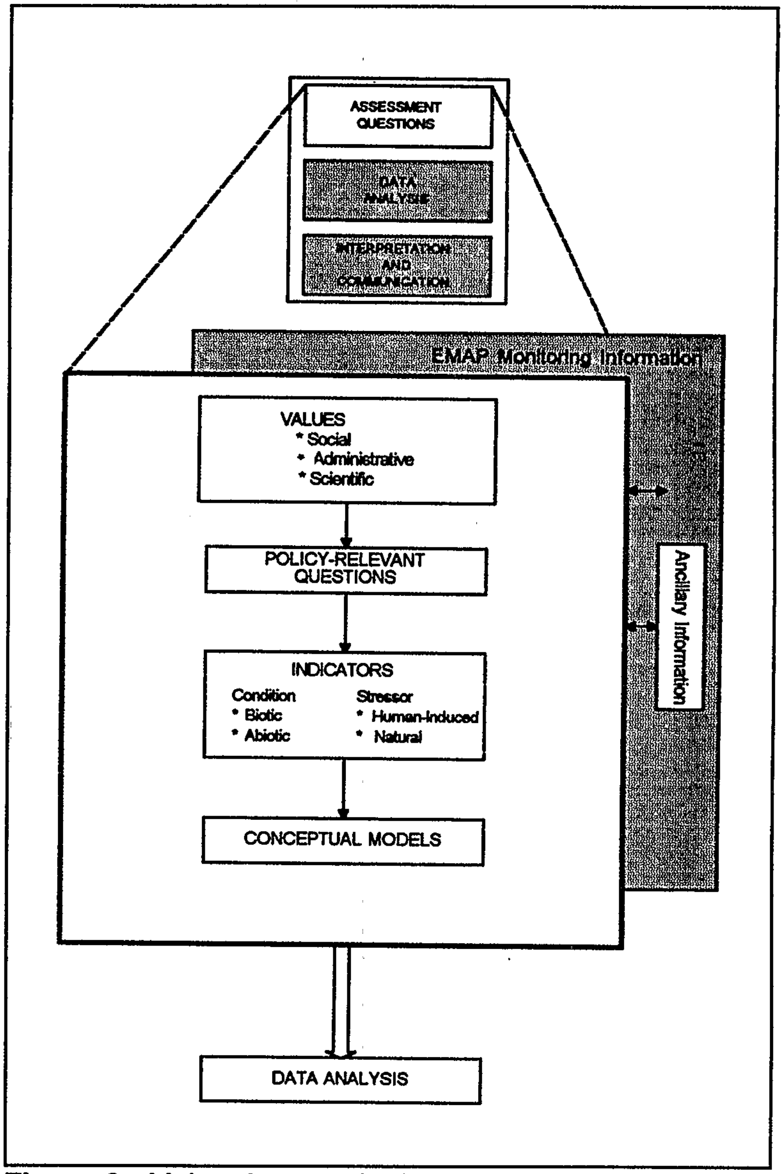


Figure 6. Major elements in the assessment questions and issues phase of EMAP's assessment framework.

Identifying social values is a critical first step in the EMAP assessment process because it provides the link to the user. Each of EMAP's resource groups has identified an initial set of values for their respective resources. This is an on-going and iterative process which reflects the changing values of society, changes in the administrative procedures to ensure these values are being attained, and advances in scientific understanding of how ecosystems function and how selected condition indicators relate to environmental values.

Policy-relevant Questions

The next step in the assessment process identifies questions based on the underlying perspective and background of the user. Social and administrative policy perspectives must be incorporated in the assessment questions and process (Cowling 1992).

Posner (1973) states that the initial representation of a question is the single most crucial factor governing the likelihood of a satisfactory answer to the question; whether the question is answered, and how long it takes to provide the answer, depends a great deal on the initial statement of the question.

The implications and frustrations of inadequate initial question formulation can be significant. Bardwell (1991) cites a study that indicates about 90% of real world problem solving is spent

1) solving the wrong problem,
2) stating the question so it can not be answered,
3) solving a solution,
4) stating questions too generically, or
5) trying to get agreement on the answer before there is agreement on the question.

An example of how these different perspectives might be expressed in formulating assessment questions is illustrated in Table 3.

A question of direct interest to the fishing sector of society might be, "Is it safe to eat the fish we catch?" Because EMAP addresses questions related to resource populations at multiple sites, this initial question must be rephrased as, "What proportion of the lakes in the region have catchable fish that are not safe to eat." The rephrased question also reflects how it is generally easier to define the range of unacceptable conditions than acceptable conditions.

From a regulatory perspective, however, there is not a straightforward answer to this general social question; the answer depends on the specific contaminant, the particular fish species, the criteria established (if any) for that particular species, and other factors. This question might have to be rephrased: "What proportion of the lakes in the region have

Table 3. Examples of different perspectives and different underlying data needs to answer an assessment question.

Perspective		Assessment Question
Social	1.	Is it safe to eat the fish I catch?
	1a.	EMAP Question: "What proportion of lakes have catchable fish that are safe to eat in the Region? [Subnominal criteria typically are easier to establish than nominal criteria, so the question becomes ". . .are not safe to eat".]
Administrative	2.	What is the risk to humans from consuming various quantities of fish flesh with different contaminant concentration?
	3.	What is the type and condition of the consumer (i.e., pregnant woman, adult male, child under 12 yr)?
	4.	What is the risk to human health from fish with different gross external pathologies?
	5.	What different risk factors exist for different fish species?
	6.	What are the cumulative effects of consuming contaminated fish?
	7.	What proportion of lakes have catchable fish with edible tissue contaminant concentrations that exceed FDA Action Levels?
	8.	What proportion of lakes have catchable fish with edible tissue with detectable contaminant concentrations?
	9.	What proportion of lakes have gamefish populations with contaminated flesh?
	10.	What additional contaminant/pathological criteria or standards exist in addition to FDA Action Levels?
	11.	What are possible sources of contamination?
Scientific	12.	What are the associations between tissue contamination concentrations and sediment concentrations? aqueous concentrations?
	13.	What are the associations between concentrations in food sources (i.e., prey species) and tissue concentrations, indicating possible pathways for exposure?
	14.	What are the appropriate criteria for assessing acute, chronic, and cumulative human physiological responses?
	15.	What proportion of lakes have the catchable fish with gross external pathologies or contaminated fish flesh?
	16.	What are the characteristics of lakes that contain a high proportion of catchable fish with gross external pathologies or contaminated fish flesh?

legally harvestable largemouth bass with methyl mercury concentrations exceeding 1 mg/kg in the edible tissue?" Scientifically, additional information is required on the bioaccumulation and biomagnification of this contaminant, by fish species, over time, the depuration rate of the chemical in the fish species and humans, the acute and chronic toxicity of the chemical, the status of the human species (e.g., pregnant female versus adult male), the quantity of fish flesh consumed, and similar information before an informative answer can be provided to the relatively simple, initial question, "Is it safe to eat the fish we catch?"

Formulating the policy-relevant assessment questions is particularly important in EMAP because the national scope and regional scale of resolution represents a different perspective from that underlying most research studies as well as local and State monitoring programs. Examples of broad assessment questions that EMAP might address are presented in Table 4.

It is equally important to identify the types of questions and issues that EMAP will not address. EMAP is neither designed to provide site-specific, compliance-oriented monitoring nor to provide information on specific, local-scale issues. It is not intended to provide substantial information about any individual sampling site, such as a specific lake, wetland, forest stand, or agroecosystem. Questions and issues at the local scale can be addressed more effectively by existing or site-specific monitoring networks. EMAP is not designed to determine if any particular ecological effect is caused by a specific pollutant; EMAP will not be able to describe the dynamics of any particular ecological process, such as nutrient cycling. EMAP will not, and is not intended to, replace existing compliance-oriented or resource-management monitoring programs, but it will supplement and add value to the information being obtained from these programs by assessing large-scale patterns and trends in ecological condition. Some of the questions EMAP will not address are listed in Table 5.

Table 4. Examples of policy-relevant questions to be addressed in EMAP.

Question	Reason Appropriate for EMAP
What proportion of estuarine area in large estuaries, tidal rivers, and small estuaries has fish with gross pathologies?	EMAP focuses on biological indicators with societal value.
What proportion of the Nation's lakes are eutrophic, mesotrophic, and oligotrophic?	EMAP produces regional and national population estimates for lake trophic state estimates, not for individual lakes.
What proportion of wetlands have less than the expected number and composition of native plant species?	EMAP targets ecosystem properties like community structure.
How is the area and geographic coverage of forest cover types in the U.S. changing?	EMAP estimates the extent and geographic coverage of the Nation's ecological resources.
What proportion of forests have vegetative structure and functions to sustain forest biodiversity?	EMAP focuses on national environmental issues such as biodiversity and sustainability.
What proportion of the surficial sediments in the Great Lakes' harbors and embayments are toxic to aquatic organisms?	EMAP's condition indicators include both biotic and selected abiotic measures.
What proportion of the southeastern U.S. has fragmented or simplified landscapes?	EMAP also addresses interactions among ecological resources on the landscape.
What proportion of arid ecosystems are experiencing desertification? What anthropogenic stressors are associated with desertification of arid ecosystems?	EMAP assesses the cumulative effects of multiple stressors and identifies possible factors that might contribute to condition.

Table 5. Examples of policy-relevant questions that are not appropriate for EMAP.

Question	Reason Not Appropriate for EMAP
What proportion of lakes in **New Jersey** are hypereutrophic?	EMAP is not a State level program, but the design is flexible and can be enhanced for State level resolution.
What proportion of degraded wetlands are **caused** specifically by inappropriate agricultural management practices?	EMAP is not a cause-effect program. Associations might provide strong inference but do not establish causality.
What is the trophic state of **Lake Tahoe**?	EMAP reports on populations of resources, not on individual systems or entities.
What proportion of improved grassland condition can be associated with the implementation of the **Conservation Reserve Agricultural Program**?	EMAP addresses the cumulative influence of national and regional policies, not the effectiveness of individual regulations or policies.
What proportion of degraded estuaries in the Virginian Province are associated with **storm event** loadings?	EMAP uses an index sampling concept to describe ecological condition. It is not designed for short-frequency, episodic events but rather for detecting longer term trends in ecological condition.

EMAP's strategy for formulating assessment questions reflects different user perspectives: the first step in this strategy is to identify a tentative list of assessment questions that are considered to have policy-relevance based on the selected values for a resource. Then, EMAP scientists and administrators meet with decision makers and resource managers in Federal agencies, Congressional staff, and representatives of environmental organizations to solicit their review and comment. The revised questions are used to identify additional indicators for testing and evaluation.

Formulating these questions is an ongoing and iterative process between EMAP scientists and users of EMAP's information, continually evolving as additional issues and new users are identified.

Indicators

In the literature, indicators are defined as characteristics of the environment that provide quantitative information on the condition of ecological resources, the magnitude of stress, or the exposure of a biological component to stress (Hunsaker and Carpenter 1990, Olsen 1992). Condition of an ecological resource is determined by the interaction of all physical, chemical, and biological components in the system. Because it is impossible to measure all components, EMAP's strategy is to emphasize indicators that represent the condition of ecological resources relative to social values. EMAP selects, develops, and evaluates indicators that (1) describe the overall condition of ecological resources, (2) permit the detection of changes and trends in condition, and (3) provide preliminary diagnosis of factors (e.g., human-induced versus natural stressors) that might contribute to observed conditions.

EMAP defines two general types of ecological indicators: condition and stressor. A condition indicator is any characteristic of the environment that provides quantitative information on the state of ecological resources and is conceptually tied to a value. Condition indicators may be classified as biotic or abiotic measures of condition, and in EMAP they are conceptually equivalent to measurement endpoints (Suter 1989, 1990, 1993; Kelly and Harwell 1990; Hunsaker and Carpenter 1990; Olsen 1992). EMAP will estimate the regional distribution of scores or measures for each of these indicators within and among ecological resource categories.

The program emphasizes the development and evaluation of biological condition indicators because they incorporate and express the cumulative effects of the complex interactions among physical, chemical and biological components of ecosystems.

Stressor indicators are characteristics of the environment that are suspected to elicit a change in the condition of an ecological resource, and they include both natural and anthropogenic stressors. The stressor indicators proposed for EMAP are selected to aid in interpreting the indicators of condition. EMAP requires an explicit relationship between the selected stressor indicator and the indicator of condition—or a testable hypothesis regarding this relationship—to monitor a stressor indicator. EMAP will seek associations among indicators of ecological condition and stressor indicators to help identify the factors that might be contributing to the observed condition. These associations can provide insight and direction for other regulatory, management, or research programs in establishing causal relationships.

Conceptual Models

Conceptual models help the assessment process because they:

1) identify links among values, indicators of condition or stress, and potentially important ecological pathways and processes;
2) guide association analyses among indicators; and
3) indicate factors that might be contributing to the status and trends in ecological condition (Olsen 1992).

One model for the estuarine resources (Figure 7) illustrates how values, indicators and stressors can be schematically linked; it also indicates potential pathways for transport, uptake and exposure of chemical stressors, as well as potential pathways for physical and biological stressors to affect desired uses or values of estuarine resources.

