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research strategy

environmental monitoring and assessment program

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Research Strategy

Environmental Monitoring and Assessment Program

U.S. Environmental Protection Agency
Office of Research and Development
National Health and Environmental Effects Research Laboratory
Research Triangle Park, NC 27711

Notice

The United States Environmental Protection Agency through its Office of Research and Development produced this research strategy. It has been subjected to the Agency's peer and administrative review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Dear Reader,

The Environmental Protection Agency's Office of Research and Development's National Health and Environmental Effects Research Laboratory (NHEERL) is pleased to present this research strategy on the Environmental Monitoring and Assessment Program (EMAP). In assessing environmental risk and determining restoration priorities, current environmental conditions must be known and rates of change must be measurable. Because of EPA's responsibilities under the Clean Water Act, this program within the Office of Research and Development has focused on improving monitoring and assessment methodologies for aquatic ecosystems and their associated landscapes. EMAP has focused on developing indicators and unbiased statistical design frameworks to assess the status and trends of aquatic ecosystems at local, state, regional, and national scales. As is EMAP's primary mission, the goal of this Strategy is the development of sound scientific approaches to determine the health of the nation's aquatic ecosystems and the stressors most closely associated with impairment.

EMAP efforts ensure that comprehensive and comparable methods are being used at a national level, allowing meaningful assessments and the first regional comparisons of aquatic ecosystem conditions across the entire U.S. These results will significantly improve the quality of performance-based reporting to Congress and will better inform EPA national and regional decisions on priority issues and areas.

State managers and technical staff frequently struggle to balance local information needs with federal reporting requirements. EMAP will continue to work with State partners to develop cost-effective monitoring methodology to aid in decision-making. Results to date from EMAP approach applications in more than 30 States show cost-savings while producing full-coverage condition estimates. Often these cost-savings are used to address priority issues also identified through the EMAP process.

Finally, EMAP's approach and associated indicators serve the Agency and the public by contributing to scientifically based reports such as EPA's upcoming state of the environment report and the Heinz Center's "The State of the Nation's Ecosystems" report. EMAP's efforts help to fill important information needs at both national and at local levels. EMAP information will improve our ability assess our progress in environmental protection and provide valuable information for decision makers and the public. For further information, please go to www.epa.gov/emap or contact Mike McDonald, NHEERL's EMAP Program Manager, at mcdonald.michael@epa.gov.

Sincerely,

Paul Gilman

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Peer Review

Peer review is an important component of research strategy development. The peer review history for this research strategy follows.

ORD Science Council

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Executive Summary

The U.S. Environmental Protection Agency's (EPA's) Environmental Monitoring and Assessment Program (EMAP) is a long-term research effort to enable status and trend assessments of aquatic ecosystems across the U.S. with a known statistical confidence. Initiated in the late 1980's within the Office of Research and Development (ORD), EMAP has addressed the condition of estuaries, streams and lakes in selected geographic regions, as well as having examined the surrounding landscapes in which these resources occur. EMAP is now progressing towards national demonstrations of monitoring science in these and other aquatic resources. This strategy forms the basis for the research needed to establish the condition of the nation's resources, as a necessary first step in the Agency's overall strategy for environmental protection and restoration.

EMAP's Goals:

Develop the science needed for a state-based statistical monitoring framework to determine condition, and detect trends in condition, for all the Nation's aquatic ecosystems.

Transfer this technology in a useable form to states, tribes, and regions.

Have this approach adopted and implemented by the states, tribes, and regions.

- EMAP has developed approaches for: state-based statistical monitoring designs for streams and estuaries; aggregation of state data to the national level; and providing scientifically defensible measures of changes in ecosystem condition in support of the Government Performance and Results Act (GPRA).

The EMAP statistical (or probability) sampling design provides the framework for unbiased, representative monitoring for condition of an aquatic resource with a known confidence level. These estimates can be aggregated from the local to the national level. The Mid-Atlantic Integrated Assessment (Region III) served as the proof-of-concept for this approach. Monitoring with this approach through time allows statistical detection of change (and subsequently trends) in condition.

- EMAP has developed and tested ecological indicators as integrators of stressors and estimators of aquatic condition.

An ecological indicator describes the condition of the ecosystem (e.g., blood pressure is an indicator that helps describe the condition of a person), and reflects an ecosystem's biological, chemical, or physical attributes. EMAP primarily uses biological indicators to integrate all the different stressors acting on an ecosystem.

- EMAP uses large-scale geographic projects for removing scientific barriers, and for demonstrating our approach to States, Tribes and EPA Regions.

These geographic studies typically include one or more major national or regional coverages, and ten smaller sub-regional studies (Regional EMAP or R-EMAP). For these large-scale studies we partner with EPA Regions, States, and Tribes in an effort to build regional assessments from the bottom up, aggregating local data into broader regional assessments. The smaller R-EMAP studies, in each of the ten EPA Regions, allow us to test our approaches in diverse geographic areas, engage additional states, and transfer our technologies, while helping address local problems.

- EMAP is well integrated with the Office of Research and Development's (ORD) Science to Achieve Results (STAR) Grants Program, and derives maximum benefit from academic research.

Scientific uncertainties continue to exist in a number of areas related to probabilistic monitoring of ecological condition (e.g., ecological indicators, ecosystem classification, reference conditions). By integrating our EMAP research plans with the STAR Grants Program, we can more effectively use academic researchers to help answer many of the current and future scientific questions necessary for developing comprehensive national aquatic ecosystem monitoring frameworks.

- EMAP's Western Pilot is a major strategic geographic study to remove scientific barriers to a national stream assessment.

The Western Pilot (encompassing 12 western states in EPA's Regions VIII, IX and X) is a scientific evaluation of the generalizability of our stream designs and indicators to a vast area of the country with high ecological variability. This work will remove the remaining scientific barriers to a national framework for monitoring the condition of the nation's streams.

- EMAP's National Coastal Assessment is a national demonstration of our approach in estuaries.

We are demonstrating the framework for a consistent, state-based, probabilistic monitoring framework in the 24 marine coastal states and Puerto Rico, This effort will produce the first national assessment of the condition of the U.S. marine estuaries, and will be the baseline for future measures.

- EMAP has a well developed information management (IM) system for public data accessibility and is integrated into EPA's STORET database for long-term storage.

IM is an integral part of our large-scale research and demonstration programs, and is guided by the need for sharing environmental monitoring data. Our IM group regularly revises and updates the EMAP public home page on the web, providing access to: our Data Directory, for ready identification of data of interest; EMAP data and metadata; and our bibliography of all EMAP-related publications (>1000+). The EMAP IM group is archiving our data in EPA's STORET database. All of our EMAP data for condition assessments typically becomes publicly accessible within two years of collection after all our sampling and data quality assurance and quality control procedures have been satisfied.

- Future plans for EMAP include: removing the scientific barriers to establishing the ecological condition of great and large rivers (as receiving waters for streams), and demonstrating a national stream monitoring framework.

Sampling designs and indicators do not currently exist to characterize the condition of large or great rivers in a scientifically defensible manner. These large rivers are unique resources and are difficult to sample. However, they are critical receiving waters for the nation's streams. An understanding of their condition is an important step in dealing with problems associated with Total Maximum Daily Loads (TMDL's). Additionally, to ensure that a nationally consistent stream monitoring framework is adopted by the states, design and technological advice may be required for other large geographic areas of the country.

With the Western Pilot, we are removing the scientific uncertainties that prevent state-to-national assessments of stream condition. EMAP has already established the scientific basis for monitoring estuarine condition nationally, and is currently engaged in a national demonstration Sampling through time using our EMAP approach will allow significant trends in stream and estuarine conditions to be identified at the local, state, regional, and national levels. An unbiased assessment of the condition of our streams and estuaries will provide the scientific basis for better-informed public decisions regarding these resources, and will provide baselines for measuring EPA's progress in improving environmental condition in support of the Government Performance and Results Act. Future EMAP work will provide the science necessary for determining the condition of other critical aquatic resources and will be necessary for the full implementation of GPRA.

I. Introduction to the EMAP Research Strategy

Calls for improvements in environmental monitoring date back to the late 1970s. Along with the National Academy of Sciences and the White House Office of Science and Technology Policy, EPA has recognized the critical need for nationally-consistent, comprehensive, and scientifically-defensible monitoring to detect environmental status and trends.

Because of EPA's statutory responsibilities under the Clean Water Act, and the ability of inland surface waters and estuaries to reflect total watershed condition, EPA has committed to advancing the state of the science in monitoring and assessing the condition of the nation's aquatic ecosystems. An historical overview of reports and initiatives that have identified the need for an improved national monitoring framework or made recommendations for improving environmental monitoring can be found in Appendix I.

EPA's focus on improving monitoring and assessment methodology derived from the need to characterize and assess environmental risk (U.S. EPA 1996). This goal required scientific advances in the way aquatic ecosystems and their associated landscapes are measured, modeled, maintained, and restored; these issues form the basis of the Ecological Research Strategy of EPA's Office of Research and Development (U.S. EPA 1998).

A critical component of this Strategy is ORD's Environmental Monitoring and Assessment Program (EMAP). EMAP focuses on developing indicators, and unbiased statistical design frameworks that allow the condition of aquatic ecosystems to be assessed at local, state, regional, and national scales. The current condition of the nation's aquatic ecosystems, and the stressors most closely associated with impaired condition, are key assessment activities. Developing sound scientific approaches for these activities has been and continues to be EMAP's primary mission.

To assess environmental risk, the current condition of the environment must be known and an estimate of the rate of change in that condition must be available. Through a probability-based sampling design, the EMAP approach provides a statistically-valid basis for determining aquatic ecological condition. The EMAP approach also exemplifies monitoring for results; when implemented over time, it can provide quantifiable estimates of the environmental benefits derived from the Agency's protection and restoration strategies in support of full implementation of the Congressionally mandated Government Performance and Results Act (GPRA). Using the EMAP approach, ORD hopes to reduce data gaps identified by the Government Accounting Office (2000), develop new hypotheses for testing cause-and-effect relationships in ecosystems, and provide scientifically defensible assessments of change and trends.

Because of the importance and innovative nature of the research undertaken by EMAP, it has undergone extensive scientific review. EMAP has had more than 25 separate peer reviews of individual program components (over the last 10 years) and a program-wide review by a National Research Council (NRC) panel. The EPA Science Advisory Board has also reviewed several aspects of EMAP, paying particular attention to the development of indicators and the integration and assessment activities within the program. Most recently (1998), EMAP was reviewed jointly by the American Statistical Association and the Ecological Society of America. These reviews have shaped the current focus of EMAP, as detailed in this strategy, and affirmed EMAP as a productive, high-quality scientific research program.

In its 10-year history, EMAP has substantially advanced the scientific basis for monitoring ecosystem condition. Selected EMAP accomplishments for this time include:

- More than 1000 scientific publications (for a complete bibliography, see http://www.epa.gov/emap/html/pubs);
- 27 scientific symposia and workshops sponsored;
- The U.S. Forest Service adopting the EMAP approach for their Forest Health Monitoring (FHM) Program;
- Demonstrating the feasibility of using an EMAP approach for regional monitoring in the mid-Atlantic (through the Mid-Atlantic Integrated Assessment or MAIA);
- Producing the first unbiased assessments of regional stream condition (U.S. EPA 903/R-00/015), estuarine condition (U.S. EPA 600/R-98-004, U.S. EPA 600-R-98-147), and landscape condition (U.S. EPA 600/R-97-130);
- EPA's Office of Water recommendation that probability surveys be incorporated into state monitoring programs (in the guidance to the States for reporting to Congress under Section 305(b) of the Clean Water Act);
- Completion of the first systematic remotely-sensed land cover characterization for the entire lower 48 states; and
- More than 30 states currently using or testing the EMAP monitoring framework to determine the condition of one or more of their aquatic resources.

EMAP's current scientific effort centers on removing the scientific barriers to application of our approach in diverse regional environments. Next, we demonstrate these approaches and technologies in national assessments of resource condition, and lastly we transfer this capacity to States, Tribes, and Regions. Ongoing efforts include:

- Adapting EMAP indicators and design to the 12 western U.S. states in EPA Regions VIII, IX, and X (Western Pilot);
- Working with the 24 U.S. coastal states (including Alaska and Hawaii) and Puerto Rico, to collect and analyze data from a core set of indicators for the first national assessment of estuarine condition (National Coastal Assessment);
- Supporting one or more studies in each of the ten EPA Regions to demonstrate the utility of the EMAP approach in addressing specific regional issues (this is Regional EMAP or R-EMAP); and
- Sponsoring a strategic array of academic research grants in emerging and cross-disciplinary fields through ORD's Science To Achieve Results (STAR) Grants Program. Among other topics, these grants are exploring scalar relationships, watershed processes, resource classification and reference gradients, and are intended to result in new indicators and design adaptations for EMAP.

Future plans for EMAP involve research and technology transfer to enable periodic national assessments of all aquatic ecosystems. Priority near-term efforts include:

- Developing the methodology and partnerships required for assessing condition of large and Great rivers;
- Continuing regional studies to familiarize staff of EPA Regions and States with effective solutions to their monitoring needs through R-EMAP; and
- Continuing sponsorship of academic research grants and partnerships through STAR Grants to augment internal expertise in indicator development, statistical designs and analyses, and other monitoring and assessment issues.

The intent of these various research activities is to develop and transfer the necessary science to meet monitoring and assessment needs for aquatic ecosystems across a range of decision makers and other user groups. At the national level, EMAP's efforts towards comprehensive and comparable methods will enable, for the first time, meaningful assessments and regional comparisons of aquatic ecosystem condition across the entire U.S. These results will significantly improve the quality of mandated reports to Congress, and will better inform EPA and other federal decisions.

EPA Regions will benefit as well from consistent and comparable environmental data as a result of the EMAP approach. Regional decision-makers must also prioritize protection activities across multiple States and environmental media, and often seek to develop unbiased State of the Region reports for their stakeholders.

At the State level, managers and technical staff frequently struggle to balance local information needs with federal reporting requirements. The goal that EMAP seeks to achieve with State partners is cost-effective monitoring methodology that simultaneously serves both levels of decision-making. Results to date from applications of EMAP tools in more than 30 States indicate that these States are improving full-coverage condition estimates while saving money. Often these cost-savings are used to address priority issues identified through the EMAP process.

Finally, EMAP intends to serve Tribes, local communities, and the general public by facilitating a technically-sound "environmental condition report." This information will provide the larger context for evaluating local conditions, and provide trends to gauge protection needs and effectiveness.

II.
EMAP Research Strategy

Our Scientific Goal: **Develop the science needed for a State-based statistical monitoring framework to determine condition, and to detect trends in condition, for all the nation's aquatic ecosystems.**

A scientifically-rigorous determination of the condition of an aquatic resource is fundamental to all subsequent research and modeling questions. Environmental risk characterization is predicated on a knowledge of condition and the rate at which that condition is changing (U.S. EPA 1996). Thus, the scientific goal of EMAP has remained virtually unchanged since its beginning, although the approaches have evolved (see Appendix 1).

The current EMAP approach is to remove the scientific uncertainties associated with developing State-based statistical monitoring designs for aquatic resources in support of Section 305(b) of the Clean Water Act. The power of this approach is that the designs provide: the framework for an unbiased, representative assessment of the condition of these resources with a known confidence level; aggregation of State data to the national level; and scientifically defensible measures of changes in condition in support of the Government Performance and Results Act (GPRA).

Our Implementation Goal: **Transfer the EMAP science and technology to the States, Tribes, and EPA Regions, and have our approach adopted for long-term use.**

The States are Congressionally mandated to assess the condition of their waters. Currently, the EMAP approach is the only statistically-valid means of assessing the condition of all waters of a State. It is a change from historic practices of fixed-site monitoring. Therefore, the increase in information and the cost-effectiveness of this approach must be demonstrated to Regions, States, and Tribes to gain their acceptance.

To gain acceptance of the EMAP approach, we partner with EPA's Regions, States, and Tribes in large- and small-scale geographic demonstrations. Using our sampling designs and collecting samples with our partners, we aggregate local data into broader state, regional, and even national condition assessments. These demonstration efforts typically serve both to remove scientific uncertainties by allowing us to test our approaches in diverse geographic areas, and to show how our scientific approaches can be effectively used in support of solutions to local, state and regional problems.

Within the five-year time frame of this strategy, EMAP intends to meet its scientific goal with respect to estuaries and streams, and be well on the way to meeting the implementation goal for these two resources. However, in order to do this, EMAP must continue to overcome the scientific barriers that would prevent development of national frameworks, and we must effectively demonstrate and transfer the technology we are developing (Figure 1).

SCIENCE BARRIERS

EMAP, an ORD-wide research program (Figure 2), maximizes and integrates intramural and extramural scientific capabilities in pursuit of

Figure 1. Science and implementation barriers to a nationally comprehensive monitoring framework for EPA high priority resources.

