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Program Guide

Environmental Monitoring and Assessment Program

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Environmental Monitoring And Assessment Program Guide

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Abstract

The *Program Guide* for the Environmental Monitoring and Assessment Program (EMAP) describes an interagency, interdisciplinary program that will contribute to decisions on environmental protection and management by integrating research, monitoring, and assessment. EMAP's strategies are based on social values and policy-relevant questions as well as rigorous science. EMAP will estimate the current status, trends, and changes in indicators of the condition of the Nation's ecological resources at regional scales of resolution with known confidence. EMAP will estimate the geographic coverage and extent of the Nation's ecological resources with known confidence. EMAP seeks to understand associations between selected indicators of natural or human-induced stresses and ecological condition. EMAP will provide annual statistical summaries and periodic assessments of the Nation's ecological resources.

Key words:

environmental monitoring, indicators (biology), ecological indicators, ecological assessment, ecological risk assessment, environmental assessment, environmental policy, environmental indicators, human ecology, United States--ecology, USEPA-EMAP

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Preface

This *Program Guide* describes the Environmental Monitoring and Assessment Program (EMAP)--its goals, objectives, approaches, and important elements--in mostly nontechnical language. The document addresses a cross-section of readers from academic scientists to Federal resource managers to decision makers responsible for environmental protection and management. The goals, objectives, and approaches of many large Federal programs are difficult to understand because the scale and magnitude of the problems being addressed requires complex solutions. This difficulty increases when a program spans multiple agencies and disciplines and when these groups adapt terms to fit their unique meanings. This *Program Guide* evolved from discussions with individuals who made the details of EMAP clear as viewed from many different professional perspectives and agencies, including Federal, State, and academic scientists and engineers; EPA Program and Regional Office personnel; administrative staff in other agencies; Congressional staff members; the EPA Science Advisory Board; and the National Research Council's Committee to Review the Environmental Monitoring and Assessment Program. Their contributions and efforts improved this *Program Guide*.

Requests for additional information on EMAP should be directed to: EMAP Director, Office of Modeling, Monitoring Systems and Quality Assurance, RD-680, U.S. Environmental Protection Agency, 401 M. Street, S.W., Washington, D.C. 20460.

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1 — Introduction

The Environmental Monitoring and Assessment Program (EMAP) is an interdisciplinary, interagency program being designed and initiated through the U.S. Environmental Protection Agency's (EPA) Office of Research and Development. The program's objectives require that EMAP be an interagency program in which EPA is but one of the participants. The scale of this research, monitoring, and assessment program and its associated supporting data and infrastructure require ongoing, active participation and involvement by many Federal agencies, such as the U.S. Department of Agriculture's Agricultural Research Service and Forest Service; the U.S. Department of the Interior's Fish and Wildlife Service, Bureau of Land Management, National Park Service, and Geological Survey; the National Oceanic and Atmospheric Administration; and others. (EMAP's collaborative efforts with these agencies are described in the Resource Monitoring Section.)

EMAP demonstrates EPA's ongoing efforts to change the way it does business: to inject science more prominently into the decision-making process and to focus its resources on those problems that pose the greatest risk to the environment. It has already begun to make scientific contributions to the decision-making process. These contributions will continue to accrue with time. EMAP addresses the large scale, longer-term environmental problems occurring at regional and national scales, and it thereby complements the local scale, shorter term monitoring programs within State and local agencies. EMAP should be viewed as an integral part of our environmental protection and management activities in the 21st century, not as a short-term solution to current problems.

This document describes EMAP in nontechnical language explaining why the program continues to be implemented, what constitutes its goals and objectives, and how EMAP's approaches differ from, yet complement, existing monitoring programs. This report also discusses the role of EMAP in ecological risk assessment, and it highlights scientific advancements needed to achieve EMAP's goals and objectives.

2 — History

EPA'S mission is to protect human health and the environment, as an integrated whole, from the adverse effects of pollutants and other environmental stresses. Traditionally, EPA emphasized risks to human health and focused on environmental problems at the local scale: the individual point source of pollution, a single landfill, a stream reach, or a lake. Historically, potential effects were evaluated using a chemical-by-chemical approach, examining how individual chemicals affected specific biological species or threaten human health. To fulfill its mission, EPA must take a long-range view of the environment and its capacity to sustain ecosystems and their species, including the human species. In the two decades since Congress enacted the National Environmental Policy Act and the President established EPA, the Nation has witnessed steady environmental progress. Many of the issues that motivated the creation of the Agency in 1970 have been addressed: discharges of raw sewage and toxic chemicals into lakes, rivers, and estuaries; high emissions of lead from automobiles; irresponsible disposal of hazardous wastes in garbage dumps; severe threats from DDT to the bald eagle and other birds of prey; and high emissions of SO_2 and NO_x.

Since the first Earth Day in 1970, however, more insidious and troublesome problems have become evident; we can no longer frequently associate current environmental problems with an easily identified, single pollution source. We know that individual chemicals and organisms do not exist in isolation but interact with other physical, chemical, and biological factors to produce ecosystem responses. We have begun to recognize and measure the cumulative effects of years of local and regional pollutant exposure. Continuing, persistent, and cumulative effects of pollution have become evident not only at the local scale but also can be measured or estimated on regional, continental, and global scales. Moreover, the yearly costs of averting harm and repairing existing damage to the environment are growing rapidly. By the end of this decade, such costs are expected to exceed 3% of the Nation's gross national product.

Mindful of these costs, the Nation must address these emerging environmental threats in order to preserve the ecological resources on which we depend. Limited financial resources, however, dictate that we set priorities. It has become important to identify the most serious environmental risks, that is, to use available information as well as new research data to distinguish chemical and nonchemical stresses that might produce adverse ecological effects. As a result, Federal agencies, Congress, and the public need accurate data to determine which risks pose the greatest threats. In addition, once we undertake corrective or preventive actions to reduce an environmental risk, we then need to monitor our efforts and confirm that we are achieving the intended results.

In 1987, EPA examined existing and future environmental problems facing the Agency and evaluated the risks these problems posed to the environment. *Unfinished Business: A Comparative Assessment of Environmental Problems* indicated the highest risks to the environment were not posed by local problems--such as sewage discharge into a single stream--but by regional and global problems such as nonpoint source pollution, habitat alteration, global climate change (EPA 1987). In a 1988 report, its Science Advisory Board (SAB) recommended that EPA reshape its strategy for addressing environmental problems in the next decade and beyond and "plan, implement and sustain a long-term monitoring and research program" (SAB 1988, 5). Several specific recommendations suggested EPA ought to (1) implement a monitoring program to report on status and trends in environmental quality; (2) explicitly develop and use monitoring systems to identify emerging environmental problems and recommend actions to address them; (3) place greater emphasis on the development and use of ecological indicators; and (4) expand Agency efforts to prevent or reduce environmental risk. SAB's direction was clear: EPA should focus additional attention on ecological risk assessment, monitoring, and management.

Shortly after William Reilly became EPA Administrator, he asked the Science Advisory Board to review *Unfinished Business* and the issue of comparative ecological risk assessment. In September 1990, SAB published *Future Risk: Setting Priorities and Strategies for Environmental Protection*, and it recommended that EPA "attach as much importance to reducing ecological risk as it does to reducing human health risk; improve the data and. . .analytical methodologies that support the assessment, comparison and reduction of different environmental risks; [and]. . .target its environmental protection efforts on the basis of opportunities for the greatest risk reduction" (SAB 1990, 6).

3 — Ecological Risk Assessment: Managing For Results

Based on the Science Advisory Board's advice, EPA has embarked on a process that will fundamentally change the way it does business; it is attempting to focus its attention on environmental problems that pose the greatest risks rather than those that have received the greatest public attention (Roberts 1990). The underlying EPA theme for the future is "Manage for Results." This process involves conducting comparative ecological risk assessments so that the highest priority risks can be identified and addressed.

Ecological risk assessment evaluates the likelihood that adverse effects might occur as a result of exposure to one or more stressors, which are agents causing changes to ecosystems (RAF 1992). Biological, chemical, or physical components of the ecosystem might be affected.

Historically, the Agency's risk assessment program focused primarily on evaluating risks to human health. While there are similarities to human health risk assessments, ecological risk assessments differ significantly in the scale of effects and in the variety of stressors. EPA, through its Risk Assessment Forum, recently developed a *Framework for Ecological Risk Assessment* that describes the basic elements of an approach for evaluating scientific information on the adverse effects of stressors on the environment (RAF 1992).

To provide the information needed to "Manage for Results" and contribute to comparative ecological risk assessment, however, requires a different approach to ecological monitoring.

4 — EMAP: Monitoring For Results

To "Manage for Results" requires EPA to "Monitor for Results." EMAP evolved from discussions about basic elements needed in a monitoring program to contribute to decision making on environmental protection and management. These elements included

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.
7) An interagency, interdisciplinary program in which all participating agencies are cooperative partners in the research, monitoring, and assessment efforts.

To contribute effectively to decisions on environmental protection and management requires that the important social values associated with our ecological resources and the related policy questions be identified and clearly stated. Then, through the establishment of an assessment framework designed to be scientifically rigorous, appropriate indicators are selected and monitored to provide the types of information required to address these questions. Measuring these indicators within a network of random 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 a "question-specific" design. 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, an ecological research, monitoring, and assessment program has been set in motion with a regional and national scope, which is integrated and scientifically-based, to address important questions about our environment.

Goals and Objectives

EMAP's goal is to monitor and assess the condition of the Nation's ecological resources, thereby contributing 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 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 and abiotic, 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 defined by the following categories: agroecosystems, arid ecosystems, estuaries, forests, the Great Lakes, surface waters (both lakes and streams), and wetlands. EMAP also will monitor and assess these resources on the landscape so Landscape Ecology is important. **Status** describes the distribution of scores for condition indicators with relation to the reference condition associated

with specific social values or desired uses for a specified time. **Trends** describes the changes in the distribution of scores for condition indicators for multiple time periods. **Changes** are differences 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.***
National geographic coverage of multiple ecological resources has been a high priority among agencies and within the scientific community for several years. In conjunction with other agencies, EMAP will provide the **geographic coverage** for the Nation's ecological resources as spatial displays at specific scales of resolution, for example, satellite Thematic Mapper images. EMAP will estimate the **extent** or amount of a resource, such as acres of forest, miles of streams, or numbers of lakes. Each of these estimates will be presented with known confidence. EMAP also will monitor and assess changes and trends in geographic coverage and extent.

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

4) ***Provide annual statistical summaries and periodic assessments of the Nation's ecological resources.***
EMAP's information will be made readily and quickly available to those 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. In addition, **periodic assessments** will provide a more detailed interpretation or translation of the results into answers for specific questions from users and decision makers.

These objectives support EMAP's goal and seek to provide scientific information useful to decision makers. In turn, decisions regarding environmental protection and management require that the important social values associated with our ecological resources and related policy questions be identified and clearly stated.

Values and Questions

There are three general perspectives on values that relate to ecological resources:

1) Social, which incorporates the broadest spectrum of environmental goals and values desired for our ecological resources and expressed through the legislative process;
2) Administrative, which includes the management-regulatory agencies and their legislative mandates to protect and manage both specific ecological resources and the total environment; and
3) Scientific, which incorporates scientific questions, principles, and knowledge of ecological structure and function with an understanding of ecological responses to human disturbances.