EMAP's Arid Ecosystems resource group has developed a conceptual model to illustrate relationships among external forces, resource class indicators, measurements, and values (Figure 8). To move through this model, start with the external components (layer 1) which drive the arid ecosystem. The broad indicator classes (layer 2) respond to these drivers and interact with each other via major indicator components or process (layer 3). Layer 4 contains measurement parameters that reflect indicator components; these are used to assess resource status. The current resource status then can be evaluated from a trend perspective (layer 5) by coupling it to retrospective indicators and long-term, historical data. Ultimately, resource status and trend data are integrated to address societal values and issues (layer 6). These two examples demonstrate the usefulness of different types of conceptual models.

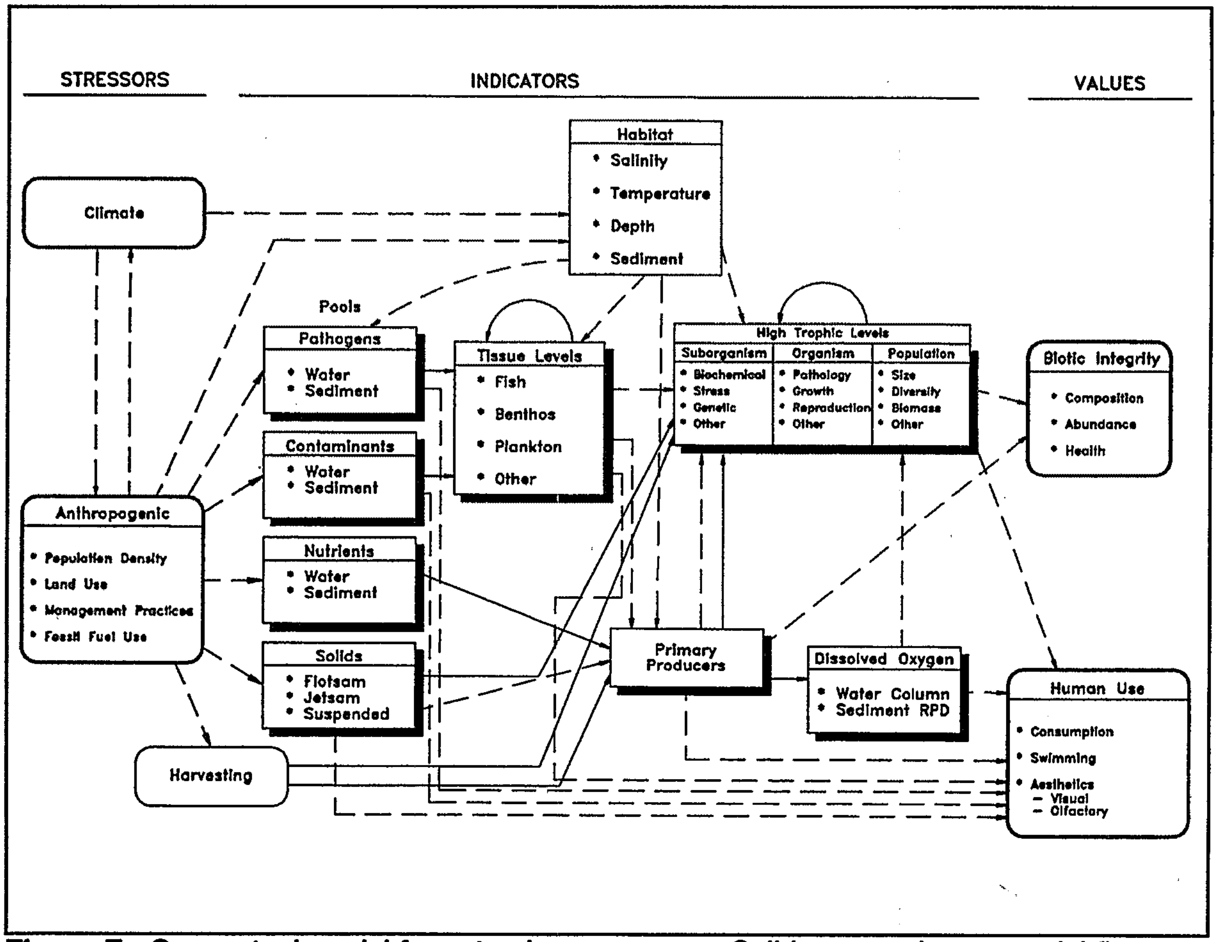


Figure 7. Conceptual model for estuarine resources. Solid arrows show material flows; dashed arrows indicate influence. (Modified from EMAP 1990.)

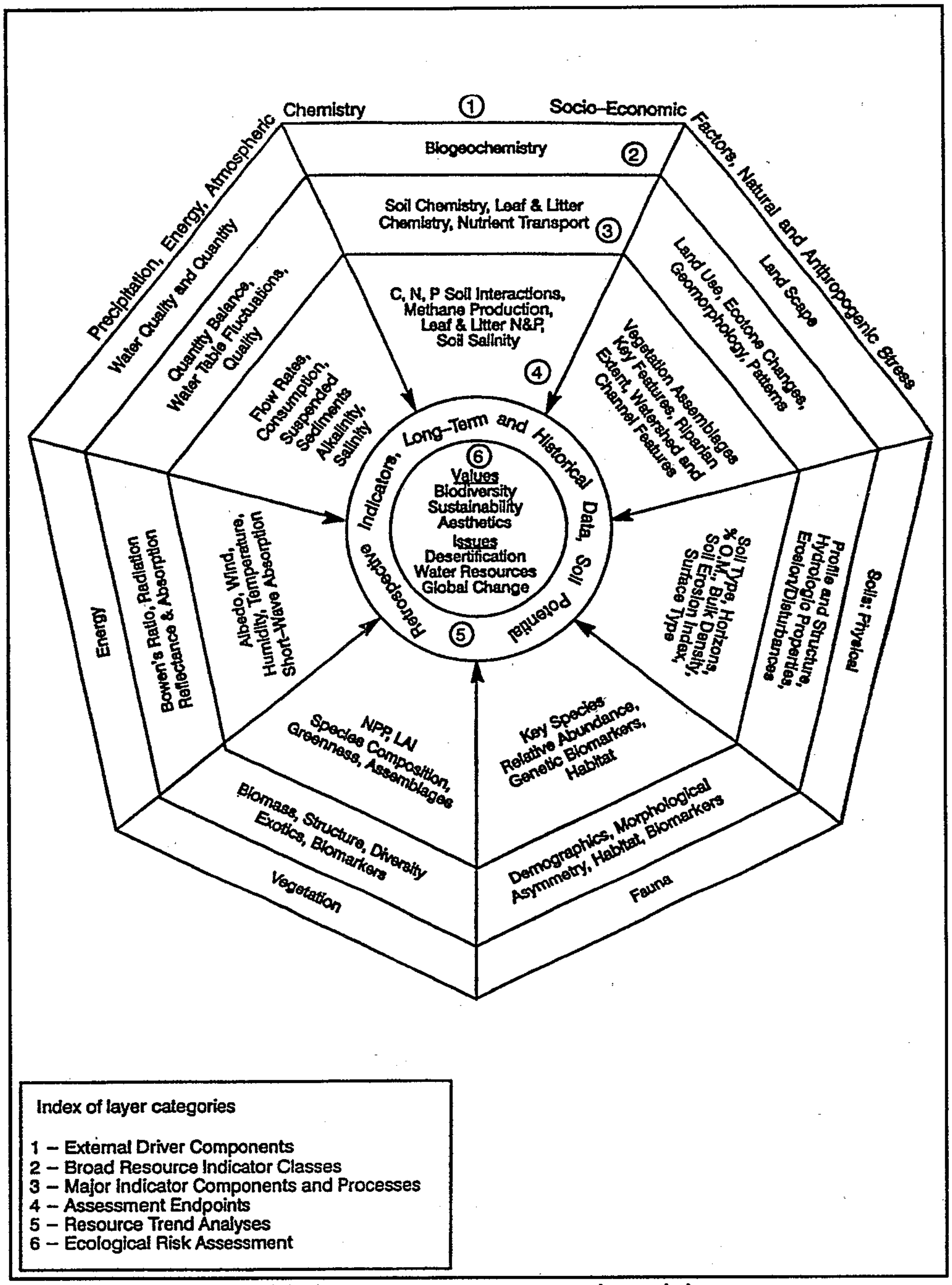


Figure 8. EMAP-Arid Ecosystems conceptual model.

Conceptual models are particularly helpful in describing relationships at large spatial scales. Different processes operate at different temporal and spatial scales (O'Neill et al. 1986), so the indicators and postulated associations are likely to be different at larger scales than at the local scale.

For example, Sala et al. (1988) evaluated the association among soil indicators and net primary productivity for grasslands throughout the Midwest and Great Plains. At any individual site, net primary productivity was a function of several variables, including soil texture, moisture holding capacity, soil nitrogen concentrations, precipitation, and solar insolation. The relative contribution of individual variables influencing net primary productivity also varied among sites. However, at the regional scale of the Midwest or the Great Plains, annual precipitation alone accounted for 90% of the variability (i.e., $r^2 = 0.90$) in net primary productivity. Conceptual models permit these links to be hypothesized and tested as EMAP data become available. In addition, conceptual models document links with other ecological resources and assist in identifying common or comparable indicators that might assist in interpreting regional patterns in ecological condition among resources. The data analyses conducted within EMAP assessments should evaluate the strength of the relationships and hypothesized links identified in the conceptual models for the ecological resource.

Data Analysis

The data analysis phase in EMAP's assessment framework can be partitioned into three distinct, interactive segments. These segments directly relate to three of EMAP objectives, namely, estimating geographic coverage and extent, estimating condition, and diagnosing those factors that might be influencing the condition of ecological resources and resource classes (Figure 9).

These analyses depend on and support EMAP's resource monitoring and research activities. Moreover, EMAP's data analyses contribute directly to the problem formulation activities of EPA's Risk Assessment Forum. For example, EMAP's analysis of a resource's geographic coverage and extent will assist RAF in characterizing ecological resources.

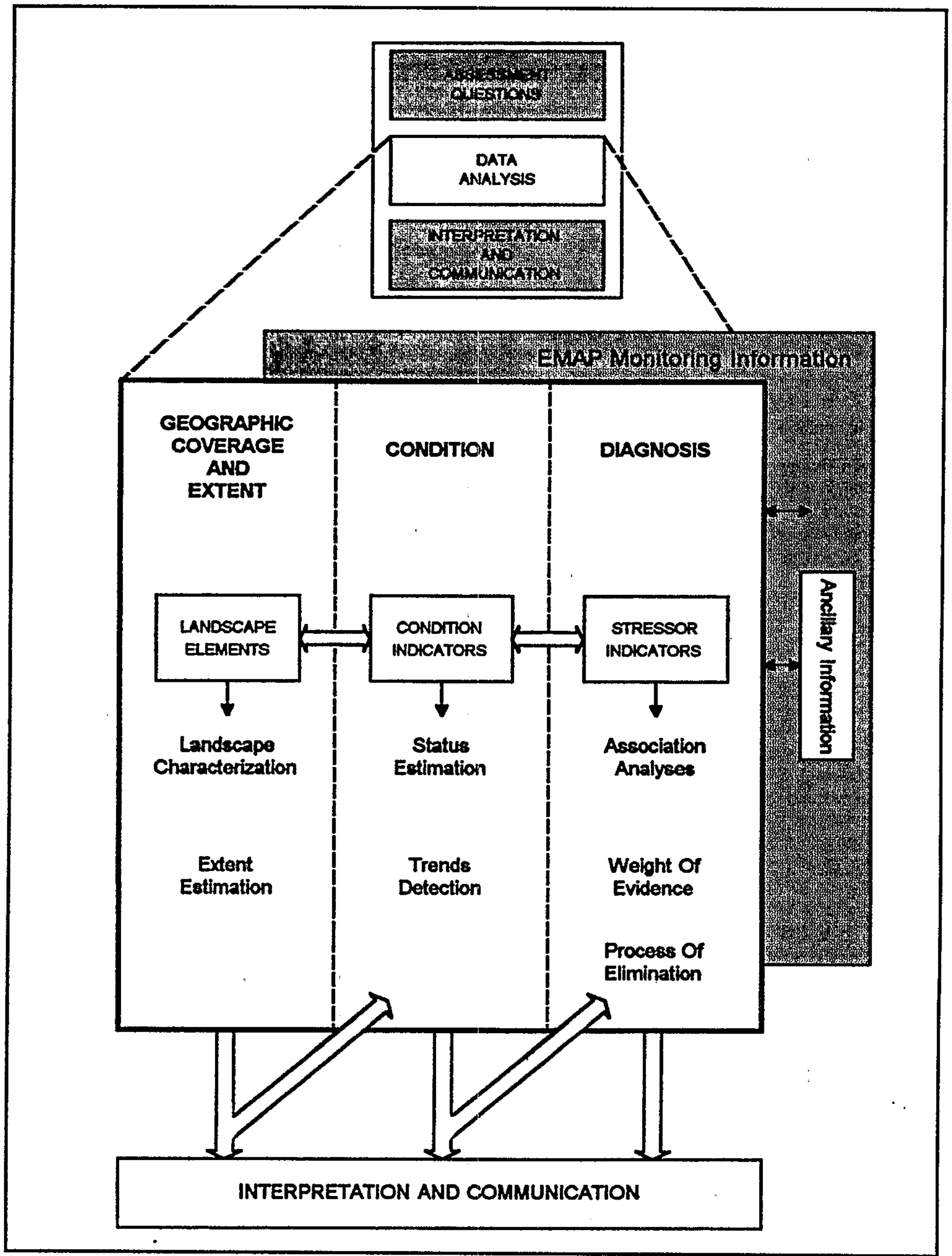


Figure 9. Major elements in the data analysis phase of EMAP's assessment framework.

