



United States  
Environmental Protection  
Agency

Office of Research and  
Development  
Washington, DC 20460

EPA/620/R-98/001  
October 1997

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# **Environmental Monitoring and Assessment Program (EMAP)**

## **Research Strategy**





*United States*

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Assessment Program*

*(EMAP)*

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## ***Environmental Monitoring and Assessment Program Research Strategy - Overview***

The Environmental Monitoring and Assessment Program (EMAP) has evaluated its progress since 1989 and the recommendations of 20 peer reviews. The program retains its goal to *Monitor the condition of the Nation's ecological resources to evaluate the cumulative success of current policies and programs and to identify emerging problems before they become widespread or irreversible.* The strategy for EMAP is based on three principles. First, pursue all tiers in the monitoring framework (i.e., Index Sites, Geographic Surveys and Landscape Monitoring). Second, focus the next three years on the research and demonstration necessary to provide the scientific credibility for the monitoring network. Third, based on the knowledge of the science necessary for success, build the national network from the bottom up, starting with effective existing networks and add to them where gaps exist. ***The later means that EMAP itself will not be the entire national monitoring network but will contribute components to it. The exact components that EMAP will implement long term will ultimately depend on the success of the CENR framework and decisions at the Administrator and Assistant Administrator level within EPA.***

1. EMAP will establish a national network of index sites with the National Park Service to serve as *Outdoor Laboratories*. This was part of the original EMAP vision and has now been added back to the program's efforts.
2. EMAP will build upon the strengths that it developed in monitoring ecological resources such as estuaries, streams, and terrestrial systems. These efforts will be focused on specific geographic regions of the country rather than occurring independently in different regions of the country. If the budget does not permit all regions to be done at once, a rotational approach will be adopted
3. EMAP will continue its interagency efforts to complete and repeat through time a national landcover database.
4. EMAP will place a high priority on research to ensure that monitoring which continues is based on strong science. The high priority research areas will be:
  - ecological indicators
  - monitoring design
  - integration and synthesis of environmental data

By addressing these scientific uncertainties in a credible manner, EMAP will make important contributions toward the goal of providing the information necessary for protecting our ecological resources.

# *Environmental Monitoring and Assessment Program Research Strategy*

*Health is the capacity of the land for self-renewal* (Aldo Leopold, 1966). As part of the U.S. Environmental Protection Agency's (EPA) mission and the Office of Research and Development's (ORD) Strategic Plan, the Environmental Monitoring and Assessment Program (EMAP) represents a major element of ORD's effort to understand and protect that capacity. Policies and programs that promote the preservation of ecosystem integrity and sustainable use of natural resources must be formulated from our scientific knowledge of the environment. While the benefits of our understanding of the environment will only be realized through control and stewardship programs at many levels of government, the Council of State Governments recently reported that most state and local agencies do not have the information needed to launch meaningful environmental protection programs.

The missing information creates uncertainties in three areas. The first is the gap in our knowledge of the mechanisms that control ecosystem structure and function and assessing the role of human actions in altering them. The second is a sound framework embracing approaches to monitor important ecosystem characteristics and the human perturbations that alter them over space and time. The third is the collective scientific, societal and political will to implement these monitoring approaches and utilize the information that they generate. ORD has chosen to focus a portion of its research to improve ecosystem risk assessment on the first two of these three factors in the belief that this will result in better information for managing and protecting our natural heritage.

*EMAP: "Monitoring to keep a finger on the pulse of the Nation's environment"*

This strategy outlines the origins of EMAP, an evaluation of progress, sets our compass heading and provides a rationale for that course. The EMAP Research Plan will describe how rapidly we can move along this course and how soon we can arrive at our long-term goal.

## **I. National Monitoring Needs**

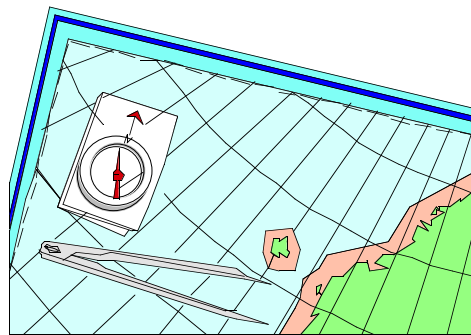
Recent calls for improvements in monitoring date back to the late 1970's. A long series of reports from the National Research Council (NRC 1977), the U.S. General Accounting Office (GAO 1981), the U.S. EPA's Office of Water (OW) and Office of Policy, Planning and Evaluation (OPPE), state, federal, and university aquatic biologists (USEPA 1987), and again by the U.S. General Accounting Office (GAO 1986) have recommended the need for significant advances in the way EPA and other federal agencies monitor the state of our environment.