The decision-making process requires that available information address values and questions based on these perspectives. EMAP's results should provide useful information to legislative, administrative, scientific, and public users. To serve this diverse group, EMAP must continually focus on environmental values and questions important to them. EMAP will not establish environmental policy, regulatory, or management strategies, but it must provide information in a format that can contribute to forming and evaluating these strategies. This interactive process requires continuous feedback with users to provide scientific information and procedures useful in answering their questions.

Identifying values and the associated questions relevant to these perspectives is an important first step in the EMAP process because it provides a direct link to the user. Values desired for ecological resources typically fall into three categories:

1) **Sustainability**—maintaining the desired uses of these resources over time.
2) **Productivity**—net accumulation of plant and animal matter, for example, food, timber, natural production.
3) **Aesthetics**—retaining the natural beauty of the landscape.

Overall, several policy-related questions have guided the EMAP design, implementation, and assessment activities that relate to these values. These questions also illustrate the scale and level of resolution at which EMAP information will be used:

1) What is the current extent of our Nation's ecological resources, and what is their geographic coverage?
2) What proportion of the resources are currently in acceptable (i.e., nominal), marginal, or unacceptable (i.e., subnominal) ecological condition?
3) What proportion of the resources are degrading or improving, in what regions, and at what rates?
4) Are these trends associated with patterns and trends in environmental stresses?
5) Are adversely affected resources improving in response to the cumulative effectiveness of control and mitigation programs?

EMAP is designed to address questions that relate to attributes of a population (in a statistical sense) of an ecological resource. The EMAP focus is not on individual lakes or streams or forest stands in a region but rather on characteristics of interest for the total number of lakes, miles of streams, and acres of forest in a region. This focus is compatible with the scale at which Federal programs typically operate. Federal agencies are responsible for protecting and managing ecological resources, such as forests (U.S. Department of Agriculture Forest Service), wetlands (Fish and Wildlife Service), and surface waters (EPA) at regional and national scales. In addition, national decisions are made on the extent and magnitude of an environmental problem across ecological resources not on a single lake or stream or grassland.

The effect of acid rain on aquatic resources illustrates the importance of knowing the condition of a population of lakes nd streams at regional and national scales. One of the important questions addressed in the initial phases of the National Acid Precipitation Assessment Program was "What proportion of lakes and streams are currently acidic and what proportion are at risk because of acidic deposition?" Early estimates of the magnitude of the problem were based on anecdotal information concerning a few acidic lakes; this limited information had special interest groups polarized at both extremes, considering the acid rain problem either a major environmental catastrophe or a trivial issue. Then, EPA's National Surface Water Survey (Linthurst et al. 1986, Landers et al. 1987, Kaufmann et al. 1988) provided estimates, with known confidence, of the proportion of the target population of lakes and streams in selected U.S. regions that were chronically acidic or that were potentially at risk from acidic deposition. Estimates revealed that, while there were no acidic lakes in the West, almost one-quarter of the lakes (23% ± 4%) in some sub-regions in the East were acidic and about 40% (38% ± 4%) of the lakes in this same subregion were sensitive to acidic deposition (Linthurst et al. 1986). These resource population estimates contributed to legislative decisions on acidic deposition and assisted in putting the acid rain issue in perspective.

Formulating 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 assessment questions that EMAP might address are presented in Table 1.

Table 1. 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.
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?	EMAP assesses the cumulative effects of multiple stressors.

Information collected, analyzed, and presented as part of EMAP will have similar relevance to regional and national policy issues. Many of the policy-relevant questions will be specific to a resource, but many questions--such as biodiversity--encompass environmental problems and issues that cross ecological resources and media.

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.

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 this scale can be addressed more effectively by existing or locally designed monitoring networks. EMAP is not a cause-effect, process-oriented program. It is not designed to determine if any particular ecological effect is caused by a specific pollutant or to describe the dynamics of any particular ecological process, such as nutrient cycling. Based on the assessment of patterns and trends in ecological condition, however, EMAP will generate hypotheses that can be tested in other research efforts. EMAP will not replace, and does not intend to supplant, existing monitoring programs that focus on compliance or resource management; EMAP will supplement and add value to the information being obtained from these programs. Typical questions EMAP will not address are listed in Table 2.

To provide information related to social values and answer policy-relevant questions requires a different approach to ecological monitoring and assessment, an approach that builds on and complements existing monitoring programs.

Table 2. 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 (the northeastern and mid-Atlantic regions) 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.

5 — EMAP's Integrated Approach

EMAP will compare the status and trends in ecological condition among multiple ecological resources and assess the cumulative effects of environmental stresses on these resources. EMAP will assess these effects by integrating measurements within and across different classes of ecological resources, for example, bottomland hardwoods, small estuaries, rivers, deserts. Integration refers to 1) combining, linking, and analyzing data from all relevant ecological resources, media, and monitoring networks; 2) ensuring the quality of these data at an acceptable level; and 3) using these data in ecological assessments to develop a holistic perspective of the condition of the Nation's ecological resources and possible factors contributing to this condition. In addition, EMAP has developed an integrated strategy for its monitoring and coordinating components.

All resource groups within EMAP are using compatible sampling designs, conducting annual field surveys, and interacting with other agencies that conduct monitoring programs. Further, EMAP has coordinated activities to ensure that resource groups follow consistent, compatible, and comparable strategies for indicator development, information management, quality assurance, methods development, logistics, and assessment and reporting. Finally, the concept of adding value or assessing the information in a policy-relevant context represents a central theme underlying all EMAP activities. Certain unique characteristics make EMAP an integrated program.

Ecological Indicators

To assess status, changes, and trends in the condition and extent of the Nation's ecological resources, EMAP will monitor ecological indicators (Bromberg 1990, Hunsaker and Carpenter 1990, Hunsaker et al. 1990). Indicators are defined as any characteristic of the environment that can provide quantitative information on the condition of ecological resources, magnitude of stress, exposure of a biological component to stress, or the amount of change in condition.

Ecological principles state that ecosystem responses and condition are determined by the interaction of all the physical, chemical, and biological components in the system. Because it is impossible to measure all these components, EMAP's strategy will be to emphasize indicators of ecological structure, composition, and function that represent the condition of ecological resources relative to social values. Through rigorous scientific research, EMAP is selecting, developing, and evaluating indicators that describe the overall condition of ecological resources; permit the detection of changes and trends in this condition; and provide preliminary diagnosis of possible factors that might contribute to the observed condition, such as human-induced versus natural stressors. The program emphasizes the development and evaluation of biological indicators.

The challenge is to determine which ecological indicators to monitor. One approach for selecting these indicators starts with those attributes valued by society and determines which indicators might be associated with these values. EMAP is also part of a collaborative effort with EPA Program and Regional Offices, the Risk Assessment Forum, and other agencies to identify and associate indicators that can contribute to ecological risk assessment.

Types of Indicators

EMAP defines two general types of ecological indicators, condition and stressor indicators. A condition indicator is any characteristic of the environment that provides quantitative estimates on the state of ecological resources and is conceptually tied to a value. There are two types of condition indicators: biotic and abiotic. Condition indicators relate to EMAP's first and second objectives: estimating the status, trends, and changes in ecological condition as well as estimating the extent of ecological resources. EMAP will estimate the regional distribution of quantitative values for each of these indicators within and among ecological resource categories. All estimates will be accompanied with specified levels of confidence so the user knows the certainty of the estimates.

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 human-induced stressors. Selected stressor indicators will be monitored in EMAP only when a relationship between specific condition and stressor indicators are known, or a if testable hypothesis can be formulated. Monitoring selected stressor and condition indicators addresses the third EMAP objective of seeking associations between selected indicators of stress and ecological condition. These associations can provide insight and lead to the formulation of hypotheses regarding factors that might be contributing to the observed condition. These associations can provide direction for other regulatory, management, or research programs in establishing causal relationships.

Indicator Strategy

Identifying values and policy-relevant, assessment questions represents the first step in the ongoing process of selecting indicators and developing strategies for their evaluation and use (Figure 1). As they are identified, indicators must be conceptually related or linked with the social value and must also provide information to address assessment questions. Before an indicator can be implemented, however, it must be explicitly linked with the value. The next step in the EMAP indicator strategy was, and is, evaluating the literature on important condition indicators for various ecological resources.

Identify Values
⇓
Develop Key Assessment Questions
⇓
Identify Existing Indicators or Develop New Indicators
⇓
Consider Relevant Stressors
⇓
Develop Conceptual Models/Evaluate Existing Models
⇓
Evaluate Condition Indicators
⇓
Implement Priority Indicators and Reassess on Periodic Basis

Figure 1. Conceptual model of EMAP indicator development and implementation strategy.

To identify initial, specific indicators at the start of the program, scientists, engineers, and public policy analysts evaluated candidate indicators that had been proposed for monitoring over the last three decades (Hunsaker and Carpenter 1990). Draft criteria for indicator selection were formulated and reviewed, and a final set of criteria was developed. Each resource group judged its candidate indicators against these criteria to identify a set of indicators for further testing and evaluation. Comments from peer reviewers and from EPA's Science Advisory Board were used to refine the indicator sets and the EMAP indicator development strategy; part of considering condition indicators also included identifying associated stressors. The same process is to be followed when proposing new indicators to measure.

Then, conceptual models of the relationships among the condition indicators, values, and possible stressor indicators are developed for each of the ecological resources. These conceptual models are useful not only in screening existing indicators but also in identifying additional indicators for development and evaluation.

Selected indicators are analyzed by each resource group in pilot and demonstration projects, refined if necessary, and evaluated for monitoring at regional and national scales. EMAP has interacted closely with EPA Program and Regional Offices and other agencies in evaluating existing data on potential indicators currently being used by these agencies as well as indicators proposed for other uses, such as biocriteria.

The complexity of ecological resources requires that indicators be considered in concert, rather than individually. Although EMAP has selected some individual indicators, the program has based its indicator selection on combinations--suites of indicators--that provide complementary information on the condition of ecological resources. For example, the Index of Biotic Integrity (Karr 1991) incorporates an array of biological measurements from the study of entire fish communities (e.g., total number of species, number of individuals, proportion of top carnivores, etc.) to produce an indicator of condition of fish communities at a sampling site. Such suites of related indicators provide greater interpretive power than that provided by analyzing a myriad of individual indicator measurements.

To provide reliable estimates of ecological condition at regional and national scales with known confidence, indicator measurements must be made within an appropriate statistical sampling design.

Sampling Design

The statistical approach being implemented in EMAP is similar in concept to other Federal statistical programs or surveys, such as those conducted by the Census Bureau, Energy Information Agency, Bureau of Labor Statistics, and National Agriculture Statistics Service. A principal difference is that these programs focus on producing estimates of characteristics for human populations, business establishments, or agricultural enterprises rather than ecological resource populations. In contrast, EMAP focuses on producing estimates of attributes from ecological resource populations such as prairie pot-hole wetlands, the Great Lakes, grasslands in the Great Basin, or forest lands in the United States.

Although an ecological survey as comprehensive as EMAP has never been undertaken, national or regional statistical (i.e., probability-based) surveys of particular ecological resources have been and are being conducted. For example, the Fish and Wildlife Service conducts a statistical survey--The National Wetlands Inventory--every 10 years to estimate the extent of the Nation's wetlands. The Forest Health Monitoring Program of the U.S. Department of Agriculture Forest Service estimates the condition of timber in selected forests throughout the United States.

To address EMAP's objectives, regional populations of all major ecological resources in the United States are emphasized, not individual ecosystems. The design must permit estimates of the condition, geographic coverage, and extent for regional populations of ecological resources. The design must permit population estimates to be provided with known confidence--statistically defensible, quantitative statements of uncertainty must accompany the estimates. EMAP requires these estimates not only for a specific point in time (current status) but also repeated over time (trends). The design must enable associations (empirical relationships) to be investigated between condition indicators and stressor indicators for the ecological resource.