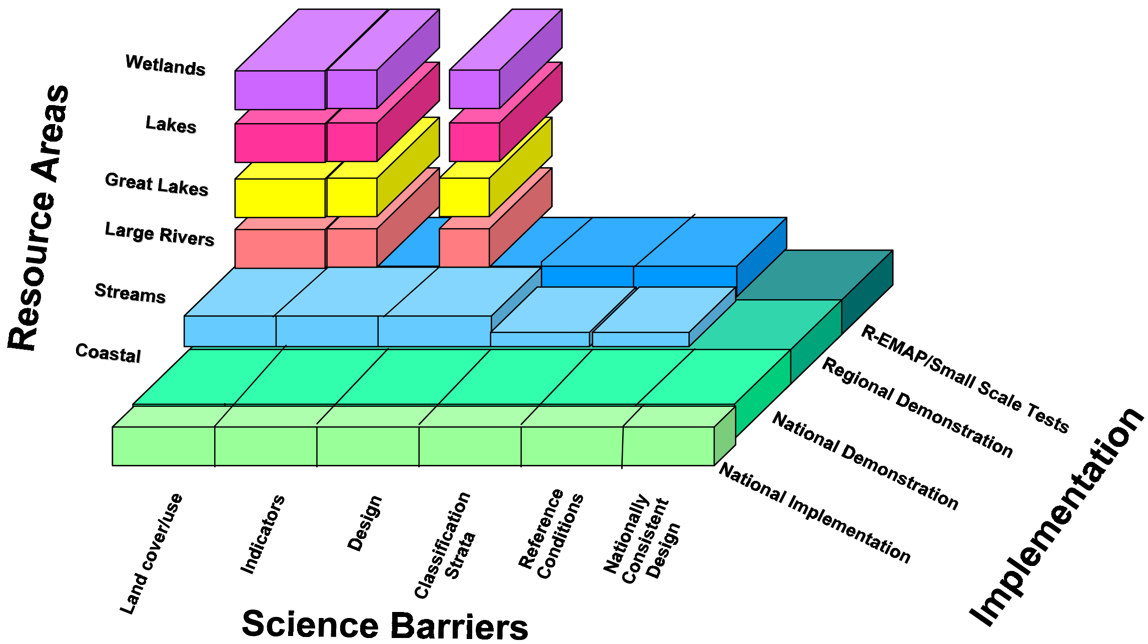
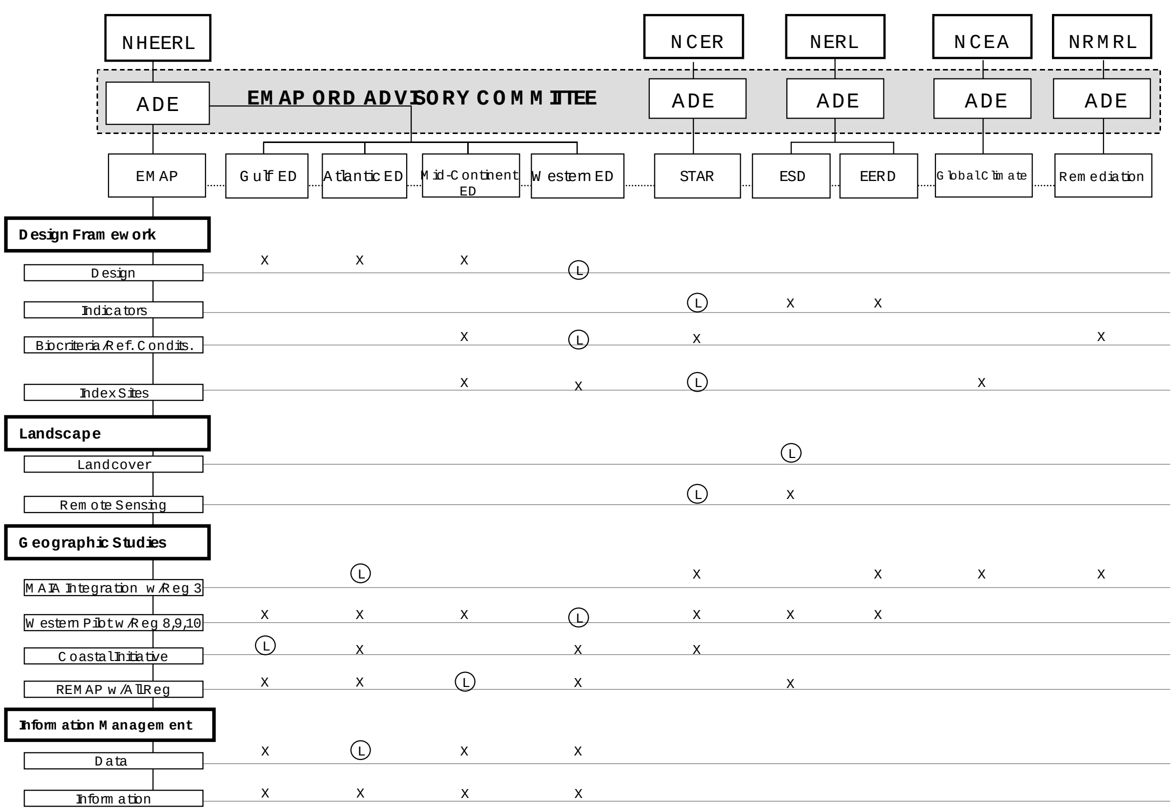


Figure 2. EMAP Programmatic Organization



our goals. By aligning our scientific expertise and linking it with the academic community (through EPA's Science To Achieve Results (STAR) Grants Program), we have established the critical research capabilities necessary to develop a national monitoring design framework for estuaries and streams over the coming years (Table 1).

EMAP's research focus includes:

- establishing the statistical variability of EMAP indicators when used in aquatic ecosystems in diverse ecological areas of the country (ecoregions);
- establishing the sensitivity of indicators and design to change and trend detection in the condition of aquatic ecosystems; and
- developing indicators and designs that will allow a nationally comprehensive monitoring framework for other EPA high-priority aquatic resources (e.g., large/Great Rivers, wetlands).

Other important research areas amenable to academic research through the STAR Grants Program include:

- developing new and better indicators of condition in various aquatic resources;
- establishing chemical and biotic index sites for estimates of seasonal variability to link to the EMAP design;
- developing new and better classification schemes for the various aquatic ecosystems and the landscapes in which they occur; and
- Linking remotely-sensed landscape indicators to the condition of aquatic ecosystems.

IMPLEMENTATION

For the EMAP approach to be successfully implemented nationally, the States and Tribes must accept it and incorporate it into their common monitoring practices. Therefore, EMAP must:

- Demonstrate the efficacy and utility of the EMAP approach broadly throughout the U.S.;
- Build state and tribal capacity to develop and analyze statistical monitoring designs;
- Build state and tribal capacity for the use of geographic information systems (GIS) to estimate land-use change, and for improving statistical design; and
- Improve information storage and transfer to optimize the available information from an EMAP-like monitoring approach.

A time line has been developed for accomplishing the major components (including field work, analysis, and demonstrations) for reaching our goal of a national monitoring framework for estuaries and streams by 2007 (Figure 3). The allocation of specific tasks related to demonstration and implementation in this time period is given in Table 1.

FRAMEWORK FOR A NATIONAL DESIGN

To determine the condition of a national aquatic resource, we must either census this resource across the entire U.S., or we must be able to make unbiased statements on the overall condition of the resource from selected samples. The first approach is currently not feasible for aquatic ecosystems. The latter approach is feasible, but complex. The validity of the latter approach depends on statistical inference from the sampling design, and subsequent analysis, to produce regionally representative information. To do this requires: a design for sampling across diverse ecosystems; indicators that are sensitive to stress and can be measured to determine condition of the resource at a wide range of sampling locations; and reference conditions to act as benchmarks against which to measure the indicators. These are fundamental research areas for EMAP.

Statistical Design - Probability-based sampling within a statistical survey design (Cochran 1977) provides the only unbiased estimate of the condition of an aquatic resource over a large geographic area from a small number of samples. The principle characteristics of a probabilistic

Table 1. EMAP Projected Research Accomplishments FY00-FY07

E - primarily EMAP Researchers
S - primarily STAR Grants Research at Academic Institutions
E/S - combination of EMAP and STAR Research

		Design Framework				Landscape		Geographic Studies				Information Management	
		Survey Design	Indicators	Reference Conditions	Index Sites	Indicators	Land Cover Mapping	MAIA Integration	Western Pilot	Coastal Initiative	R-EMAP	Data	Info
FY00	Monitoring Framework for Streams in Western Pilot developed	E	E	E					E			E	
FY00	Remotely Sensed Land Cover for Western U.S. (MRLC) produced						E		E				
FY00	Designs for National Coastal Monitoring developed	E	E	E					E	E			
FY01	Draft State of U.S. Estuaries Report produced								E	E		E	E
FY01	Monitoring Protocols developed for condition of Regional Aquatic Resources	E	E/S	E/S				E/S	E/S	E/S	E	E	E
FY02	Integrated Ecosystem Assessment Protocols developed for MAIA							E				E	E
FY03	Biocriteria Monitoring Protocols developed for Aquatic Systems in Western U.S.	E	E/S	E/S	S				E/S	E/S	E	E	
FY03	National Land Cover Map for U.S. produced for land cover/land use change (MRLC)						E						
FY04	Draft State of U.S. Near-shore Coastal Ecosystems Report produced								E	E		E	E
FY04	Report on Trends in Select Estuarine Ecosystems produced							E		E		E	E
FY04	Models for Integrating Survey and Remote Sensing applications developed	E/S	E/S		S	E/S							E
FY04	Scaling Protocols for Multi-tier Design developed	S			S		E/S						
FY05	State of Western Streams Report produced								E			E	E
FY05	Ecosystem Classification Protocols developed	S	S	E/S			E/S						
FY06	Design Framework for Integrated Monitoring in the West developed	E/S	S	E/S	S	E/S	E/S		E/S	E/S		E	E
FY06	Additional/new Ecological Indicators for environmental condition developed		S			E/S					E		
FY06	National Landscape Changes Assessed					E	E						
FY07	State of the Western Surface Waters Report produced			E/S	S	E/S			E		E	E	E
FY07	Design for National Estuarine and Stream Monitoring Framework established	E/S	E/S	E/S	S	E/S	E/S		E/S	E/S	E	E	E

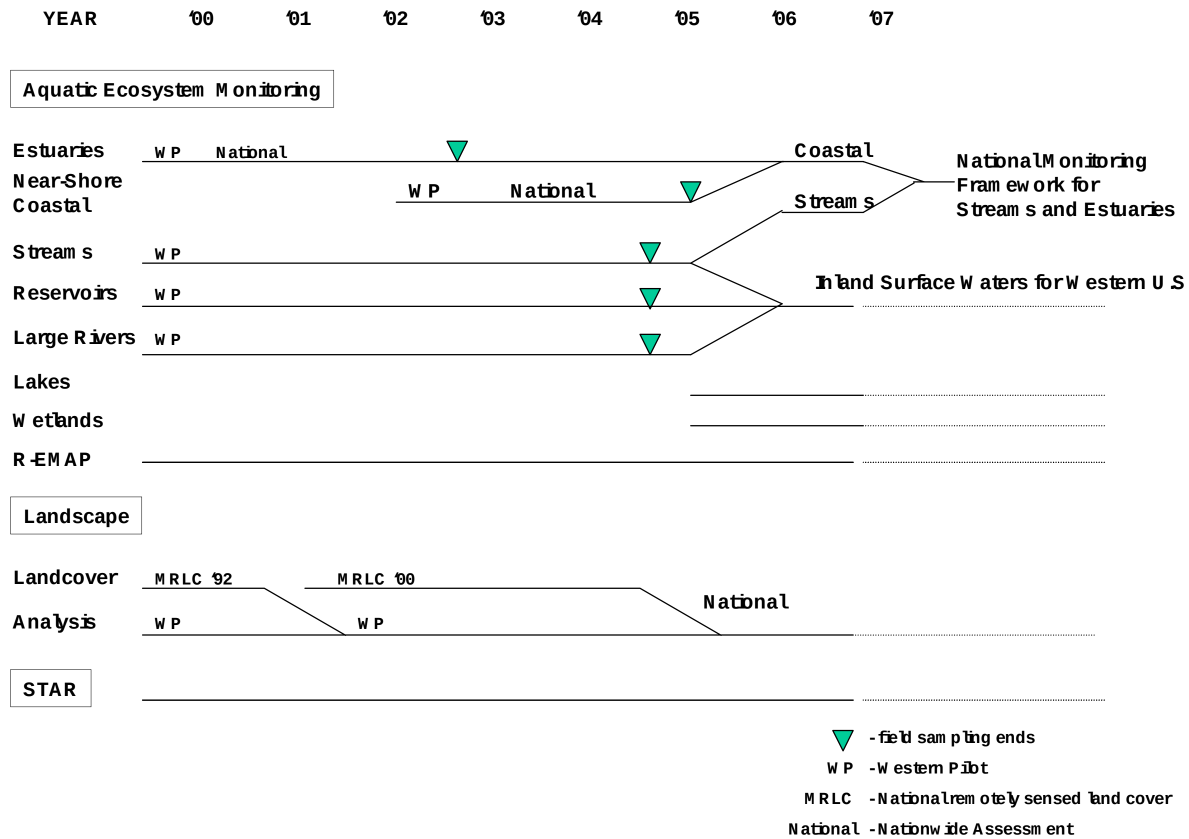


Figure 3. Timeline for major EMAP research components, including field work and analysis. By 2007 we intend to have a national monitoring framework for streams and estuaries.

design are: (1) the population being sampled is unambiguously described; (2) every element in the population has the opportunity to be sampled with a known probability; and (3) sample selection is carried out by a random process. This approach allows statistical confidence levels to be placed on the estimates and provides the potential to detect changes and trends in condition with repeated sampling.

Current Status of Design - EMAP uses a probabilistic survey design to select sampling sites for an unbiased representation of the condition of aquatic resources over large areas. Our design specifies the information to be collected and at what locations. The validity of the inference rests on the design, and subsequent analysis, to produce regionally representative information.

Sampling Site Selection - In attempting to describe the condition of large geographic areas, samples should be distributed throughout the study area to be maximally representative. EMAP's design accomplishes this by taking samples at regular intervals from a random start (a systematic random design). The systematic element spreads out the sampling locations geographically, but still ensures that each element has an equal chance of being selected.

Grids are used to add systematic elements to the EMAP design (Figure 4). The grid is positioned randomly on the map of the target area, and sample locations from within each grid cell are selected randomly. The grid ensures spatial separation of randomly selected sampling units (systematic random sample). Within this design approach there is some additional and important flexibility. There is the potential to divide the entire target population into any number of sub-populations (or strata) of interest. Subsequent random sampling within these strata allows statistical inferences to be made about each sub-population. Each of these strata can have a different level of sampling effort depending on the inference to be made, but the weighting due to the differential effort must be accounted for in the analysis. As an example, stratified sampling could be used in a regional stream survey to enhance sampling effort in a watershed of special interest so that its condition could be compared with the larger regional area. Simple random sampling of the region would not likely provide sufficient samples in the watershed to reliably estimate the watershed's condition.

Classification for Strata - EMAP's primary interest in classification is to better define different strata of aquatic systems for which similar expectations exist. This allows for improved information about each of the strata and can improve statistical estimates of condition.

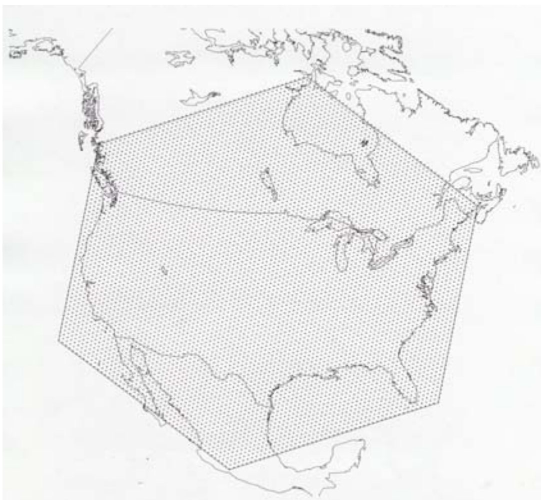


Figure 4. The EMAP base grid overlaid on the United States. There are about 12,600 points in the conterminous U.S. with approximately 27 km between points in each direction. A fixed position that represents a permanent location for the base grid is established, and the sampling points to be used by EMAP are generated by a slight random shift of the entire grid from this base location. (Full descriptions and rationale for the cartography and geometry of the grid are given in White et al. 1991).

At the coarsest level, EMAP divides aquatic resources into different water body or system types, such as lakes, streams, estuaries and wetlands. Our rationale is that the biological, chemical and physical characteristics for these systems are fundamentally different from one another and we expect different indicators and different designs will be necessary. Subsequently, we use a second level of strata, ecoregions, to capture regional differences in water bodies. Ecoregions are areas which have generally similar ecosystem characteristics (geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology, see Omernik 1995). We have compiled ecoregion maps for use in strata development that are based on the patterns and the composition of biotic and abiotic characteristics (Wiken 1986; Omernik 1987, 1995).

The lowest level of strata in the EMAP design allows us to distinguish among different "habitat types" within an aquatic resource in a specific geographic region (see Appendix II). For example, portions of estuaries with mud-silt substrate will have much different ecological characteristics than portions of estuaries with sandy substrates. It is within this lowest stratum that our sampling is done. Within the lowest stratum, our sampling design takes one of two very different forms depending on whether the aquatic ecosystem to be sampled is *discrete* or extensive. A discrete resource consists of distinct natural units, such as small to medium-sized lakes. Our population inferences for a discrete resource are based on numbers of units that possess a measured property (e.g., 10% of the lakes are acidic). Extensive resources, on the other hand, extend over large regions in a more or less continuous and connected fashion (e.g., rivers), and do not have distinct natural units. Our population inferences here are based on the length or area of the resource. The distinctions between discrete and extensive are not always clear, and in some cases a resource may be viewed as both at different times (e.g., discrete - estuaries in a region; extensive - sample units within an estuary). Each aquatic resource has its own unique sampling characteristics. The approach used depends on the nature of the resource and the available information for that resource.

We use an intensification of our EMAP grid to sample discrete aquatic resources. If the units of the resource have appreciable area relative to the grid density, then the grid can be used directly by selecting those units in which one or more grid points fall (e.g., estuaries in a state). With this method, the probability that a unit gets into the sample (its inclusion probability) is proportional to the unit's area. The inference to the entire population is then in terms of area (e.g., 8% of the bottom water area in the mid-Atlantic estuaries is severely hypoxic in summer). Alternatively, a unit of a discrete resource can be treated as a point in space. In this case, there must be a rule identifying a point that is uniquely associated with each resource sample unit. The point can be defined and located based on properties of the resource unit, regardless of the location of the grid. For example, the center point of lakes could be used. This method of sampling is appropriate for inference in terms of numbers of units in a particular condition (e.g., 7% of Northeastern lakes are chronically acidic).

We use two different approaches for taking a probability sample of an extensive aquatic resource. Depending on the nature of the ecosystem, our approach is to use area sampling (e.g., sampling for rivers) or point sampling (e.g., sampling for estuaries). In area sampling, the extensive resource is broken up into disjoint pieces, much like a jigsaw puzzle. The extensive resource is basically converted into a discrete resource, and sample selection is from a random (within the systematic, stratified random sampling design) selection of these pieces. The value we obtain from the samples is then used to characterize the entire piece. The point sampling approach locates points at random within the extensive resource, and sampling occurs at these points. With this approach, the sample value is usually taken to represent the value of the resource at that point.

Our EMAP designs provide the unbiased statistical framework for where we sample, and define how we extend our inference from our samples to the entire population of interest. However, within this context, we must have indicators which establish the condition of an aquatic ecosystem.

Ecological Indicators - An indicator is one (or more) measure(s) or model(s) that describes the condition of the system in question (e.g., blood pressure is an indicator of human health). Historically, chemical indicators have been used to monitor the condition of aquatic systems, but these chemical measures do not necessarily tell us anything about ecological condition. Additionally, our perturbations of aquatic environments have expanded from chemical inputs to include disruption of physical habitat, alteration of hydrologic patterns, introduction of non-indigenous biota and widespread alteration of the landscape. All of these are stressors which may potentially affect the condition of aquatic ecosystems.

Effective aquatic ecological indicators are central to determining the condition of our aquatic resources. We have been able to develop or modify a number of ecological indicators (see Appendix III). The most successful have been multi-metric indices formed by combining biological indicators within a taxon (e.g., those indices related to fishes - number of species present, number of pollution-tolerant species, etc.) found in aquatic ecosystems. Separate indices for different taxa (from plants to fishes) are important because they may be critical components of aquatic ecosystems, and because they integrate various natural and anthropogenic stressors into their responses. However, further interpretation of these biological indicators requires additional measurements of the fundamental and associated components of the abiotic environment, including physical measures of habitat (e.g., substrate type and quality, depth) and chemical measures of the ambient water quality (e.g., dissolved oxygen, temperature, salinity, nutrients, and toxics).

Current Status of Ecological Indicators - Most of the current EMAP aquatic community or assemblage indicators come from analysis of the fish, benthic macroinvertebrate and plant communities. Fish are of immense interest to the public, and many species are declining. Because many species are relatively long-lived and mobile, fish can be useful indicators of multi-year and broad-scale environmental conditions. Fish assemblages contain species representing a variety of trophic levels (omnivores, herbivores, invertivores, planktivores, and piscivores); since they tend to integrate changes in lower trophic levels, they often reflect overall ecosystem condition. Macroinvertebrates (e.g., snails, aquatic insect larvae, crayfish) are important intermediate members of the food web. They integrate changes in the lower trophic levels and, because they are not as mobile as fish, they often can provide more information on specific stressors. Plants are the base of the food chain and can act as the primary link between the chemical constituents in aquatic ecosystems and the higher trophic levels. Changes in their abundance or species composition can greatly affect food availability at higher trophic levels.