In 1988, the U.S. EPA Science Advisory Board's (SAB) report *Future Risk: Research Strategies for the 1990s* (U.S. EPA 1988) was the stimulus for many of the changes in EPA

research. The report concluded that EPA needed more research on relating the effects of cumulative, regional, and long-term anthropogenic disturbances to ecosystem responses. Increased research was also needed to develop ecological indicators, protocols for monitoring, and to analyze and quantify uncertainty in assessments resulting from monitoring data. The goals of such research were improved detection of ecosystem status and trends, and greater predictive capability. The authors recognized that great benefit could be derived from the identification of trends in environmental quality before they begin to cause serious ecological or human health problems. They recommended that EPA take steps to enhance its ability to anticipate environmental problems before public fears are aroused, and before costly, after-the-fact clean-up actions are required. They also recommended that EPA broaden its data-gathering and assessment efforts. Embodied in their recommendation was the perspective that monitoring programs can be valuable for their ability to paint a picture of present conditions and if continued, they can help describe what has happened to the quality of an ecosystem over time. Their recommendations urged EPA to begin monitoring a far broader range of environmental characteristics and contaminants than it has in the past.

Toward these ends, the SAB recommended that EPA undertake research on techniques that can be used to help anticipate environmental problems, and make a more concerted effort to be aware of and interact with the research efforts of other Federal agencies concerned with the anticipation of environmental problems. EPA was urged to evaluate environmental trends and assess other predictors of potential environmental problems before they become acute.

The Environmental Monitoring and Assessment Program, known as EMAP, was created in response to these recommendations. Taking the "pulse" of the nation's ecological resources and producing an "environmental report card" became the driving focus for EMAP. Developing the tools necessary for measuring the condition of many types of ecological resources and the designs for detecting both spatial and temporal trends is not a challenge to be taken lightly. EMAP embraced these basic scientific needs with an emphasis on developing indicators of ecological condition and new monitoring designs for major classes of natural resources such as forests, wetlands, deserts, agricultural systems, and surface waters. The recommendations that spawned EMAP fit well with the emerging vision of ecological risk assessment within EPA and the importance of high quality information from monitoring in the risk assessment paradigm.



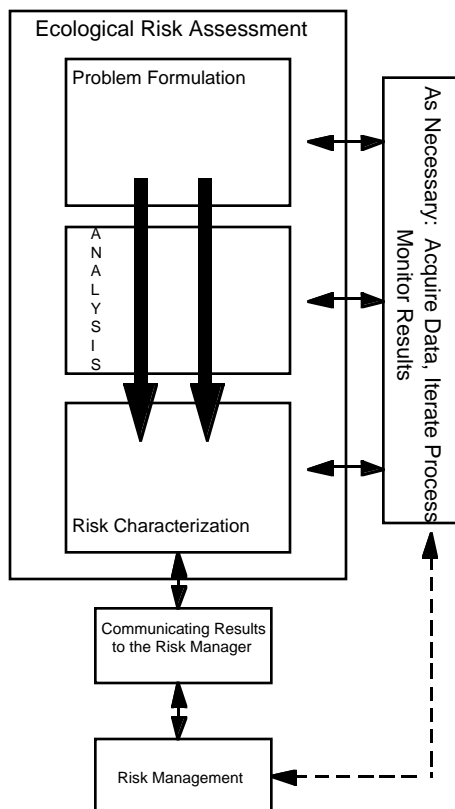
**The Strategy Charts Our Course**

## **II. EMAP - The Early Years**

EMAP's initial vision was to *Monitor the condition of the Nation's ecological resources to evaluate the cumulative success of current policies and programs and to identify emerging problems before they become widespread or irreversible* (Messer et al. 1991). This goal was established to ensure that we would eventually be able to answer very simple questions: What have we accomplished with our collective efforts to restore and protect our ecological

resources? How do we know our programs, in aggregate, are or have been successful? Can we provide data to confidently verify the answers? Is the aggregate of our regulatory decisions protecting our ecological resources? This goal was further expressed in four operational objectives:

- 1) Estimate current status, trends, and changes in selected indicators of the Nation's ecological resources on a regional basis with known confidence;
- 2) Estimate the geographic coverage and extent of the Nation's ecological resources with known confidence;
- 3) Seek associations between selected indicators of natural and anthropogenic stresses and indicators of the condition of ecological resources;
- 4) Provide annual statistical summaries and periodic assessments of the Nation's ecological resources.



### Risk Assessment Paradigm

The program outlined a four-tier approach to this monitoring. The foundation of this tiered approach was national landcover characterization based on remote sensing. The second level incorporated national and regional estimates of status and trends for important indicators of condition and exposure. A subregional focus for geographic areas that were of special concern formed the third tier. Finally, a tier of sites spread across the U.S. for intensive monitoring and research. This tiered approach incorporated concepts of both temporal and spatial scales and of the importance of different monitoring approaches: wall-to-wall coverage (census), statistically valid subsampling (probability-based surveys) and temporally intensive studies of a single or small collection of sites. Both indicators of stressors (e.g., metals in deposition, UV-B, tissue contamination, habitat alteration) and indicators of condition (e.g., external anomalies, fish index of biotic integrity, forest crown dieback) were incorporated into the overall approach.