To achieve its objectives, EMAP uses a probability-based sampling design over time and space to develop a cost-effective monitoring program (Overton et al. 1990). EMAP's sampling design uses a number of features that have been tested in other probability-based environmental surveys:

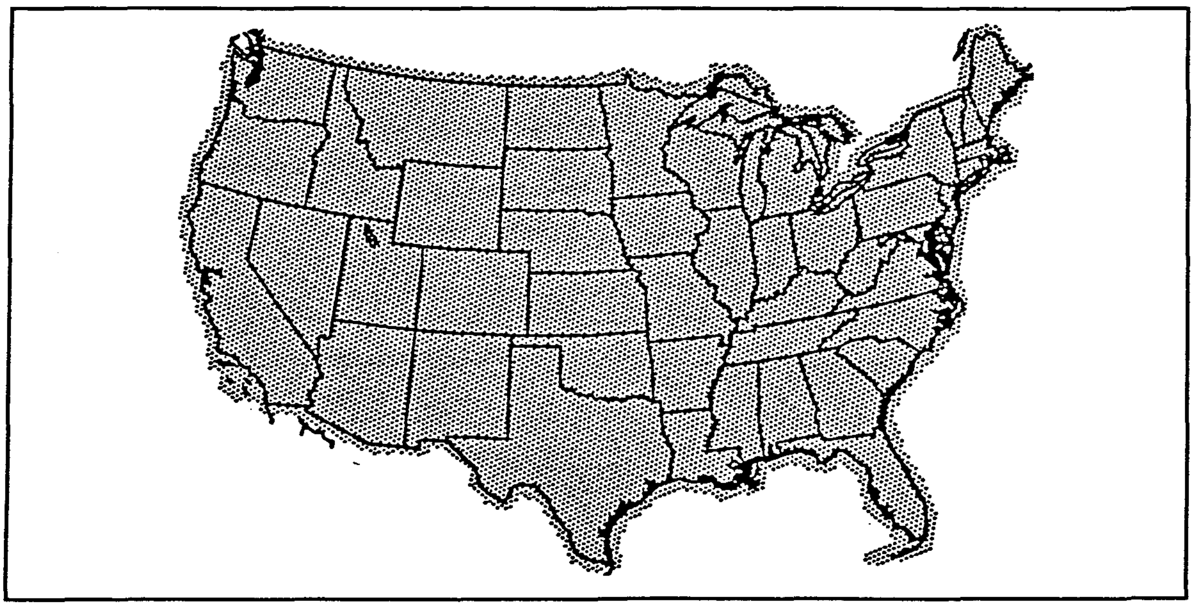


Figure 2. Baseline EMAP grid for the United States.

- Samples are spatially distributed over the geographic distribution and extent of the resource.
- Visits to survey sites over several years are repeated, with provisions not to visit every site every year.
- Scientific and cost advantages are derived from selecting probability-based samples in two stages, that is, by taking an initial sample, then selecting a subsample from the initial sample.

Building on the experience gained from previous surveys, EMAP's sampling design incorporates all of these features, ensuring sample coverage in both time and space. EMAP's design uses a specific pattern for repeated sampling of sites over time and a systematic grid structure as a basis for distributing the sample sites over space. These two basic procedures are implemented jointly, not independently, to further enhance the cost-effectiveness of the selected approach (Overton et al. 1990). A systematic grid superimposed over the entire United States (Figure 2) is the basic structure used to implement the sampling design over time and space.

The EMAP grid emphasizes geographic coverage and ensures that each ecological resource can be sampled in proportion to its geographic presence. It does not require or assume that ecological resources are distributed systematically. Because different ecological resources are not necessarily distributed similarly, sampling requirements for selected indicators may differ for different resources or resource classes. The power and flexibility of the EMAP design, however, accommodates the use of different sampling strategies among and within ecological resource types to estimate status, changes, and trends in indicators of ecological condition of the Nation's resources. Sections below describe each ecological resource category to provide specific information on the target populations of each ecological resource category included in EMAP and the general sampling strategies used. Because the scope of EMAP is national, the number of samples required annually to estimate condition with known confidence for any particular resource group may be prohibitively expensive to obtain. EMAP's sampling design accommodates economy with a strategy of sampling approximately one-quarter of all monitoring sites annually; therefore, in four years, EMAP will have collected samples at all the sites selected at a national scale. Then, the program will repeat sampling in year 5 at sites first visited in year 1.

There are several advantages to a design which can accommodate this type of sampling schedule through time. Each year's sample provides, in itself, both national and regional estimates of condition, with uniform spatial coverage. Revisiting sites on a 4-year cycle provides sufficient time for recovery from possible measurement stress. Sampling approximately one-quarter of all sites each year makes the EMAP approach cost-effective without compromising power to detect changes in condition. The design is well adapted for detecting persistent, gradual change on diverse subpopulations and for representing patterns in indicators of ecological condition.

Resource Monitoring

EMAP will monitor all the major categories of ecological resources:

1) **Agroecosystems,**
2) **Arid Ecosystems,**
3) **Estuaries,**
4) **Forests,**
5) **The Great Lakes,**
6) **Surface Waters,** and
7) **Wetlands.**

It will also conduct research on the interaction of these resources on the landscape (**Landscape Ecology**). EMAP's eight resource groups are named after these resource categories (including Landscape Ecology).

For these resource categories, EMAP will monitor selected indicators of ecological condition and will collect and compile data on selected stressor indicators, including climate and atmospheric deposition. The program will integrate its monitoring of indicators within and across resources, such as forests, surface waters, and wetlands, so that researchers can detect changes in indicators of ecological condition at large spatial scales over time. Large-scale integration represents one of the greatest technical challenges in EMAP. The following sections describe each resource category and its target population in EMAP. Since definitions of resources vary among sources, areas of extent overlap, and EMAP's national data sets are not yet assembled, the numbers cited below need to be considered with their limitations kept in mind.

Agroecosystems

An agroecosystem is a dynamic association of crops, pastures, livestock, other flora and fauna, soils, water, and the atmosphere. Agroecosystems are contained within larger landscapes, which include uncultivated land, drainage networks, rural communities, and wildlife.

The target population includes all agricultural lands and adjoining natural areas in the United States, an area that comprises between 43% (USDA 1992, 355) and 46.0% (CIA 1992, 358) of total terrestrial acres in the 50 States (Figure 3). The sampling frame for agroecosystems will incorporate sampling units currently used by the U.S. Department of Agriculture's National Agricultural Statistics Service.

EMAP's Agroecosystems Resource Group plans to collect data through surveys of growers and by field sampling of cropland to include annual crops, pastures, woody perennial crops, adjacent natural areas, and farm ponds. (Uncultivated rangeland, however, will be studied by Arid Ecosystems.) EMAP performs agroecosystems monitoring in close cooperation with several U.S. Department of Agriculture agencies, such as Agricultural Research Service, National Agricultural Statistics Service, and Soil Conservation Service.

Arid Ecosystems

EMAP defines arid ecosystems as terrestrial systems characterized by a climate regime where the potential evapotranspiration exceeds precipitation, annual precipitation ranges from less than 5 to 60 cm, and air temperatures range from -40 to 50°C. The vegetation is dominated by woody shrubs, grasses, cacti and leaf succulents, and drought resistant trees.

The target population for arid ecosystem sampling includes the arid, semi-arid, and subhumid regions of the conterminous United States. Arid ecosystems include desert scrub, prairies,

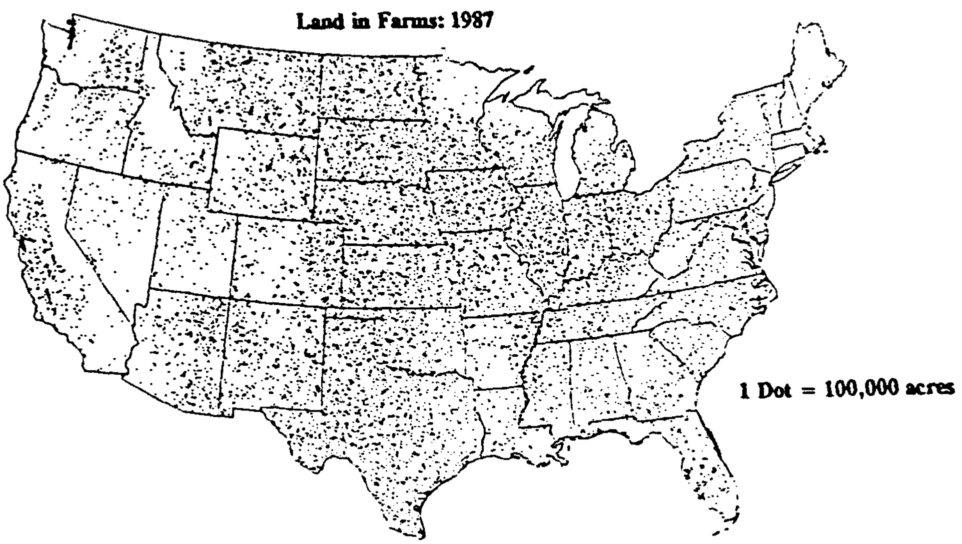


Figure 3. Distribution of agroecosystems in the United States (Bureau of the Census 1987).

grasslands, chaparral, open woodland, alpine tundra, arctic desert, and riparian communities but excludes intensively managed agriculture such as irrigated farmlands.

Many individuals think of arid ecosystems only as deserts. As noted above, however, arid ecosystems include a diverse set of resource classes. Arid ecosystems once comprised nearly 40% of the United States (Figure 4). As with wetlands, arid ecosystems have been converted into other land uses such as agriculture, especially in the subhumid region. Arid ecosystems are now estimated to comprise approximately 25% of the land in the United States (CIA 1992, 358). Although there has been a decline in the proportion of arid ecosystems, they still comprise a significant portion of the landscape, particularly in the West, where almost 65% of the area is under state and federal management.

Estuaries

EMAP defines estuaries to be semi-enclosed bodies of water where freshwater mixes with the seawater. Estuaries include fjords, bays, inlets, sounds, lagoons, and tidal rivers. The outer boundary is the coastal waters, and the inland boundary for estuaries is the limit of tidal influence.

The target populations for these resources are all of the Nation's estuarine waters (Figure 5). EMAP has adopted the same seven coastal regions, or biogeographical provinces used by the National Oceanic and Atmospheric Administration and the U.S. Fish and Wildlife Service (Terrell 1979).

EMAP's Estuaries Resource Group is developing the estuarine monitoring strategy cooperatively with National Oceanic and Atmospheric Administration. EMAP has divided estuaries into the following classes: large estuaries, large tidal rivers, and small estuarine systems (including bays, inlets, and tidal creeks and rivers). Large estuaries, such as Chesapeake Bay, will be sampled from an augmented EMAP grid, large tidal rivers, such as the Mississippi River, from systematic grids, and small estuarine systems from a list of all possible small estuarine systems.