<u>Streams</u> - EMAP uses fishes, benthic macroinvertebrates, and algae attached to rocks as biological indicators of stream ecosystem condition. Stream fishes have been well studied and have been shown to be suitable indicators (Matthews and Heins 1987, McAllister et al. 1986, Miller and Rolbison 1980, Minckley 1973, Moyle 1976, Plafkin et al. 1989, Platts et al. 1983, Rankin and Yoder 1991). EMAP uses an index of biotic integrity (IBI, a multi-metric biological indicator, similar to Karr et al. 1986) to evaluate the overall

fish assemblage, which provides a measure of biotic condition.

Stream benthic macroinvertebrates (a heterogeneous assemblage of animals inhabiting the stream bottom) have a long history of use as a biomonitoring tool. Changes in the assemblage structure (abundance and composition) and function can indicate water resource status and trends (Cummins and Klug 1979, Plafkin et al. 1989). Different stressors on stream ecosystems have been studied and have been found to result in different assemblages and/or functions (Armitage 1978, Hart and Fuller 1974, Hilsenhoff 1977, Metcalfe 1989, Resh and Unzicker 1975). EMAP currently uses a benthic invertebrate IBI for stream macrobenthos.

Algae on stream rocks are the food for many primary consumers, such as macroinvertebrates and herbivorous fish. The algal component of stream periphyton (a mixture of organisms attached to substrates, including algae, bacteria, microinvertebrates, and associated organic materials) has been used extensively in the analysis of water quality for several decades (Lange-Bertalot 1979, Patrick 1968, Stevenson and Lowe 1986, Watanabe et al. 1988). It has proven to be a useful indicator for environmental assessments because algal species have rapid reproduction rates and short life cycles, and thus respond quickly to perturbation (Stevenson et al. 1991).

Estuaries - To establish estuarine biological condition, we currently use benthic invertebrates (e.g., oysters, shrimp) and fishes. Benthic invertebrates are reliable indicators of estuarine condition because they are sensitive to water quality impairments and disturbance (Rakocinski et al. 1997). We have developed a benthic index of estuarine condition (similar to the stream invertebrate IBI) that incorporates changes in diversity, structure, and abundance of selected estuarine benthic species (Engle et al. 1994, Engle and Summers 1999). The EMAP estuarine benthic index has been used successfully in estimating the ecological condition of Atlantic coast estuaries from Cape Cod, Massachusetts, to central Florida (Paul et al. *submitted*, Paul et al. 1999, Van Dolah et al. 1999), and estuaries in the Gulf of Mexico (Macauley et al. 1999). It is currently being tested nationally as part of the National Coastal Assessment (see below).

Unlike streams, fishes in estuaries are typically difficult to sample quantitatively. Because these fishes are important commercially and recreationally, we have chosen to use a generalized fish health assessment in EMAP. This assessment consists of examining fishes for gross pathological disorders and pathologies of the spleen (specifically, splenic macrophage aggregates). High rates of gross pathological and/or spleen abnormalities can be associated with environmental contamination.

Having indicators that are sensitive to changes in their biotic and abiotic surroundings, and statistically rigorous monitoring designs, still does not guarantee an accurate estimate of the condition of an aquatic ecosystem. We must understand how variable our ecosystems and indicators are, and reduce this “noise” in the system in order to better detect our condition “signal.”

Variability - Variability, both natural and anthropogenic, can reduce the accuracy of estimates of aquatic ecosystem condition, perhaps leading to erroneous conclusions. Therefore, prior to the development of a national monitoring design, variability-induced statistical errors associated with condition estimates must be reduced. To accomplish this, the components of variability must be calculated, and design alternatives evaluated. Sources of variability may include: indicator response at different spatial and temporal scales, technician error, and choices in allocating sampling effort within and among population elements (e.g., the trade-off between more samples within a lake or sampling more different lakes). The sources of variability affecting condition estimation will also affect change and trend detection capabilities for aquatic ecosystems.

Current Status of Variability Research - EMAP has expended considerable research effort to understand variability and how it impacts status and trend detection under different design considerations (Larsen et al. 1995). To date, we have been able to: (1) summarize variance components for several indicators of aquatic condition; (2) evaluate the influence of sources of variability on trend estimation; (3) evaluate the sensitivity of different sample survey design options for trend detection; and (4) demonstrate the ability of sample survey designs to detect trends in indicators of condition, given the summarized variance components. (See Appendix IV.)

Even as we reduce the variability in our indicators and designs and develop more accurate regional estimates of our indicators, we must have some reference against which we measure our current conditions. We can measure relative changes and trends without reference conditions, but to determine the current quality and to guide protection and restoration, reference conditions for the various aquatic ecosystems are needed.

Reference Conditions - A reference condition establishes the basis for making comparisons and for detecting use impairment. It should be applicable to an individual water body, such as a stream segment, but also to similar water bodies on a regional scale. A critical dimension to the use of biological indicators is the standard or "reference condition" against which existing indicators can be compared to determine impairment. When these reference conditions become legally adopted as water quality standards, they become biocriteria. EPA (U.S. EPA 1998) requirements for biocriteria include: (1) being scientifically sound, (2) being protective of the most sensitive biota and habitats, (3) being protective of healthy, natural aquatic communities, (4) being protective of biological integrity, (5) using specific aquatic community assemblage characteristics to assess attainment of designated uses, (6) providing for non-degradation of water resource quality, and (7) being defensible in a court of law.

Current Status of Reference Condition Research - Our reference condition research has identified and examined a number of approaches ranging from best professional judgement to selection from a frequency distribution based on probability sampling (e.g., the condition of the sites above the 80th percentile). However, no explicit comparison of approaches has been made. Currently, we use a combination of best professional judgmental and probability-based selection for the development of reference conditions. Judgement is used to select sites from excellent to poor along a pre-defined condition gradient; these are then sampled for the indicator of interest. Indicator values from the reference sites are plotted on a frequency distribution, along with those derived from probability sampling in the same area of interest. Best professional judgement is again used to determine the percentile of the probability sample associated with the lowest level of excellent condition as defined by the reference sites, and that becomes the nominal threshold for excellent condition for the indicator within the area of interest. In all cases, we provide the explicit criteria by which we judged reference sites to be classified along the condition gradient. The criteria are sufficiently rigorous that the sites can be classified consistently.

EMAP ecological indicators in a probability sampling design can provide estimates of aquatic ecosystem condition in a region where reference conditions have been established. However, the EMAP approach cannot determine cause and effect, nor can it currently provide estimates of the seasonal variability in condition. This type of work must be done at index sites.

Index Sites - Index sites are localized study areas that offer opportunities for intensive research and monitoring. They permit detailed research on ecological processes and mechanisms, and can serve as known points along a condition gradient. Continual monitoring at these sites can also provide estimates of seasonal variability and capture catastrophic events.

There are numerous existing models for index site networks. One of these is the National Science Foundation's (NSF's) Long-Term Ecological Research (LTER) network, which collects data at sites across the U.S. Sites have selected process studies in common and researchers coordinate some common measurements across sites. The LTER sites have provided valuable insights into processes across a broad range of ecosystems. Another approach to index sites is to identify a set of stressors to monitor across all sites within a network.

Current Status of Index Site Research - EMAP researchers have used seasonal data from a few intensive study sites to improve our assessments of lakes affected by acidic deposition in the northeastern U.S. In our regional probability surveys of northeastern lakes, we determined the proportion of acidic lakes during a summer index period (Figure 5). However, because of the number of lakes visited, it was not possible to re-sample each of them during the spring snowmelt when episodic acidification occurs.

At a smaller number of intensively studied sites, visited multiple times during the year, the lakes which experienced episodic acidification during spring snowmelt were determined. No regional estimates of spring acidification could be generated directly from these lakes, because they were not a statistically random subset of all lakes. By developing a classification system which identified sensitive watershed and lake properties, models relating spring episodes to summer chemistry for each of these classes were established. These models were then applied back to the survey data, allowing the estimation of the regional extent of episodic acidification (Figure 5).

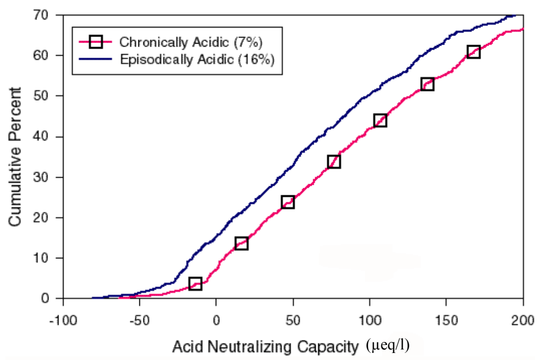


Figure 5. Proportion of chronically and episodically acidic Northeastern lakes. Episodic proportion modeled from Long Term Monitoring (LTM) data.

Clearly, index sites are key to complementing large-scale monitoring with continual, intensive research that addresses causal mechanisms and seasonal events. In addition to NSF's LTER network, the USDA Forest Service has instigated Intensive Site Monitoring as part of the national Forest Health Monitoring program, and the National Oceanic and Atmospheric Administration (NOAA) supports National Estuarine Research Reserves for intensive studies. While EMAP scientists have explored these and other index site networks, the program has learned that it often requires specialized data from index sites in order to integrate them effectively with EMAP indicators and assessment questions.

To address this need, EPA developed an additional network of sites with the National Park Service (see Appendix V). This network focuses on UV_B radiation; it is now part of the ORD Global Climate Change Program. EPA's STAR Grants Program, through funds provided by EMAP, has also established a set of coastal index research sites, known as CISNet (http://es.epa.gov/ncer), in cooperation with NSF and NOAA. EMAP scientists helped to frame the research questions for the initial proposal solicitations for CISNet sites and participated in the relevancy review of the resulting proposals. As the awarded research is currently underway, ORD and grantee scientists are just beginning to explore methods to utilize index-site information to advance EMAP indicators and design.

Key Research Issues for Developing a National Design Framework - We have made a strategic decision to focus our EMAP researchers on the survey design and reference conditions specifically for inland surface waters and estuaries in support of a national monitoring framework. We will use the EPA STAR program to solicit academic research on new indicators, designs, and index sites for other aquatic ecosystems (e.g., wetlands). STAR will also be instrumental in bringing academic research to bear on our ongoing EMAP research issues. This research will be incorporated into EMAP as the research results develop, and as EMAP moves more fully into establishing the condition of other aquatic ecosystems in the future**.**

Survey Design - For survey designs: (1) our stream design must include all sizes of flowing waters and not just wadeable streams; (2) our estuarine design must be applicable to Pacific estuaries and must include estuaries beyond the three initially used (large, >260 km^2; small, 2.6 - 260 km^2; and large tidal rivers (> 260 km^2)); and (3) our design must allow for the detection of change and trends in the condition of streams and estuaries.

Approach: EMAP scientists will conduct research to resolve these issues using our geographic study areas. We will expand our core technical design group to a larger multi-divisional team approach to increase our capabilities.

Classification - Classification research is needed to provide consistent structural frameworks for different types of aquatic ecosystems. This would enable states that share the same or similar ecoregions to collaborate on establishing monitoring programs and reference conditions.

Approach: EPA's STAR program will play a major role in developing new and consistent classification schemes for the various aquatic ecosystems by engaging the academic research community. STAR will use EMAP-designated grant funds for open requests for assistance (RFAs) to obtain the best relevant scientific proposals in support of improved classifications. There is also classification research being planned in ORD with respect to aquatic stressors. EMAP will coordinate with this research effort in addition to the work done by the academic community through STAR funding.

Indicators - EMAP's intramural research on ecological indicators will focus on assessing and reducing the variability of our current indicators when applied in highly diverse new geographic areas (e.g., Western Pilot, and on calibrating indicators across geographic areas to facilitate national data aggregation. We will also begin establishing more formalized procedures for selection of reference conditions.

Approach: The development of new and novel indicators for future use will be pursued through the STAR Grants Program. STAR will develop RFAs to stimulate academic research on new indicators (such as the current work on indicators of wetland condition) using EMAP funds in their extramural program. Through STAR RFAs, we will expand the analysis of variability in existing and proposed indicators. The value of each indicator for describing current resource condition and for trend detection will be determined during the course of the grant. STAR researchers will also test hypothesized responses of indicators to different anthropogenic and natural stresses and evaluate these hypotheses in field studies conducted along known environmental disturbance gradients. This will allow evaluation of the optimum balance of indicators and indices from different taxa. As part of the grant completion process, all indicators developed will be screened using EMAP's Evaluation Guidelines for Ecological Indicators (Jackson et al. 2000). Peer-reviewed publications resulting from the funded research will allow wider dissemination, testing, and use of the new indicators within the scientific community. To ensure that the findings of their grantees are relevant to EPA, STAR intends to integrate them into Agency science through the development of state-of-the-science documents and workshops.

Variability - Our variability research issues are: (1) extracting variance components for our remaining indicators in all resource areas, and evaluating trend detection capabilities; (2) evaluating the variability associated with aquatic ecosystems in different parts of the country; and (3) evaluating different design options for trade-offs between determining status and detecting trends.

Approach: This research will be conducted by EMAP scientists using data from our large-scale geographic studies and initiatives, and through regional applications of EMAP.

Reference Conditions - Defining reference conditions for biological indicators to allow quantifiable measurements of deviation is critical to the EMAP approach and for the derivation of biocriteria. These reference conditions, and the approach to producing them, must be broadly applicable over large, diverse areas.

Approach: We intend to accomplish this primarily through EMAP researchers, using our probability-based sampling design to provide the basis for scientifically credible, regionally representative, reference conditions. We will use the results from a probabilistic monitoring design within the resource to examine the distribution of conditions for subsequent use in developing the criteria necessary for determining reference conditions. We will also examine improvements in reference condition determination by integrating results from index sites and our probabilistic monitoring. Lastly, we will establish approaches for developing reference conditions in impaired areas, where reference communities are rare or no longer exist.

Index Sites - EMAP must determine the proper level of integration between survey and index sites in order to fully evaluate the condition of aquatic ecosystems at multiple spatial and temporal scales. A critical component of index-site research is in developing criteria for reference conditions.

Approach: Index site research will be pursued through EPA's sites, other agencies' sites, and through sites associated with academic institutions via the STAR program. For example, the impaired portions of condition gradients may be explored at urban LTER sites, and at urban index sites maintained by U.S. Geological Survey's (USGS's) National Water Quality Assessment (NAWQA) program.

LANDSCAPES

Land-use activities within watersheds are the major causes of non-point source pollution problems affecting aquatic ecosystems. By using satellite-based remote-sensing techniques, a complete census of the landscape and determination of the different land-cover types (e.g., pine forest, grass lands, pasture) in an area can be made. Changes in landscape composition and pattern can influence water quality, the biological condition of streams, and the risk of watersheds to flooding. If relationships can be established between landscape pattern indicators and aquatic ecosystem condition, then a comprehensive low-cost alternative to field monitoring can be developed.

Current Status of Landscape Research - In 1993, realizing the potential for remote sensing, EMAP initiated a partnership with other federal programs to deliver processed land-cover imagery from across the conterminous U.S. with reduced cost to each agency. The other partners in the Multi-Resolution Land Characteristics (MRLC, http://www.epa.gov/mrlc) Consortium were: the USGS Biological Resources Division's Gap Analysis Program, the NOAA CoastWatch Change Analysis Program, USGS NAWQA, and the USGS EROS Data Center.

The first step towards developing a remote-sensing capability for monitoring condition was the production of a national land-cover data base with 30-meter resolution from MRLC data (completed in Spring, 2000). The data base was produced from Landsat Thematic Mapper images taken during 1991-1993, and purchased by Consortium members. The national land-cover data base consists 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. The MRLC consortium is committed to an ongoing land-cover characterization effort on a 10-year cycle. Work has begun on a revised national land-cover data base for the year 2000.

Landscape Indicators - With a comprehensive and internally-consistent spatial data coverage (MRLC), indicators of status and changes in landscape composition and pattern can be developed (e.g., Normalized Differential Vegetation Index (changes in greenness), and percent anthropogenic cover). We expect spatial correlations between a watershed's terrestrial components and aquatic ecosystems. Even if these relationships are not always strong, it may be possible to use a landscape screening approach (through an assessment of indicators) to identify those areas where on-the-ground sampling would need to occur. Streams draining areas with agriculture on slopes greater than 3% may be at increased risk from sedimentation, and potentially from non-point source pollution (Figure 6). Areas with high amounts of urban development or agriculture (e.g., >60% of the land surface) may be sufficiently degraded so that variation in landscape pattern has little influence on the area's aquatic ecosystem condition. Conversely, areas with very low human occupancy may possess significant resilience and variation in landscape pattern that these areas will also have little effect on aquatic ecological processes and conditions. It is the area with moderate levels of human occupancy where the pattern of use may have the greatest influence on aquatic ecological conditions. It may be possible to use remote sensing to identify and screen out areas that fit the two extremes, and to focus our ground sampling on those areas where pattern matters to aquatic ecological condition. Even this reduction in ground sampling effort could result in a large reduction in the monitoring costs for aquatic systems.

Figure 6. Occurrence of agriculture on slopes >3% in the Mid-Atlantic.

Key Landscape Research Issues - A systematic approach to developing landscape indicators to assess aquatic ecosystem condition at regional scales is a key research need, if remote monitoring is to be feasible. Landscape indicators research will focus on the degree to which landscape composition and pattern co-vary with water quality and stream biotic condition. This research will also help determine the role of riparian habitat in landscape-water interactions, and evaluate critical threshold values of landscape indicators with regard to the quality of aquatic resources.

Landscape indicators are only as good as the remotely-sensed landscape data from which they are built. Data problems can include the number of samples (land-cover data sets may vary from a few hundred to several million samples), the number of attributes (e.g., land-cover classes), and scale of analysis. Interpretation of landscape indicators is also influenced by sensitivity of individual indicators to misclassification embedded within land-cover and other primary spatial data. Moreover, many landscape indicators are calculated by overlaying different spatial coverages (e.g., woody vegetation (from land-cover data) and adjacent streams (from Digital Line Graph data)), which may compound problems. We must be able to account for the uncertainties introduced by these components.

We also need to determine how our indicators and their variability are affected by changing the scale of measurement and the scale of assessment. We must begin to evaluate the scales at which specific types of anthropogenic stresses operate, and the scales at which they can be detected. Only by understanding the differences in response to scale issues among landscape indicators, and their aquatic ecological analogs, can we evaluate and integrate information generated at each tier (index sites, geographic surveys, and remote sensing) of our monitoring framework (see Appendix 1).

A final research challenge will be to develop statistically valid procedures for testing landscape change over time. Parametric statistical procedures require independent and similar experimental units, which are unlikely to be obtained in regional-scale investigations (Hurlbert 1984, Hargrove and Pickering 1992). Neutral models (Gardner et al. 1987, Gardner and O'Neill 1991, O'Neill et al. 1992) may be used to specify null hypotheses as benchmarks to test observed changes, but there is no *a priori* neutral model which is appropriate for all tests that could be made.

Approach: Landscape indicator research will be conducted both by EMAP scientists and extramural academic researchers. The academic community will be engaged in this research topic through our extramural funds in the STAR program. We envision three major focus areas for our intramural and extramural research activities: (1) indicators of landscape condition that are linked to aquatic ecological condition, (2) indicators of stress on landscapes, and (3) effects of data properties on landscape indicator interpretation.

STRATEGIC GEOGRAPHIC STUDIES

The EMAP geographic studies consist of one or more major regional assessments and ten or more sub-regional studies (R-EMAP). These geographic foci are intended to advance monitoring science by reducing the variability associated with describing the status and trends in the condition of individual ecological resources (e.g., estuaries, streams/rivers) or land cover across the nation.

Current Status of Geographic Studies - In the Mid-Atlantic Integrated Assessment (MAIA), we focused on characterizing both the ecological quality of the region and the important environmental stressors at multiple scales. This resulted in the first "State of the Region" baseline assessments for individual types of ecological systems (stream, estuarine, and landscape). MAIA served as the "proof of concept" for the EMAP approach (see Appendix VI).