In practice, however, the early years of EMAP focused only on developing and demonstrating the remote sensing and survey tiers. Operating under common approaches to indicators and design, individual components of the program (arid lands, agroecosystems, estuaries, forests, Laurentian Great Lakes, surface waters, wetlands) began to develop and evaluate the approaches in different portions of the country. These studies explored the range of useful indicators, the natural and anthropogenic variability and its influence on status and trends information, and the range and applicability of probability surveys for monitoring that resource. EMAP recognized early on that full implementation of this framework or even the landscape and resource survey tier could only be achieved if the budget was to grow to \$100,000,000 per year and if other federal agencies became active

partners, bringing their own resources to the effort. However, national demonstration or implementation was not achieved for any of the resource areas despite significant interagency partnering in many of the components, largely due to declining budgets rather than technical issues.

During this initial phase, EMAP and its components underwent 20 separate peer reviews of individual components of the program and a program-wide review by a panel under contract between EPA and the National Research Council (NRC). This panel published 4 individual reports. The EPA Science Advisory Board also reviewed several aspects of EMAP paying particular attention to the development of indicators and the integration and assessment activities within the program. ORD spent 1995 evaluating the results of these initial studies and reviewing the aggregate of peer reviews which had taken place. 1996 was spent developing this revised strategy and research plan that is founded on the same EMAP goals, many of which are now shared by other agencies (see CENR discussion).

### **III. Review of Progress**

In synthesizing the results of the 20 peer reviews, several themes emerged. Common questions or concerns across several or more reviews were:

- *EMAP's success will be diminished if it does not develop reliable, scientifically defensible indicators for measuring change. The development of indicators of ecological health or integrity appears to be particularly challenging.*
- *The EMAP sampling program may operate at too coarse a scale in space and time to reflect information needs for management decisions.* This concern reflects what some have called "the tyranny of numbers." Information is needed for management decisions at multiple scales, from the EPA Administrator to the local lake manager. Clearly, if national assessments for the Administrator can be aggregated from the local level data, then all scales are represented.
- *EMAP's success will be diminished if the retrospective or prospective monitoring approach does not match the assessment needs and the needs of policy makers.* This concern reflects the continuous balancing act between measuring stressors and their effects. We believe it is not an issue of one versus the other, but a balance of both.

Key recommendations emerging from the National Research Council review include:

- *EMAP should consider design changes such as the inclusion of a set of nonrandomly selected sentinel sites with intensive data collection. If EMAP does not adopt these design changes itself, then it should become extremely closely and explicitly coordinated with a program that has these features.*
- *EMAP should consider further combining effects-oriented and stressor-oriented monitoring approaches.*
- *EMAP should undertake more analyses of variability and its relationship to sampling design and power to describe status and detect trends, similar to the analyses conducted with the lakes data.*



- *EMAP should initiate a major, focused research program on indicator development. Indicator development is at the heart of the EMAP program. The difficulty and importance of indicator development requires that EPA attract the highest quality researchers in the environmental sciences to this program. The program should include a combination of internal research (by EMAP scientists) and external research involving open announcements of funding availability with peer-reviewed grants.*
- *EMAP should provide program-wide guidance for numerous evaluation issues: indicator selection strategy, approaches to integration and assessment, the primary scale for summarizing and reporting data, impact of variability on design.*
- *EMAP should continue in its efforts to develop close working relationships with the EPA Program Offices and other Federal Monitoring efforts.*

#### **CENR National Framework**

Under the auspices of the National Science and Technology Council, the Committee on Environment and Natural Resources (CENR) formed the Environmental Monitoring Team. The Environmental Monitoring Team took the crucial step of bringing federal agencies together to shape a national framework for integration and coordination of environmental monitoring and related research. The Team published *Integrating the Nation's Environmental Monitoring and Research Networks and Programs: A Proposed Framework* (CENR 1996). The framework calls for all environmental agencies to merge efforts in forming a national monitoring and research network which will link remote sensing, regional surveys, and intensive, multi-resource monitoring areas such as the Long-Term Ecological Research program (LTER) of the National Science Foundation (NSF). Also, this framework unites the respective agencies in an effort to achieve a common national goal: that of understanding and managing our ecological systems for their sustained use (e.g., ensuring their continued and sustained vitality, diversity, and abilities to provide important resources, services for humans, and habitat) and enjoyment (e.g., recreational opportunities and cultural values).

Three areas of emphasis for the CENR:

- **National Environmental Report Card** by the year 2001 - A challenge laid down by Vice President Gore.
- **National Network of Index Sites** - Pilot the concept.
- **Regional Mid-Atlantic Pilot** - Examine the Framework concepts.