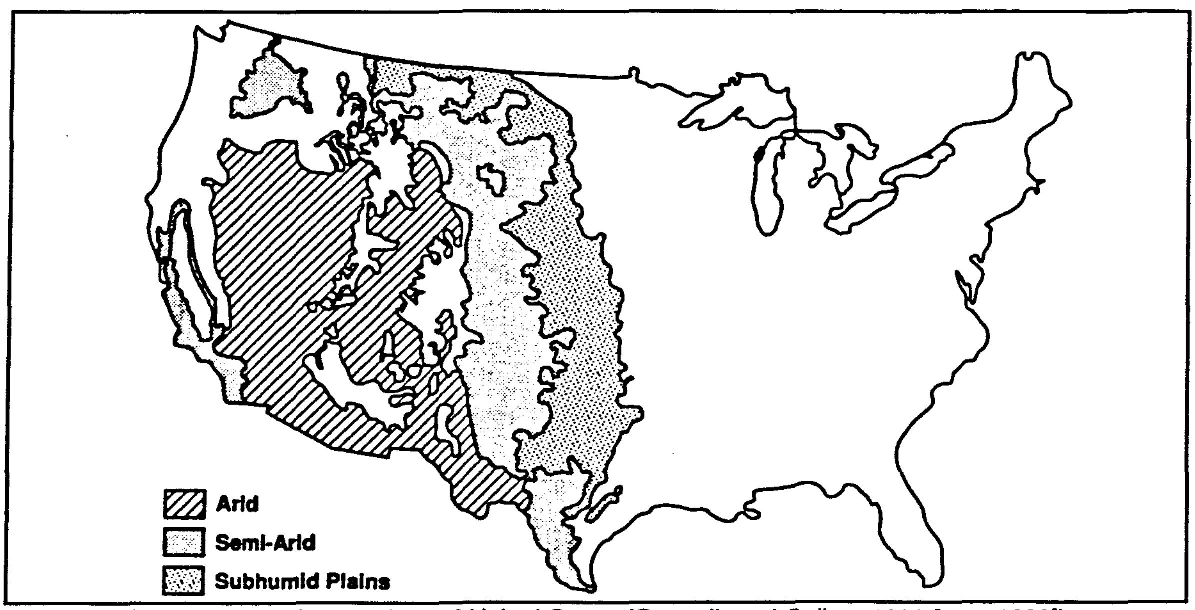


Figure 4. Aggregated arid ecoregions of United States (Omernik and Gallant 1990 [map 1989]).

In monitoring arid ecosystems, EMAP will use a hierarchical biogeographic classification system (Brown et al. 1979) that allows interpretations at multiple levels of biological organization. EMAP's Arid Ecosystems Resource Group plans to collect data using both sample-based and remotely sensed information, for example, satellite imagery, as part of their indicator research and monitoring strategy. Arid ecosystems are predominately managed by State and Federal agencies; the U.S. Bureau of Land Management, U.S. Soil Conservation Service, U.S. Department of Agriculture Forest Service, U.S. Fish and Wildlife Service, National Park Service, and EPA cooperate in the research development, monitoring, and assessment of arid ecosystems.

Forests

Forest land is defined as land with at least 10% of its surface area covered 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).

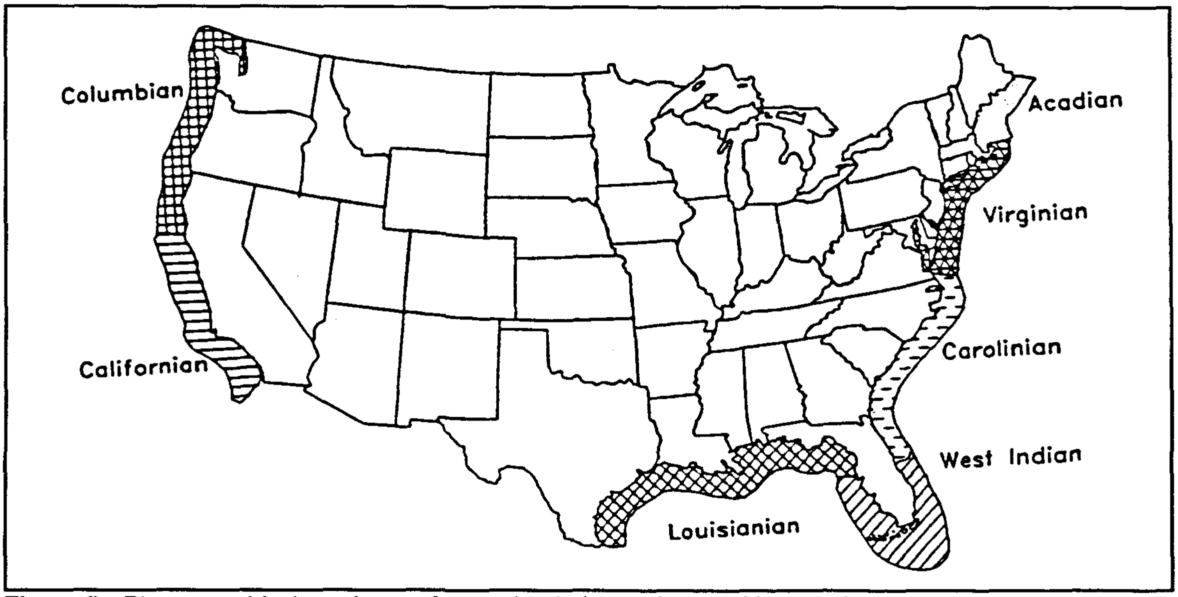


Figure 5. Biogeographical provinces of estuaries (adapted from EMAP 1990).

The target population for EMAP's forest sampling design is all of the forested land in the United States (Figure 6). Forests currently cover between 29% (CIA 1992, 358; CEQ 1989, 73) and 32% (USDA 1992, 458) of the total U.S. land area.

Cooperatively with the U.S. Department of Agriculture, specifically the Forest Service's National Forest Health Monitoring Program, EMAP's Forests Resource Group will monitor indicators of forest resource condition on all forested sample sites defined on the EMAP systematic grid.

Great Lakes

The Great Lakes resource comprises 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 (Figure 7).

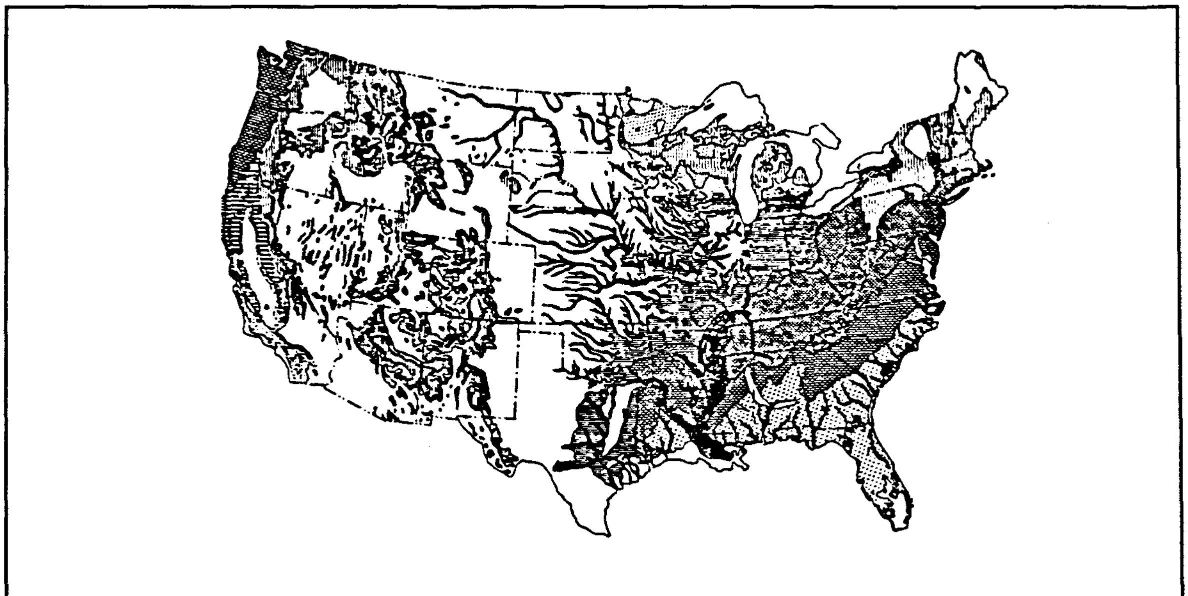


Figure 6. Forest vegetation of the United States (Fowells 1965).

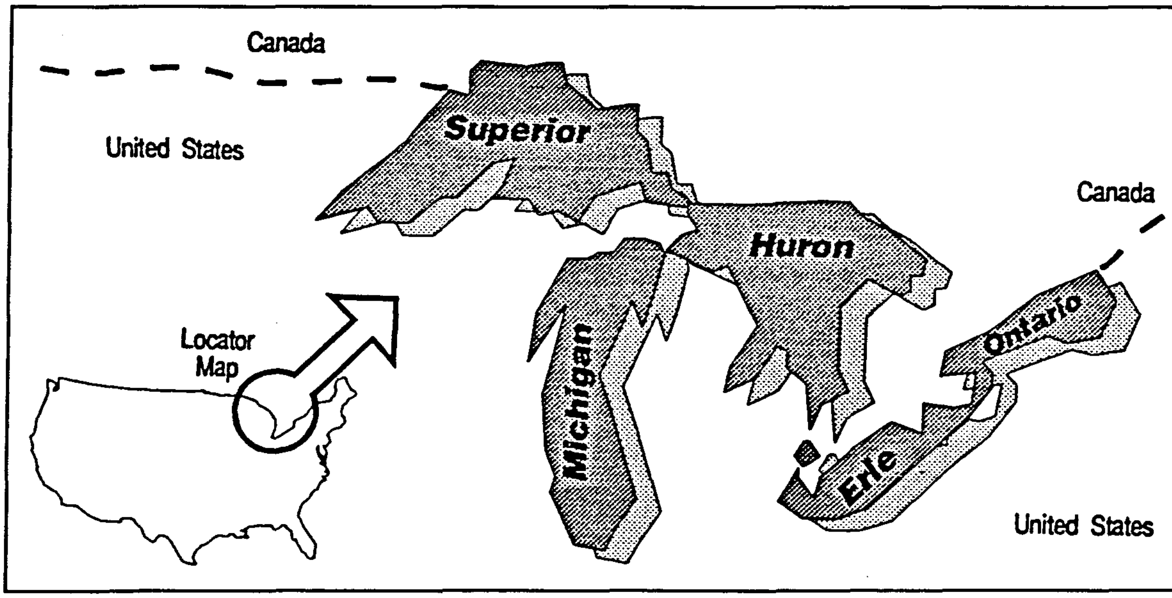


Figure 7. The Great Lakes.

Although the lakes are interconnected, EMAP will consider each as an independent unit for sampling purposes. The EMAP grid will identify sample locations within a lake. Resource classes within a lake include offshore areas, nearshore areas, harbors and embayments, and contiguous wetlands. Sample sites for offshore areas will be identified by the EMAP grid; near-shore areas from an augmented EMAP grid; harbors, embayments, and wetlands randomly selected from a list of all these areas.

EMAP's Great Lakes Resource Group works with the international community, the Canadian government, as well as the National Oceanic and Atmospheric Administration, EPA Regions, and the surrounding States in the design and testing of the Great Lakes monitoring program.

Surface Waters

Inland surface waters consist of all the Nation's lakes (other than the Great Lakes), reservoirs, rivers, and streams. Lakes are distinguished from wetlands by depth and by size. A lake is defined as a standing body of water greater than 1 hectare (about 2.5 acres) 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. Streams (and rivers) will be identified from stream traces on maps and confirmed by field visits. Streams are operationally defined as any first or higher order stream that is represented as a blue line on a U.S. Geological Survey 1:100,000 topographic map.