In MAIA, where the feasibility of the EMAP approach has been extensively tested, the ecosystems are relatively homogeneous and representative primarily of the mid-Atlantic and the southeastern U.S. For the EMAP approach to be applicable to other regions of the country, we must reduce the uncertainty associated with our indicators and designs in more ecologically diverse areas of the country. We must also demonstrate that the EMAP approach can be used by the States to assess the condition of an aquatic ecosystem nationally.

Key Geographic Research Issues - Reducing the uncertainty and variability associated with applying EMAP's design and indicators for estuaries, streams, and landscapes to areas of the country that differ dramatically from the mid-Atlantic is a key EMAP research need.

Approach: EMAP is focusing its major design and monitoring research on the twelve conterminous western states within EPA Regions VIII, IX, and X. This is the Western Pilot. Its vast extent supports high ecological variability, and ecosystems that differ dramatically from those in MAIA. We will also continue to use the smaller R-EMAP studies in each of the EPA Regions to test our designs and indicators in other diverse ecological areas of the country. In R-EMAP, we can further reduce our statistical design uncertainties and engage the Regions, States, and Tribes in using the EMAP approach to address their local environmental problems (see Appendix VII).

Western Pilot - The EMAP Western Pilot will be the largest comprehensive study conducted by EPA on the ecological condition of the West. The Western Pilot is a cooperative venture involving 12 western states, tribes, universities, and the western EPA Regional Offices. Initiated in the spring of 1999 as a five-year effort, the EMAP Western Pilot will establish the condition of aquatic ecosystems throughout the West, and identify stressors associated with the degradation of these resources.

EMAP's Western Pilot research effort includes three core components: estuaries, surface waters (streams and rivers) and landscapes. A probability-based sampling approach will be used to monitor the ecological condition of estuarine and surface waters, and produce state and regional condition assessments. The landscapes component will make use of remotely-sensed imagery for a census of land cover types, and produce a landscape atlas for the western U.S.

Estuaries - Our first year's effort (1999) involved sampling the small estuaries in California, Oregon and Washington in partnership with these states, NOAA, and USGS. In 2000, the Western Pilot coastal component focused on the large estuarine systems: Puget Sound, WA; Columbia River Estuary, OR; and San Francisco Bay, CA. In subsequent years, we will develop the techniques and designs necessary for monitoring the Pacific Coast wetlands and the near-shore environment. "Near-shore" is used here to mean the shallow-water ocean area near the coastline (approximately from high tide to 5 km offshore).

Our hierarchical design for western coastal estuarine resources includes a minimum of 50 locations in the small estuaries of Washington, Oregon, and California (not including Puget Sound, Columbia River Estuary, or San Francisco Bay) as a base. Our intent is to modify existing state programs as little as possible, but still meet our probabilistic requirements, and to provide estimates of estuarine health and guidance for the development of estuarine reference conditions for use with biocriteria.

In 1999, areas of design and sampling intensification were included because of specific regional interests. Region IX selected Northern California coastal streams (Bodega Bay, CA, north to the California-Oregon line) and Region X selected Tillamook Bay as their desired areas of intensification. Nested designs were created for these areas that add approximately 30 sites in each of the respective sub-regions.

Over the period of 1997-1999, Washington Department of the Environment (DOE) sampled 300 locations within Puget Sound and its adjacent systems to characterize sediment contaminants, toxicity, and benthic communities. This effort used an EMAP-type probabilistic design and collected EMAP indicators. The Washington DOE data will be incorporated into our analyses.

NOAA had an intensification effort in 2000 that resulted in 200 sites located in San Francisco Bay. USGS/BRD's Biomonitoring of Environmental Status and Trends (BEST) program has also proposed intensifications to complement our Western Pilot; these would focus on western wildlife refuges and measure contaminant effects on birds, fish and mammals. While still preliminary, we will work to integrate any potential intensifications by the BEST Program into the Western Pilot. Also in FY2000, we organized the EMAP field effort that focused on San Francisco Bay, Columbia River and Puget Sound; this was conducted by the resource/protection agencies of California, Oregon, and Washington, respectively.

Estuarine conditions are typically assessed by EMAP through the use of biological indicators such as benthic community structure, fish community analysis, and the incidence of disease or other pathologies in fish. The presence of stressors is evaluated by assessing water quality parameters, sediment contamination and toxicity, and the presence of contaminants in fish tissue. The core EMAP coastal indicators (Table 2) were developed in the estuaries of the Southeast, MAIA and the Gulf of Mexico, and will be tested in the Western Pilot.

Streams and Rivers - EMAP has not previously undertaken a large-scale sampling of streams and rivers in the West. In order to produce unbiased estimates of the ecological condition of surface waters of the West, we must establish that our current design framework (stream survey design, biological indicators, and estimates of reference condition developed in MAIA) is effective. We will also include an assessment of the potential importance of stressors (habitat modification, sedimentation, nutrients, temperature, grazing, timber harvest, etc.) in the streams and rivers of the western U.S. EMAP, in conjunction with the States, is sampling perennial streams in the twelve western states over four years to produce statewide estimates of condition. In this period, a total of 50 sites per state will be monitored. Intensive study areas in each EPA Region will also be sampled to address more specific issues of impairment and reference conditions. Our sampling will build on existing state capacities in implementing our probability sampling framework, which will allow for the aggregation of ecological condition information across the West.

Biological, physical habitat, and water chemistry indicators will be used in our assessment of stream condition in order to characterize the biological communities, habitat attributes and levels of stress. All of our state partners in the Western Pilot have agreed to a group of core stream indicators that will be used (Table 3). An additional set of research indicators (riparian condition, continuous temperature, microbial organisms, sediment toxicity, additional tissue contaminants, etc.) may also be experimentally tested on a smaller scale in focused areas. These indicators may be added depending on local importance and available funds.
Landscapes - Unlike the sampling required for individual aquatic resources, landscape data can be gathered "wall-to-wall." Through the use of remote-sensing techniques and the availability of the MRLC data, the entire western U.S. will be censussed. In the landscape component, we will assess spatial variability in landscape pattern and the degree to which landscape pattern influences the conditions of estuaries and inland surface waters. If we can link watershed-level aquatic resource condition with landscape patterns, then it may be possible to assess conditions of aquatic resources from remotely-sensed landscape data at many scales across the western US.

The western U.S. presents a challenge to developing and interpreting landscape indicators. There are limitations to processing the data for an area this large. There are also some unique stresses on western landscapes, including grazing and timber harvest, that do not result in changes in land-cover types, but rather in substantially altered states of land-cover conditions. New remote-sensing data and analytical approaches will be needed to determine the extent and magnitude of these stresses.

We intend to develop a regional-scale land-cover database for the western U.S. based on the MRLC

Table 2. Core EMAP coastal indicators

Water Column	Sediments	Biota
Dissolved oxygen Salinity, temperature, depth PH Nutrients Chlorophyll	**Grain size Total organic carbon Sediment chemistry Sediment toxicity**	**Benthic community structure & abundance Fish community structure & abundance Fish pathologies Fish tissue residues Submerged vegetation**

Table 3. Core EMAP surface water indicators

Core	Additional Indicators	
Conventional water quality parameters Fish assemblage Macroinvertebrate assemblage Periphyton assemblage Physical habitat structure Riparian vegetation	**Fish tissue chemistry/toxics Sediment metabolism Sediment chemistry Sediment toxicity Water column toxicity**	**Amphibians Bacteria Biomarkers Riparian birds**

data set. This database, along with other regional landscape coverages (e.g., topography, soils, road networks, stream networks, and human population density), will be used to assess landscape conditions across the entire region down to a resolution of 30 m^2. This assessment will use a set of landscape indicators to evaluate the spatial patterns of human-induced stresses and the spatial arrangement of forest, forest edge, and riparian habitats, as they influence aquatic resources.

The components necessary for a western landscape assessment are: (1) spatial data acquisition, assembly, and accuracy assessment; (2) development of new remote-sensing methods to detect watershed-level stresses; (3) landscape indicator generation; (4) quantify the degree to which existing and new landscape indicators explain variation in aquatic resource conditions; and (5) development of multi-indicator assessment techniques. During 1999-2002, aquatic and landscape data will be assembled, landscape indicators will be developed and calculated, and aquatic resource-landscape indicator quantification will begin. In 2002-2003 landscape indicators will be quantified across the entire West to establish potential risks to aquatic resources.

R-EMAP - Our R-EMAP projects will provide numerous small-scale ecological monitoring research opportunities across the wide biogeographic and political boundaries associated with the ten EPA Regional Offices (see Appendix VII). We typically sponsor one or two R-EMAP projects annually in each Region, with a focus on applications of the EMAP approach to local problems. EMAP will continue to use R-EMAP to complement our larger geographic assessments, and to provide us with additional opportunities to develop and test indicators and designs across the nation.

NATIONAL RESOURCE ASSESSMENTS

A key issue for EMAP is building the capacity for, and demonstrating the feasibility of, using our approach by the States and Tribes for environmental condition assessments that can then be aggregated to regional and national levels.

National Coastal Assessment - We are now demonstrating that EMAP's integrated probabilistic monitoring approach can be used to produce a comprehensive assessment of the condition of the nation's estuaries and near-shore coastal environments. This is EMAP's National Coastal Assessment. During 2000-2001, all 24 marine coastal states (including Alaska and Hawaii) and Puerto Rico will be sampled to estimate the condition of their estuarine resources. A minimum of 50 sampling locations in each state have been established within EMAP's probabilistic sampling framework. The results of the coastal component of the Western Pilot in 1999-2000 (see previous section) will be integrated into this national effort and constitute the assessment of the West Coast estuaries.

At all selected sampling sites, measurements are focused on ecological and biological response variables (see Western Pilot - estuaries). However, sufficient environmental stressor and habitat information is also collected in order to interpret our response variables. A special effort is being conducted to test ecosystem-level response variables delineating function (e.g. system productivity, nutrient cycling, and systems energetics) as measures of system condition (see NRC 1999).

Partners in the EMAP National Coastal Assessment are EPA Regions, the Office of Water, state resource/protection agencies in the 24 marine coastal states and Puerto Rico, USGS and NOAA, all of whom are participating in sampling during the late summer months of 2000 and 2001. In 2002, we will begin our assessment of the conditions of the near-shore marine coastal environment. This effort will complement our work on the nation's estuaries and EPA's increased efforts in beach monitoring.

National Stream Assessment - The Western Pilot is removing the major scientific barriers to the use of the EMAP approach for a national stream monitoring framework. As we remove the uncertainties associated with using our designs and indicators in the western U.S., we will be in a position to provide designs for all the conterminous states. Use of these monitoring frameworks by the states will allow the collected data to be aggregated nationally into the first national stream assessment.

Large and Great Rivers - Within the Western Pilot, EMAP has begun developing sampling designs and indicators for large and Great Rivers. Large/Great Rivers have been determined by EPA's Office of Water as one of the next major national resources that requires a monitoring design for establishing ecological condition. Current and future EMAP research will focus on developing indicators and a monitoring design that will allow the condition of large/Great Rivers to be established. This resource is one of our most poorly understood aquatic ecosystems. Our focus on large/Great Rivers would also allow the integration of the findings from a National Stream Assessment with the condition of the ultimate estuarine receiving waters through the National Coastal Assessment. Large and Great Rivers are the crucial link between wadeable streams and estuaries, and an understanding of their condition will be requisite to developing rational total maximum daily loads (TMDLs) for both upstream and downstream waters.

EMAP plans to address the rivers of the Mississippi basin (which drains approximately 41% of the conterminous U.S.) to lay the groundwork for exploring integrated watershed processes from the upper Midwest to the Gulf of Mexico. Potential partners with ORD in this effort, and who have already participated in preliminary planning discussions, include USGS (NAWQA, BRD, and Long-Term Resource Monitoring Program), the U.S. Army Corps of Engineers, EPA Regions IV - VIII and EPA's Gulf of Mexico Program Office.

INFORMATION MANAGEMENT

As with any large environmental effort, an effective information management program is critical. There are two key components to EMAP information management: data management and information/technology transfer.

Data Management - The data management component of EMAP has been a key feature of the Program for many years (see Appendix VIII). It supports the programmatic and policy objectives, and is an integral part of the landscapes, surface waters, and coastal groups. EMAP data are used primarily by study participants to fulfill study objectives—assessments of the environmental conditions of a region or regions. In addition, because these ecological data are collected under a consistent design and with consistent methods over broad regions, are of high-quality, and are well-described, they have many potential uses beyond the original study. These circumstances lead to both EMAP's analytical databases that support the statistical analyses (Hale and Buffum, 2000), and general-use databases that are widely available to secondary users (Hale et al. 1998).

EMAP's data management team will continue to: provide a Data Directory so that data of interest can be readily identified; provide access to EMAP data and metadata (including data authorship information); and revise and update the EMAP home page for the Internet on a regular basis. However, our approach will be guided by considerations for sharing national environmental monitoring data that will allow national environmental assessments to be conducted. An element of this will be to ensure long-term data archival through EPA's STORET system. We are currently working with STORET data managers to modify their system to accommodate EMAP data, and those from States using the EMAP approach.

EMAP will continue to use the Internet for distribution of data and metadata through our existing EMAP World Wide Web (WWW) home page (http://www.epa.gov/emap/). Our intent is to have all EMAP data publicly accessible through our EMAP web page within two years of collection. To this end, each EMAP research group will initially manage the data it collects and be responsible for documentation and transfer to the EMAP home page in accordance with our standards and formats (see EMAP Information Plan, Hale et al. 1999). This will provide for a sustainable, consistent, and continuously updated data system in support of our continuing research on aquatic ecosystem condition assessments. Our metadata files are periodically uploaded to ORD's Environmental Information Management System (EIMS) for broader public exposure (see Appendix VIII).

Information/Technology Transfer - The transfer of our approaches and techniques generally occurs by direct interaction with our partners (EPA Regions, States, and Tribes) in our study areas. However, in some cases (e.g., remote sensing, statistical design), the techniques or approaches are sufficiently new or novel that our partners may have limited expertise. In these cases, we will establish work groups in each of the involved EPA Regions, with an overall steering committee that is chaired by the EMAP technical lead in the subject. EMAP will also train and support regional representatives to help in the immediate use of the technology or techniques, and to further transfer this capability to Regional staff. We have previously established a GIS/remote sensing team in EPA Regions VIII, IX, and X in conjunction with the Western Pilot. Similarly, we intend to establish a design and analysis team in the near future. In addition, we intend to enhance the usefulness of EMAP data to our partners and the public by developing interactive approaches to simplify interpretation of EMAP data through our Internet site.

PROGRAM MANAGEMENT

EMAP is an ORD-wide program which receives strategic guidance from all of the ORD National Laboratories and Centers (Figure 2). These laboratories and centers are also directly involved in conducting the research associated with EMAP's goals.

Administratively, EMAP resides in the National Health and Environmental Effects Research Laboratory. However, the EMAP Director is advised by a Steering Committee made up of the Associate/Assistant Directors for Ecology from each of ORD's National Laboratories and Centers. The EMAP Director is responsible for developing the detailed research directions and ensuring that the research is implemented through the working groups in the laboratories and centers.

Quality Assurance - EMAP intramural research is conducted by scientists within the organizational divisions of ORD Laboratories and Centers. As such, each research product is subject to the quality assurance (QA) procedures established by its originating organization. Extramural scientists conducting EMAP-sponsored research through STAR grants are required to submit a quality assurance plan prior to collecting data. ORD's rigorous QA standards ensure that research results intended for EMAP assessments have been thoroughly verified.

Measures of Success - Since its inception in the late 1980s, the tenet of EMAP has been "monitoring for results." This was reinforced by the enaction of the Government Performance and Results Act (GPRA) in 1993. EMAP's success is predicated on improving the science behind environmental decisions. Our progress will be measured in four key areas:

- **Effect on Decision-Making -**
  Most directly, we can examine the use of program results in environmental decisions and policies. Already, EMAP data on streams in the mid-Atlantic have provided the justification for EPA to require a full Environmental Impact Statement for proposed mountain-top removal for mineral extraction in West Virginia. And, in Maryland, the Department of Natural Resources (using EMAP's design) developed the report "The State of Maryland's Freshwater Streams" (EPA/903/R-99/023), which is being used to make planning decisions in support of the Governor's Smart Growth Initiative.

- **Adoption of Methodology -**
  Implementation and routine use of EMAP's statistical design and ecological indicators by States and other monitoring agencies is an unmistakable sign of acceptance. To date, more than 30 States have implemented or are testing EMAP protocols. In addition, the U.S. Forest Service has adopted EMAP's rotating panel design for its national survey programs. Also, EPA's Office of Water has issued draft guidance to the States on using probability designs (EMAP approach) for monitoring the condition of all waters within the State under 305(b) of the Clean Water Act.

- **National Data Aggregation -**
  The National Coastal Assessment is currently demonstrating that EMAP indicators can be meaningfully aggregated and compared across U.S. regions. Similar verification for streams data is expected within the next few years.

- **Trends Detection -**
  The ability to detect changes over time will complete validation for EMAP's statistical design. It will require long-term implementation of EMAP methods, as continued sampling over multiple years will be necessary to analyze for trends. We have begun looking at change detection between sampling periods as a prelude to having sufficient data to detect trends. We have been able to detect trends at the basin-level through R-EMAP, and we will be examining change detection at the scale of estuarine provinces through our National Coastal Assessment.

Appendix I.
Needs for Improved Environmental Monitoring

The need for significant advances in the way EPA and other federal agencies monitor the condition of our environment has been, and continues to be, recognized (National Research Council (NRC) 1977, U.S. General Accounting Office (GAO) 1981, 1986, 2000, USEPA 1987).

In 1988, the U.S. EPA Science Advisory Board's (SAB's) report, *Future Risk: Research Strategies for the 1990s* (U.S. EPA 1988), was the stimulus for many 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 and 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 had 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 these problems. EPA was urged to evaluate environmental trends and assess other predictors of potential environmental problems before they become acute.

The SAB recommendations, the emerging vision of ecological risk assessment within EPA, and the importance of high quality monitoring information in this risk assessment paradigm were responsible for the creation of the Environmental Monitoring and Assessment Program (EMAP) within EPA's Office of Research and Development (ORD). EMAP's challenge was to develop the tools necessary for measuring the condition of many types of ecological resources and the designs for detecting both spatial and temporal trends (Messer et al. 1991). EMAP used a tiered monitoring approach (Figure 7) and focused on developing indicators of ecological condition and new monitoring designs for major classes of natural resources such as surface waters, estuaries, forests, and wetlands.

It became apparent that EMAP alone could not develop the designs and indicators for all the nation's resources. Also, EMAP would not be able to implement and maintain a national monitoring program in the states without additional resources and the partnership of tribal, state, and federal agencies. Since States, Tribes, and EPA have statutory responsibilities within the Clean Water Act to monitor the surface waters in their States and in the country, respectively, and because these waters integrate the atmospheric, landscape and upstream inputs, aquatic ecosystems were chosen as EMAP's focus.

Under the auspices of the White House Office of Science and Technology Policy, the Committee on

Environment and Natural Resources (CENR) formed the Environmental Monitoring Team in 1995. 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 (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. Also, this framework unites the respective agencies in achieving a common national goal of understanding and managing our ecological systems for their sustained use and enjoyment. Their framework was very similar to EMAP's multi-tier monitoring approach (Figure 7). The interagency nature of the framework allowed EMAP to focus on priority EPA needs associated with aquatic ecosystems.