#### **IV. EMAP - The Next Steps**

The goal of EMAP remains the same: *Monitor the condition of the Nation's ecological resources to evaluate the cumulative success of current policies and programs and to identify emerging problems before they become widespread or irreversible.* The strategy for EMAP will be centered on three principals. First, all tiers in the monitoring framework must be pursued (i.e., Index Sites, Geographic Surveys and Landscape Monitoring). Second, focus the next three years on the research and demonstration necessary to provide the scientific credibility for the monitoring network. Third, based on the knowledge of the science necessary for success, build the national network from the bottom up starting with those existing networks and add where gaps exist. *The latter means that EMAP itself will not be the entire*

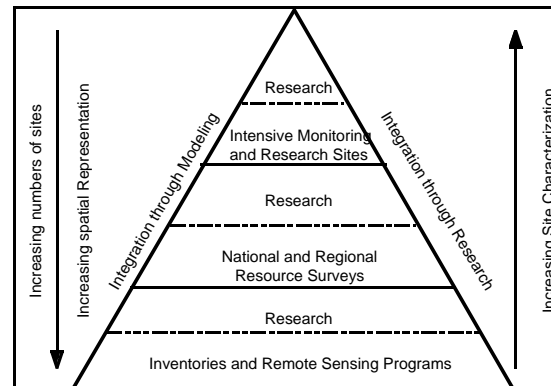
***EMAP itself does not strive to be the entire national monitoring network but will contribute components to the Federal Monitoring Framework***

*national monitoring network but will contribute components to it. The exact components that EMAP will implement long term will ultimately depend on the success of the CENR framework and decisions at the Administrator and Assistant Administrator level within EPA.*

Below we outline the three monitoring approaches that EMAP will pursue: Index Sites, Geographic Regions and Landcover. In addition, the key research areas that must be addressed by EMAP are outlined.

### A. Index Sites

The dominant approach to integrated ecological studies historically has been to study individual systems intensively. One limitation of past work has been the short period of intensive study; many limited to the 3-year period of a single government grant. Individual studies of greater duration have resulted from the perseverance and creativity of a few individual investigators. The research of Likens and Bormann at Hubbard Brook (Likens et al. 1977), Goldman's studies at Lake Tahoe (Goldman 1988), and Keeling's tracking of CO<sub>2</sub> increases at Mauna Loa (Earth Systems Sciences Committee 1988 ) are among the well known examples of dedication to long-term studies and how these long-term data records document changing conditions and stimulate many new hypotheses.



Three Tiers of Monitoring in the EMAP and CENR Strategy

The Index Site concept can be found in the monitoring programs of many agencies including the earliest designs of EMAP. EMAP now adds the concept of index sites back into our research, monitoring and assessment efforts. Our intent is to pilot a national network in collaboration with other federal partners that can be used to monitor long-term changes in atmospherically mediated stresses and their effects. The results of this network are not intended to be extrapolated to all locations in the U.S. but rather to provide a range of latitudinal, longitudinal and elevation gradients in locations with minimal impact from other anthropogenic stresses so that the potentially weak signals of atmospheric problems can be teased from the background noise. One major importance of this tier is the dynamic linkage created between the other tiers. Index sites can monitor trends requiring technology not readily portable and can establish cause-effect linkages within important environmental processes. Concomitantly, the other tiers can be used to determine how representative the research results of index sites are at larger scales. However, consensus on how best to define an index site and how to locate such sites in a network is still quite elusive. Because these questions are not likely to be resolved without research, EMAP will establish an effort to evaluate designs for index sites with respect to specific hypotheses and to evaluate the multiple options for linking survey networks with networks of intensive sites.

Strategically, the Intensive Site Network meets the following criteria:

- The selected sites are of interest to multiple Federal agencies and at least one agency is interested in participating in the development of the network;
- The selected sites exist in all major ecosystem types;
- The sites have long-term accessibility (i.e., no potential for property rights issues); and,
- The sites have some degree of environmental monitoring and/or ecological effects research already in place.