The target population for Surface Waters resources consists of all inland lakes (excluding the Great Lakes) and streams in the United States (Figure 8). Lakes and streams constitute different resource categories. Initially, lakes and streams will be subdivided into a portion of the population to be selected from the EMAP grid (for example, lakes < 500 hectare) and into another portion that will be selected from a list of all lakes or streams greater than a certain size (for example, lakes > 500 hectare). Certain lake and stream characteristics, such as geographic location, elevation, size, length, and ecoregion, will be used to help classify the resource category. Samples will be obtained for each lake and stream class to estimate ecological condition.

EMAP's Surface Waters Resource Group is interacting with the U.S. Geological Survey to interface EMAP with the U.S. Geological Survey surface water monitoring networks and the EPA Office of Water, U.S. Fish and Wildlife Service, and State monitoring programs.

Wetlands

EMAP will use the U.S. Fish and Wildlife Service's National Wetlands Inventory definition of wetlands (from Cowardin et al. 1979): Wetlands are 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) the land predominantly supports aquatic plants at least periodically; 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. Wetlands are characterized and distinguished by soil, hydrology, salinity, vegetation, and other factors. The variety of common names for wetlands--marshes, swamps, potholes, bogs, fens, and pocosins--attest to the diversity of wetland types. In wetlands, water saturation is the dominant factor determining the nature of the soil and the types of plant and animal communities living in the soil and on its surface.

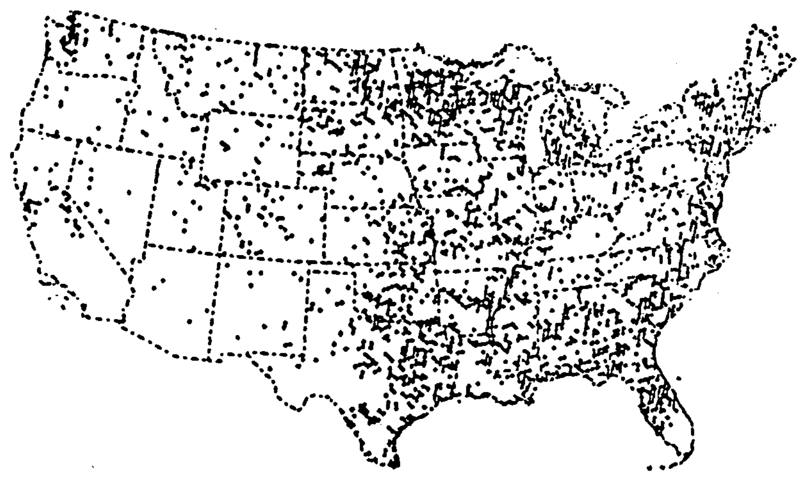


Figure 8. Surface Waters. .Density of points reflects the relative density of lakes and reservoirs across the conterminous United States.

The target population for wetland sampling includes all vegetated emergent wetlands in the United States greater than one-half hectare (a little larger than 1 acre) (Figure 9). The EMAP grid will be adequate to determine regional and national wetlands condition, define trends, and estimate the extent of common wetland resources. Regional estimates of the rare wetland resources, however, will require a sampling frame with finer resolution (Ernst et al. 1993). These sampling units could be derived by increasing (augmenting) the EMAP grid density or by listing all the rare wetlands in a region and sampling from this list frame.

EMAP's Wetlands Resource Group cooperates with the Fish and Wildlife Service National Wetlands Inventory to design and implement this EMAP component.

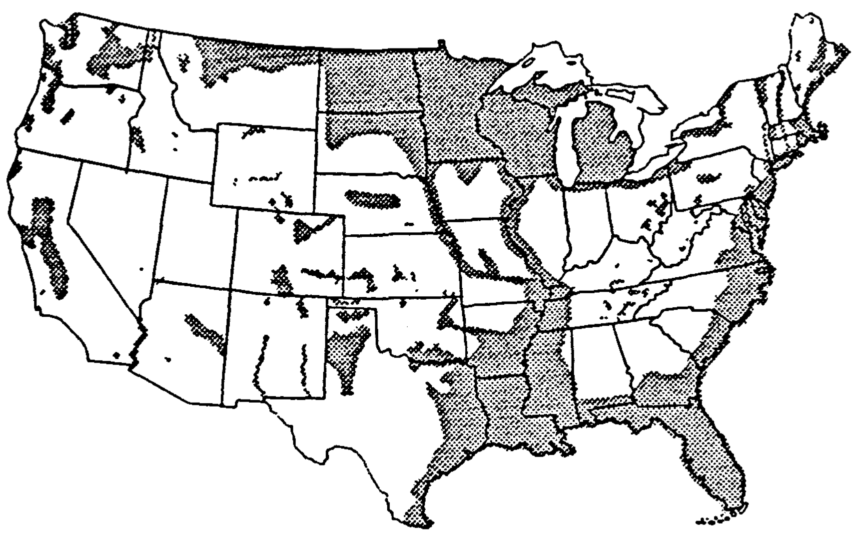


Figure 9. Distribution of wetlands in the United States (adapted from Dahl 1991).

Landscape Ecology

A landscape is defined as a heterogeneous land area composed of a cluster of interacting ecosystems that is repeated in a similar form throughout the area (Figure 10). Just as individual physical and chemical elements in ecosystems do not exist in isolation, ecosystems interact and influence the condition of adjacent systems. Landscape patterns reflect ecological processes operating within and among ecological resources. EMAP's Landscape Ecology Group will study of the distribution patterns of communities and ecosystems and the ecological processes that affect those patterns and changes in pattern and process over time.

Figure 10. Example of a landscape mosaic near Millersburg, Ohio. (Forman and Godron 1986 [photo courtesy of USDA Soil Conservation Service]).

Assessment

Assessment is the process of interpreting and evaluating EMAP results for the purpose of answering policy-relevant questions about ecological resources. It includes determining the fraction of the population that meets a socially defined value or relating associations among indicators of condition and stressors. Rigorous science is necessary to the decision making process, but it is not sufficient. One of the primary lessons learned from the 10-year National Acid Precipitation Assessment Program was that applying the scientific process to decision making requires a continuous emphasis on assessment (CEQ 1991).

Assessment, however, includes several different levels of scientific capabilities along a continuum of increasing complexity (Figure 11). EMAP contributes directly to the first four levels in the continuum and indirectly to the latter three levels.

1) **Current status**—This first step involves measuring selected indicators to describe the status in ecological condition of resources at a particular time or during a particular period. The first two EMAP objectives incorporate this level of complexity.

2) **Detection of change**—The next level is the capability to detect changes and trends in selected indicators of condition and extent. The first two EMAP objectives incorporate detection of change.

3) **Evaluation of the significance of change in condition**—Going beyond the statistical significance in condition of the previous level are issues of significance with regard to values. Evaluating the significance of status and trends in resource condition is the primary function of the assessment component of EMAP. The fourth EMAP objective focuses on adding value and significance to changes in condition.

4) **Association of change/stress**—The fourth level of complexity is establishing statistical associations between spatial/temporal patterns in selected indicators of stressors and condition. The third EMAP objective emphasizes association of change/stress.

5) **Establishment of Causality**—Establishing cause-and-effect relationships between specific changes in ecological indicators and particular anthropogenic stresses is a fifth level of complexity. These analyses include assessing interactions among multiple anthropogenic stresses and natural variability. EMAP is not a program to determine cause and effect, but it should be able to associate the ecological conditions with possible stressors to guide and direct other research in determining the causes of these responses.

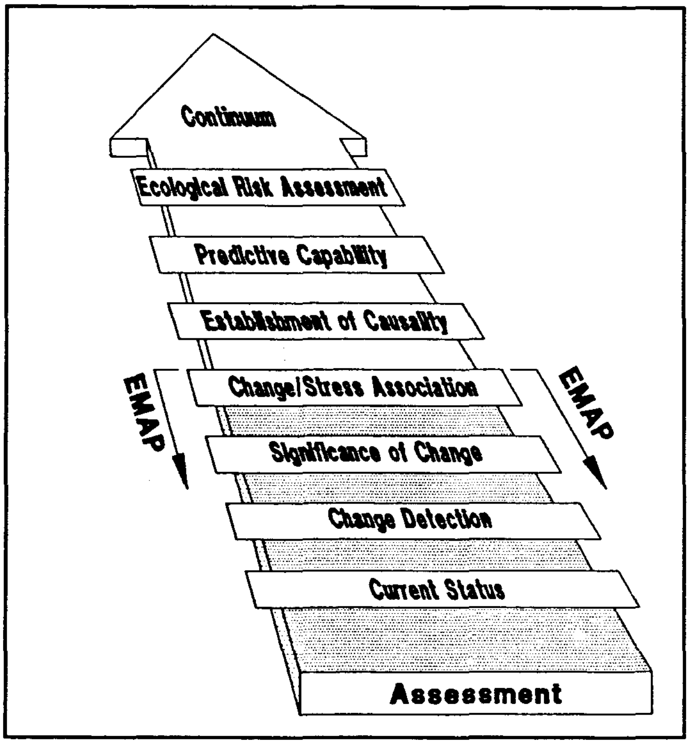


Figure 11. Complexity of activities on the assessment continuum.

6) **Predictive Capability**—Each of the previous levels retrospectively utilize historical and current monitoring data to establish change and association. Predictive capability is intrinsically prospective and requires the development of predictive tools that go beyond monitoring and retrospective assessment. EMAP will estimate past and present trends in resource condition and provide information against which to compare predictions of ecological conditions. It is not an anticipatory program and will not predict future trends.

7) **Ecological Risk Assessment**—This is a much broader set of activities that includes problem formulation, ecological effects and exposure characterization, and risk characterization (RAF 1992). Ecological risk assessment represents one of the fundamental ways EPA is attempting to change the way it does business. EMAP contributes to formulating problems and translating scientific information to address these problems within EPA's framework for ecological risk assessment.

To understand how EMAP contributes to ecological risk assessments, we must be familiar with the EPA's Framework for Ecological Risk Assessment.

Ecological Risk Assessment and EMAP

Recently, through the Risk Assessment Forum, EPA developed a framework for ecological risk assessment that describes the basic elements of an approach to evaluate scientific information on the adverse effects of stressors on the environment (RAF 1992). The framework consists of three major phases, namely, problem formulation, analysis, and risk characterization (Figure 12).

Problem formulation, a planning and goal-setting process, establishes the scope, objectives, and focus of the risk assessment. Its end product, a conceptual model, identifies the social, societal, or ecological values to be protected, the data needed, and the analyses to be used (RAF 1992).

The analysis phase develops profiles of the ecological exposure and ecological effects that result from a stressor. Exposure profiles characterize the ecosystems in which the stressor might occur as well as the biological organisms that might be exposed. It also describes the magnitude and patterns of exposure through time and across space. An ecological effects profile summarizes data on the effects of the stressor and relates them to the assessment endpoints (RAF 1992).

The risk characterization phase integrates the exposure and effects profiles to estimate ecological risk from the stressor. Risks can be estimated using a variety of techniques, for example, comparing individual exposure and effects values, comparing the distribution of exposure and effects, or using simulation models. The expression of risk as a qualitative or quantitative estimate depends on available data; risk characterization describes ecological risk in terms of the values to be protected, discusses the ecological significance of the characterization, describes ecological risk in terms of the values effects, and summarizes the overall confidence in the assessment.