Also in 1996, the National Research Council (NRC) convened the first National Forum on Science and Technology Goals. The NRC called for a greater focus on monitoring in order to build better understanding of our ecological systems. They felt current ecological data and understanding were inadequate to: 1) Detect, monitor, and characterize environmental changes; 2) evaluate the consequences of human activities; and 3) provide an information base for sustainable management (i.e., "no loss") of both natural and human-designed ecological systems. Current programs did not address these issues in a sufficiently coherent and comprehensive manner on a national basis to determine what actions were needed to achieve a desired environmental quality; these programs also could not detect changes between current and past conditions or trends in condition for projection of future ecological states. Indicators were needed to measure the status of ecological systems, to gauge the likelihood of meeting society's environmental goals, and to anticipate problems resulting from economic growth. The NRC concluded that we were spending substantial time and money to collect data that were neither compete nor always relevant to the decisions that society needed to make about land use, transportation, industrial activity, agriculture, and other human activities. A cost-effective approach to monitoring the condition of the environment on a national level needed to be developed.

Currently, all states monitor a subset of their waters because it is cost-prohibitive to physically monitor all their waters. However, most of this monitoring does not allow for statistically valid assessments of water quality conditions in unmonitored waters (GAO 2000). These data gaps limit the state's and EPA's abilities to identify water quality problems and set priorities, and to carry out key management and regulatory activities. These data gaps are particularly serious for non-point sources, which are widely accepted as contributing to the majority of the nation's water quality problems (GAO 2000).

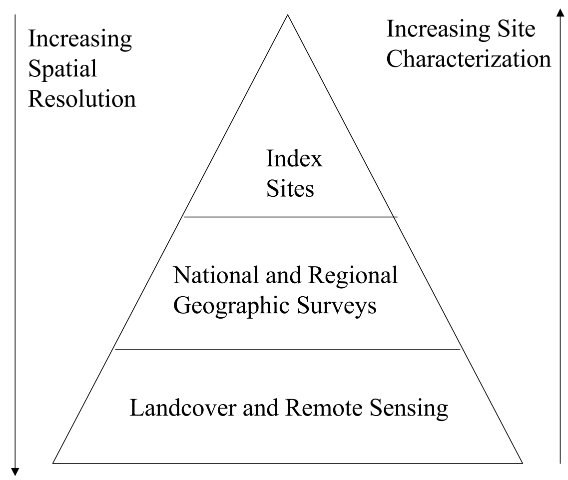


Figure 7. Tiered monitoring approach used in EMAP and the CENR Strategy.

APPENDIX II. Resource Sampling

Lake Sampling - EMAP defines target lake populations as standing bodies of water >1 ha, with 1,000 m^2 of open water and a maximum depth >1 m, (Larsen and Christie, 1993). Lakes are treated as a discrete resource, and a two-stage approach is used to identify the unique probability-inclusion point for each lake. We use digitized databases (USGS Digital Line Graphs (DLG) database and USEPA RF3 river reach files) to identify lakes in the templates around each grid point. These databases contain information at the same scale as 1:100,000 topographic maps. The lake coverages are extracted from the databases and a unique label point is associated with each lake by a geographic information system (GIS) for use as the point for the lake. The DLG representation also provides the surface area for each lake, and only lakes with areas >1 ha are extracted.

A GIS is used to overlay the random templates on the lake points, and a list of the lake points covered by templates is extracted. The identified lakes are then checked against several sources to remove any known non-lakes. Some non-lakes will still remain, but these will be detected during reconnaissance or the field visit. This list of lakes makes up the first-stage sample.

The size distribution of the first-stage sample of U.S. lakes is strongly skewed toward the small end. Almost 25% of the lakes have areas <2 ha, 80% have areas <10 ha, and almost 95% have areas <50 ha. Equal probability sampling of the first-stage sample would result in very few samples in the ecologically important moderate and larger-sized lakes. Moreover, experience with pilot studies indicates that many of the sites identified in the digitized database will not meet the operational definition of a lake. This problem is particularly acute for the sites identified as small (<5 ha) lakes. In order to counter these features of the population in the second-stage framework, several size classes were defined and target sample numbers were assigned for each size class.

Stream Sampling - The stream resource does not fall neatly into either the discrete or extensive category. To deal with this, EMAP focuses on the population of stream miles, and we characterize the population in terms of the condition of miles of streams. Therefore, we want a sampling method that samples a stream in proportion to its length. To accomplish this we view streams as an extensive resource with length. This method has been used in MAIA, and it appears suitable for use in other regions.

The sampling templates used in lake selection are also used in stream selection. Stream traces are identified on 1:100,000-scale DLGs, and a GIS is used to intersect these with the sampling templates. Each stream segment within a template is identified and its length determined. The endpoints of a segment are defined as confluences, headwaters ends, or intersections with a template edge. Sets of connected segments of the same order are always kept together in the sample selection process. The appropriate stream order is also determined for each segment (e.g., headwater streams are 1st order).

As with lakes, some differential weighting by size is necessary because of the predominance of lower-order streams. The weighting factors that are used are 1, 2, and 4 for orders 1, 2, and 3, respectively. The weighting factors are chosen to produce approximately equal sized samples of 1st, 2nd, and 3rd order streams.

The sample selection proceeds in very much the same manner as for lakes, with inclusion probability for a segment proportional to its length times the weight for its order. The total inclusion probability for each template is calculated as the weighted sum of stream lengths in the template, the templates are partitioned into groups using a partitioning algorithm, and the samples are selected. The same systematic selection protocol is used; the partitions are randomized, the templates are randomized within the partitions, and the sets of connected segments are randomized within the templates. The selection not only identifies the stream segment to be sampled, but also identifies the point on that segment where the sample is to be located. This is accomplished by recording the relative distance from the beginning of the segment to the selected point on the segment.

Estuarine Sampling - EMAP uses estuarine provinces for classification purposes. In the continental United States these provinces are: Acadian Province, Virginian Province, Carolinian Province, West Indian Province, Louisianian Province, Californian Province, and Columbian Province (Figure 8; Holland, 1990). We use a classification scheme to subdivide estuaries within a province into classes that have similar physical features and are likely to respond to stressors in a similar manner. The defined classes include (1) large, continuously distributed estuaries (e.g., Chesapeake Bay, Long Island Sound), (2) large, continuously distributed tidal rivers (e.g., Potomac, Delaware, Hudson Rivers), and (3) small, discretely distributed estuaries, bays, inlets, and tidal creeks and rivers (e.g., Barnegat Bay, Indian River Bay, Elizabeth River).

Within each estuarine class, elements of systematic and random sampling are used. Large, continuously distributed estuaries are sampled using a randomly placed systematic grid. A ninefold enhancement of the EMAP grid is used, with one-quarter of the points sampled each year. Grid points are about 18 km apart in all directions, and the entire estuary is sampled. Large tidal rivers are sampled along systematically spaced transects across the river channel. Transects are located about 25 km apart. The starting point for the first transect is randomly selected between 0 and 25 miles from the mouth of the river. Two sampling points are located on each tidal river transect; one is randomly selected and one is an index sample, located in the deep channel of the river. Small, relatively discrete estuaries are sampled using a population approach. First, a list of all small estuaries is defined, then the estuaries to be sampled are randomly selected from the list without replacement. The list is geographically ordered from north to south, split into groups of four, and one unit is selected from each group. Two sampling points are located in each small estuary that is sampled; one is randomly selected and one is an index sample, located in the deep, depositional portion of the estuary.

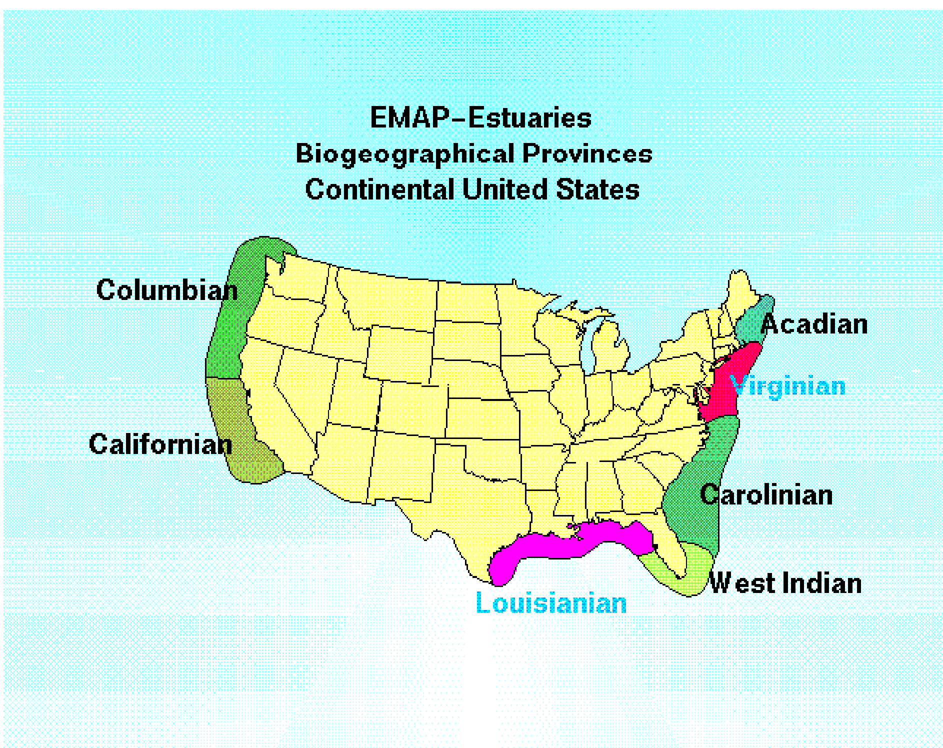


Figure 8. EMAP Ecological Provinces used for classification of estuaries in the continental U.S.

Wetland Sampling - We have not yet settled on a single approach to sampling wetlands. Our pilot studies, including one on coastal salt marshes, selected sample sites using an intensified grid. We are engaged in identifying suitable means of locating, characterizing, and delimiting wetlands, and in developing suitable indicators of wetland condition both through intramural efforts and extramurally through the STAR Grants Program.

Great Lakes Sampling - Hedtke et al. (1992) defined the Great Lakes resource as the waters of the Great Lakes and the sediments below them at high water 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.

The domain of the Great Lakes resource consists of five regions within the Great Lakes basin corresponding to the five Great Lakes: Superior, Michigan, Huron, Erie, and Ontario. Each of the lakes is physically distinct. The connecting channels tend to have some basic characteristics of their upstream lakes but are physically unique. EMAP is initially pursuing a monitoring program that will provide status and trends in the five Great Lakes through intramural efforts.

The Great Lakes resource can be split into four classes for sampling purposes: nearshore waters, offshore waters, harbors and embayments, and wetlands. Because of the different spatial and biological properties of each of the classes, the sampling strategy will likely be different for each of them. The nearshore resource class consists of waters adjacent to the shoreline and no more than 85 m deep, and the offshore class is the remaining central portion of the lake. The offshore and nearshore areas of the lakes will be determined from GIS-based bathymetric maps digitized on a 2-km grid (except Lake Superior which is on a 4-km grid). The two open-water classes are extensive resources, and the EMAP grid can generate a frame for these classes. A threefold enhancement of the grid would be used for the nearshore class in order to provide an adequate number of samples. For both open-water classes, sampling would take place at the grid point.

Harbors and embayments would be treated as a separate resource class for two reasons. First, many embayments are formed by tributaries that are a source of nutrients and contaminants, and thus have differing water quality and higher variability. Second, harbors are often the site of more intense human activity, such as industry, shipping, recreation, and dredging, and thus may be sources of nutrients and contaminants to the rest of the nearshore zone and to offshore waters. Harbors and embayments do overlap. For example, there are harbors at the mouths of tributaries in Lake Michigan such as Milwaukee Harbor, Benton Harbor, and Green Bay. There are also embayments that are not harbors and harbors that do not have tributaries associated with them. Rather than try to make distinctions between these two types of subclasses, we would consider them as one resource class. Definitions of these areas will be physical (natural), based on structures such as breakwalls and docks or easily recognizable land features such as peninsulas or points.

The lateral extent of the harbor or embayment area will be the same as the general nearshore area (i.e., 85-m depth contour). If the harbor or embayment includes a tributary, the area will include the tributary mouth and upstream to the zone of lake influence as defined by conductivity gradients. If the tributary is dammed, the area would include the first dam or zone of influence as applicable. Those areas of the lakes that are often referred to as bays (e.g., Saginaw Bay, Green Bay) and yet are themselves large enough to contain smaller bays, would be treated as part of the general nearshore class. Minimum size for an embayment has yet to be determined. Preliminarily we would use a minimum area approach, rather than a minimum distance across the mouth of a harbor or bay.

Two techniques could be used for sampling harbors and embayments. One approach treats them as a discrete resource, where all harbors and embayments would be identified by examining the lake perimeter with the aid of a GIS. A natural ordering would be induced by the lake perimeter, so a systematic sample of the ordered list of harbors and embayments would have good spatial coverage, and characterization would be in terms of numbers of harbors and embayments. The other approach would be to characterize them as units, which would require multiple samples per unit, or carefully selected index samples.

Wetlands in the Great Lakes will be sampled similarly to our general sampling of wetlands (see above), once we have identified a consistent sampling approach.

APPENDIX III. Indicators

Indicator Development - Indicators can be developed for any level of biological organization (Table 4). However, the structural and functional aspects of the biological or ecological characteristic to be used as an indicator must be appropriate to the question being asked.

Indicator Measurement - To measure an indicator requires a standard protocol, whether in the field or the laboratory, and a documentation of the type and amount of sampling necessary. An example might be using the number of fish species present in a stream reach as an indicator of water quality. A protocol such as electroshocking could be defined and then the length of stream reach necessary for a predetermined level of accuracy must be found. In fact, Reynolds et al. (in prep.) have determined the length of stream required to do this in terms of stream channel width (Figure 9).

Indicator Responsiveness - Evaluating the degree to which a particular indicator actually responds to various stressor gradients, or if a stressor indicator responds to changes in the source, is an important aspect of the indicator development process. Without some knowledge of the shape of the response curve and the variability associated with the response, it is difficult to evaluate the utility of any particular indicator. This process must begin with an hypothesis about the expected direction of response and then a quantification of the actual response to stressor gradient (Figure 10).

Indicator Variability - A description of the components of variability which impact status and trends estimation in monitoring is provided by Larsen et al. (1995). The important consideration to EMAP is the extent to which variability in measuring the indicator (noise) masks detection of the "change of status" signal. This may be natural variability such as the real differences within a body of water or real differences due to period when the sampling site is visited. It also contains variability due to crew errors and differences among crews, the laboratory processing and other extraneous components. One way to evaluate the signal to noise for a particular indicator is to look at the ratio of population variability relative to the measured indicator's variability. If the ratio is small, then detecting signals will be difficult (Figure 11).

Ultimately, sufficient information on indicator variability is needed to determine the power of the indicator to detect a trend. Power analysis for detecting trends in lakes using Secchi transparency and zooplankton species richness was shown in Figure 11. In this example, if we have a sample size of 50 lakes per year and have a 2% per year change in Secchi transparency, we would be able to detect it after eight years with 90% power. In contrast, it would take 11 years to detect a similar trend in zooplankton species richness, with comparable power.

Indicator Demonstration - During the final stages of indicator development, potential users must be given some sense of how well the indicator performs and how it can be used. This often implies demonstrating the indicator in a regional scale project such as a geographic initiative or R-EMAP assessment and showing the results and potential conclusions which may derive from using the indicator (Figure 12). This is part of a necessary "proof-of-concept" for the indicator to be accepted into widespread use (see Jackson et al. 2000 for complete guidelines).

Table 4. Levels of biological organization to consider during indicator development with examples of structural and functional aspects of each level.

Structure	Level of Organization	Processes
Heterozygosity	Gene	Polyploidy Rate Mutation Rate Recombination Rate
Condition Anomalies/Deformities Maximum Size Tissue Contamination	Individual	Metabolic Rate Growth Rate Fecundity
Abundance Age Class Distribution Size Class Distribution	Population	Reproduction Rate Growth Rate (of Population) Death Rate Evolution/Speciation
Relative Abundance Richness -Native Richness - Total Evenness Trophic Composition Reproductive Composition Habitat Guilds	Assemblage (Community)	Competition/Predation Disease/Parasitism Mutualism Recovery Rate
Regional Diversity (gamma) Homogeneity Hot Spots Patches Patterns Fragmentation/Recovery	Watershed or Landscape	Water Delivery Chemical Delivery (Native and Exotic) Material Delivery (Sediment, Wood) Energy Flow Nutrient Cycles and Spiraling Population Sources and Sinks Fragmentation Rate/Recovery Rate

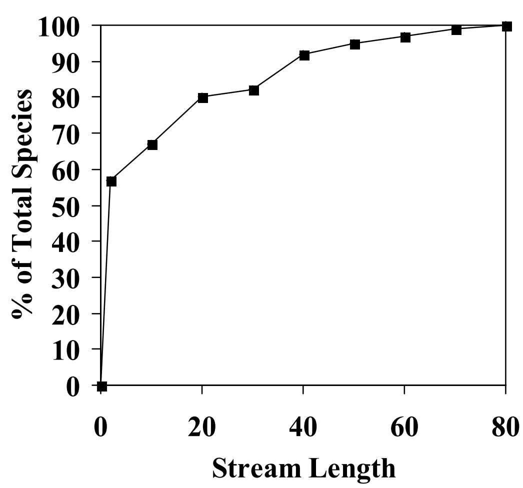


Figure 9. Electrofishing in small streams indicates that sampling a stream length equal to 40 channel widths would result in about 90% the toal species present.

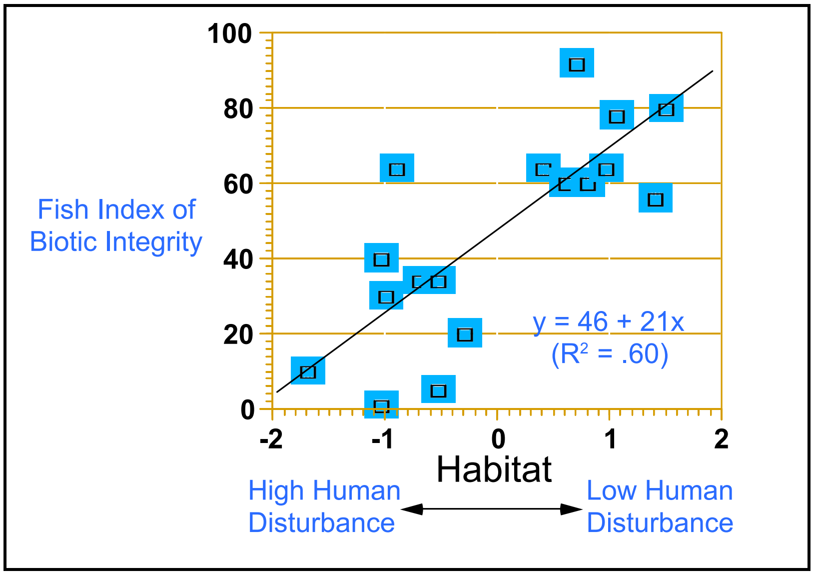


Figure 10. Example of observed response of indicator to stressor gradient.