**A National Park Network of “Outdoor Laboratories”.** The National Park system has the potential to provide for all terrestrial ecosystem types and many of the goals and objectives of the NPS Inventory & Monitoring Program are similar to those of EMAP. The National Park Service’s Air Monitoring Division and Inventory and Monitoring Program and EMAP will co-develop a 10-15 site terrestrial intensive monitoring/research network. Both agencies will contribute funds and efforts toward this development with the intent to invite other federal agencies to participate in the longer term. In 1996, EPA and NPS created a formal interagency agreement to create DISPro, the Demonstration of Intensive Sites Project. This project represents an inter-agency effort between EPA/ORD and DOI/NPS to develop a demonstration of an intensive site network of monitoring and research locations throughout the United States utilizing the Nation's parklands as "outdoor laboratories". Twelve parks were selected to establish this demonstration. All 12 parks are readily accessible, have a history of monitoring environmental information, and represent a broad, sometimes unique, spectrum of ecological communities. Through this network, EMAP and the Park Service are examining whether a "network" of sites existing within the parks can be used to address monitoring issues for global-scale environmental stressors (e.g., air deposition) as well as locale-specific stressors (e.g., air deposition, water-borne) and coordinated with cause-effect, issue-based research related to these environmental stressors. The intent of the program is to initiate a consistent air monitoring program at each site to be followed by consistent monitoring within other media. The network will also initiate research projects at all of the sites to examine the effects of environmental stressors of importance at each of the sites.

**DISPro:  
A Network of *Outdoor  
Laboratories* through Our  
National Parks**

Effects research during this period will be based on known stressors at the sites. For example, the Everglades site offers the opportunity to examine the flux of materials and nutrients from Everglades canals into Florida Bay, to examine the role of humic materials in the complexation and transport of mercury through the canals, to investigate the effects of increased nitrogen and phosphorus from the canals on primary and secondary productivity in Florida Bay, and to investigate the cause of black band disease in corals in the Florida Keys National Marine Sanctuary. At the Great Smoky Mountain site, opportunities exist to validate forest stand models of ozone effects using new forest stand micro-meteorological and dosimetry equipment, as well as mechanistic studies of the effects of atmospheric nitrogen deposition in watersheds which would expand the representativeness of findings with similar studies at the Sequoia, Acadia, and Rocky Mountain sites. EPA proposes to initiate extramural and/or cooperative (with other CENR-member agencies) research examining the effects of increased UV-B exposure on the reproductive success of amphibians and reptiles (Big Bend, Everglades,

Sequoia), UV-B exposure on coral community structure (Virgin Islands), and UV-B exposure on plankton community structure and productivity (Everglades, Virgin Islands).

## **B. Regional-Scale Geographic Assessments**

The geographic studies in EMAP are intended to describe the status and trends in the condition of ecological resources within a region and evaluate the likely causes of effects that are observed. This is consistent with the regional and national survey tier in the CENR framework. These geographic studies will result in "State of the Region" assessments. EMAP geographic studies will focus on characterizing both the ecological quality of the region and the important environmental stresses at multiple scales and are based on assessment questions of importance to that region. The assessments will provide a picture of comparative risk for the region. Monitoring and assessment will take place in four "resource" categories (terrestrial, inland aquatic, estuarine, landscape) and then integrated across the four components for the region. These studies build on the strengths from past EMAP research utilizing important concepts of probability surveys developed in earlier studies.

### ***Geographic Monitoring for Environmental Report Cards***

Several features will be added to these efforts that are enhancements to past work. Previously, EMAP studies were designed specifically to address regional scale assessments. In future geographic studies, we will partner with others in an effort to build the regional assessments from the bottom up, that is, aggregate local data where possible for the broader regional assessments. In the mid-Atlantic area, for example, at least two states already utilize probability survey concepts for they're state-wide monitoring networks. For that portion of the region, they provide a data source that does not need to be duplicated and can be used in the assessment process. Additional monitoring need only fill in portions of the region where similar studies are not taking place. The other addition will be a focus on integrating temporally intensive studies into the assessment with spatially extensive data. Bringing the best of both approaches should enhance the quality of any resulting assessment.

Conceptually, it would be preferable to have geographic studies performed concurrently across the country. For the foreseeable future however, the EMAP resources alone will be sufficient for only one to two large geographic studies at a time. As the CENR framework begins to spread across federal and state agencies, it may be possible to collectively reach a point where several similar studies are in progress. Toward this end, EMAP will continue to sponsor smaller geographic studies in each of the 10 EPA Regions. These studies will utilize design concepts and indicators developed by EMAP to address more localized assessment questions that are of interest to the EPA Regions and their partners. The first regional scale geographic study in EMAP will be conducted in the mid-Atlantic geographic region. The mid-Atlantic region of the eastern United States is defined by the land and near-coastal area that includes all of Standard Federal Region III and parts of Regions II and IV. States completely covered are: Pennsylvania, Maryland, Delaware, Virginia, and West Virginia. Also included are parts of New Jersey, New York, and North Carolina. The communities in the mid-Atlantic are diverse in size, type, values, economic and cultural influences. They include the

fishing and crabbing communities of Delaware, eastern Maryland, Virginia and North Carolina; the farm communities of central Pennsylvania and western Maryland; the coal-mining communities of West Virginia and western Pennsylvania; and the major metropolitan areas of Baltimore, Washington, D.C., Philadelphia, and Norfolk. The mid-Atlantic has also been selected by the CENR as the first demonstration of the multi-tiered monitoring framework. The EMAP and CENR effort will be well coordinated.