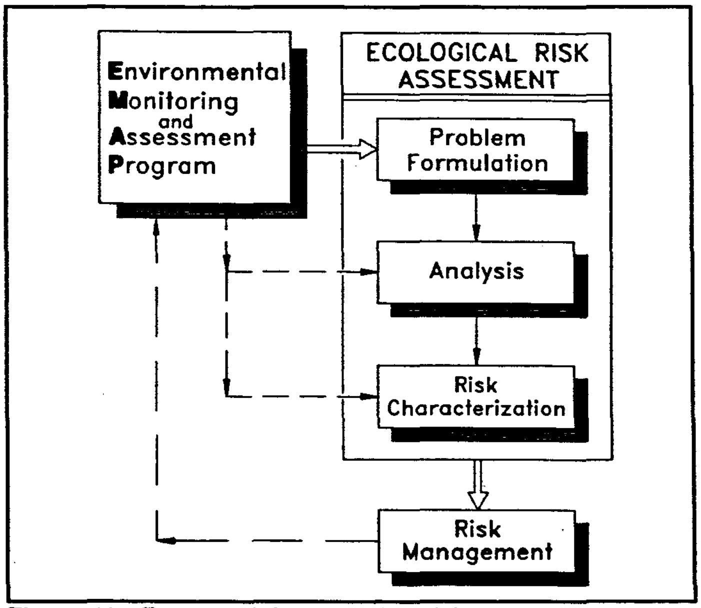


Figure 12. Framework for ecological risk assessment.

These results form the basis for subsequent risk management. Risk management then evaluates alternative policy and management practices, their costs, and benefits, in reducing this risk.

EMAP contributes primarily to problem formulation in this framework for ecological risk assessment. EMAP has selected and will continue to choose ecological indicators that can be directly related to social and societal values. EMAP's monitoring approach will permit it to determine the annual status of ecological resources at regional scales of resolution across the United States. It will monitor changes and trends in the condition and extent of these ecological resources so that regional-scale, environmental problems and improvements can be detected over time. It will contribute to comparative ecological risk assessment by providing comparable information on the condition of multiple ecological resources in a region, such as forests, lakes, streams, wetlands, grasslands, estuaries, and croplands. EMAP integrates its activities with other efforts; it will continue contributing to future activities that assess ecological risk. EMAP represents a fundamental change in environmental monitoring and assessment.

Cross-cutting Activities

The scope and complexity of EMAP require extensive coordination across the program if it is to be fully integrated and successful. Consequently, EMAP places a high priority on coordination at both the technical and administrative levels.

Integration and Assessment

Seven cross-cutting groups--each lead by a technical coordinator (TC) who organizes the group's functions across resource groups--ensure that EMAP scientists can go to the field and collect consistent and compatible data to answer important policy-relevant questions. Design and Statistics, Indicator Development, Landscape Characterization, Information Management, Assessment and Reporting, Logistics and Methods, and Quality Assurance are the cross-cutting groups.

The Design and Statistics Group is responsible for the strategic development of a national monitoring network design, coordinating and evaluating the implementation of the strategy, and conducting required environmental statistics research. This cross-cutting group assists the resource groups in developing their specific resource designs and statistical methods to achieve required consistency and compatibility across EMAP. (Sections beginning on page 10 above provide information on the EMAP sampling design.)

The Indicator Development Group is responsible for preparing a strategy for indicator development, developing procedures for ensuring there are consistent and comparable indicators among resource groups, and conducting research on ecological indicator methodologies to support EMAP. The Indicator Development Group assists resource groups in selecting, testing, and evaluating the indicators proposed for monitoring in their respective groups. This group also reviews and approves the indicator development plans of each resource group prior to field implementation, ensures consistency across the program, and coordinates with other EPA offices, other agencies, and the scientific and international communities to advance ecological monitoring.

The Landscape Characterization Group is responsible for developing and implementing a geographic reference database, developing a land-use/land cover classification system, and generating land-use/land cover information for use throughout the program. Landscape characterization will provide information on the geographic coverage and extent of the Nation's ecological resources at specific scales of resolution, for instance, through Satellite Thematic Mapper images.

The Information Management Group is responsible for providing the capability to manage EMAP information from field sampling through the delivery of products to the user. The intent is for EMAP to deliver quality information in an accessible form to users quickly and easily. This cross-cutting group provides direction and guidance on developing an information management infrastructure which will enable EMAP to achieve its long-term objectives. The group provides the hardware, software, documentation support, and system designs tailored to the needs of the EMAP resource and cross-cutting groups. The Information Management Group also will ensure EMAP data are available for access by external EMAP users and that EMAP can access other data sources.

The primary responsibility to facilitate communication between environmental decision makers, the public, and EMAP rests with the Assessment and Reporting Group. It will ensure that, where appropriate, assessments are conducted consistently across the program, and information is provided in a format that meets the needs of its users. The Assessment and Reporting Group also will be involved in developing assessment techniques, strategies for determining resource condition (i.e., nominal, marginal, or subnominal) and methods to accomplish multi-resource assessments.

The Logistics and Methods technical coordinator provides guidance for planning and implementing field sampling programs, including the procurement, maintenance, and replacement of material and personnel. The roles of the TC for logistics are to assist the resource groups in developing their specific logistics plans, to identify common elements among resource groups for greater efficiency and cost effectiveness in field implementation, to coordinate logistics and implementation activities with resource groups ensuring continuity and comparability among groups, and to assist with guidance for all phases of field implementation (from pre-field planning through sample tracking to public relations). In order to coordinate methods, this technical coordinator helps guarantee that needed information is generated through the use of the most effective and appropriate biological, chemical and physical methods. This TC also provides guidance and direction to ensure the methods used by the resource groups are consistent across the program and produce comparable data, ensuring continuity in results as new methods are incorporated in the program.

EMAP's Quality Assurance (QA) technical coordinator provides guidance and direction for EMAP's QA activities. The QA Coordinator develops EMAP's QA program plan, key QA data policies and procedures, and QA guidance; provides training to assist resource groups in developing QA project plans; and reviews and recommends approval of QA plans prior to pilot, demonstration and full implementation field work. In addition, the QA Coordinator cooperates with other agencies on QA issues; provides recommendations to assist in eliminating weaknesses related to environmental data collection methods; and conducts independent, follow-up audits and reviews.

Program Coordination

EMAP's program coordinating activities include five components: R-EMAP (Regional-EMAP), International Activities, Arctic Contaminants Research Program, Air and Climate, and EMAP Central Operations. Moreover, EMAP personnel collaborate with EPA's Risk Assessment Forum for ecological risk assessments, EPA's Science Advisory Board for internal peer review, and the National Academy of Science, National Research Council for external peer review.

Implementation

Because of scientific, logistical, and funding constraints, EMAP is being implemented in phases that occur both within and among ecological resources and among geographic regions. As a result, implementation generally progresses through four phases: a pilot project, then a demonstration project, then regional implementation, and finally national implementation.

Pilot and Demonstration Projects

Pilot projects have two purposes. First, they test and evaluate whether EMAP indicators are applicable and feasible for determining current status and detecting changes among resource types. Pilot projects also help evaluate field and laboratory methods, identify logistical problems, and note other design considerations. Each resource group typically begins its field activities with a pilot project focused on the highest priority resource class, using a limited number of indicators. To proceed from the pilot phase to the demonstration project, the resource group must satisfy five criteria:

1) The indicators being measured are appropriately related to the ecological values.
2) The assessment questions relate indicator information to values.
3) The overall sampling approach is logistically and economically feasible.
4) The sampling design is acceptable within the EMAP design framework.
5) The indicator variance components have been quantified.

The demonstration project evaluates the regional applicability of the sampling design, evaluates a full suite of proposed indicators, focuses on assessment questions, and estimates resource condition with known confidence at the regional scale. Upon completion of the demonstration project, but prior to moving ahead to full implementation, the resource groups must ensure the project satisfies the following seven criteria:

1) Relationships or linkages between ecological values and the indicators selected to monitor ecological condition are documented.
2) Assessment questions have been developed and reviewed by users who have regulatory/management, policy and social perspectives.
3) An approved quality assurance/quality control program exists, and the selected indicators can satisfy the program's data quality objectives.
4) The design permits quantitative statistical estimates of ecological resource condition to be made with confidence intervals.
5) Preliminary criteria have been established, through peer review, for nominal (acceptable), subnominal (unacceptable) or marginal ranges of resource condition.
6) Annual statistical summaries can be prepared in a timely manner following the completion of field sampling.
7) All approvals are in place with the cross-cutting groups.

The steps and criteria in this process, along with rigorous peer review, constitute EMAP's strategy for ensuring that the program moves forward on a scientifically sound basis.

A critical part of this process is for each resource group to document the lessons learned during the pilot and demonstration projects, not just for the implementing resource group, but also for the benefit of other resource groups. For example, some of the field and laboratory methodologies as well as certain logistical and sampling protocols for soil indicators will be as applicable for Arid Ecosystems and Agroecosystems as they are for the Forest Resource Group, which first evaluated them as part of its pilot and demonstration projects. An example of how the planning and analysis of a resource group demonstration project was conducted is provided through a brief description of the Estuaries Demonstration Project in the Mid-Atlantic Region (Virginian Province).

Estuaries Demonstration Project

In 1990, the Estuaries Resource Group initiated a demonstration project in the Virginian Biogeographic Province (from Cape Code southward to the mouth of the Chesapeake Bay; see Figure 5) to evaluate the utility of regional-scale monitoring for assessing the ecological condition of the Nation's estuaries. The Virginian Province was selected for several reasons: there is a general public perception that estuaries in this area are rapidly deteriorating; a considerable amount of information based on intensive studies of estuaries in this area exists; and management and regulatory decisions are being considered for the region. The main objectives of the demonstration project were 1) testing and evaluating the degree to which proposed indicators of ecological condition could distinguish polluted from unpolluted environments, 2) constructing a data set that would provide the information required to evaluate the alternative sampling designs for assessing estuarine condition on regional scales, 3) identifying and resolving logistical problems associated with conducting a regional sampling program in estuaries, and 4) completing an statistical summary of the present status of the estuaries in the Virginian Province.

Planning

A team of scientists was assembled from within EPA, the National Oceanic and Atmospheric Administration, the scientific community, and the private sector to design and conduct the demonstration project. Small workshops were used to formulate estuarine design options, to characterize estuaries within the Virginian Province, to identify and screen potential indicators for measurement during the demonstration project, and to identify potential logistical problems. Different teams were organized to pursue different activities, such as compiling existing data sets for testing different design options through simulated sampling; evaluating indicator variance and analytical methodology; evaluating and assessing the information management requirements of the project; and preparing research, field, and laboratory methods including training, quality assurance/quality control, information management, and logistical plans.

Review

The Estuaries Demonstration Project Plan was peer-reviewed by a committee of scientists selected by the Estuarine Research Federation. This committee was asked to continue to serve as technical advisors through data analyses and assessment activities. Each of the other planning documents was peer-reviewed by committees consisting of three to four scientists. In addition, an example of an interpretive assessment was prepared so that, before the data were collected, researchers understood how the information might be analyzed, presented, and interpreted. This approach resulted in consideration of a benthic index for summarizing some of the information, improving the data management and analysis plan, and clearly identifying policy-relevant questions to be addressed in the demonstration project.

Design

The estuaries in the Virginian Province region were divided into three classes:

1) Large estuaries (e.g., Chesapeake Bay, Long Island Sound).
2) Large tidal rivers (e.g., Potomac River, Delaware River).
3) Small estuarine systems, including bays, and tidal creeks and rivers (e.g., Barnegat Bay, Elizabeth River).

The estuaries assigned to each class have similar physical features and were expected to respond similarly to environmental stresses.