Similarly, EMAP's analyses of condition indicators can be used by RAF to determine ecological effects. Finally, association analyses can contribute to exposure and ecological effects characterization in EPA-RAF.

Quality Assurance/Quality Control

All data used in EMAP assessments will undergo rigorous quality assurance and quality control (QA/QC) analyses, approvals, and documentation during resource monitoring and research activities. Protocols for QA/QC have been established for the Program and implemented within certain EMAP components. Quality assured data are primary assessment products derived from routine monitoring that will be available directly to EMAP users and clients.

Geographic coverage and extent

As EMAP periodically determines national geographic coverage and estimates extent of ecological resources, it will provide a basis for examining current condition, future changes, and trends in ecological resources. EMAP will provide information, such as spatial displays of forest cover types (Figure 10) at specific scales (e.g., satellite Thematic Mapper images at 30 m resolution), and estimate with known confidence the extent of such ecological resources as hectares of large estuaries, kilometers of streams, or number of lakes. As evidenced by U.S. Census Bureau data, the knowledge of geographic coverage, the extent of resources, and the change in coverage and extent carries significant policy-relevant information for decision makers and resource managers. In addition, these data contribute to the diagnosis of factors influencing resource condition.

Condition

The probability-based sampling design employed throughout EMAP provides a basis for estimating the current condition of ecological resources. Descriptive statistics (e.g., means, medians, standard deviations, quantiles, and cumulative distribution functions) will be used to characterize the distribution and central tendencies of indicators of condition. Status will be portrayed through cumulative distributions and visual displays of spatial patterns. Measurements of indicators of condition over time provides data to examine changes in status and detect trends in resource condition. One essential feature of this approach is the ability to estimate the cumulative proportion of a resource class with a condition indicator score less than or equal to some specified threshold score that can be related to achieving some societal value (e.g., nominal-marginal-subnominal condition—see section on Interpretation and Communication).

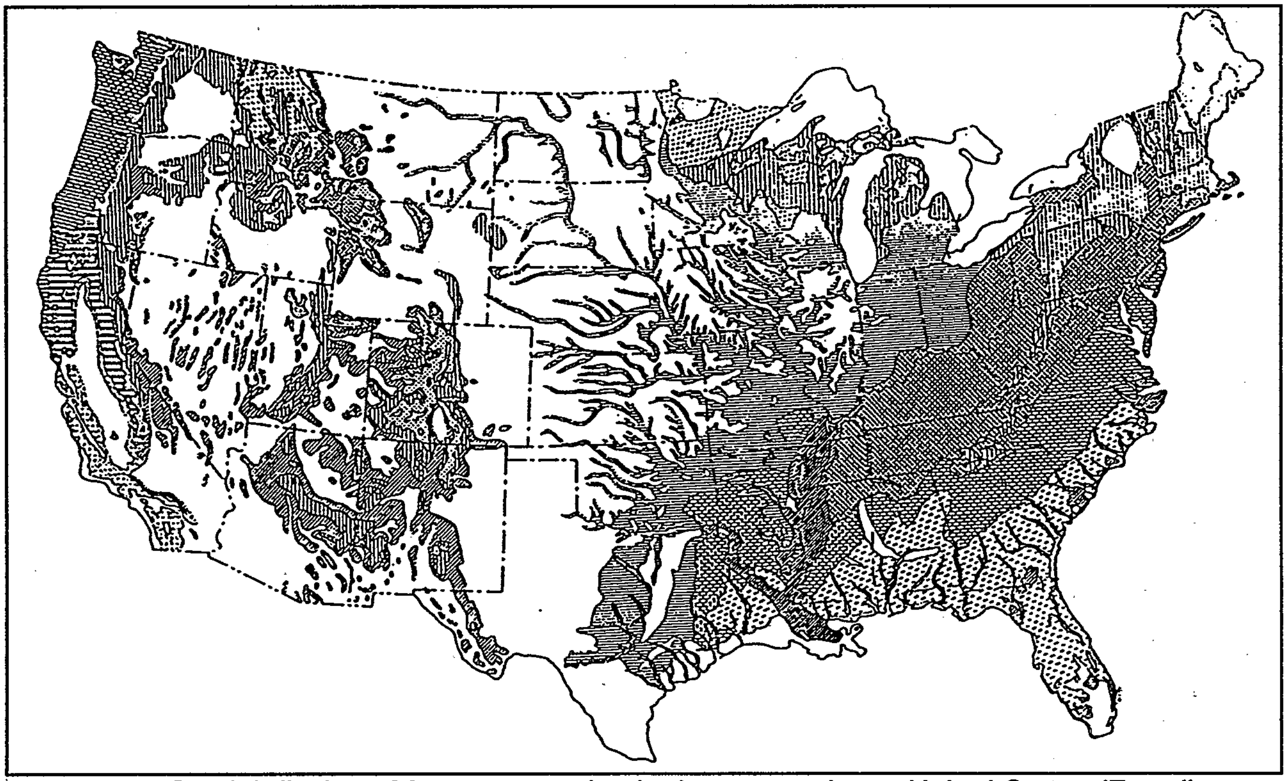


Figure 10. Spatial display of forest vegetation in the conterminous United States (Fowells 1965).

The complexity of ecological resources requires that indicators be considered in concert rather than individually. Although EMAP has selected a few individual indicators, the program has based its indicator selection on combinations, or suites, of indicators of ecological condition. One approach to using suites of indicators is the development of indices. For example, the Index of Biotic Integrity (Karr 1987, 1991; Karr et al. 1986) incorporates an array of biological measurements from the study of entire fish communities (e.g., total number of species, number of individuals, and proportion of top carnivores) to produce an index of condition of fish communities at a sampling site.

Properly developed indices of ecosystem condition should be compared more easily across regions than the measurements from which they are derived (Hughes 1989). The underlying model or aggregation process, however, can be controversial and mathematically complex, and the results tend to be extremely dependent on the model, the indicators and the aggregation procedures used (Westman 1985). Also, the formation of indices reduces multivariate measures of ecosystem condition to a more limited set of metrics. Although reduction in the number of indicators typically loses specific information, indices are one option for integrating or summarizing measures of ecosystem condition.

Diagnosis

EMAP uses retrospective approaches to systematically examine data in its effects-oriented analyses to identify factors which might be contributing to the current status or trends in ecological resource condition. This strategy is analogous to diagnosis in the branch of medicine called environmental epidemiology (NRC 1991) and the emerging area of ecosystem health (Costanza et al. 1992, Rapport 1992). EMAP's conceptual models propose links among condition indicators and stressors, and initial association analyses will focus on these links. Association analyses, in the broadest context, describe a range of exploratory and multivariate statistical procedures that will be applied to EMAP's data, ancillary data, and auxiliary data.

Ancillary information includes data collected from studies within EMAP but not used directly in the computation of an indicator. Ancillary data can help characterize parameters and assist in the interpretation of data sets; time, stage of tide, and watershed characteristics are examples of ancillary data. Auxiliary data are derived from a source other than EMAP, that is, from field studies or other monitoring or sampling programs. The sampling methods and quality assurance protocols of auxiliary data must be evaluated before the data are used, and it is always important to establish the population represented by auxiliary data. Auxiliary data might include climatic data, flow or discharge data, and census information on population demographics.

Association analyses will range from simple bivariate plots (Figure 11) among indicators to more computationally extensive multivariate techniques. Land cover and land use information as well as landscape indicators (e.g., fractal indices, connectivity) will be used in conjunction with specific indicators of condition and stressors to help identify factors contributing to the condition of ecological resources at regional and national scales.

These association analyses will be evaluated both over space and over time. Spatial associations among atmospheric sulfate deposition and lake sulfate concentrations at the subregional scale (Figure 11), for example, were used to infer that atmospheric deposition of sulfate was influencing the acidity of lakes in various regions of the United States (Baker et al. 1990). Association analyses conducted at the Great Plains regional scale found a strong spatial relationship between total annual precipitation and net primary productivity even though the association was not that strong at any individual site (Sala et al. 1988).

The temporal associations among indicators also will be investigated because the associations among stressor and condition indicators might be displaced in time. For example, there is a strong relationship between land use changes and the loss of productivity in arid ecosystems through time (i.e., desertification) (Reining 1978, UNEP 1992).

Association analyses, however, are not causal. EMAP is not designed to establish cause and effect relationships. The design, however, does not diminish the power for explaining and interpreting factors that might be contributing to the condition of ecological resources. Association analyses are part of the weight-of-evidence strategy that will be used to conduct EMAP assessments and contribute hypotheses for testing in other programs.

Weight of Evidence

A weight of evidence approach uses multiple statistical and other analytical techniques, ancillary and auxiliary information, scientific literature, and both probability and non-probability based field observations to reach assessment conclusions. While each of these approaches might provide only circumstantial evidence supporting a conclusion, multiple lines of evidence strengthen the conclusion (NRC 1991).

Establishing causal relations for large-scale phenomena requires a weight of evidence approach because it is difficult, if not impossible, to conduct cause-effect experiments at regional or subregional scales of resolution. However, Mosteller and Tukey (1977) state that if two of three criteria—consistency, responsiveness, and mechanism—are satisfied, then causation can be implied. Consistency implies that the relationship between variables is consistent across

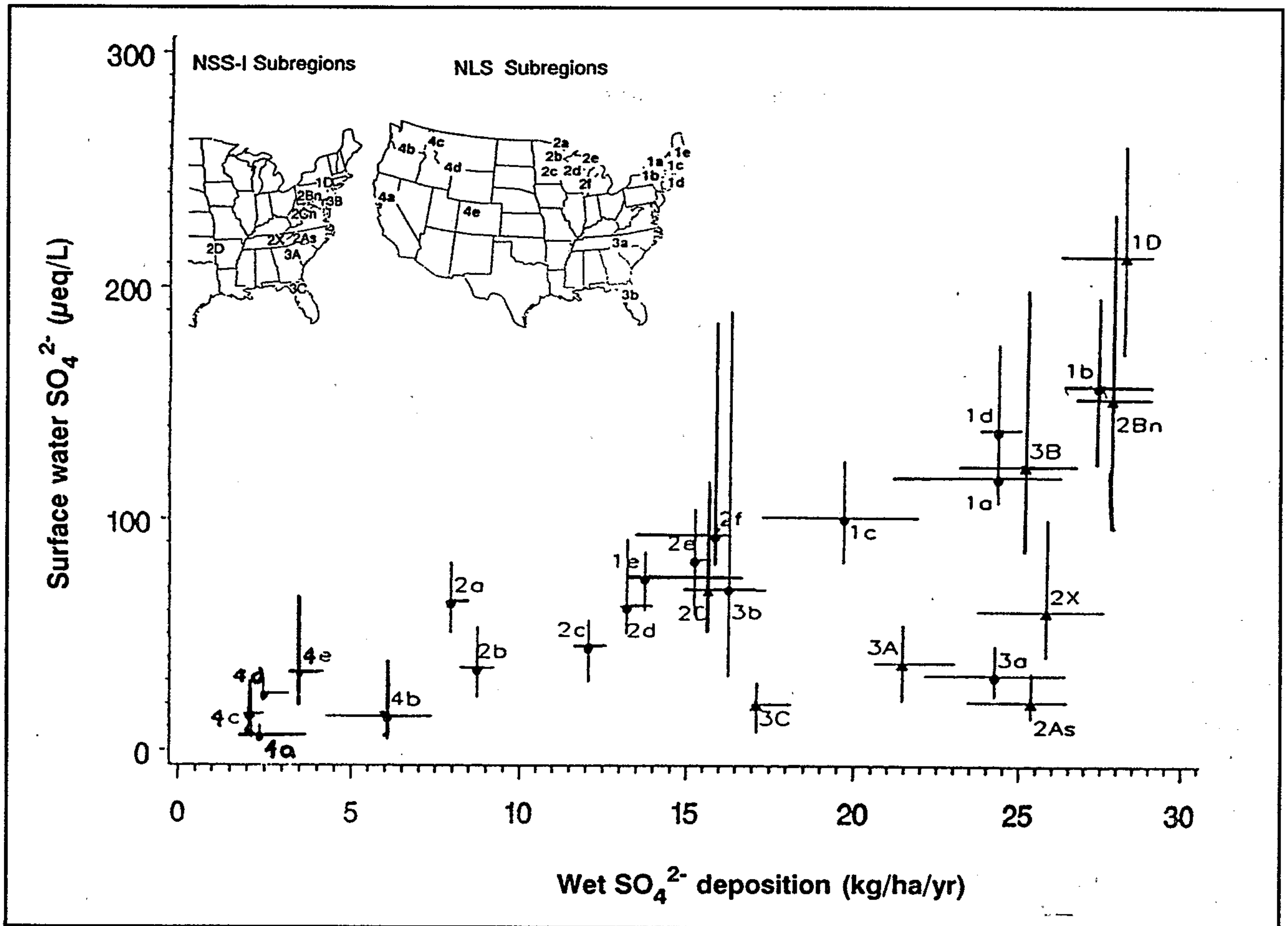


Figure 11. Association of median wet sulfate deposition and median surface water sulfate concentrations in National Surface Waters Survey subregions (after Baker et al. 1990).

populations, in both direction and amount (NRC 1986). Responsiveness involves experimentally manipulating a system by changing one variable and observing the expected change in the response variable. Mechanism implies a step-by-step path from the cause to the effect with links established between each step (NRC 1986). Based on the Mosteller and Tukey (1977) criteria, the NRC (1986) inferred that in eastern North America, a causal relationship existed between anthropogenic sources of SO_2 and the presence of sulfate aerosols, reduced visibility and wet deposition of sulfate. Similarly, Hill (1965) suggested, and Rothman (1986) corroborated, a set of nine criteria for inferring causality (Table 6).