### C. National Landcover Monitoring

Remote-sensing provides the information base of our multi-tier effort. This important tool ensures that we will have consistent and high quality analysis of how our national landscape is being used. Repeated analysis of satellite imagery over time will provide the ability to monitor the single largest anthropogenic impact on earth, changes in land-use and land-cover brought about by human activity (Vitousek 1994). This perspective is also essential for interpreting changes seen in specific ecological resources such as streams and wetlands in different regions of the country. In addition to describing changes in land use, satellite imagery provides the data necessary for integrating information about ecological patterns and processes at multiple scales. The field of landscape ecology is a discipline that potentially provides a unique and integrative view of ecological systems. It seeks to understand how the patterns of spatial heterogeneity reflect important changes in ecological functions at multiple levels of biological organization (Pickett and Cadenasso 1995).

Remote sensing also offers great promise for reducing the cost of monitoring or, at a minimum, provide the broad spatial context within which other monitoring is interpreted. Because the infrastructure for remote sensing is largely in other federal agencies, EMAP will develop research partnerships with these agencies as an end-user that seeks to define the science applications as they relate to ecological condition. In this spirit, there are several research areas in which EPA can have a major impact and for which EMAP can provide necessary leadership. The EMAP contribution to research on the remote sensing tier will be limited to the field of landscape characterization and ecology.

In 1993, EMAP initiated a partnership with other federal programs to deliver processed imagery from across the coterminous United States, at a fraction of the cost to individual agencies. In addition to

***EMAP and MRLC will provide  
National Landcover Data***

EMAP, partners in the Multi-Resolution Land Characteristics (MRLC) Consortium include the NBS Gap Analysis Program, the NOAA Coast Watch Change Analysis Program, the USGS National Water Quality Assessment Program, and the USGS EROS Data Center.

The goal of the MRLC is to produce a national land cover data base by late 1999 (MRLC, 1996). The data base will be produced mainly from the nominal 1992 Landsat TM coverage purchased earlier by consortium members. The national land cover data base will consist of four components: 1) the land cover legend; 2) the spatial and digital format of the data base; 3) the data layers contained in the national land cover data base; and 4) the supporting documentation. Although the immediate goal is to produce a national 30m land cover data base from the 1992 Landsat TM data set, the MRLC Consortium is committed to an ongoing,

cyclic land cover characterization activity. Parallel with the effort to produce the national land cover product from the 1992 Landsat TM data set, planning is beginning for sequential national land cover classifications.

#### **D. Monitoring Research**

The fourth major emphasis for EMAP is research on the tools necessary for effective monitoring. The primary thrusts of this research are: 1) Indicator Development, 2) Monitoring Network Design, and 3) Integration. Our strategic direction for each is outlined below.

##### **1. Ecological Indicators**

The reviews of EMAP and our own evaluations, agree that development of effective indicators of ecological condition are central to the goal of EMAP. In general terms, we are concerned about whether or not our human activities are having an adverse effect on the ability of ecosystems to sustain themselves (functionally and structurally) and to provide a variety of goods and services into the future. Have our actions somehow limited the options available to future generations by impacting certain ecological processes or systems? The scientific community has variously described this attribute of ecological systems as sustainability (Lubchenco et al. 1991), integrity (Karr 1991) or health (Steedman 1994).

EMAP research must contribute to developing an understanding of the conceptual basis for defining sustainability and integrity for single ecological resources and complexes of ecological resources. What mechanistic model(s) will provide a foundation for monitoring? What ecological units of organization (e.g., watersheds, ecoregions or landscapes) best describe sustainability and integrity? Can individual ecological resources such as lakes, streams, forests, or rangelands exhibit sustainability and integrity or are these concepts applicable only to complexes of ecological resource types? These are critical information gaps which research in EMAP can help to fill.

*Developing scientifically rigorous, ecologically meaningful and policy relevant indicators is paramount to EMAP's success*

We have long marked our progress in environmental protection by administrative measures such as the changes in the number of permits issued. We have also tracked the occurrence of individual contaminants in the environment and occasionally their presence in biota. However, the range of chemicals continues to expand and we have a limited ability to track them all. Our perturbations of the environment have extended beyond the simple addition of

traditional chemicals to exotic chemicals such as endocrine disruptors, disruption of physical habitat, alteration of hydrologic patterns, introduction of non-indigenous biota and widespread alteration of the landscape. The primary question we face is: To what extent do these disturbances actually alter sustainability and integrity of our ecological resources and how can we measure this? To achieve this will require that we develop and understand new indicators that allow us to detect and track changes in integrity and sustainability

Toward this end, research in EMAP, conducted both through an investigator driven grants program and the in-house EPA expertise, will focus considerable effort on the area of indicator development. EMAP will promote research to improve ecological indicators by coordinating an intramural indicator research program and by developing RFAs to stimulate academic research on new indicators using the EMAP funds in the ORD grants program.