Sampling sites within each estuarine class were selected using a statistical procedure that permitted researchers to quantitatively estimate the proportion of the estuarine area in poor ecological condition. An augmented EMAP grid served for the large estuaries, while a spine-and-rib design (a linear analog of the grid) was used for the large tidal rivers. The small estuarine systems were sampled from a list frame, where the estuaries were organized by groups in a list and randomly selected in a manner to preserve the spatial distribution of small estuaries throughout the Province. These procedures illustrated the flexibility of the design, and they also permitted the uncertainty of these estimates to be calculated. In addition, embedded in the demonstration project were a number of special studies, such as evaluation of the index sampling period, comparison of continuous dissolved oxygen measurements over the index period, and indicator evaluation at subjectively selected good and poor sites.

Sampling and Analysis

The Virginian Province Demonstration Project was conducted during the summer of 1990, and over 95% of all anticipated samples were collected and analyzed. Data were analyzed during 1991 and were used to prepare a Demonstration Project Report, which was scientifically reviewed by a committee selected by the Estuarine Research Federation. Certain significant results were reported by the Virginian Province Demonstration Project:

1) Less than 0.1% ± 2% of all commercially important fish collected showed obvious signs of external abnormalities.
2) Approximately 21% ± 7% of the area in the province had bottom dissolved oxygen concentrations below 5 ppm.
3) Small estuarine systems had a higher proportion of toxic sediments (32% ± 18%) than large estuaries (2% ± 3%).
4) About 14% ± 5% of the Virginian Province area had observable trash on the surface or bottom.

In addition, the researchers formulated a benthic index that appears to discriminate between sites considered by professional judgment to be in either good or poor condition. This index and these results will be evaluated further, using results from 1991 sampling activities in the same Province and comparison with the 1991 Louisianan Province Demonstration Project. A summary of the lessons learned in the demonstration project, included in the Demonstration Report, will benefit not only future estuarine monitoring activities but also other EMAP resource group monitoring activities.

Regional Implementation

Because EMAP is implementing ecological resource monitoring in a series of phases, it will take several years for the program to be fully implemented in all regions of the country and in all resource classes within a resource category.

The proposed regional priorities for implementation are shown by resource and standard Federal regions in Figure 13. The first region listed under each resource group represents the first region being considered for implementation, the next region is second and so forth. As noted earlier, each resource group will conduct a pilot study and demonstration project prior to implementing the monitoring program in each of the regions. The names assigned to various regions generally differ among resource groups to conform with the current or accepted regional designations of the other cooperating Federal agencies. Once EMAP is fully implemented, sociopolitical regions will become arbitrary designations that can be partitioned as necessary to respond to specific assessment questions from users of EMAP's information.

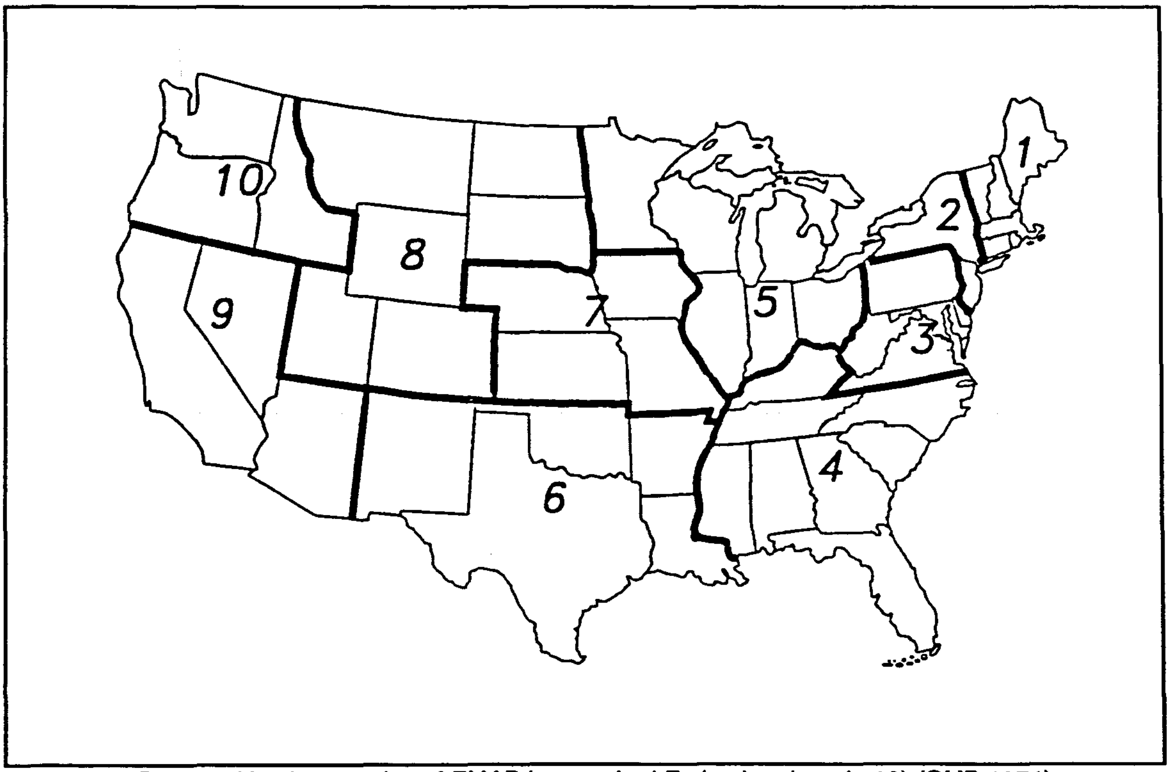


Figure 13. Proposed implementation of EMAP by standard Federal regions (1-10) (OMB 1974).

Agroecosystems
Southeast (4)
Mid-Central (7)
Mid-Atlantic (3)
North Central (5)
South Central (6)
West (8, 9, 10)
Northeast (1, 2)

Arid Ecosystems
Mogollan (6, 8, 9)
Great Basin (8, 9, 10)
Sonoran (9)
Mohavian (8, 9)
Plains (6, 7, 8)
Chihuahuan (9)
Californian (9)

Forests
Northeast/North Central (1,2,3,5)
Southeast/Southwest (4, 6)
Rocky Mountain/
Intermountain (7, 8)
Pacific Northwest/
Pacific Southwest (9, 10)

Great Lakes
Lake Michigan (5)
Lake Ontario (2)
Lake Superior (5)
Lake Huron (5)
Lake Erie (2, 3, 5)

Near-Coastal Waters and Estuaries
Virginian (1, 2, 3)
Louisianian (4, 6)
Carolinian (4)
Acadian (1)
West Indian (4)
Californian (9)
Columbian (9, 10)

Surface Waters
Northeast Lakes (1, 2)
Mid-Atlantic Streams (3)
Midwest Lakes (5, 7, 8)
Western Streams (6, 8, 9, 10)
Western Lakes (6, 8, 9, 10)
Southwest/West Streams (6, 8, 9, 10)
Southeast/Mid-Atlantic Lakes (3, 4, 6)
Midwest Streams (5, 7, 8)
Southeast Streams (4, 6)
Northeast Streams (1, 2)

Wetlands
Coastal - Gulf (6)
Emergent - Midwest (5, 7, 8)
Forested - Southeast (4)
Coastal - Atlantic (1, 2, 3, 4)
Emergent - Northwest (8, 10)
Forested - Northeast (1, 2)
Coastal - Pacific (9, 10)

Landscapes
To be determined.

6 — Reporting Results

For EMAP to contribute to the decision-making process, program results must be readily accessible, available in a timely manner, relevant to the assessment questions, and presented in an understandable and usable format for its audiences. EMAP must reach a variety of users: Congress, environmental groups, news media, as well as the scientific community and other groups. These audiences will include many individuals who may not fully understand ecology, sampling statistics, and other disciplines needed to interpret the scientific or technical details of EMAP's results. Consequently, the ways or devices by which these results can be most effectively communicated will differ according to the target audience. Complex scientific reports provide significant detail about analytical methods as well as copious presentations of data and results to meet the needs of the scientific community. Such technical detail may not be satisfactory to present information to other EMAP users. EMAP will involve communication specialists and adopt or develop techniques that convey useful information to targeted audiences. Decisions about appropriate media will be based on the accessibility and usability of those media for the targeted audience. EMAP will use focus groups to critique proposed presentation material for clarity, accuracy, and conciseness. Focus groups will be composed of members representing the scientific community, environmental decision-makers, policy-makers, and the public.

In general, EMAP will produce three types of products--verified, aggregated data; annual statistical summaries; and ecological assessments.

Data

Many users desire access to the data being collected by EMAP, either the individual, verified sample data or the data aggregated by specified units. The demand for data in the EPA STORET and USGS WATSTORE information management systems attests to the interest many users have in performing their own assessments. Currently, no information database includes regional and national ecological data on multiple ecological resources. Consequently, data are likely to be one of the earlier products from EMAP; moreover, these products will continue to be used over time.

Annual Statistical Summaries

EMAP resource groups will produce annual statistical summaries on selected indicators of condition. These summaries will contain descriptive statistics such as means, medians, distributions, ranges, and standard deviations for the various indicators monitored within the sampling frame or for selected indices computed from these data. These statistical summaries are anticipated to be similar to the annual summaries prepared by the Bureau of Labor Statistics, the U.S. Department of Agriculture National Agriculture Statistics Survey, and the USGS Water Data Summaries. The summaries will be prepared based on the standard Federal regions, and also can be prepared for biogeographic regions appropriate for the ecological resource.

Assessments

EMAP will produce regional, multi-regional, or national assessments that will address the condition of a particular resource, the condition of selected resources, and the condition of all resources that occur in a region. EMAP's design permits assessments on biogeographic regions--geographic areas characterized by specific plant formations and associated fauna--or on large political regions such as the standard Federal regions.

EMAP will produce two basic types of ecological assessments: periodic condition of ecological resource reports and special topic assessments to answer new questions or concerns of users. The principle difference between these assessments is that assessments for the condition of the ecological resource are designed as part of EMAP, whereas special topic assessments address specific issues raised by the user. Both assessments will assist in the continual improvement and evolution of the monitoring and research activities in EMAP. Condition of the ecological resource reports may be done at the resource-specific level, across multiple resources, or at the landscape level. Assessment reports will be produced as collaborative efforts with partner agencies, by other agencies using EMAP data, and by EMAP staff. These reports will assess ecological resource condition and suggest possible factors contributing to this condition, as well as evaluate the cumulative effectiveness of regulations and policies in protecting the environment.

7 — Measures Of Success

Success in EMAP occurs whenever the program's information contributes to decisions on national and regional environmental management and protection. The following factors will be evaluated to determine if EMAP is successfully contributing to these decisions:

1) **Ecological Condition**—EMAP will estimate the condition of ecological resources at regional scales by focusing principally on biotic indicators. EMAP will also monitor selected abiotic and stressor indicators to provide preliminary assessments of possible factors contributing to both degrading and improving ecological condition. The biotic indicators must be related to those values or variables used in the decision-making process.

2) **Quantitative Estimates**—A focus on data quality objectives in monitoring indicators and assessing ecological condition dictates that EMAP will produce quantitative estimates with known confidence intervals.

3) **Timeliness**—EMAP's monitoring data will be released to the public in a timely manner. Assessment reports will be distributed to the public periodically, and a limited number of "rapid-response" reports will be produced for users with special needs.

4) **Peer-Review**—The science and policy peer-review process by organizations, such as the EPA Science Advisory Board and the National Research Council at the programmatic level and advisory groups at the resource group level, ensures that EMAP information follows established science and policy principles.