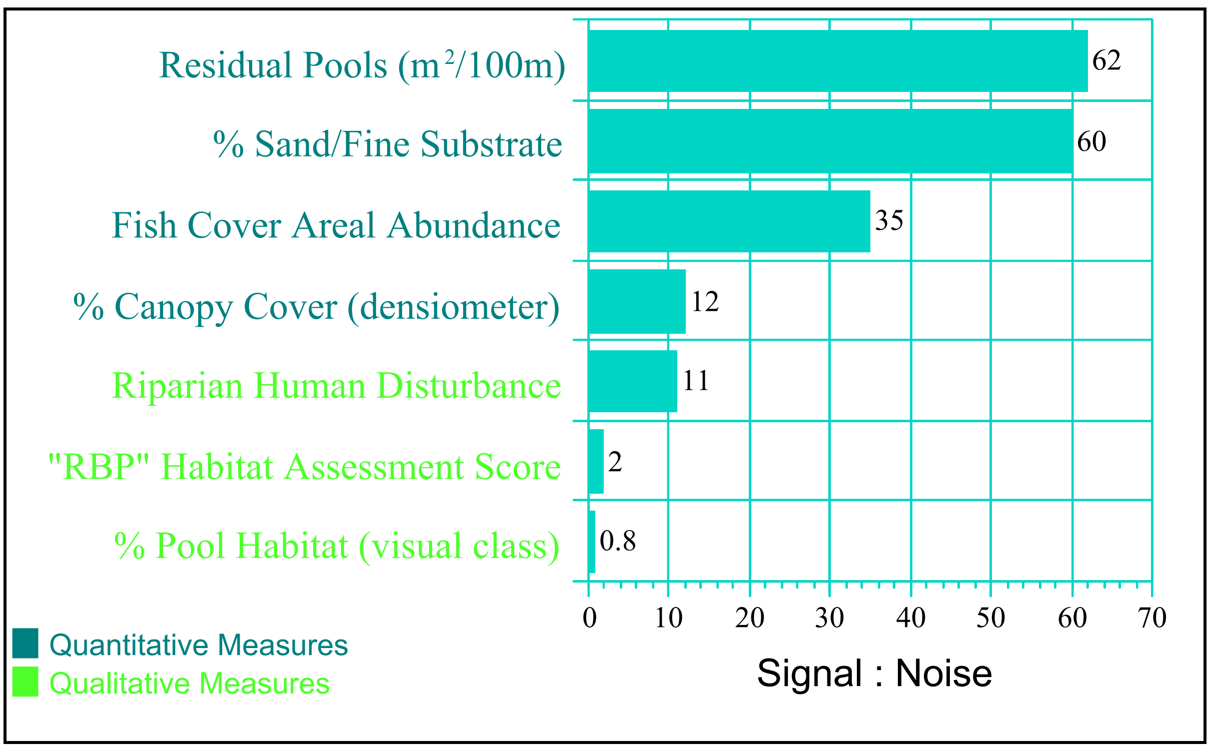


Figure 11. Signal to noise ratio for stream physical habitat indicators. If the ratio is small, then detecting signals will be difficult. The first 3 indicators would be potentially useful.

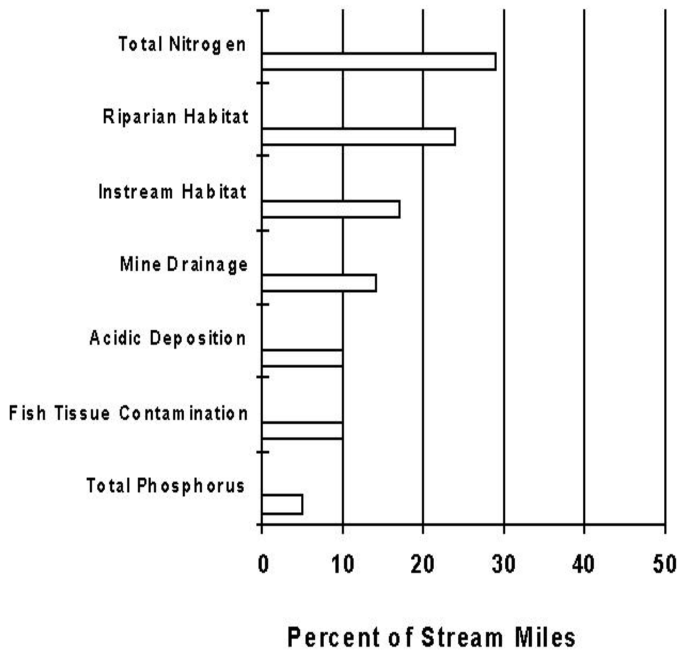


Figure 12. Stressors associated with impaired stream water quality (as determined by our stream benthic invertebrate IBI) in the Mid-Atlantic Highlands.

APPENDIX IV. Components of Variance in Indicators

The use of particular indicators in estimating status and trends requires evaluation of the magnitude and the effects of different components of variance. The choices for minimizing variance components, or their effects on estimates of status and trends, depends upon their relative magnitudes. Using indicators of lake trophic status as an example, the components of variance that could have important effects on status description and trend detection are:

$$\sigma^2_{Tot} = s^{2}_{lake} + \sigma^2_{year} + s^{2}_{lake*year} + \sigma^2_{index}$$

total variance	=	population variance	+	year variance	+	interaction effects variance	+	index variance

It is possible to separate some of the variance components into deterministic and random parts to the extent that exogenous covariates can be identified. For example, some of the seasonal variation in water quality variables in streams can be associated with variation in stream flow. The identifiable effects of the deterministic component can be removed from the variance associated with the covariate (Steel and Torrie, 1980). In the following examination of variance, the deterministic components are treated as if they have already been accommodated, and what remains must be handled in other ways.

Population Variance (σ^2_{lake}) - lake effects - Population variance describes the measured differences among lakes in a regional population or subpopulation during the index period. For example, suppose there were 20,000 lakes in our population of interest. One hundred were picked at random as the sample of lakes on which indicators of condition were monitored in a particular year. In the absence of other variance (described next), this snapshot expresses the status of the population during the yearly index window. We use cumulative distribution functions (CDFs), histograms, or other population descriptors to represent a population's status. If no other forms of variation interfere with the sampling process, index snapshots derived from the randomly chosen sample of lakes would unambiguously express population variance.

Year Variance (σ^2_{year}) – year effects – Year variance measures the amount by which all lakes in a population or subpopulation are high or low in a particular year (Figure 13A). The condition of regional populations of lakes fluctuates around a central value in the absence of a trend. In the presence of a trend, this variance component measures the year-to-year variation from the trend line or curve. Regional trend detection capability is very sensitive to the relative magnitude of this component of variance. This population level variation is sometimes called a year effect, since it is a measure of the amount by which all lakes in a

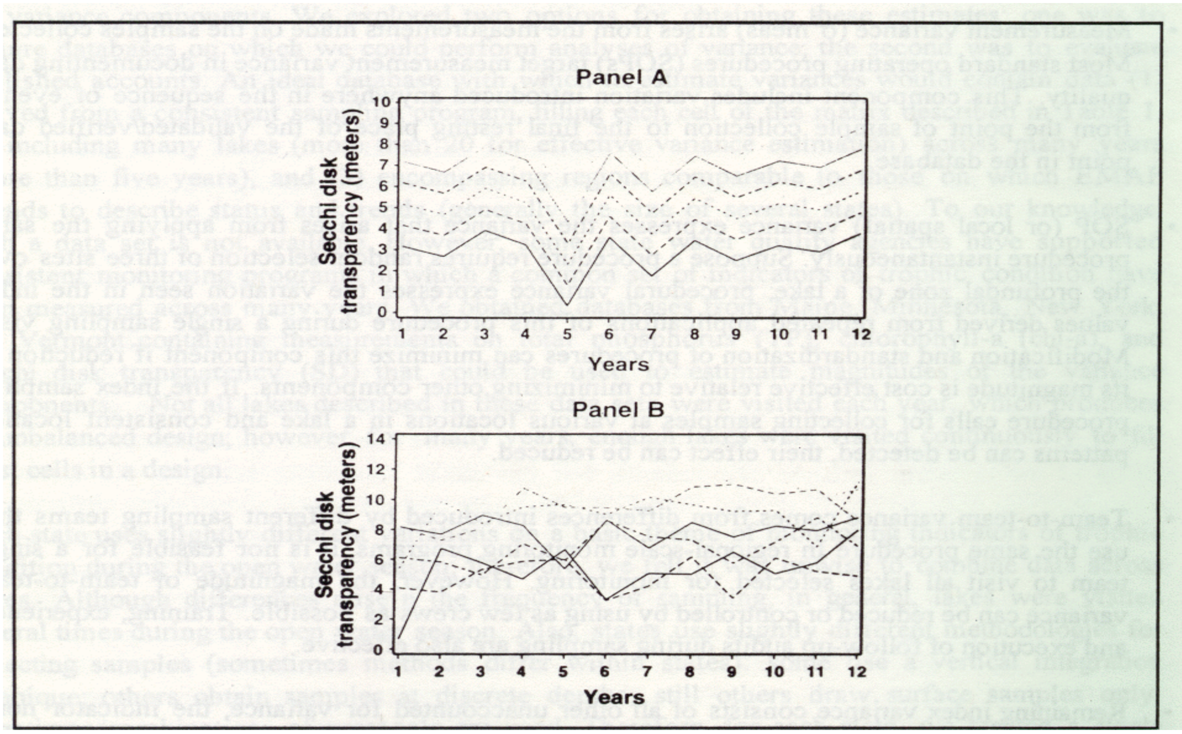


Figure 13. A hypothetical example of time series for Secchi transparency data in five different lakes; approximately 2 percent per year trend was imposed. This illustrates the concordant pattern if Year Variance is high (A) vs. the nonconcordant pattern if Interaction Variance is high (B). In Panel A, $\sigma^2_{year} = 2.25$, with $\sigma^2_{lake*year} = 0$; in panel B, $\sigma^2_{year} = 0$, with $\sigma^2_{lake*year} = 2.25$.

particular year are above or below a long-term central value or trend. This common pattern of variation among lakes is caused by regional-scale factors affecting the population in a consistent way, such as regional-scale climatological conditions (e.g., wet years or dry years). Magnuson et al. (1990) refer to this variance component as temporal coherence.

Resource-year Interaction ($\sigma^2_{lake*year}$) - interaction effects – The condition of an individual lake fluctuates from year to year around its central value or around a trend for that lake (Figure 13B). These fluctuations are responses to local effects operating at the individual lake level and are unrelated among lakes. This component of variance specifically describes that part of a lake's year-to-year variation not already accounted for by the year component. This interaction variance is a natural feature of the populations under study and could be of interest in itself as an indicator of stress or change in ecosystems. It can be estimated by repeat visits to lakes across years. However, if lakes are sampled each year without revisiting during the index period, the variance estimated from the year-to-year differences confounds two components of variance, $\sigma^2_{lake*year}$ and σ^2_{index} (described next). There is no way to separate these without revisiting multiple lakes for several years.

Index Variance (σ^2_{index}) - index effects - Index variance is the aggregate variation seen by repeated applications of a sampling protocol for the indicator of interest during the index period. Index variance can be broken down into several components that can be estimated, some of which are natural features. If index variation is unacceptably high it is worth evaluating the components of index variance to determine a strategy for minimizing its effect. A useful strategy is to estimate this by repeat visits during the index period and evaluate its magnitude relative to other variance components. If it is unacceptably high, then one should determine which of the subcomponents can be reduced. The following is a partial list of components of index variance that might be targets for reduction:

- Temporal (or seasonal) variance and trends within the index period describe the variation and consistent temporal patterns in the indicator of interest during the index period. Identification and characterization of variance and trends within the index period could allow removal of the effects by redefining the index period. For example, if sampling during the rainy season increases sample variance, then this would be a poor choice for an index period.

- Measurement variance arises from the measurements made on the samples collected. Most standard operating procedures (SOPs) target measurement variance in documenting data quality. This component includes variation introduced anywhere in the sequence of events, from the point of sample collection to the final resting place of the validated/verified data point in the database. This might include measurement error in reading the depth at which a sample was taken or a transcription error in recording the data.

- Procedural variance expresses the variance that arises from applying the same approach within a single sampling period. For example, if the index sampling procedure calls for collecting samples at various locations in a lake and consistent location patterns can be detected, then their effect can be reduced. Modification and standardization of procedures can minimize this component, if reduction in its magnitude is cost effective.

- Team-to-team variance comes from differences introduced by different sampling teams that use the same procedure. In regional-scale monitoring programs, it is not feasible for a single team to visit all lakes selected for monitoring. However, the magnitude of team-to-team variance can be reduced or controlled by using as few crews as possible. Training, experience, and execution of follow-up audits during sampling are also effective at reducing this variance component.

- Remaining index variance consists of all other unaccounted for variance (e.g., the indicator noise exhibited during the index period).

Neither $\sigma^2_{lake*year}$ nor σ^2_{year} are subject to reduction by methodological improvements, as might be possible with index variance. These components of variance are natural features of the ecosystems we study, and just as we characterize the condition of lakes, we must also characterize these components of variance. We must both estimate their magnitudes and evaluate the resulting influence on the precision of estimates for status and sensitivity in detecting trends. If these components are unacceptably high, the options for improving precision are to increase the number of lakes sampled ($\sigma^2_{lake*year}$) or the number of years of monitoring (σ^2_{year}), or to identify covariates that can be used to remove the effect of variance. We sometimes combine $\sigma^2_{lake*year}$ and σ^2_{index} as residual variance and use:

$$\sigma^2_{res} = \sigma^2_{lake*year} + \sigma^2_{index}$$

Estimates of Variance Components - Evaluating the potential sensitivity of monitoring designs, such as EMAP, requires estimates of the variance components. There are two options for obtaining these estimates. We can acquire databases on which to perform analyses of variance or use published accounts. An ideal database with which to estimate variances would contain data derived from a consistent sampling program, including many lakes (more than 20 for effective variance estimation) across many years (more than five years), and encompassing large regions (generally the size of several states). To our knowledge, such a data set is not available. However, some state water quality agencies have supported consistent monitoring programs in which a common set of indicators of trophic condition have been measured across many years. We obtained databases from Maine, Minnesota, New York, and Vermont containing measurements on total phosphorus (TP), chlorophyll-a (chl-a), and Secchi disk transparency (SD) that could be used to estimate magnitudes of the variance components.

Each of these states uses slightly different approaches to monitoring the trophic condition of lakes. Thus, it would be unwise to combine data across states. Differences arose in the frequency of sampling, but all lakes were visited several times during the open water season. The states were also using slightly different methodologies for collecting samples (sometimes methods differ even within states). However, we were able to create a single number representing each water column sample for each state.

These were the databases we used to isolate the components of variance pertinent to evaluating EMAP's trend detection capability. We selected a set of lakes for which data were available over many consecutive years (at least 4) and during periods corresponding to a July-August index period. From this we were able to estimate the variance components by the General Linear Model procedure (SAS, 1989).

Effect of Variance on Trend Detection - Trend is considered here as a consistent change in an ecological attribute over time. At the site-specific scale, this usually means the time series trajectory of the particular attribute (e.g., population mean).

Trend Detection Models - We use two models to show the effects of the variance components on trend detection. The first is a regression model based on simple linear regression techniques. The role of the variance components is explicit in this model. This can be used for a quick assessment of the effects of the different variance components, but the model leaves out some of the technical details. The second model is a more detailed description of the variance components that affect trend detection capability, including effects of temporal autocorrelation. It was initially used to evaluate several alternative monitoring designs for estimating population trends for EMAP-like designs (Urquhart et al. 1993).

Trend detection capability can be described in terms of the variance associated with the slope of a trend line, Var(β). Var(β) can be translated into a 95% confidence interval estimate, (approximately ±2 standard errors of the slope). Casting this as a null hypothesis, we can test whether the slope = 0. For the null hypothesis to be rejected, the slope must be greater than two times its standard error to be detected at $\alpha=0.05$. We could then be reasonably sure of detecting trends which are of greater magnitude.

The general strength of a trend is a function of the variance in the attribute under study and the measure of time. The ability to “see” the trend depends upon the magnitude of these two features (e.g., the greater the period of record the clearer the trend and the smaller the variance of the attribute around the trend line, the clearer the trend).

The variance of the slope is calculated as the ratio of these two components (e.g., Draper and Smith, 1981; Snedecor and Cochran, 1967):

$$\operatorname{var}(\beta) = \frac{\sigma^2}{\sum (X_i - \overline{X})^2} \qquad (1)$$

The numerator contains the variance of the attribute around the possible trend and the denominator contains a variance-like term associated with time (years). Fundamentally, the development of monitoring designs and their resultant sensitivity to trend detection depend on our ability to minimize the numerator and maximize the denominator.

This basic framework is useful for evaluating choices in designing monitoring systems and for focusing our efforts on important sources of variance over which we might have some control. Expansions of the numerator of Equation (1) show how the effects of different variance components (both natural and measurement error) can be accommodated or reduced. This framework is a useful approach for evaluating choices about allocating sampling effort.

Trend detection in a particular ecosystem attribute at a site across years requires one or more within-year measurements of the attribute taken across multiple years. Two general components of the attribute's variation are important: 1) the combination of within-year natural variability and measurement error ($\sigma^2_{\mathrm{index}}$) that produces variation around the central tendency for that year; and 2) the year-to-year differences in condition that might not be attributable to trend ($\sigma^2_{\mathrm{annual}}$). How well the yearly condition is specified depends on the magnitude of variation and the number of measurements. Even if we estimate the yearly condition variation, a trend could arise due to the year-to-year differences in condition. Equation (1) can be rewritten to incorporate these two components of variance in the numerator:

$$\mathrm{var}(\beta)=\frac{\sigma^2_{annual}+(\sigma^2_{index}/r)}{\sum(X_i-\overline{X})^2} \tag{2}$$

where r = # repeat visits/yr

Trend detection is a function of the magnitude of the two variance components in the numerator. From a design perspective, the effects of the index variance term can be reduced by increasing the number of measurements taken during the index period (r) or by improving measurement techniques (if measurement error accounts for a large part of this variance component). This increases the precision of estimating the yearly condition. Also, the gain in precision declines with increasing r. Not much can be done to control year-to-year variance in the absence of identifiable covariates. The only solution is to extend the monitoring record by waiting for more years to pass. Consequently, the limitations in our ability to improve trend detection capability can be quickly evaluated by using Equation (2) under different variance scenarios and lengths of record. Incremental improvement becomes more and more expensive as the required number of measurements increases.

Two additional components of variance are introduced when we consider multiple sites. One component merely expresses the true differences among the sample of sites (σ^2_{lake} - site-to-site variation). The second component is the common year-to-year variance exhibited by all sites in the sample (σ^2_{year}) (Figure 13A). The year-to-year term in Equation (2) is also altered to reflect the site*year interaction (the independent variation sites exhibit) and the nonconcordant year-to-year variation. Equation (2) now becomes:

$$Var(\beta)=\frac{\dfrac{\sigma^2_{lake}}{l}+\sigma^2_{year}+\left[\dfrac{\sigma^2_{lake*year}+\dfrac{\sigma^2_{index}}{r}}{l}\right]}{\sum(X_i-\overline{X})^2}$$

where l = # sites in the sample (3)

Equation (3) describes situations in which different sites are visited each year. The number of sites in the sample (l) improves the precision of estimating the yearly condition across sites. A large variance component is introduced by the site-to-site differences. The effect of this variance term disappears if the monitoring design includes site revisits across years. If we assume revisits across years is the basic format, Equation (3) reduces to:

$$Var(\beta)=\frac{\sigma^2_{year}+\left[\dfrac{\sigma^2_{lake*year}+\dfrac{\sigma^2_{index}}{r}}{l}\right]}{\sum(X_i-\overline{X})^2} \tag{4}$$

The variance component models described here can be used effectively to evaluate alternative design protocols and estimate the potential payoff of various alternative sampling allocations. Equation (4) is especially useful, since all the important features related to trend detection capability are clearly expressed in terms of variance components (sample allocation both within and among years and length of the interval over which trend is to be detected). More elaborate models can be used for refined exploration of alternatives after initial scoping with Equation (4). This is especially true for power calculations and for exploration of the effects of temporal and spatial autocorrelation.