## 2. Monitoring Network Designs

Improved network design is a major research issue. Monitoring designs most often are directed at rather narrowly defined problems and are seldom explicit in terms of quantifying bias, predictive power, or value to a concept for holistic risk assessment. In the U.S., there are dozens of intensive study sites and hundreds of specialized monitoring sites nationwide with no unifying scientific concept to integrate data. Monitoring data often cannot be aggregated to answer larger questions.

That individual monitoring programs have not been optimized in design will not come as a surprise to scientists in most agencies and universities. Experts in design have often seen the science of monitoring yield to pragmatic judgment, with the result that the data may answer a narrow question but cannot be applied to larger, more difficult monitoring questions.

***Sound statistical designs are critical to the success of monitoring programs in detecting trends***

The CENR Monitoring and Research Framework began the process of describing what an integrated, multi-agency monitoring effort should entail. However, there is a great deal that the initial framework document did not outline such as the details that are necessary for further progress to be made by the participating agencies. EMAP will address EPA's perspective on these framework details. Examples of such issues are the specific nature of the status and trends questions that are importance to EPA Program Offices and Regions, the function of the proposed tiers in addressing these assessment questions, and the minimum ecological resource coverage needed from EPA's perspective.

In addition to the interest in a more integrated approach to monitoring ecosystems, we know that there is a need for and interest in better approaches to monitoring individual ecological resources such as estuaries, forests and riverine systems. Better ecological indicators of these resources are necessary but not sufficient. Improved designs must be developed if we are to effectively determine status and detect trends in the quality of these resources. Evaluating the work done to date and the comments of the more than 20 reviews conducted of EMAP, we will propose improvements to the approaches outlined earlier by EMAP.

EMAP will consolidate the intramural expertise in ORD and stimulate an effort aimed at improving multi-tier designs and engaging design specialists in all agencies for their essential participation. Success in this research will be measured by the ability of new designs to adjust individual monitoring programs to answer regional-scale assessment questions without any of these programs losing their ability to address their respective original objectives.

### 3. Integration

The science of integration is sufficiently complex and difficult that most monitoring programs have ignored this issue. The sciences of landscape ecology and spatial analysis have yet to develop a systematic approach that integrates data to assess condition at regional scales. Over the course of the next several years, EMAP will bring these integration issues associated with regional-scale assessment to the forefront of research.

The most significant aspect of the CENR framework is that remote sensing, regional surveys, and integrated site-specific monitoring are proposed to be conducted in a coordinated fashion, allowing the full range of integration that has so far been impossible. All three types of monitoring identified are essential for an integrated environmental monitoring capability. While key elements of the CENR framework can be put into place now, additional research will be required before complete implementation is possible. Within each of the three tiers described, research must be conducted at appropriate scales to improve survey and monitoring methods, to understand our ability to detect and interpret meaningful changes that are observed, and to link these results to the development of descriptive or predictive models. Research on our ability to determine cause and effect must integrate information on processes that occur across the range of scales from large regions to individual sites. EMAP will focus on these research questions. The research necessary to effectively implement the framework can be captured in four general questions discussed below.

The proposed CENR framework provides an opportunity and challenge in integrating information from multiple ecological resources, taken at multiple spatial scales and over varying temporal scales to describe the sustainability and integrity of our ecological resources. The first challenge in integration will be integrating the results of the research outlined above to provide a final suite of indicators and sampling design for each of the tiers in the framework. For example, the definition of the fundamental measurement units for each resource will have a major impact on how or if a statistical survey can be developed for the second tier and how large an area will be necessary for the intensive study site tier. Our research must evaluate multiple design options for each tier to determine the appropriate blend of activities.

A second level of integration will be in the synthesis of information in a tier, both within and among ecological resources. For example, currently data are collected in streams for three taxa: fish, macroinvertebrates and periphyton. Each taxon tells a particular story about the integrity and sustainability of that aquatic resource. How are the results from those three taxa synthesized to characterize the integrity of that system? In addition, data are likely to be collected on stressors at the regional, watershed, riparian, and waterbody scales. How are these data best synthesized to develop a picture of the relative magnitude of different stresses to aquatic systems within a region? Finally, if biodiversity represents one key attribute of regional sustainability, how can diversity information be aggregated across ecological resources as different as forests, rivers, wetlands and estuaries? Is simple aggregation of taxa richness sufficient or is a more quantitative approach required? These are all integration issues that EMAP will address in a series of regional pilot studies.