5) **Quality**—EMAP's quality control process guarantees that the monitoring data are of the highest quality and that the assessments represent the most rigorous interpretations based on the data available at the time. EMAP upholds the highest information quality standards.

6) **Outreach**—The EMAP assessment framework requires that EMAP continually seek feedback from users to ensure that the program is meeting their changing needs.

7) **Communication**—Through the latest communication techniques, EMAP will produce visually appealing, readable documents and electronic databases that effectively record and convey its information. This will be an iterative, evolving process of improving communication with EMAP users.

From its inception, EMAP has emphasized the importance of making its products responsive to the information needs of its users.

8 — Interagency Cooperation and Partnerships

EMAP collaborates with the Nation's best scientists from over 12 Federal agencies, 20 States, and 40 universities in research, monitoring, and assessment activities.

Moreover, EMAP will use existing data wherever possible. Data and related assistance are already being obtained from the Bureau of Land Management, National Oceanic and Atmospheric Administration, Fish and Wildlife Service, Geological Survey, Forest Service, Agricultural Research Service, National Agricultural Statistics Service, Soil Conservation Service, and the National Aeronautics and Space Administration. Interacting with these agencies will increase the efficiency and cost-effectiveness of EMAP and will strengthen relationships and interactions among agencies.

As EMAP seeks to gather and assess information at regional and national scales regarding the condition of ecological resources, it will be able to derive important benefits, opportunities, challenges, and issues from contacts with local, State, and regional agencies, and other Federal programs.

These opportunities and challenges permeate all levels of EMAP's research, monitoring, and assessment. In an effort to document and enhance these cooperative efforts and its multiagency nature, EMAP has secured numerous memoranda of understanding with other agencies. EMAP will continue these outreach efforts and will extend them to other agencies and programs.

9 — Remaining Challenges

Although EMAP has made great strides toward implementing regional and national networks for monitoring the Nation's ecological resources, many challenges remain. Some will require the development of new scientific methodologies, for example, spatial statistics techniques to detect regional trends, tools to analyze landscape patterns, and methods to develop indicators that better characterize structural and functional ecological attributes. The development of indices that integrate economic, ecological, and social perspectives into easily understood measures of the ecological condition will require considerable research and testing. Issues, such as how to efficiently sample multiple resource categories within a selected sample area and how to accommodate site confidentiality issues associated with sampling specific sites, will require extensive evaluation and interagency cooperation. A critical challenge is developing a strategy and methods to incorporate social, societal, resource management, and scientific perspectives in the assessment process in order to develop criteria that distinguish good (nominal), marginal, or poor (subnominal) ecological condition for various resources. EMAP continues to collaborate with the Risk Assessment Forum to develop approaches for comparing the risk to ecological resources within and among regions.

Communication poses an ongoing challenge. Rubin et al. (1992) suggest that the failure of NAPAP to influence recent environmental legislation was because findings were not reported in a timely fashion and because results and conclusions were not understandable to policy makers. Consequently, EMAP will further emphasize communication by supporting professional interactions within the scientific community to maintain technical competence and by encouraging professional exchanges among managers and decision making communities to maintain policy relevance.

Glossary

A

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

acid rain: 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.

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.** (New term 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 frequency distributions**, estimates of the extent of **nominal** or **subnominal** condition, comparisons among regions, or comparisons of data over time.

area frame: A **sampling frame** obtained by dividing a **region** into well-defined, identifiable subregions that in aggregate comprise the total area of the **region** of interest. The subregions are **sampling units** defined on maps or other cartographic materials. (See related: **frame.**)

arid ecosystems: Terrestrial systems characterized by a climate regime where the potential evapotranspiration exceeds precipitation, annual precipitation is not less than 5 cm and 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.

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. (See related: **continuous.**)

auxiliary data: Data derived from a source other than EMAP, that is, from the literature 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.**)

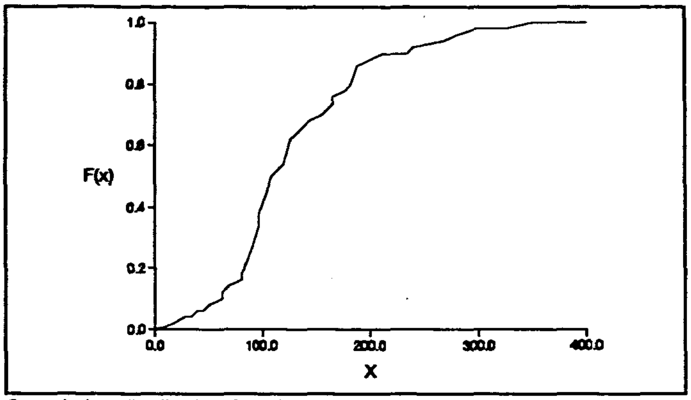
B

baseline grid: The fixed position of the EMAP grid as established by the position of the hexagon overlaying the United States. This is distinguished from the sampling grid, which is shifted a random direction and distance from the **baseline grid.**

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).

biogeographic province: Geographic areas characterized by specific plant formations and associated fauna.

biotic: Of or pertaining to living organisms. (New term 1993. See related: **indicator, condition indicator, abiotic condition indicator, stressor indicator. Biotic condition indicator** replaces: "response indicator.")



Cumulative distribution function

C

changes: As used in EMAP, the difference in the distribution of measurements of **condition indicators** between two time periods.

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

confidence interval: An interval defined by two **values**, called *confidence limits*, calculated from sample data using a procedure which ensures that the unknown true value of the quantity of interest falls between such calculated **values** in a specified percentage of samples. Commonly, the specified percentage is 95%; the resulting confidence interval is then called a 95% confidence interval. A one-sided confidence interval is defined by a single calculated value called an upper (or lower) confidence limit.

continuous: A characteristic of an **attribute** that is conceptualized as a surface over some region. Such **attributes** are measured at points and represented by fitted surfaces or contours.

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, such as Landscape Characterization, Design and Statistics, Indicator Development, Information Management, Assessment and Reporting, Logistics, Methods, and Quality Assurance.

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(α) 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.*)

D

data quality objective (DQO): Quantitative and qualitative statement of the level of uncertainty one is willing to accept with regard to a given variable being measured. 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**.

demonstration project: A field research project designed to provide preliminary estimates of a **resource condition** for a single **indicator** over a standard Federal region for one or more **resource classes**. Separate **demonstration projects** are defined for each **indicator** of **condition**; in a **demonstration project, quality data objectives** are stated for preliminary statistical estimates.

distribution function (See **cumulative distribution.**)

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

E

ecology: The relationship of living things to one another and their environment, or the study of such relationships.

ecological risk assessment: 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).

ecoregion: A geographic area which is relatively homogeneous with respect to ecological systems (Omernik 1987).

ecosystem: The interacting system of a biological community and its non-living environmental surroundings.

ecosystem function: Energy flow and material cycling processes within an ecosystem.

ecosystem structure: Spatial and temporal patterns of organisms in an ecological system.

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

environmental value (See: **value**.)

estuary: Regions of interaction between rivers and nearshore 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. (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).

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.

H

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

I

inclusion probability: The probability of including a specific **sampling unit** within a **sample**.

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

index period: The period of the year when measurement of an **indicator** yields meaningful information.

index sample (See: **sample**.)

indicator: Characteristics of the environment, both **abiotic** and **biotic**, that can provide quantitative information on ecological **resources**. EMAP emphasizes biological **indicators** in contrast to the traditional approach of **monitoring** chemical and physical **indicators**. (Revised definition 1993. Preferred term for environmental indicator, deleted 1993.)

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**. An **indicator** is considered a core **indicator** when it is selected for long-term, **ecological monitoring** as a result of its acceptable performance and demonstrated ability to satisfy **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**, and the coordination of **monitoring** efforts, 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

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.

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 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).

list frame (See **frame.**)

M

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

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

monitoring: In EMAP, the periodic collection of data that is used to determine the condition of ecological **resources.**

N

nominal: Referring to the state of having desirable or acceptable ecological condition.

P

pilot project: A sampling effort conducted over a small area usually during a single **index period. Pilot projects** are used to evaluate **indicators, sampling design**, methods, and logistics. (See related: **demonstration project.**)

population: 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 an extensive resources, about which inferences are desired or made. In **ecology**, the term **population** refers generally to a group of individuals of the same species residing in close proximity to each other such that the individuals share a common gene pool.

population estimation: Classic survey estimation of **population** parameters. Such estimates will not reflect spatial configuration except through identification of the **population**, or of **subpopulations**, which may be defined by spatial **attributes.**

population units: The entities that make up a target **population.** The units can be defined in many ways, depending on the **survey** objectives and the type of measurement to be made. Typically, definitions of environmental units include (1) an explicit statement of the characteristics each **population** unit must possess in order to be considered a member of the target **population** and a (2) specification of location in space and time.

precision: The degree to which replicate measurements of the same **attribute** agree or are exact. (See related: **accuracy.**)

probability sample: A **sample** chosen in such a manner that the probabilities of including the selected units in the **sample** are known, and all **population units** have a positive probability of selection. This implies that the target **population** is represented by the **sample** and that the target **population** is explicitly defined.

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 to ensure that all **data quality objectives** are achieved (See related: **quality assessment, 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).

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 the 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 is used more broadly in EMAP. (Term added 1993.)

reference site: One of a **population** of bench mark or control sampling locations that, collectively, represent an ecoregion or other large biogeographic area; the sites, as a whole, represent the best ecological conditions that can be reasonably attained, given the prevailing topography, soil, geology, potential vegetation, and general land use of the region.

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

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. Seven such categories currently are identified within EMAP: estuaries, Great Lakes, inland surface waters, wetlands, forests, arid ecosystems, and agroecosystems. EMAP also considers landscape ecology a resource. These categories define the organizational structure of **monitoring** 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 assessment (See: **assessment.**)

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 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, Inland Surface Waters, Wetlands, Forests, Arid Ecosystems, Agroecosystems, and Landscape Ecology.

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.

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.

risk characterization: Determination of the nature of a given risk and quantifying of the potential for adverse change to the environment from that risk. Characterization is accompanied by a statement of uncertainty.

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.

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.** (See related: **probability sample.**)

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.

spatial statistics: Statistical methodology and theory that accounts for spatial aspects of a spatially distributed data set. Conventional **population** estimation does not normally account for spatial **attributes**, except perhaps for spatial identity of **subpopulations**.

status: The distribution of scores for **condition indicators** with relation to the **reference condition** associated with specific social values or desired uses for a specified time period. (Term added 1993. See related: **condition, trends.**)

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 are known, or a testable hypothesis can be formulated.

subnominal: Having undesirable or unacceptable ecological condition. (See related: **nominal.**)

subpopulation: Any subset of a **population**, usually having a specific **attribute** that distinguishes its members from the rest of the **population**, for example, lakes from a specified **population** that are above 1000 m in elevation. **Subpopulations** are important entities in the EMAP plan. Any defined **subpopulation** is subject to characterization via estimation of **subpopulation attributes** and comparison to other **subpopulations**. It is this focus that imposes the greatest restrictions on the EMAP design and establishes the primary directions of the EMAP analyses.

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. A lake is defined as 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. 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.

systematic sample: A sampling design that utilizes regular spacing between the **sample** points, in one sense or another. The EMAP design selects **samples** via the systematic grid. Spatial arrangement of the selected **resource** units is not always strictly systematic, but the systematic grid is an important aspect of the design.

T

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

trends: The changes in the distribution of scores for **condition indicators** over multiple time periods.

V

value: 1) 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).

2) A quantity's magnitude.

variance: A measure of the variability or precision of a set of observations.

W

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).

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