Sensitivity of Trend Detection to Variance Components - Inspection of Equation (4) reveals the relative importance of year effects (σ^2_{year}) and residual effects (σ^2_{res} - within the brackets) for describing the potential sensitivity of designs, such as EMAP's, for trend detection. The effect of σ^2_{year} is sensitive to the length of the monitoring interval (i.e., denominator of Equation 4), but not to the number of lakes visited or the number of revisits. Thus, it places a fundamental limit on trend detection capability that cannot be altered by the numbers of lakes visited or the number of revisits. Its effect can only be accommodated by extending the period of record. If its magnitude is large relative to σ^2_{res} expending additional effort minimizing the effect of σ^2_{res} yields little.

On the other hand, if σ^2_{res} is large relative to year effects, there are several options for increasing trend detection sensitivity. One is to evaluate the components of variance comprising σ^2_{index} to determine the extent to which methodological improvements will decrease its magnitude as this is the only variance component subject to methodological improvements. Methods evaluation should always be a routine part of any QA program, oriented toward cost-effective variance reduction. Training, improved analytical techniques, and refined sampling protocols all can contribute to reduction of σ^2_{index}.

Another option is to evaluate the allocation of lake visits. Both revisits to lakes during the index period and visits to additional lakes can improve trend detection capability. Revisits to lakes (r) reduces only σ^2_{index} and its influence on trend detection. Adding additional lakes reduces the effect of both σ^2_{index} and $\sigma^2_{lake*year}$. Therefore, when resources are fixed, sampling additional lakes rather than revisiting lakes is always an improvement (or equal, if $\sigma^2_{lake*year} = 0$). The amount of benefit derived from adding lakes to the sample is related to the relative magnitude of $\sigma^2_{lake*year} \div \sigma^2_{index}$, where the larger the ratio, the greater the benefit of adding lakes. However, if all lakes in a population or subpopulation can be monitored in a year, then additional resources should go toward revisits.

These concepts of a variance component framework and the estimates of these components, from the literature and our own sampling, have allowed us to begin rigorously evaluating design options for surveys. Urquhart et al. (1998) have taken the lake variance estimates for indicators like Secchi transparency, chlorophyll a, total phosphorous and zooplankton species richness and applied them to the common design options which have been used or proposed by various groups (see Figure 14). Using the estimates of these lake variance components, we then evaluated the power of these design options to detect trends over time. All of the designs with an element of repeat visits (designs 1, 3, or 4) have similar power to detect a 1-2% trend (Figure 15). Only design 2 which visits completely different systems every year stands out as a poor option. We also examined how they functioned with different levels of σ^2_{year} (this has the largest impact on trend detection, Figure 16). It is clear from this analysis that decreasing σ^2_{year} can have a dramatic effect on power for detecting trends.

Given that one of the competing objectives of monitoring is also status estimation, we felt it was important to also compare designs for this. We used the standard error (SE) of the estimated status as a comparison among designs (Figure 17). In this instance, a higher SE indicates a less precise estimation of status. Design 1, which revisits the same sites every year, has a significantly poorer ability to estimate status compared with the designs which visit a larger number of different sites. The other three designs converge on one another over time. When balancing the need for status and trend estimation, it appears that either design option 3 or 4 are preferable to design options 1 and 2.

Our other application of this framework is to compare indicators for their ability to detect trends. Secchi transparency is quite good for detecting trends, but the zooplankton species richness, which many would consider too variable, also reaches a similar power after only a few additional years (Figure 18). The variance component estimates were derived from EMAP and State data for northeastern lakes. These types of analyses allow us to compare different indicators, and if necessary, choose among them.

Panel	Size	TIME PERIODS (= YEARS)												
		1	2	3	4	5	6	7	8	9	10	11	12	…
DESIGN 1 = SAME SITES (e.g., lakes) EACH YEAR														
1	60	X	X	X	X	X	X	X	X	X	X	X	X	…
DESIGN 2 = NEW SITES EACH YEAR														
1	60	X												
2	60		X											
3	60			X										
4	60				X									
5	60					X								
6	60						X							
7	60							X						
8	60								X					
9	60									X				
10	60										X			
11	60											X		
12	60												X	
…	…													…

PANEL	SIZE	TIME PERIODS (= YEARS)												
		1	2	3	4	5	6	7	8	9	10	11	12	…
DESIGN 3 = AUGMENTED SERIALLY ALTERNATING														
1	50	X				X				X				
2	50		X				X				X			
3	50			X				X				X		
4	50				X				X				X	
Common	10	X	X	X	X	X	X	X	X	X	X	X	X	…
DESIGN 4 = PARTIALLY AUGMENTED SERIALLY ALTERNATING														
1	35	X				X				X				…
2	35		X				X				X			…
3	35			X				X				X		…
4	40				X				X				X	…
1A	5	X	X			X				X				…
2A	5		X	X			X				X			…
…	…													…
1B	5	X				X	X			X				…
…	…													…
1C	5	X				X				X	X			…

Figure 14. Design options considered for evaluation. 1. same sites visited every year, 2. different sites visited every year, 3. rotating panel with 4 different sets of sites in each of 4 years and then revisiting them plus a constant set visited each year, and 4. a more complex variation of design 3.

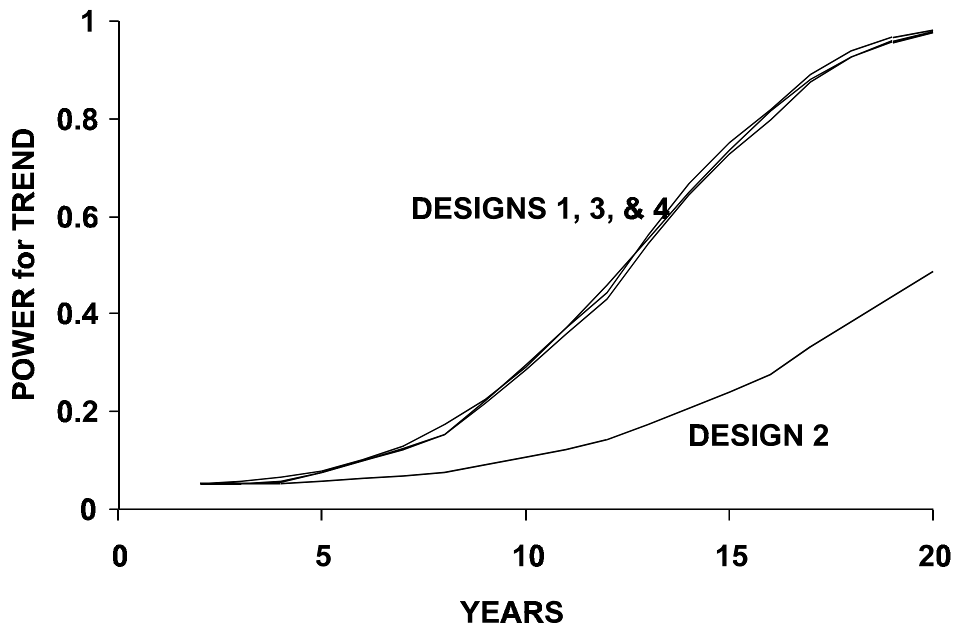


Figure 15. Power for detecting trends using the four design options. It is clear that designs with repeat sampling have significantly greater ability to detect trends.

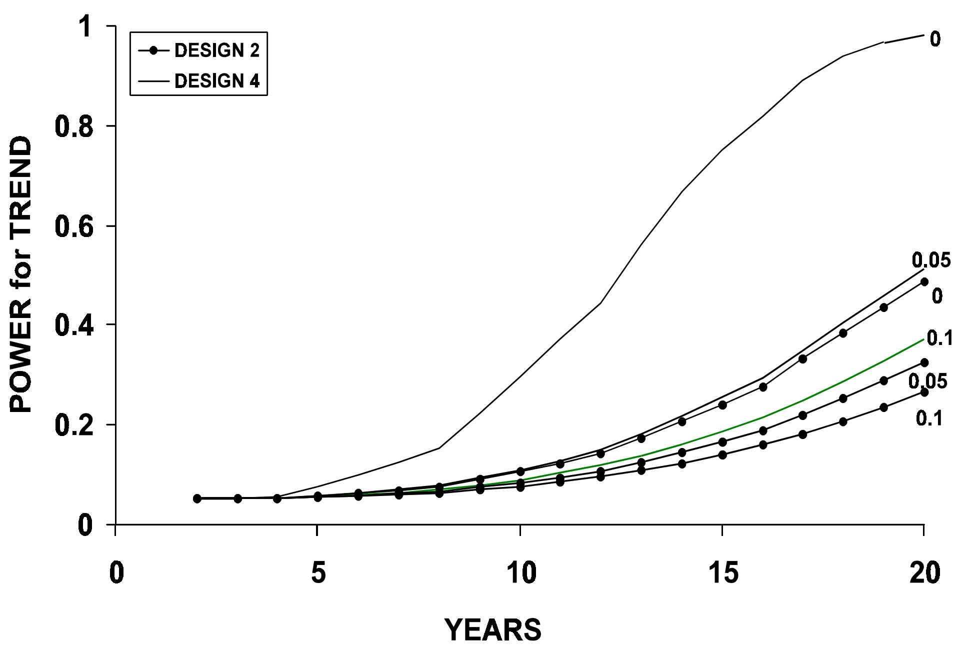


Figure 16. Power for trend detection with varying levels of σ^2_{year}.

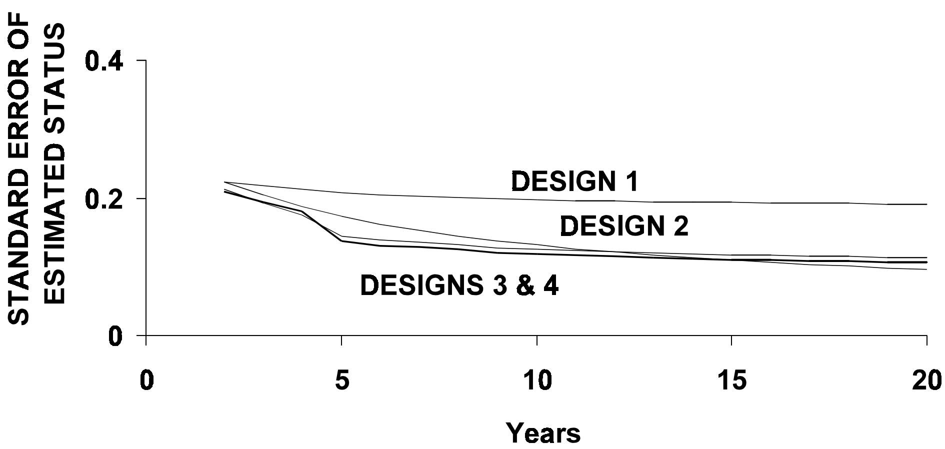
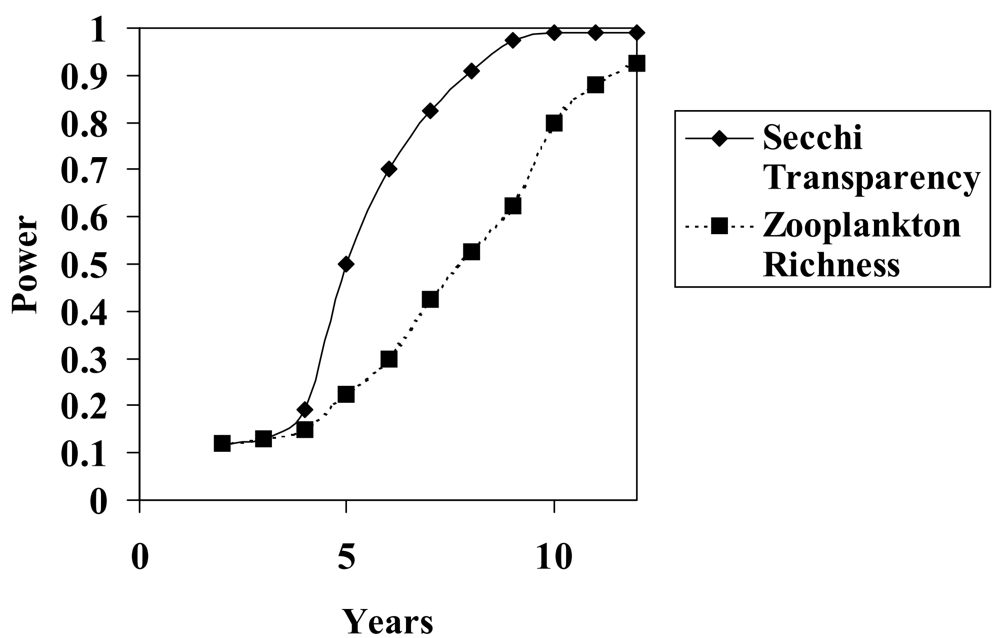


Figure 17. Standard error of estimated status compared among designs. Design 1 is significantly poorer than the other 3 options.

Figure 18. The power to detect a 2% peryear trend in Secchi transparency and zooplankton species



richness with a sample size of 50 lakes per year. Data were generated from the 1991-1994 EMAP lakes study in New England.

APPENDIX V. Index Sites

National Park Intensive Monitoring Network (PRIMENet) - The National Park system provides the potential coverage of all terrestrial ecosystem types, and many of the goals and objectives of their Inventory & Monitoring (I&M) Program are similar to those of EMAP. The National Park Service (through their Air Monitoring Division and their Inventory and Monitoring Program) co-developed a 14 site terrestrial intensive monitoring/research network with EMAP. Both agencies contributed funds and efforts toward this development. Other federal agencies have been invited to participate in the longer term. In 1996, EPA and NPS created a formal interagency agreement to create the Demonstration of Intensive Sites Project (now PRIMENet - Park Research and Intensive Monitoring of Ecosystems Network). This inter-agency effort between EPA/ORD and DOI/NPS selected 14 parks in a demonstration of an intensive site network of monitoring and research at locations across the United States (see http://www.epa.gov/uvnet). All 14 parks are readily accessible, have a history of environmental monitoring, and represent a broad and sometimes unique spectrum of ecological communities. Through this network, EMAP and the Park Service are using park sites for monitoring of global-scale environmental stressors (e.g., air deposition) and locale-specific stressors (e.g., water-borne contaminants), and to coordinate with cause-effect research related to these environmental stressors. The intent was to initiate a consistent air monitoring program at each site followed by consistent monitoring within other media.

Effects research was based on known stressors at the sites. For example, at the Everglades site we have: examined the flux of materials and nutrients from Everglades canals into Florida Bay; examined the role of humic materials in the complexation and transport of mercury through the canals; investigated the effects of increased nitrogen and phosphorus from the canals on primary and secondary productivity in Florida Bay; and investigated the cause of black band disease in corals in the Florida Keys National Marine Sanctuary. At the Great Smoky Mountain site, opportunities existed to validate forest stand/ozone models using new forest micro-meteorological and dosimetry equipment, and to initiate mechanistic studies of atmospheric nitrogen deposition effects on watersheds, expanding on similar studies at the Sequoia, Acadia, and Rocky Mountain sites. EPA also proposed extramural and/or cooperative research (with other CENR-member agencies) to examine the effects of increased UV-B exposure: on the reproductive success of amphibians and reptiles (Big Bend, Everglades, Sequoia); on coral community structure (Virgin Islands); and on plankton community structure and productivity (Everglades, Virgin Islands).

With the interagency agreement in place, EPA and NPS developed a management structure for the PRIMENet network to determine the monitoring and research needs at the sites and across the sites, and management of the information to come from these sites. In late 1996, EPA and NPS initiated the PRIMENet Oversight Committee with membership from both agencies, including EPA's Offices of Air and Water.

The Oversight Committee created 14 site committees, one at each National Park, to establish the monitoring and research needs at each site. Each of these committees is comprised of three to five members representing the park, academic researchers involved in park research, and an EPA Regional representative, when possible. Each committee developed a prioritized list of monitoring and research needs for their site to characterize the long-term exposure of parklands to the various environmental stressors. These stressors do not include human use of the parklands and its facilities as a public land.

The initial phases of PRIMENet focused on augmenting monitoring of stressors via atmospheric pathways. However, the intent is to include additional monitoring indicators and issue-based effects research at the NPS sites. To do this, the partners and cooperators have worked together to establish research and monitoring plans for the 14 intensive sites. The cooperating agencies formed the Joint Intensive Monitoring Committee and Joint Effects Research Committee to guide these studies. The Joint Intensive Monitoring Committee will coordinate all new monitoring, such as atmospheric nitrogen deposition or water quality monitoring. In addition, the Joint Effects Research Committee will develop and implement cause-effect research programs at appropriate sites to provide additional index sites.

Specific implementation activities included: NPS establishing UV-B monitoring at 14 sites; setting up support infrastructure in the parks, implementing quality assurance/quality control procedures, developing a data management system, and organizing reporting methods. EPA provided UV-B sensors for each site, and statistical analysis and support for the network. EPA provides for information management and the long-term storage of data. In addition, EPA supports both intramural and extramural research at several of the proposed sites that will increase the value of long-term records at these sites (e.g., ecosystem process research on mercury and nutrient stress in the Everglades (South Florida), and a variety of process research in the Big Bend, Great Smoky Mountains, Virgin Islands, and Sequoia sites.

APPENDIX VI. Mid-Atlantic Integrated Assessment (MAIA)

The first regional scale geographic study in EMAP was conducted in the mid-Atlantic area (EMAP's Mid-Atlantic Integrated Assessment). 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 (Figure 19). 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.

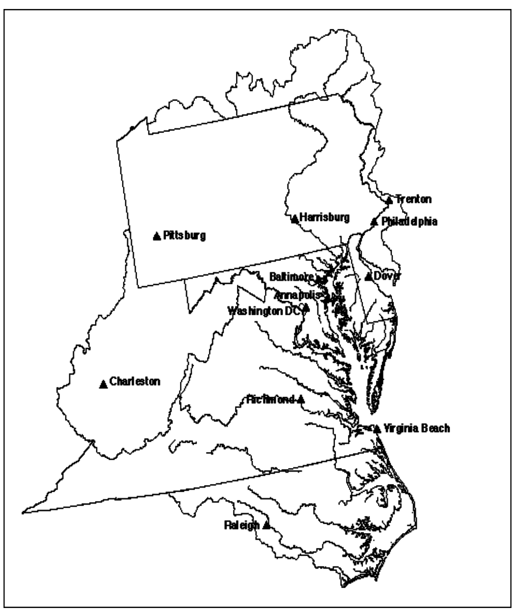


Figure 19. Geographic scope of MAIA.

The assessment activities within MAIA focused first on single resource assessments and subsequently have begun to focus on integrated assessments across multiple resources. The assessments were based on the measurement of ecological condition and the major stressors associated with impaired condition in the region using a probabilistic monitoring design. EMAP stressor indicators cannot determine cause and effect, but can provide weight-of-evidence for the relative magnitude of the various stressors impacting that resource. (See EPA reports: An Ecological Assessment of the United States Mid-Atlantic Region, EPA/600/R-97/130: Condition of the Mid-Atlantic Estuaries, EPA 600-R-98-147; Condition of the Streams of the Mid-Atlantic Highlands, EPA/903/R-00/015).