A weight of evidence approach was used to demonstrate the effects of acidic deposition on aquatic ecosystems in the United State (Table 7). In the early 1980's there was anecdotal information that acidic deposition contributed to surface water acidification, but groups were polarized at opposite ends of a continuum, considering the acidic deposition problem either a trivial issue or a major environmental catastrophe. As aquatic research and surveys were conducted during the 1980s, additional information accumulated that provided additional weight to support the hypothesis that acidic deposition resulted in surface water acidification and negatively impacted aquatic ecosystems. In 1984, a NRC Panel agreed on the processes affecting surface water acidification (NRC 1984). In 1986, the NRC stated national surface water surveys estimated the population of acidic lakes and lakes sensitive to acidic deposition in selected eastern subregions (Linthurst et al. 1986). In 1987, subregions in the eastern United States in which acidic lakes were located were determined to be in steady state with sulfate deposition, which was consistent with the watershed processes assumed to control surface water acidification (Rochelle and Church 1987). In 1988, a linear relationship between wet sulfate deposition and surface water sulfate concentrations was demonstrated for lakes in the eastern United States on a subregional basis (Sullivan et al. 1988) (Figure 11). The relationship was consistent with predictions and measurements of prevailing wind directions and subregions with the highest sulfate deposition from the Ohio Valley to the Atlantic Ocean (NADP 1988). In 1989, paleolimnological studies in acidic lakes within these same eastern subregions determined a temporal change in diatom species that reflected

Table 6. Hill's (1965) criteria adapted for evaluating the likelihood of probable cause from associations in ecological assessments (after RAF 1992, Suter 1993).

Hill's Criteria*	Associations
Strength	A high magnitude of effect is associated with exposure to the stressor, e.g., a large proportion of the population responding in the exposed area relative to the reference area.
Consistency	The association of observed effect and stressor is repeatedly observed under different stressor circumstances.
Specificity	The more specific the effect, the more likely it is to be diagnostic of the stressor. Also, the more specific the stressor, the easier it is to associate with an effect.
Temporality	The stressor always precedes the effect in time.
Biological Gradient	The effect should increase or decrease with corresponding changes in the stressor.
Plausibility	The association is consistent with our current understanding of physical, chemical and biological principles and the characteristics of the stressor and effect.
Coherence	The hypothesis or postulated relationship between stressor and effect is consistent with available evidence.
Experimental Evidence	Changes in effects following changes in the stressor, observed through experimental manipulation or through recovery of the population following abatement of the stressor.
Analogy	Similar stressors are associated with similar effects.

*Not all these criteria need to be satisfied, but each additional criteria that is satisfied adds to the strength of the inference that there is probable cause. Negative evidence does not rule out a causal relationship but likely indicates incomplete knowledge of the association between the stressor and the effect (Rothman 1986).

Table 7. Example of weight of evidence approach for relating acidic deposition to surface water acidification.

	Postulate
1980	Acidic deposition from atmospheric emissions of sulfur dioxide results in surface water acidification.
Year	**Evidence**
1984	Watershed processes controlling surface water acidification elucidated.
1986	Anthropogenic sources of SO_2 are causally related to wet deposition of sulfate.
1986	Surface water surveys identified acidic and sensitive lakes in selected subregions of the eastern United States.
1988	Wet sulfate deposition is linearly related to surface water sulfate concentrations in eastern lakes.
1988	Sulfate deposition gradients correspond with prevailing wind directions based on predicted and observed measures.
1988	No western lakes are acidic, corresponding with low sulfate deposition.
1989	Paleolimnological evidence correlates changes in diatom assemblages and pH with changes in surface water acidification.
1989	Historical changes in surface water acidification correspond with historical changes in emissions and coal combustion.
1989	Watershed models predict similar distributions of acidic and sensitive lakes based on historical deposition patterns.
1990	Laboratory and field experiments indicate surface water acidification (pH changes, associated aluminum and metal changes) is associated with loss of sensitive fish species and changes in community structure.
	Weight of Evidence Conclusion
1991	NAPAP concludes surface water acidification has been caused, in some aquatic systems, by anthropogenic sources of SO_2 and sulfate deposition.

declining surface water pH in lakes and corresponded with temporal increases in regional emissions over the same time period (Charles et al. 1989). Watershed models predicted similar distributions of acidic and sensitive lakes in the surveyed regions based on historical deposition patterns and indicated that if acidic deposition continued, additional lakes and streams in selected subregions might become acidic in the future (Church et al. 1989). Laboratory and field experiments indicated that the changes in aquatic community structure—loss of fish species sensitive to pH, changes in aluminum and other metal concentrations—were consistent with observations made on lakes receiving acidic depositions (Schindler 1988, Baker et al. 1990). Similar changes were not occurring in the western lakes where sulfate deposition was significantly lower; no acidic lakes were found during a western lakes survey (Landers et al. 1987).

By 1990, there was sufficient evidence to support the statement that acidic deposition had contributed to surface water acidification in some eastern aquatic systems, sensitive fish species had been lost, and this condition would continue unless emissions decreased (NAPAP 1991). While each of the individual pieces of information was not sufficient to support these conclusions, the weight of evidence clearly supported the conclusions and satisfied the Mosteller-Tukey criteria and many of Hill's criteria. Weight-of-evidence methods are complemented by process-of-elimination procedures.

Process of Elimination

This method reduces the number of factors that might be contributing to an observed change in a condition indicator by associating stressors common to many indicators. Process of elimination provides insight and possible direction for other programs, offices, or agencies in determining the underlying causal factors. Establishing criteria for distinguishing among possible stressors is an initial step.

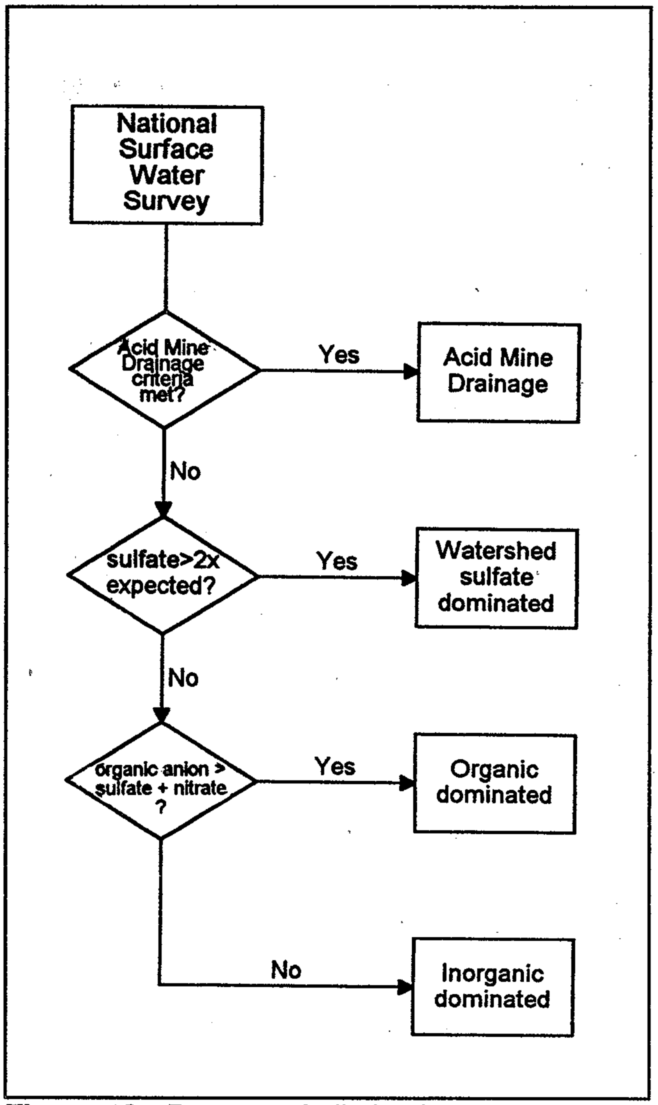


Figure 12. Process of elimination of possible sources of acidity to acidic lakes and streams.

Continuing the acidic deposition example, a process of elimination approach was used to identify the dominant source(s) of acidity contributing to the target population of acidic lakes and streams in the eastern United States. Acidic deposition was one source of acidity, but there also were other acidic sources that might have contributed to acidic ecosystems such as acid mine drainage, watershed sulfur sources, or organic acids. Criteria were established to distinguish each of the possible sources and determine what proportion of the target population of acidic lakes and streams was likely acidic because of this source (Baker et al. 1990). For example, streams that had sulfate concentrations > 2000 ueq/l or specific conductivity values > 500 uS/cm were assumed to be significantly influenced by acid mine drainage (Figure 12). If sulfate concentrations exceeded two times the expected value based on atmospheric deposition and evapoconcentration, then watershed sources of sulfate were assumed to significantly influence surface water acidity. If organic acid concentrations exceeded the sum of sea-salt corrected sulfate plus nitrate, then organic acidity was assumed to influence surface water acidity. Chloride acidity also was considered (Baker et al. 1990). Initially, there were 1,132 lakes and 4,768 stream reaches that were estimated to be acidic (Baker et al. 1990). Through the process of elimination, about 3% of the acidic lakes were assumed to be influenced by watershed sources, 22% of the acidic lakes were influenced by organic acids, with about 75% of the acidic lakes being influenced by acidic deposition (Figure 13). For the acidic stream reaches, the process of elimination combined with weight of evidence, indicated about 26% and 27% of the acidic stream reaches were assumed to be influenced by acid mine drainage and organic acids, respectively, with about 47% of the stream reaches influenced by acidic deposition (Figure 13, Baker et al. 1990). The process of elimination, combined with the weight of evidence, indicated that acidic deposition was a likely factor in the number of acidic lakes and streams in the eastern United States.

The assumptions and uncertainties inherent in the association analyses also are documented in the Data Analysis phase. This information contributes to the interpretation of assessment results. Furthermore, users of the information need to understand how these assumptions and uncertainties can influence or support conclusions across resources or regions. The next phase in EMAP's assessment framework addresses how these assessment results are communicated to the users of the information.

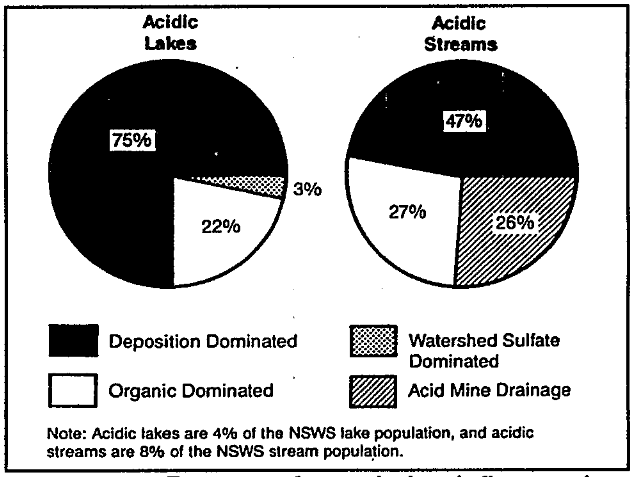


Figure 13. Percent of population influenced by dominant source of acidity.

Interpretation and Communication

EMAP's success will be measured by the contributions of Program information to decisions on environmental management and protection at regional and national scales. For assessment results and conclusions to be used, they must be communicated and understood by the client or user, including full disclosure of the assumptions and uncertainties and their implications for the assessment conclusions (Figure 14). Assessments must provide information that relates to the status, trends, changes, and possible factors affecting those resource attributes valued by users of the information. The first step in this process is to interpret the analysis results.

Interpretation

Scientifically defensible interpretation involves experience and judgement. Judgement is used to answer assessment questions in relation to social values, desired resource uses, and other criteria. EMAP is developing an approach to delineate nominal, marginal, and subnominal categories for the condition of ecological resources. These categories and criteria provide a basis for incorporating different societal perspectives and values in the assessment process.