Integrating sampling designs is a third level on which EMAP will conduct research. An



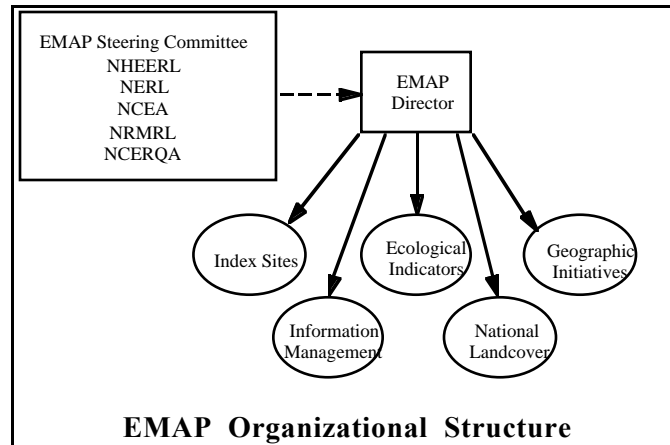
example will illustrate the concept. For acidic deposition, EMAP has been using a combination of intensive study sites and regional surveys. The regional probability based survey of lakes in the northeast provides information on the proportion of lakes which are acidic during a summer index period. Because of the number of lakes visited, it is not possible to also sample each of them during the spring snowmelt when episodic acidification occurs. A set of intensively studied sites, fewer in number however, is visited multiple times during the year. These sites can be evaluated for episodic acidification during spring snowmelt. Data from these sites have been used to develop models relating spring episodes to summer chemistry. These models are then applied back to the survey data allowing the estimation of the regional extent of episodic acidification. This integration of information generated from two different sampling designs allows the emergence of information that cannot be obtained from either effort independently. EMAP will evaluate other environmental stresses and assess the type of design integration between surveys and intensive studies necessary to fully evaluate sustainability and integrity at multiple spatial scales and how these ecosystem attributes are affected by various environmental stresses.

Root and Schneider (1995) describe a similar integration of information from different study approaches, but the studies were run consecutively rather than concurrently. They describe the limitations of conducting only scale-up studies or only scale-down studies. They propose as an alternative, strategic cyclical scaling (SCS). In this paradigm, large-scale associations are used to focus small-scale investigations to ensure that tested causal mechanisms are generating the large-scale relations. The process is a continuous cycling between strategically designed large- and small-scale studies, with each successive investigation building on previous insights obtained from all scales. This paradigm offers an alternative for the implementation of the multi-tier framework to the current proposal of the CENR. As part of the research on scale and design options, EMAP will evaluate a number of ecological scenarios and apply both the SCS paradigm and the current CENR paradigm to determine the relative merits of each under different environmental conditions.

Integrating within and among tiers: To a certain extent, the types of monitoring proposed in the framework are not new. But what could be unique in the implementation of this framework is the integration of the monitoring approaches for a more complete answer to questions facing the U.S. in environmental management and regulation. At least three conceptual approaches exist for integrating the tiers and these are not necessarily mutually exclusive. The most straightforward would be to design the tiers independently for specific functions and then use the remote sensing tier and the probability survey tier to evaluate what portion of the ecological resources are similar or represented by the index site tier. A second approach would be to design the survey tier and index tier together around specific environmental problems like nutrient enrichment or habitat alteration. The third approach would be to have no fixed probability surveys or index sites but to cycle between them, modifying the next effort based on the information derived from the proceeding effort. In addition to evaluating these options conceptually, we will use the mid-Atlantic geographic initiative to demonstrate the options proposed.

## V. EMAP Management

The organizational home of EMAP is within the National Health and Environmental Effects Research Laboratory. EMAP itself however is an ORD-wide program with implementation responsibilities and strategic guidance from all of the ORD Laboratories and National Centers. The EMAP Director is advised by a Steering Committee made up of the Associate Directors for Ecology from each of the National Laboratories and Centers (National Health and Environmental Effects Research Laboratory (NHEERL), National Exposure Research Laboratory (NERL), National Center for Environmental Assessment (NCEA), National Risk Management Research Laboratory (NRMRL), and the National Center for Environmental Research and Quality Assurance (NCERQA). The EMAP Director is then responsible for developing further detailed directions and implementation through working groups operated by the Laboratory research divisions.



## The Future

The important scientific uncertainties described above and our long-term goal shape the strategic direction of EMAP. ORD will direct its EMAP resources to address the primary scientific barriers that all monitoring organizations face together in attempting to implement the CENR framework. ORD bring the results of that research to CENR for consideration in implementing the framework. ORD is prepared to play a leadership role in advancing the science of ecological risk assessment by making EMAP an intramural research program as well as by engaging the academic community through the ORD investigator-initiated grants (STAR) program. Moreover, we expect EMAP to stimulate new approaches to monitoring in EPA regional and program offices and the state and local agencies with whom they work through a regional program (REMAP) of smaller community-based projects in each region. By addressing these scientific uncertainties in a credible manner, EMAP will make important strides toward the goal of providing the information necessary for protecting our ecological resources.

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