Classification of Condition

Nominal, marginal, and subnominal conditions are defined and illustrated in Figure 15 as:

✓ **Nominal condition** means the social value (e.g., desired use) is being achieved when compared with specific criteria.

✓ **Subnominal condition** means the social value is NOT being achieved when compared with specific criteria.

✓ **Marginal condition** exists when the nominal and subnominal criteria are NOT coincident.

Typically, identification of the extremes or ends of the condition continuum is relatively straightforward, and general consensus can be achieved among individual scientists or agencies. There is general agreement, for example, that rivers with no fish and no dissolved oxygen, matted with sewage-related fungus, and that catch fire regularly are subnominal systems; conversely, relatively pristine areas, minimally impacted by humans, with rich species diversity, that are aesthetically pleasing, with abundant wildlife are acknowledged as nominal systems. It is in the intermediate portions of this continuum, not the extremes, that the assessment of resource condition becomes more difficult.

A number of approaches, strategies, and methods for developing nominal, marginal, subnominal ranges to use in EMAP's assessments have been initiated (Table 8), but clearly this is an on-going and evolving process. These approaches must integrate the natural variability in ecological systems as well as the variability in societal values into these nominal-subnominal ranges.

In addition to providing ways for incorporating social values in the interpretation of assessment results, establishing a nominal-subnominal continuum also provides a strategy to normalize information across resource groups or across regions within a resource group. For example, there might be different nominal/subnominal categories and classification criteria for different subregions within a region (Figure 16). The nominal-subnominal strategy permits the proportion of the resource in each of the three subregions that is classified as subnominal (marginal or nominal) to be aggregated into an estimate of subnominal condition for the larger administrative region. Similarly, estimates of subnominal resource condition in these regions can be aggregated for national estimates. EMAP scientists also are testing the nominal/subnominal strategy to see if it provides a method for aggregating data across resource groups. For example, the area (hectares) of wetlands, surface waters, forests, arid ecosystems, or other ecological resources in subnominal condition in a subregion, region, or at the national scale can be estimated based on this strategy. While procedures for combining or associating these estimates are still being developed, the general approach does permit comparisons based on social values to be included in interpretations of assessment results together with the attendant assumptions and uncertainties.

Assumptions and Uncertainties

A complete discussion of assumptions and uncertainties is beyond the scope of EMAP's *Assessment Framework*; these topics are developed in Finkel (1990), Holling (1978), Suter (1990), and Bartell et al. (1992). Uncertainty analysis identifies and quantifies (if possible) the uncertainties encountered in conducting an ecological assessment, provides an evaluation of the overall impact of those uncertainties on the interpretations and conclusions derived from the assessment, and (when feasible) provides information to reduce uncertainty.

In its *Framework for Ecological Risk Assessment*, EPA's Risk Assessment Forum lists four primary sources of uncertainty in ecological risk assessments: incomplete or flawed conceptual model formulation, incomplete information and data, natural variability (stochasticity), and introduced errors (RAF 1992).

Incomplete knowledge is the source of uncertainty that can not be quantified; it is one of the greatest concerns in decision-making. This source of uncertainty includes lack of knowledge, which can only be reduced through research and investigation. It also includes assumptions, inferences about non-measured species or systems, incomplete conceptual model structures and similar sources of uncertainty. Weight of evidence approaches can minimize but not eliminate this uncertainty.

Stochastic uncertainty can be described and quantified but can not be reduced because it is inherent in the system being assessed (Suter 1993).

Analytical error includes measurement, sampling, analysis, model input, parameter and similar sources of error. These sources can be quantified through QA/QC programs and stochastic modeling methods. This is the source of error that can be reduced through proper analytical procedures.

EMAP has integrated a research component in the program to continually work toward reducing uncertainty due to incomplete information and data. In addition, data from EMAP's monitoring activities undergo strict QA/QC to quantify natural variability, reduce analytical error, and check assumptions.

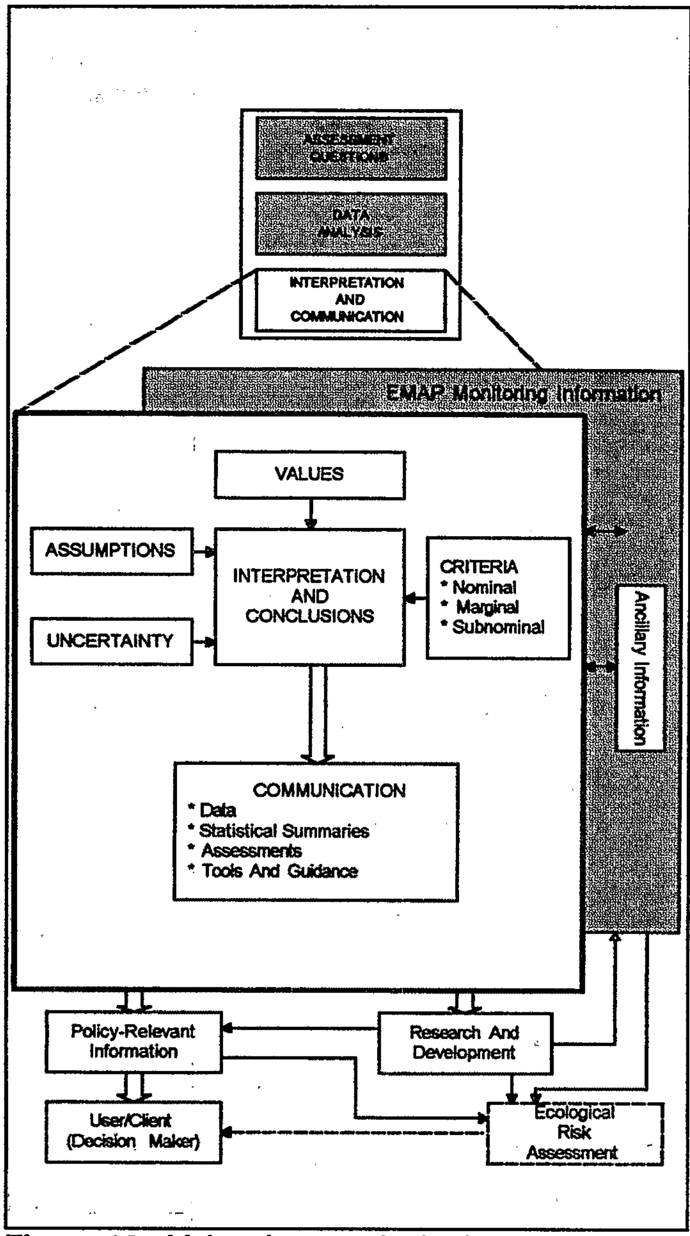


Figure 14. Major elements in the interpretation and communication phase of EMAP's assessment framework.

Communication

The purpose of environmental risk communication is to provide people with the uncertainties, assumptions, facts, and interpretations they need to make informed judgements about risks to the environment (Morgan et al. 1992). Only then can assessment results contribute to environmental management decisions. Moreover, communication between decision makers and researchers is the most important element in keeping research and assessment relevant to policy needs (SPA 1992).

Rubin et al. (1992) suggest that NAPAP's failure to influence recent environmental legislation resulted from lack of communication: findings were not reported in a timely fashion and results and conclusions were not understandable to policy makers. In a study conducted as part of EPA's Global Climate Change Program, workshops were held separately with

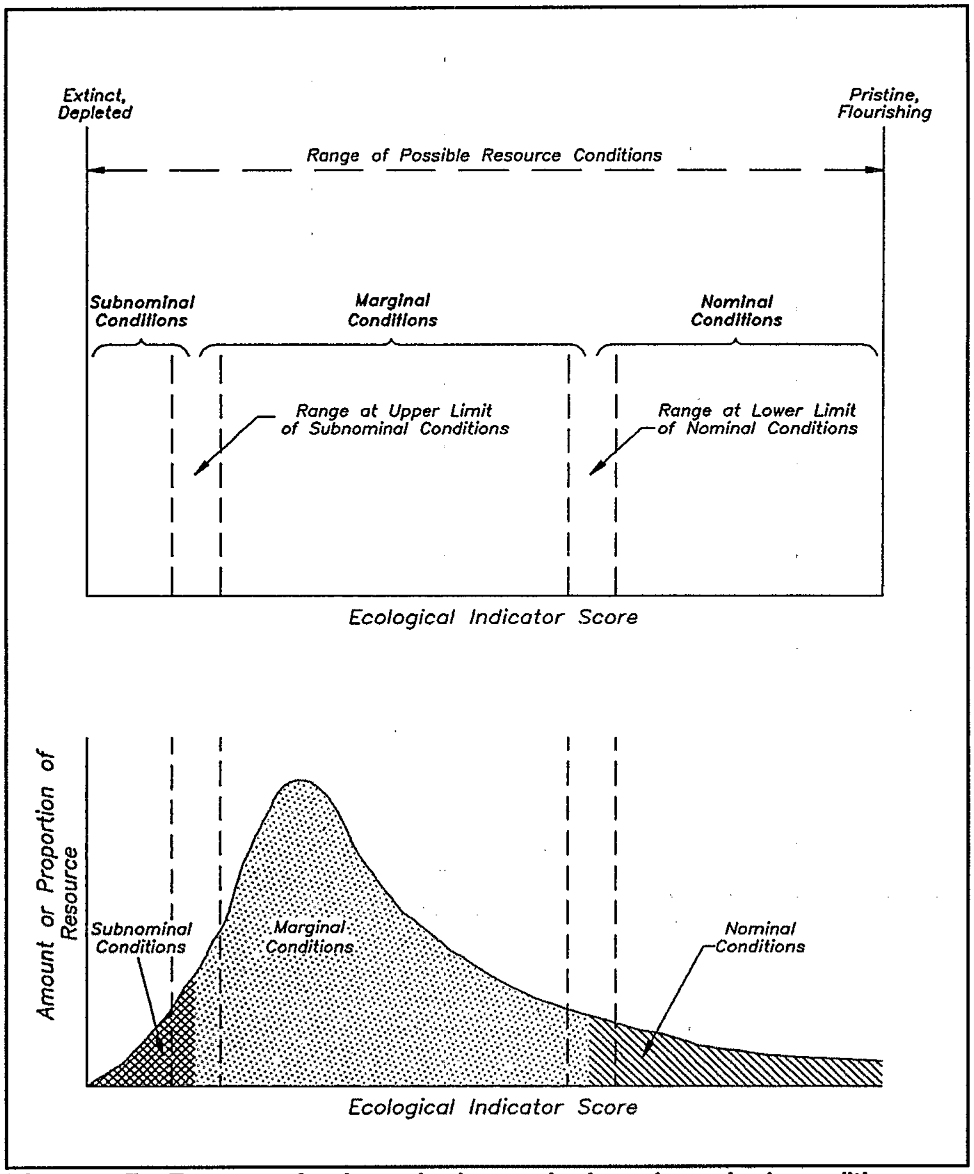


Figure 15. Ranges of subnominal, marginal, and nominal conditions that might be delineated along a condition continuum.

decision makers and scientists to evaluate the needs and expectations each group had of the other (SPA 1992). Both groups discovered many useful communication lessons by conducting this exercise (Table 9). These lessons will be used as a primer for improving communication between EMAP and its information users.

The results of EMAP assessments will be tailored to client's needs, contain important information relevant to the assessment issues, and be understandable and useable. The forms and media by which these results are to be most effectively communicated will differ according to the target audience. Complex scientific reports providing significant detail on the analytical methods and copious presentations of data and results may meet the needs of the scientific community, but they may not be satisfactory for presenting information to other users. Spatial displays, photographs, line art, conceptual models, graphics, and other visuals also can effectively present relationships or interpretations of data. The use of decision support systems such as computerized data summaries and interactive graphic presentations can help decision makers quickly examine management alternatives. The use of focus groups, user networks, and extensive client interactions are other ways to fine-tune assessment results to meet clients' needs.

Table 8. Suggestions for how EMAP could establish preliminary nominal-subnominal categories.

Type		Suggestion
Approaches	1.	Adopt documented desired uses, societal perspectives, and social values for different resource classes.
	2.	Use public meetings, hearings, focus groups, special interest groups and other outreaching activities to determine what the public considers to be nominal and subnominal condition.
Strategies	3.	Use retrospective analyses and paleoecological analyses to define a nominal background or baseline condition that can be compared with current and future conditions.
	4.	Conduct specific experimental research directed at determining nominal/subnominal scores and ranges.
	5.	Set priorities for indicators based on their relative position in the indicator development scheme; criteria might establish priorities by how indicators respond to change. Scientists currently are close to achieving consensus on the nominal/subnominal continuum for some indicators, but others are still in the research stage.
Methods	6.	Use Delphi procedures to refine the range and scores for subnominal and nominal classes.
	7.	Test hypotheses where *a priori* expected values are compared with actual measured indicator scores in "good" and "bad" systems.
	8.	Evaluate temporal (e.g., succession) and spatial (geographic location and landscape position) processes that might influence the nominal/subnominal scores and ranges.
	9.	Assess the literature for consensus in the professions.
	10.	Collate scores and ranges in peer review papers.
	11.	Conduct additional workshops, to review state-of-the-art research in environmental indicators

Assessment Products

EMAP will produce four basic assessment products (Figure 14):

- Quality-assured data.
- Annual statistical summaries.
- Ecological resource assessments.
- Assessment tools and guidance.

Quality-Assured Data

Many clients and users want access to the data being collected by EMAP. The demand for data in EPA's STORET and USGS WATSTORE information management systems attests to the interest users have in performing their own assessments. EMAP's policy is to ensure the integrity, utility, and accountability of its data so that decision makers can have confidence in the summaries and assessments based on those data. EMAP data will be verified and validated prior to its release to the user community. The data will not be the individual site data but rather aggregated data to maintain data confidentiality requirements. One of the early products from EMAP will be this aggregated data.

Annual Statistical Summary Reports

EMAP's annual statistical summaries will contain such descriptive statistics as means, medians, distributions, ranges, and standard deviations for indicators monitored within the sampling frame. EMAP expects these reports to be similar to annual summaries prepared by the Bureau of Labor Statistics, National Agriculture Statistics Surveys, and USGS Water Data Summaries; these data summaries have proved to be exceptionally useful even without substantial interpretation of the results. The status of ecological resource condition can be assessed by including the pertinent nominal/subnominal criteria.

Statistical summaries will be prepared for standard Federal regions. Additional summaries might be provided for regions based on biogeographic or political designations appropriate for a specific resource category (e.g., Great Basin biographic region for arid ecosystems or USDA Forest Service Northeast Region for forests). The format will be refined as monitoring results for other resource groups become available and are presented to the users. Annual statistical summaries will be produced within one year following the date of the last field sampling to ensure that EMAP results are provided to the users in a timely manner.

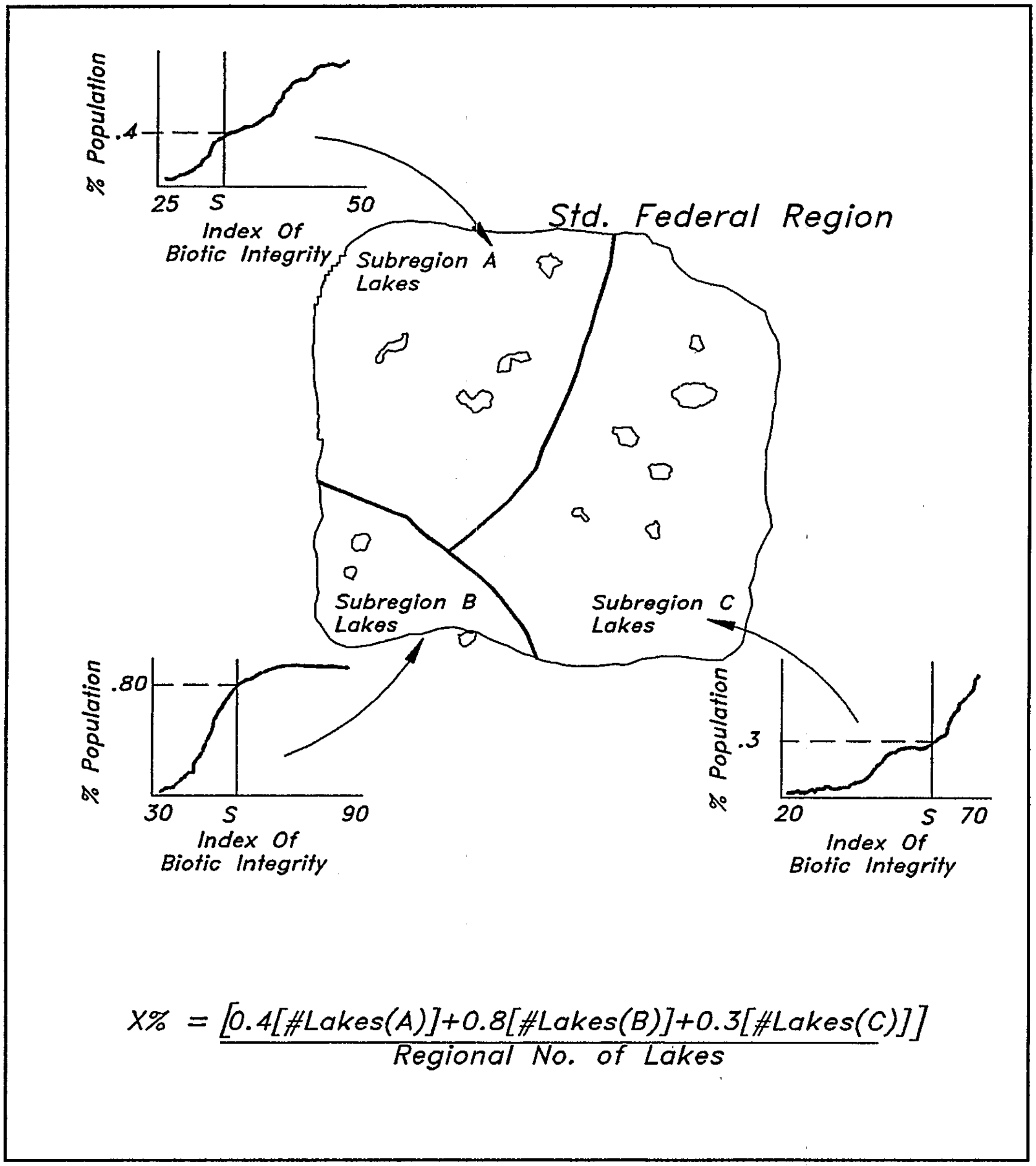


Figure 16. One method of aggregating measures of resource condition among different subregions (standard Federal region; EPA, USDA, or Forest Service region; or biogeographic province).

Ecological Resource Assessment Reports

EMAP will produce two general types of assessment reports: preplanned assessments, called *Status of the Ecological Resource* reports, and special request assessments that address new issues and concerns of EMAP's information users. The principle difference between these assessments is that assessments for status of an ecological resource are planned to be based primarily on EMAP data, produced on a periodic basis (e.g., every 4-5 years), and focused on the regional and national condition of ecological resources. EMAP expects special assessments to address specific issues or problems that arise on an *ad hoc* basis. Both types of assessments will assist in the continual improvement and evolution of the monitoring and research activities in EMAP. Status of the ecological resource reports will be prepared for individual resources and for multiple resources both within and across administrative or biogeographic reporting regions. These reports will assess ecological resource condition and suggest possible factors contributing to this condition; they will also evaluate the cumulative effectiveness of regulations and policies in managing and protecting the environment.

Assessment Tools and Guidelines

As EMAP develops its assessment capabilities, the techniques and guidelines developed in the process will be of value to environmental managers and other research and

Table 9. Actions suggested by lessons learned in communicating between decision makers and scientists through the global climate program (SPA 1992).

Action	Lesson Learned
Supply interim information.	Decision makers need interim information on relevant findings, in addition to periodic assessments. Decisions do not conform to the dates for assessment reports. Interim information is required for informed decisions driven by short-time frames.
Tie assessment to important policy time frames.	Assessments should be keyed to important dates such as international policy discussions, reauthorization of environmental legislation (e.g., Clean Water Act Amendments, Wetland Protection Act Amendments), policy formulation and other decision making activities.
Provide useful information before reliable predictions.	Assessments can provide useful information even if the "penultimate" model predictions of the effects of stressors are not yet available. Existing information can be synthesized and integrated with results from simple empirical models, statistical analyses and similar analytical approaches to provide useful, interim information for decision makers.
Know decisions are not either/or.	Decision makers' choices are not simply either to pursue research or to implement management alternatives. The challenge is to define the appropriate levels of each over time. Researchers need to provide a broad array of information to address the complex and interacting decisions. Decision makers, for their part, need to recognize the long time scales involved in research and, thus, the importance of continuity of funding and program goals.
Place comparative risk in relative context.	Assessing change in a relative risk context is difficult, but extremely important.
Address urgent need for education.	A concerted effort is needed to educate decision makers on the facts and uncertainties of any environmental issue. Considering that public concern is often the impetus for formulating policy, scientists need to communicate technical information to the public more effectively, as well as more frequently. In addition, scientists need to learn more about the decision making process and the types of information most useful for policy. Frequent two-way communication between decision makers and researchers is fundamental if research is to play an effective role in the decision making process.
Manage uncertainty.	There are more ways to manage uncertainties than simply trying to reduce them. For example, building resilient institutions and methodologies would provide a flexible response to any future change albeit at potentially significant costs. Contingency plans could allow decision makers to prepare for possible climate outcomes through R&D technologies, without needing to employ them.
Know research does not always provide the answer.	Decision makers need to realize that additional research actually could increase the amount of uncertainty in some areas. Researchers should inquire about how much certainty decision makers are requiring to take a specific action. To this end, uncertainties that do not matter for decision making should be so identified.
Develop an ongoing assessment process for research.	To improve communication and better inform decision makers, research efforts should include an iterative assessment process. These assessments would not only help identify the relevant questions, but also serve to structure the research results and, thus, facilitate clearer communication between the two communities. Furthermore, the assessment process would provide valuable input to the planning of policy-relevant research.

monitoring programs. EMAP's strategy emphasizes monitoring ecological indicators with state-of-the-art technology to provide a new generation of ecological monitoring methods that may be applied in other programs. The monitoring design provides agencies an opportunity to evaluate problems at finer or smaller scales than the regional resolution of EMAP by enhancing the monitoring grid. Regional and other large-scale tools developed to integrate monitoring data across landscapes and resources will be invaluable to other large-scale monitoring programs. Guidelines developed to guide the aggregation, analysis and interpretation of ecological resource assessments will help EMAP evolve and maintain its policy relevance. Peer-reviewed scientific articles, technical presentations, and reports written by EMAP scientists, partners, or interested individuals also will help advance assessment technology.

4 — Evolving Program and Process

Currently, EMAP is demonstrating the capability of a network to monitor the Nation's ecological resources; however, it will take a number of years before routine monitoring of all resources in all regions of the country will be fully implemented. As a result, the ability of the Program to conduct ecological resource assessments will correspond to the phased implementation of its research and monitoring activities. Initial assessments will focus on determining extent, geographic coverage, and condition for individual ecological resources. Single region, single resource assessments will be conducted before assessments encompassing multiple regions or national levels. Assessments of multiple ecological resources in a single region will be conducted as other resources start monitoring in that region.

The assessment framework proposed in this report provides a common strategy for planning and conducting a wide variety of ecological assessments within EMAP. The framework also demonstrates how EMAP complements the assessment approach proposed in EPA's *Ecological Risk Assessment Framework* (RAF 1992). EMAP assessments can contribute directly to the problem formulation phase of EPA-RAF's proposed ecological risk assessment framework by identifying and quantifying factors which might be contributing to condition of ecological resources. Other EMAP products (e.g., ecological resource condition and stressor data) will provide significant information needed to conduct ecological risk assessments that verify model predictions and the cumulative effectiveness of environmental protection regulations and environmental management decisions.

Glossary

A

abiotic: Nonliving characteristic of the environment; the physical and chemical components that relate to the state of ecological resources. (Term added 1993. See related: **biotic, condition indicator, indicator.)**

acid deposition: "A complex chemical and atmospheric phenomenon that occurs when emissions of sulfur and nitrogen compounds and other substances are transformed by chemical processes in the atmosphere, often far from the original sources, and then deposited on earth in either a wet or dry form. The wet forms, popularly called "acid rain," can fall as rain, snow, or fog. The dry forms are acidic gases or particulates" (EPA 1992, 1).

agroecosystem: A dynamic association of crops, pastures, livestock, other flora and fauna, atmosphere, soils and water. **Agroecosystems** are contained within larger landscapes that include uncultivated land, drainage networks, rural communities, and wildlife.

ancillary data: Data collected from studies within EMAP but not used directly in the computation of an indicator. **Ancillary data** can help characterize parameters and assist in the interpretation of data sets; time, stage of tide, and weather conditions are examples of **ancillary data.** (Term added 1993. See related **auxiliary data.)**

annual statistical summary: A document that presents a brief and comprehensive report of EMAP data collected on a single EMAP **resource** for a specific year. **Annual statistical summaries** may include **cumulative distributions**, estimates of the extent of **nominal** or **subnominal** condition, comparisons among regions, or comparisons of data over time.

arid ecosystems: Terrestrial systems characterized by a climate regime where the potential evapotranspiration exceeds precipitation, annual precipitation ranges from less than 5 cm to not more than 60 cm, and daily and seasonal temperatures range from -40°C to 50°C. The vegetation is dominated by woody perennials, succulents, and drought resistant trees.

assessment: Interpretation and evaluation of EMAP results for the purpose of answering policy-relevant questions about ecological resources, including (1) determination of the fraction of the population that meets a socially defined value and (2) association among indicators of ecological condition and stressors.

assessment endpoint: Formal expressions of the actual environmental value that is to be protected (Suter 1990). Risk Assessment Forum defines this as an "explicit expression of the environmental value that is to be protected" (RAF 1992, 37). Operationally in EMAP, an **assessment endpoint** is the range, proportion, or percentage of a resource that is known with confidence to be in a specified condition (See related: **condition indicator, nominal, measurement endpoint, subnominal.)**

attribute: Any property, quality, or characteristic of a **sampling unit.** The **indicators** and other measures used to characterize a **sampling site** or resource unit are representations of the attributes of that unit or site. A characteristic of a map feature (point, line, or polygon) described by numbers or text; for example **attributes** of a tree, represented by a point, might include height and species. (See related: **continuous, discrete resource.)**

auxiliary data: Data derived from a source other than EMAP, that is, from an experiment or from another monitoring or sampling program, either Federal or State. The sampling methods and quality assurance protocols of auxiliary data must be evaluated before the data are used. It is always important to establish the **population** represented by **auxiliary data.** (Preferred term 1993; replaces "non-EMAP data" and "found data," deleted in 1993; see related: **ancillary data.)**

B

bias: In a sampling context, the difference between the conceptual weighted average value of an estimator over all possible samples and the true value of the quantity being estimated. An estimator is said to be unbiased if that difference is zero. The "systematic or persistent distortion of a measurement process which deprives the result of representativeness (i.e., the expected **sample** measurement is different than the sample's true value. A **data quality indicator**" (QAMS 1993, 3).

biodiversity: The variety and variability among living organisms and the **ecosystems** in which they occur. **Biodiversity** includes the numbers of different items and their relative frequencies; these items are organized at many levels, ranging from complete ecosystems to the biochemical structures that are the molecular basis of heredity. Thus, **biodiversity** encompasses expressions of the relative abundances of different **ecosystems**, species, and genes (OTA 1987).

biotic: Of or pertaining to living organisms. (See related: **abiotic, indicator, condition indicator, stressor indicator.** In 1993, **biotic condition indicator** replaced "response indicator.")

C

***cdf*:** Cumulative distribution function. (See: **cumulative distribution**).

change: As used in EMAP, the difference in the distribution of measurements of **condition indicators** between two time periods. (See related: **status, trends.**)

characterization: Determination of the attributes of **resource units, populations,** or **sampling units.** A prominent use in EMAP is characterization of 40-hexes.

classification: The process of assigning a resource unit to one of a set of classes defined by values of specified attributes. For example, forest sites will be classified into the designated forest types, depending on the species composition of the forest. Systematic arrangement of objects into groups or categories according to established criteria.

community: "All of the **populations** occupying a given area (Odum 1959, 6); Odum's definition was adapted by the Risk Assessment Forum to read: "an assemblage of populations of different species within a specified location in space and time" (RAF 1992, 37). "In ecology, a group of interacting populations in time and space. Sometimes a particular subgrouping may be specified, such as the fish **community in a lake** or the soil arthropod **community** in a forest" (EPA 1993, 6).

comparability: The degree to which different methods, data sets and/or decisions agree or can be represented as similar; a **data quality indicator**" (QAMS 1993, 6).

completeness: The amount of valid data obtained compared to the planned amount, and [it is] usually expressed as a percentage; a **data quality indicator**" (QAMS 1993, 6).

conceptual model: A "**conceptual model** describes a series of working hypotheses of how the stressor might affect ecological components. The **conceptual model** also describes the ecosystem potentially at risk, the relationship between **measurement [endpoints]** and **assessment endpoints**, and exposure scenarios" (RAF 1992, 37).

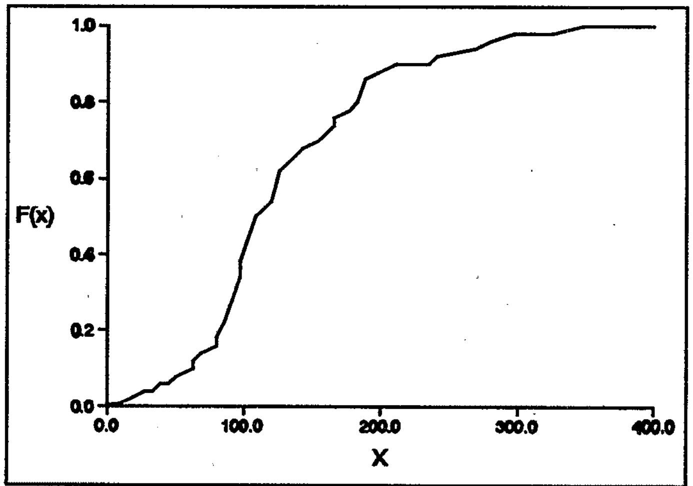
condition: The distribution of scores describing resource attributes without respect to any societal value or desired use, that is, a state of being. (New term 1993.)

condition indicator: A characteristic of the environment that provides quantitative estimates of the state of ecological **resources** and is conceptually tied to a **value.** (New Term 1993; replaces environmental indicator. See related: **indicator, abiotic, biotic, stressor indicator.**)

continuous: A characteristic of an **attribute** that is conceptualized as a surface over some region. Examples are certain attributes of a resource, such as chemical **stressor indicators** measured in estuaries.

cross-cutting group: A group of scientific and administrative personnel headed by a technical coordinator and charged with addressing specific cross-program, integrative issues in EMAP. These groups are named Assessment and Reporting, Design and Statistics, Indicator Development, Information Management, Landscape Characterization, Logistics and Methods, and Quality Assurance. (See related **resource group.**)

cumulative distribution: A means of representing the variation of some **attribute** by giving running totals of the **resource** with **attribute** values less than or equal to a specified series of values. For example, a *cumulative areal distribution* of lakes would give, for any value α of area, the total area covered by lakes with individual area less than or equal to α. A *cumulative frequency distribution* for lake area would give the total number of lakes with area less than or equal to α. The *cumulative distribution function (cdf)* of some specified **attribute** of a **population** is the function $F(x)$ that gives the proportion of the **population** with value of the **attribute** less than or equal to x, for any choice of x. For example, if the **attribute** was lake area in hectares, $F(\alpha)$ would give the proportion of lakes with area less than or equal to α ha. (In some cases, the word "cumulative" may be omitted in discussions of the ***cdf***, and the ***cdf*** is called the *distribution function.*)



Cumulative distribution function

D

data quality: "The totality of features and characteristics of data that bears on their ability to satisfy a given purpose; the sum of the degrees of excellence for factors related to data" (QAMS 1993, 7).

data quality indicators: "Quantitative statistics and qualitative descriptors that are used to interpret the degree of acceptability or utility of data to the user. The principal **data quality indicators** are **bias, precision, accuracy, comparability, completeness,** and **representativeness**" (QAMS 1993, 7).

data quality objective (DQO): "Quantitative and qualitative statements of the overall level of uncertainty that a decision-maker is willing to accept in results or decisions derived from environmental data. **DQOs** provide the statistical framework for planning and managing environmental data operations consistent with the data user's needs" (QAMS 1993, 8). A **data quality objective** may include goals for **accuracy, precision,** and limits of detection. It may also include goals for **completeness, comparability,** and **representativeness. Data quality objectives** are established before **sampling** is begun and may influence the level of effort required to select a **sample.**

discrete resource: A **resource** consisting of a collection of distinct units, such as lakes or stream reaches. Such a **resource** will be described as a finite population of such units. (See related: **attribute, continuous, resource.**)

domain: The areal extent of a **resource**; the region occupied by a **resource.**

E

ecological health: A metaphor used to invoke ideas about the integrity, complexity, and autonomy of an ecosystem (Norton 1991). A definition of ecosystem health as an actual entity with specific scale has not been resolved; the terms are useful because they facilitate "a set of rules of thumb, which can be thought of analogically, for analyzing what is going wrong when environing (sic) systems undergo rapid change" (Norton 1991, 116).

ecological risk assessment: A process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors (RAF 1992, 37). (See related: **risk assessment.**)

ecology: "The relationship of living things to one another and their environment, or the study of such relationships" (EPA 1993, 9).

ecosystem: "The interacting system of a biological community and its non-living environmental surroundings" (EPA 1993, 10).

entire: Being whole, not convoluted or divided into distinct spatial parts. In EMAP, this property affects the precision of certain sample statistics. (See related: **fragmented.**)

environment: "The sum of all external conditions affecting the life, development, and survival of an organism" (EPA 1993, 10). (See related: **habitat.**)

environmental assessment: An environmental analysis prepared pursuant to the National Environmental Policy Act to determine whether a Federal action should significantly affect the environment and thus require a more detailed environmental impact statement.

estuary: "Regions of interaction between rivers and near-shore ocean waters, where tidal action and river flow mix fresh and salt water. Such areas include bays, mouths of rivers, salt marshes, and lagoons. These brackish water **ecosystems** shelter and feed marine life, birds, and wildlife" (EPA 1992, 11). In EMAP, large estuaries are defined as those estuaries greater than 260 km^2 in surface area and with aspect ratios (i.e., length/average width) of less than 20. Large tidal rivers are defined as that portion of the river that is tidally influenced (i.e, detectable tide > 2.5 cm), greater than 260 km^2, and with an aspect ratio of greater than 20. Small estuaries and small tidal rivers are those systems whose surface areas fell between 2.6 km^2 and 260 km^2. (See related: **wetlands.**)

F

forest: Land with at least 10% of its surface area stocked by trees of any size or formerly having had such trees as cover and not currently built-up or developed for agricultural use (USDAFS 1989).

fragmented: Being divided or convoluted into distinct parts, rather than **entire.** In EMAP, the spatial fragmentation of **resources** and the spatial/temporal fragmentation of **resource attributes** affect the precision of certain **population** statistics, so that attention must be given to this state. (See related: **entire.**)

frame: A representation of a **population**, used to implement a sampling strategy as, for example, (1) a list frame, containing the identity of all the units in the **population**—for instance, a list of all the lakes in the United States between 10 and 2000 ha—or (2) an area frame that consists of explicit descriptions of a partition of the areal extent of an areal universe—like the NASS **frame.** (See related: **sampling unit.**)

G

geographic information system (GIS): A collection of computer hardware, software, and geographic data designed to capture, store, update, manipulate, analyze, and display geographically referenced data.

Great Lakes: In EMAP, the resource that encompasses the five **Great Lakes**—Superior, Michigan, Huron, Erie, and Ontario, including river mouths up to the maximum extent of lake influence; **wetlands** contiguous to the lakes; and the connecting channels, Lake St. Clair and the upper portion of the St. Lawrence Seaway.

grid: A data structure commonly used to represent map features. A cellular-based data structure composed of cells or pixels arranged in rows and columns (also called a "raster").

grid, triangular (EMAP): A lattice of points in exact equilateral triangular structure on a plane. The EMAP grid points are 27.1 km apart.

H

habitat: "The place where a population (e.g., human, animal, plant, microorganism) lives and its surroundings, both living and non-living" (EPA 1992, 14).

I

index: Mathematical aggregation of **indicators** or metrics.

indicator: Any expression of the environment that quantitatively estimates the condition of ecological resources, the magnitude of stress, the exposure of a biological component to stress, or the amount of change in condition (after Hunsaker and Carpenter 1990, Olsen 1992). "Any expression of the environment" includes **abiotic** and **biotic** characteristics that can provide quantitative information on ecological **resources.** (Revised definition 1993, 1994. Preferred term for environmental indicator, deleted 1993.) "In biology, an organism, species, or community whose characteristics show the presence of specific environmental conditions, good or bad" (EPA 1992, 15). (See related: **condition indicator, stressor indicator, biotic, abiotic.**)

indicator development: The process through which an **indicator** is identified, tested, and implemented. A candidate **indicator** is identified and reviewed by peers before it is selected for further evaluation as a research **indicator.** Existing data are analyzed, simulation studies are performed with realistic scenarios, and limited field tests are conducted to evaluate the research **indicator.** In the past, this research **indicator** was called a "probationary core **indicator**" or a "development **indicator**" as it was evaluated in regional demonstration projects. An **indicator** is considered a core **indicator** when it is selected for long-term, ecological monitoring as a result of its acceptable performance, demonstrated ability to satisfy the **data quality objectives.**

integration: The formation, coordination, or blending of units or components into a functioning or unified whole. In EMAP, **integration** refers to a coordinated approach to environmental **monitoring**, research, and **assessment**, both among EMAP **resource groups** and with other environmental **monitoring** programs. **Integration** in EMAP also refers to the technical processes involved in normalizing and combining data for interpretation and **assessment.**

L

lake: In EMAP, a standing body of water greater than 1 hectare (about 2.5 acre) that has at least 1000 m^2 (about 0.25 acre) of open water and is at least 1 meter (about 3 feet) deep at its deepest point. (See related: **surface waters, wetlands.**)

landscape: The set of traits, patterns, and structure of a specific geographic area, including its biological composition, its physical environment, and its anthropogenic patterns. An area where interacting **ecosystems** are grouped and repeated in similar form. In EMAP, Landscapes is the name of a **resource group.**

landscape characterization: Documentation of the traits and patterns of the essential elements of the landscape, including **attributes** of the physical environment, biological composition, and anthropogenic patterns. In EMAP, landscape characterization emphasizes the process of describing land use or land cover, but it also includes gathering data on **attributes** such as elevation, demographics, soils, physiographic regions, and others.

landscape ecology: The study of distribution patterns of communities and **ecosystems**, the ecological processes that affect those patterns, and changes in pattern and process over time (Forman and Godron 1986).

M

marginal condition: The state that exists when the **nominal** and **subnominal** criteria are not contiguous.

measurement: A quantifiable **attribute** that is tied to an **indicator.**

measurement endpoint: A measurable ecological characteristic that is related to the valued characteristic chosen as the assessment endpoint (Suter 1990). RAF added to Suter: "**Measurement endpoints** are often expressed as the statistical or arithmetic summaries of the observations that comprise [sic] the measurement" (RAF 1992, 38). (See related: **assessment endpoint.**)

modeling: "Development of a mathematical or physical representation of a system or theory that accounts for all or some of its known properties. Models are often used to test the effect of changes of components on the overall performance of the system" (EPA 1992, 18).

monitoring: In EMAP, the periodic collection of data that is used to determine the condition of ecological **resources.** "Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media (air, soil, water) or in humans, plants, and animals" (EPA 1993, 18).

N

National Academy of Sciences (NAS): The **National Academy of Sciences/National Research Council** (NRC) performs level 2 peer review to determine if EMAP projects have overall scientific merit and integrate both internally and with other government-sponsored monitoring programs. Two commissions of the **NRC**—the Commission on Geosciences, Environment, and Resources (specifically, its Water Science and Technology Board) and the Commission on Life Sciences—jointly organized the Committee to Review EPA's Environmental Monitoring and Assessment Program in 1991. This **NAS/NRC** committee holds about 12 meetings and produces two or three reports every two years; its primary purpose is to consider the scientific and technical aspects of EMAP as designed as well as considering ways to increase EMAP's usefulness in monitoring conditions and trends in six representative types of ecosystems. The Committee also reviews the overall design objectives of the program, the indicator strategies, data collection methods, data analysis interpretation, and communication plans. Preparation for **NAS/NRC** reviews is coordinated by the Director of OMMSQA, EPA-ORD, who is also responsible for funding.

nominal: Referring to the state of having desirable or acceptable ecological condition. The quantified standard established for a **condition indicator** to represent the desirable or acceptable condition is called a **nominal assessment endpoint.** (See related: **assessment endpoint, marginal, subnominal.**)

NRC (National Research Council, see **National Academy of Sciences.**)

O

Office of Modeling, Monitoring Systems, and Quality Assurance (OMMSQA): The office within EPA's Office of Research and Development responsible for EMAP management within the Agency.

P

parameter: "Any quantity such as a mean or a standard deviation characterizing a population. Commonly misused for 'variable,' 'characteristic,' or 'property'" (QAMS 1993, 15).

pattern: In EMAP, the location, distribution, and composition of structural **landscape** components within a particular geographic area or in a spatial context.

peer review: In EMAP, **peer review** means written, critical response provided by scientists and other technically qualified participants in the process. EMAP documents are subject to formal peer review procedures at laboratory and program levels. In EMAP, Level 1 **peer reviews** are performed by EPA's Science Advisory Board, level 2 by the NAS National Research Council, level 3 by specialist panel peer reviews, and level 4 by internal EPA respondents. (See related: **National Academy of Sciences, Science Advisory Board.**)

population: "A group of interbreeding organisms occupying a particular space; the number of humans or other living creatures in a designated area" (EPA 1992, 22 after Odum [1953] 1959, 6). In statistics and sampling design, the total universe addressed in a sampling effort; an assemblage of units of a particular resource, or any subset of extensive resources, about which inferences are desired or made. RAF defines **population** to be "an aggregate of individuals of a species within a specified location in space and time" (RAF 1992, 38).

precision: The degree to which replicate measurements of the same **attribute** agree or are exact. "The degree to which a set of observations or measurements of the same property, usually obtained under similar conditions, conform to themselves; a **data quality indicator**" (QAMS 1993, 16). (See related: **accuracy, bias.**)

Q

quality assurance (QA): "An integrated system of activities involving planning, **quality control, quality assessment**, reporting and quality improvement to ensure that a product or service meets defined standards of quality with a stated level of confidence" (QAMS 1993, 17).

In EMAP, **quality assurance** consists of multiple steps taken to ensure that all **data quality objectives** are achieved. (See related: **data quality objectives, quality control.**)

quality control (QC): "The overall system of technical activities whose purpose is to measure and control the quality of a product or service so that it meets the needs of users. The aim is to provide quality that is satisfactory, adequate, dependable, and economical" (QAMS 1993, 17).

In EMAP, **quality control** consists of specific steps taken during the data collection process to ensure that equipment and procedures are operating as intended and that they will allow **data quality objectives** to be achieved. (See related: **data quality objectives, quality assessment, quality assurance, QA/QC.**)

QA/QC: Quality Assurance/Quality Control. "A system of procedures, checks, audits, and corrective actions to ensure that all EPA research design and performance, environmental monitoring and sampling, and other technical and reporting activities are of the highest achievable quality" (EPA 1992, 23).

R

reference condition: The set of attributes of ecological **resources** that assist in identifying the location of a portion of the **resource population** along a **condition** continuum from worst possible **condition** to the best possible **condition** given the prevailing topography, soil, geology, potential vegetation, and general land use of the region. **Reference condition** typically refers to the best resource **condition**, but it is used more broadly in EMAP (Term added in 1993).

region: Any explicitly defined geographic area. In the EMAP objectives, **region** refers to the ten standard Federal regions (OMB 1974).

relation: The concept of function, correlation, or association between or among **attributes**, which may be qualitative as well as quantitative.

representativeness: "The degree to which data accurately and precisely represent the frequency distribution of a specific variable in the population; a **data quality indicator**" (QAMS 2993, 20).

resource: In EMAP, an ecological entity that is identified as a target of sampling and is a group of general, broad ecosystem types or ecological entities sharing certain basic characteristics. Eight such categories currently are identified within EMAP: estuaries, Great Lakes, surface waters, wetlands, forests, arid ecosystems, agroecosystems, and landscapes. These eight categories define the organizational structure of **resource monitoring** groups—called **resource groups**—in EMAP and are the **resources** addressed by EMAP **assessments. A resource**

can be characterized as belonging to one of two types, discrete and extensive, that pose different problems of sampling and representation.

resource class: A subdivision of a **resource;** examples include small lakes, oak-hickory forests, emergent estuarine wetlands, field cropland, small estuaries, and sagebrush dominated desert scrub.

resource domain: The areal extent of a **resource;** the **region** occupied by a **resource.**

resource group: A group of scientific and administrative personnel, headed by a **technical director,** responsible for research, **monitoring,** and **assessments** for a given EMAP **resource.** There are eight such groups in EMAP: Estuaries, Great Lakes, Surface Waters, Wetlands, Forests, Arid Ecosystems, Agroecosystems, and Landscapes. (See related **cross-cutting group.**)

resource unit: A unit of a **discrete resource,** for example, a **lake.** A **population** of such a **resource** will be an explicit set of **resource units.**

risk: "A measure of the probability that damage to life, health, property, and/or the environment will occur as a result of a given hazard" (EPA 1992, 25). In statistics, "the expected loss due to the use of a given decision procedure" (QAMS 1993, 20).

risk assessment: "Qualitative and quantitative evaluation of the **risk** posed to human health and/or the environment by the actual or potential presence and/or use of specific pollutants" (EPA 1992, 25).

risk characterization: Determination of the nature of a given **risk** and quantifying of the potential for adverse change to the environment from that **risk.** "A phase of ecological **risk assessment** that integrates the results of the exposure and ecological effects analyses to evaluate the likelihood of adverse ecological effects associated with exposure to a **stressor.** The ecological significance of the adverse effects is discussed, including consideration of the types and magnitudes of the effects, their spatial and temporal patterns, and the likelihood of recovery" (RAF 1992, 38).

risk communication: "The exchange of information about environmental risks among **risk** assessors, **risk** managers, the general public, news media, special interest groups, and others" (EPA 1992, 25).

risk management: "The process of evaluating and selecting alternative regulatory and non-regulatory responses to **risk.** The selection process necessarily requires the consideration of scientific, legal, economic, and behavioral factors" (EPA 1992, 25).

S

sample: A subset of the units from a **frame.** A **sample** may also be a subset of **resource units** from a **population** or a set of **sampling units.**

sampling strategy: A sampling design, together with a plan of analysis and estimation. The design consists of a **frame,** either explicit or implicit, together with a protocol for selection of **sampling units.**

sampling unit: An entity that is subject to selection and characterization under a sampling design. A sample consists of a set of **sampling units** or sites that will be characterized. **Sampling units** are defined by the **frame;** they may correspond to **resource** units, or they may be artificial units constructed for the sole purpose of the sampling design.

Science Advisory Board (SAB): A peer review panel internal to EPA. The Ecological Effects Committee of the **SAB** conducts reviews of EMAP's overall program and the conceptual framework for integrating EMAP with the Ecological Risk Assessment program. Preparation for **SAB** reviews is coordinated by the Director of the Office of Modeling, Monitoring systems, and Quality Assurance (OMMSQA); the Assistant Administrator for ORD is responsible for funding. **SAB** review is considered level 1 peer review.

status: The distribution of scores for **condition indicators** with relation to the reference **condition** associated with specific social values or desired uses for a specific time period. (See related: **change, condition, trends.**)

stressor: "Any physical, chemical, or biological entity that can induce an adverse response" (RAF 1992, 38).

stressor indicator: A characteristic of the **environment** that is suspected to elicit a change in the state of an **ecological resource,** and they include both natural and human-induced stressors. Selected **stressor indicators** will be monitored in EMAP only when a relationship between specific **condition** and **stressor indicators** is known, or a testable hypothesis can be formulated. (See related: **indicator, condition indicator.**)

subnominal: Having undesirable or unacceptable ecological **condition.** The quantified standard established for a **condition indicator** to represent unacceptable or undesirable ecological **condition** is called the **subnominal assessment endpoint.** (See related: **assessment endpoint, marginal, nominal.**)

surface waters: The inland surface waters consisting of all the Nation's **lakes** (other than the **Great Lakes**), rivers, and streams. **Lakes** are distinguished from **wetlands** by depth and by size. Streams (and rivers) will be identified from stream traces on maps and confirmed in field visits. Streams are operationally defined as any first or higher order stream that is represented as a blue line on a USGS 1:100,000 topographic map.

"All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water" (EPA 1992, 28). (See related: **lake, wetlands.**)

T

target population: A specific **resource** set that is the object of target of investigation.

technical coordinator (TC): The individual responsible for directing the activities of an individual **cross-cutting group.**

technical director (TD): The individual responsible for directing the activities of an individual **resource group.**

total quality management (TQM): A system that is implemented in every aspect of an organization with the focus of providing quality; that is, highly **valued** products. The system provides a framework for planning, documentation, communication, etc. and strongly emphasizes a client-oriented perspective. "The process whereby an entire organization, led by senior management, commits to focusing on quality as a first priority in every activity. **TQM** implementation creates a culture in which everyone in the organization shares the responsibility for continuously improving the quality of products and services in order to satisfy the customer" (QAMS 1993, 26).

trends: The change in the distribution of scores for **condition indicators** over multiple time periods. (See related: **change, status.**)

U

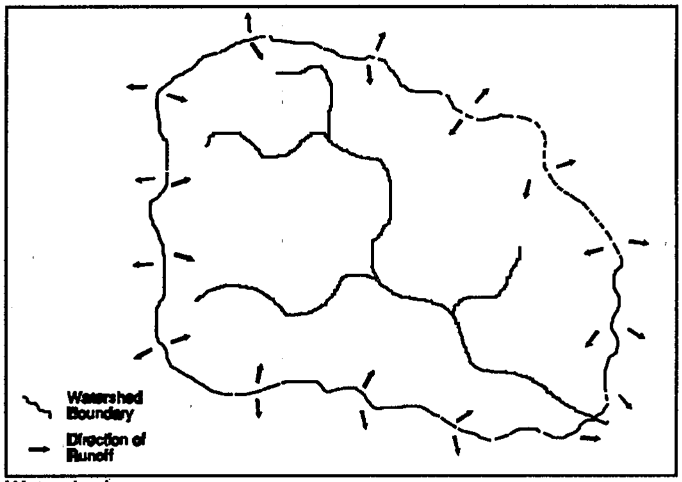
universe: The total entity of interest in a **sampling** program, often together with some structural features. The EMAP **universe** is the entire United States, together with adjoining waters. (See related: **population.**)

V

value: A characteristic of the **environment** that is desired. In the past, the term "environmental value" was defined to mean characteristic of the environment that contributes to the quality of life provided to an area's inhabitants, for example, the ability of an area to provide desired functions such as food, clean water and air, aesthetic experience, recreation, and desired animal and plant species. **Biodiversity**, sustainability, and aesthetics are examples of environmental **values** (Suter 1990). A quantity's magnitude.

W

watershed: "The terrestrial area of the **landscape** contributing to flow at a given stream location. The land area that drains into a stream" (EPA 1992, 31).



Watershed

wetlands: Lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or where shallow water covers the land and where at least one of the following attributes holds: (1) at least periodically, the land supports aquatic plants predominantly; (2) undrained hydric soils are the predominant substrate; and (3) at some time during the growing season, the substrate is saturated with water or covered by shallow water (Cowardin et al. 1979). An area that is saturated by surface or ground water with vegetation adapted for life under those soil conditions, as swamps, bogs, fens, marshes, and estuaries (EPA 1992, 31).

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Index

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