Estuaries - EMAP conducted surveys of the estuarine resources within the Virginian Province, which includes the area designated as MAIA between 1990-1993. The results of that effort (Strobel et al. 1995) have been combined with those from other agencies and programs in our Condition of the Mid-Atlantic Estuaries Report (EPA600-R-98-147). This report included:

- integrated EMAP surveys, and Chesapeake Bay and Delaware Bay Programs;
- common indicators and common designs, to offer better coverage and comparability for MAIA estuaries;
- multiple indicators of biological resource condition to improve the assessment of the condition of the estuaries;
- the need for additional stressor indicators, especially for eutrophication.

The other primary partners in MAIA's estuarine research were: EPA Region III, Chesapeake Bay Program, Delaware Bay Program, National Oceanic and Atmospheric Administration, Delaware, Maryland, Virginia, and North Carolina.

The EMAP study of the Virginian Province considered estuaries an extensive resource (Stevens 1994) and used an appropriate probability-based sample survey design. The survey considered three strata based on the subpopulations of interest, large estuaries (> 260 km^2), small estuaries (2.6 - 260 km^2) and large tidal rivers (> 260 km^2) (Figure 20).

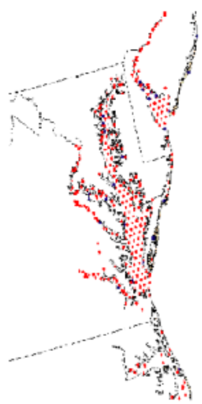


Figure 20. EMAP estuarine sampling locations in MAIA, 1990-1993. Sampling in 1997-1998 was modified to improve coverage of smaller estuaries and link with efforts on larger systems, such as Chesapeake and Delaware Bays.

In MAIA we worked with our partners to collectively arrive at a design which met multiple objectives. However, the probability basis for the design was fundamental. Sampling locations and site selection criteria were used to allow as many existing state sampling sites to be included and aggregated for quantitative regional statements as possible. Where significant gaps existed, we added sampling to fill the gap. For example, it was necessary to increase the coverage to adequately describe the Virginia, Delaware and Del Marva Coastal Bays. While the coastal bays did not constitute a large percentage of the estuarine area, they are an important resource which had not been adequately described previously.

Wadeable Streams - Hydrologic alterations in MAIA have resulted from a variety of human activities and primarily impact the timing, amount and path of water flow. Physical habitat alterations have become a concern more recently and include changes in habitat complexity, substrate size and embeddedness, bank stability, and riparian vegetation. Biological alterations have often been overlooked by water quality agencies as a potential source of problems in streams. These biological alterations include introduction of plants and animals, exotic species, and management practices, such as stocking and harvesting. MAIA provided an opportunity for EMAP to examine these issues on a broad regional scale.

The objectives for the wadeable streams portion of MAIA were to:

- Estimate the total miles of wadeable streams;
- Determine the condition of wadeable streams;
- Establish factors associated with poor conditions in these streams;
- Demonstrate the EMAP approach for regional and subregional scale monitoring of wadeable streams;
- Demonstrate the use of biocriteria, ecoregions, watersheds, and probability surveys to address environmental issues within a region; and
- Develop the baseline for future change and trend comparisons for wadeable streams.

We used a probabilistic sampling survey to characterize the wadeable streams of the mid-Atlantic. To ensure characterization of the stream reaches in the region it was necessary to classify streams on the basis of their size, using stream order as a size surrogate. Stream order is relatively easy to calculate for all stream segments. Any metric used as a size surrogate must be calculated for all segments or it cannot be used. This precluded other size surrogates (watershed area, discharge, stream width) which may have been better indicators of stream size, because of the difficulty in defining them for the entire population.

The survey sample for wadeable stream systems for 1997 is shown in Figure 21.

In MAIA we also linked our EMAP sample survey data with data from the more deterministic, temporally intensive effort of the USGS National Water Quality Assessment Program (NAWQA, Hirsch et al. 1988). Through this joint effort we are evaluating the links between our regional data and the data from USGS index sites. Conceptual and empirical models are being developed to describe links between spatial and temporal bio/physical/ chemical data. From these models we should be able to assess the "representativeness" of the "index" monitoring sites within NAWQA. The models should also allow us to spatially interpret the loading models developed at NAWQA study sites. The linkage between EMAP sample survey information and NAWQA temporal information, will allow EMAP to include seasonal variability in its assessments of condition and will provide NAWQA with greater spatial capability for more regional level assessments. Our studies began in three basins of the Mid-Atlantic Highlands, the Potomac, Susquehanna, and James river basins (Figure 22), and are reported in Mid-Atlantic Highlands Streams Assessment (US EPA 2000).

The information generated in MAIA has helped identify areas of concern and suggest high priority stressors. In addition, the study provided baseline information for comparing ecological condition of wadeable streams throughout the mid-Atlantic region. (e.g., Mid-Atlantic Highland Streams Assessment , EPA/903/R-00/015). With continued monitoring through time, the States (i.e., Delaware, Maryland, New York, North Carolina, Pennsylvania, Virginia, and West Virginia) and federal agencies (e.g., USEPA, USGS) will have critical information on change, and then trends, in the condition of these Mid-Atlantic streams. Quantitative estimates of change (and trends) would provide a measure of the efficacy of state and federal environmental programs and policies in reducing current environmental problems.

Landscapes - In MAIA we used measurements derived from satellite imagery to develop a land cover map for the Mid-Atlantic (Figure 22). This, combined with spatial data bases on biophysical features (e.g., soils, elevation, human population patterns), were used to produce an ecological assessment of the impact of changing landscape conditions. Using fine-scale spatial resolution (e.g., 30-90 meters) to census MAIA, we were able to analyze and interpret environmental conditions of the 125 watersheds in the mid-Atlantic region based on 33 landscape indicators. The results of this study were published in the report An Ecological Assessment of the United States Mid-Atlantic Region (EPA/600/R-97/130). This report included:

- spatial patterns of agriculture and urban lands;
- proportions of forests, forest connectivity, and forests near streams (riparian zones);
- Condition estimates for watersheds; and
- watershed conditions around major metropolitan areas.

We are currently conducting multiple watershed studies to determine quantitative relationships between landscape metrics (e.g., riparian forest, interior forest, and agricultural land cover) and in-stream variables (e.g., stream total nitrogen concentration, benthic invertebrate community condition). From this, we will be able to interpret the hydrological and ecological meaning of landscape metrics relative to aquatic resource condition.

EMAP Integration in MAIA - EMAP is continuing intramural work in MAIA to develop better approaches to integrating the various estuarine, stream and landscape condition estimates into an integrated assessment of the overall environmental condition. This work is being done in conjunction with all of ORD's Laboratories' and Centers' ecology programs to develop better techniques for assessing: overall environmental condition, environmental risks and their trade-offs, and ultimately, restoration and protection foci.

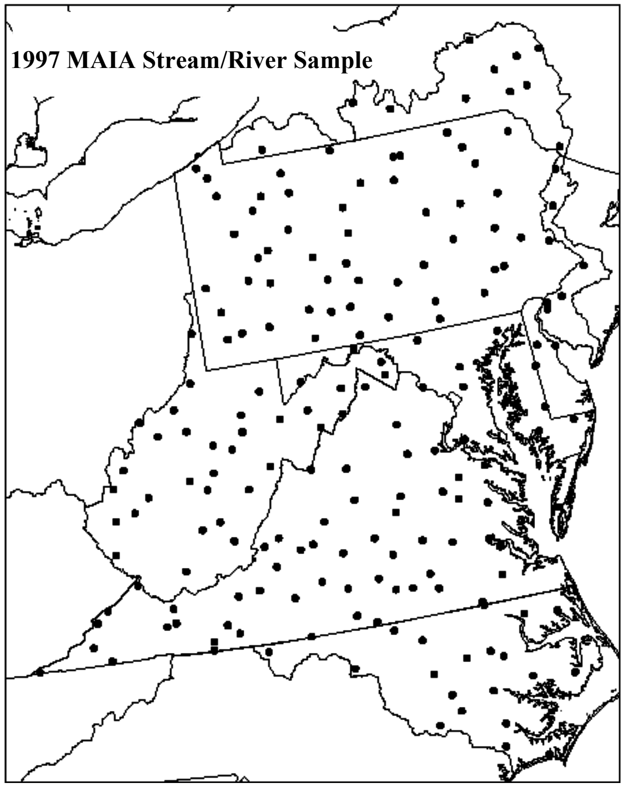


Figure 21. The 1997 stream/river probability sample sites. An additional set of ~200 sites was sampled in 1999.

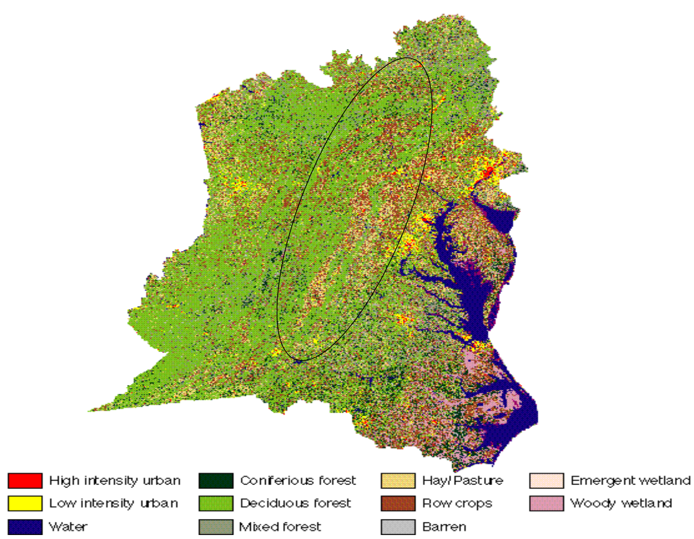


Figure 22. Mid-Atlantic land cover map. The Highlands region (in the oval) served as the initial study area for our joint USGS-EPA streams monitoring.

Appendix VII. Regional Environmental Monitoring and Assessment Program (R-EMAP)

The Regional Environmental Monitoring and Assessment Program (R-EMAP) is a partnership between the EPA Regional Offices and ORD's EMAP for improving monitoring as a tool for regional decision makers and resource managers. The goals for R-EMAP are to transfer EMAP's latest scientific techniques for ecological monitoring to EPA Regions, States, Tribes, and local decision-makers. EMAP works with the EPA Regional Offices to identify and support projects meeting our criteria, and of importance to the Regions. R-EMAP provides numerous smaller scale ecological monitoring opportunities across wide the biogeographic and political boundaries of the EPA Regions, and complements our larger geographic assessments. R-EMAP projects also provide initial opportunities to develop and test indicators across the nation.

EMAP support for these projects includes: contributing to development of the scientific design of the projects; selection and evaluation of appropriate indicators and methods for measurement; application of information management approaches; analysis and interpretation of data; and providing a source of funding. It is expected that the organizations involved with EPA's Regions and EMAP could include States, Tribes, local governments, and academic institutions. Because much of the research will use approaches and techniques that have not been traditionally employed by monitoring programs, ORD's experience and expertise in these new techniques will often be required to fully develop the proposals. This is consistent with R-EMAP's goal of transferring these new techniques into Regional, State, Tribal, and local decision-making.

EPA Regions submit pre-proposals to the ORD R-EMAP Work Group for possible funding. The R-EMAP Work Group selects pre-proposals for which full proposals will be requested. Each of the selected proposals is adopted by one of ORD's Ecological Divisions. These Divisions assume responsibility for helping in the development of a high quality full proposal. Each R-EMAP full proposal undergoes a rigorous external peer review, prior to any funding decisions. The R-EMAP projects undertaken and proposed can be viewed on the R-EMAP website: http://nraxp.nar.epa.gov/emap/html/remap/).

Example of Recent R-EMAP Results - In 1994 the State of Nebraska (Region VII), started using a 5-yr rotating basin design for its ambient surface water monitoring program (a basin level monitoring that is rotated to different basins in subsequent years, such that all major river basins in the state are monitored after a period of 5 years). This rotating basin framework worked from an organizational standpoint, but the state realized it was negatively biasing its sampling by targeting its monitoring to waters with suspected problems. With targeted monitoring, it was impossible for the state to make an unbiased estimate of the status and trends in condition of its streams. As a result the state's assessment of waters meeting designated use ("305(b) Report") tended to show a disproportionately large percentage of the state's monitored waters with water quality problems.

In 1997, the state decided to try an EMAP approach within its rotating basin assessment through R-EMAP. Using an EMAP sampling design, random stream segments were selected within the basins of interest (Figure 23). The random selection of stream segments permitted unbiased estimates of conditon of the stream resources with known confidence intervals (Figure 24). Using water quality information from this R-EMAP study with data from a previous R-EMAP project (Region VII, 1994-

1995), the state was able to detect a significant trend towards improved water clarity in the river basins sampled (Figure 25).We will continue to work with the Regions in the development new R-EMAP projects. Pre-proposals for projects for funding in 2000 include:

1. Region 1. Condition of New England's Wadeable Streams.

2. Region 2. NY/NJ Harbor Study, Cohansey-Maurice Watershed Assessment, and an Environmental Assessment of Barnegat Bay, NJ.

3. Region 3. Watershed-based Design frame for estimating Biotic Integrity of West Virginia Streams.

4. Region 4. Everglades Ecosystem Assessment and Condition of Southeastern Wadeable Streams.

5. Region 5. An Ecological Assessment of Invasive and Aggressive Plant Species in Coastal Wetlands of the Laurentian Great Lakes.

6. Region 7. A Probabilistic Survey of Iowa Stream Resources and Probability-based Monitoring Design within Missouri's Statewide Resource Assessment and Monitoring Program.

7. Region 8, 9, & 10. Development of Reference Conditions and Use of Intensification Sites in the EMAP Western Pilot Design.

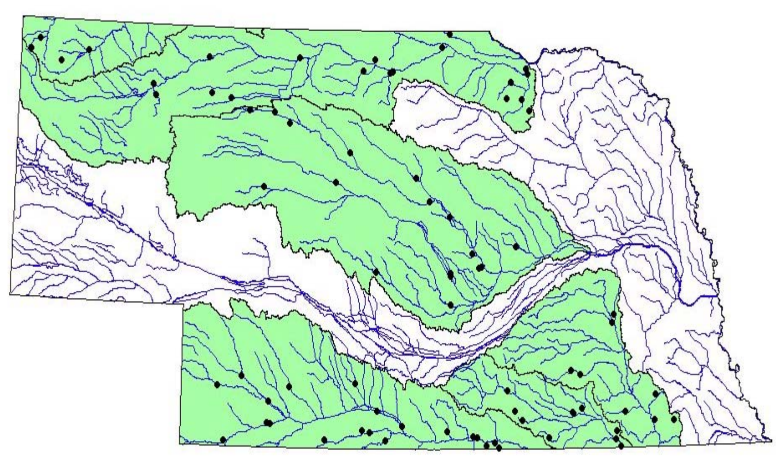


Figure 23. Distribution of probability-based stream sample sites on the Big/Little Blue, Loup, Niobrara, Republican and White-Hat River Basins in Nebraska in 1997-1998.

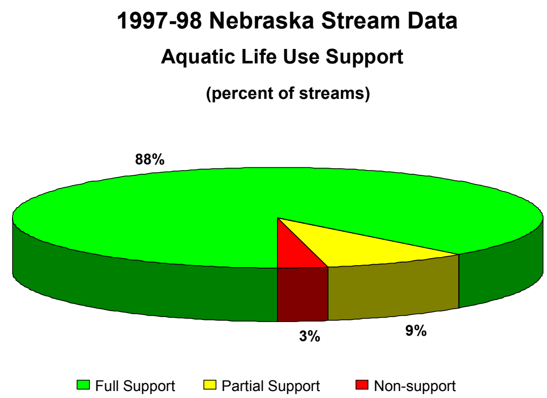


Figure 24. Percentages of Nebraska streams in the Big Blue, Loup, Niobrara, Republican and White river basins supporting aquatic life use. These percentagesare based on a draft IBI. All estimates are at the 90% confidence level and are +/- 10%.

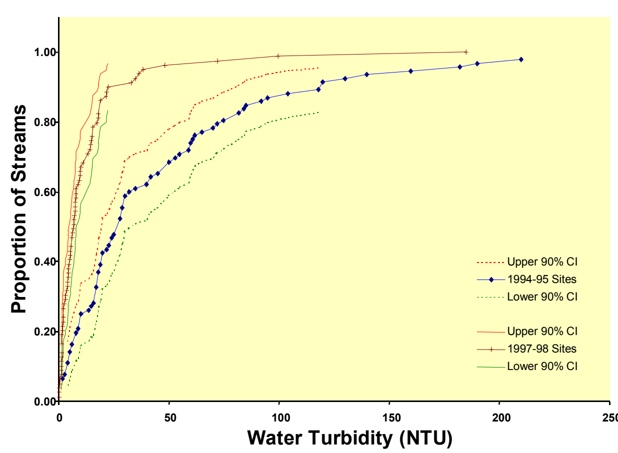


Figure 25. CDFs and confidence boundaries showing a statistically significant improvement in water clarity from the 1994-95 to 1997-98 sampling seasons for the Big Blue, Republican, Loup, Niobrara and White river basins.

APPENDIX VIII. Information Management

Compiling, maintaining, and distributing the data from EMAP has presented unique issues. The information superhighway has stimulated new information management possibilities as well as general appreciation for the need to coordinate data and network standards. Early EMAP work supported an information management program that anticipated the expanding use of the Internet. The program developed much of the software for linking EMAP to the Internet. The Information Management Workgroup was established to maintain our data infrastructure and place a priority on making the early EMAP field data available in electronic format for analysis. The information management priorities for EMAP (see Hale et al. 1999 for details) are: to make all the data electronically available; to provide linkages or flags to useful external data sets (as identified by the EMAP researchers); to inventory environmental monitoring data in the various management programs in our study regions and elsewhere (an extensive, interactive inventory has been developed for MAIA (Jackson and Gant 1998, WWW.epa.gov/monitor); and provide data interpretation templates for end users.

EMAP Data Directory - The EMAP Data Directory is the primary means for users to find out what EMAP data are available and where the data files can be found. It contains all EMAP and MAIA data set information. The EMAP Data Directory is based on the NASA Directory Interchange Format (DIF), and is now FGDC (Federal Geographic Data Committee) compliant.

Not all groups who will be making Directory entries have access to Oracle. Thus, we will use templates, including Web tools, to help in acquiring this information easily.

EMAP Data Catalog - EMAP policy states that Data Catalog files must accompany all data files. Therefore, no data files will be moved to the public access EMAP home page without the metadata files. This requirement allows us to provide information about the data files so that the data can be correctly interpreted and used. Also, we are then interoperable with other federal agency data catalogs (FGDC standards). The Data Catalog is maintained with a WordPerfect template and converted to HTML for the EMAP home page.

EMAP World Wide Web Site - Primary objectives of the EMAP home page (http://www.epa.gov/emap/) are to provide information about the EMAP program, and to allow access to the Directory of EMAP data sets, the metadata files, and the EMAP data sets. Links are provided from the EMAP home page to other appropriate home pages (e.g., Global Change Master Directory, STORET, NAWQA, and the Chesapeake Bay Program).

EMAP home page contents include:

- Data Directory (HTML)
- Data and metadata files (ASCII, SAS, Oracle)
- Publications (WordPerfect, RTF, PDF)
- List of contacts (HTML)
- EMAP Bibliography (HTML)
- EMAP Information: EMAP Research

Strategy, EMAP Information Management Plan, EMAP Updates (WordPerfect, RTP, PDF, ASCII summaries)

- Links to other environmental monitoring research sites (HTML)

- Geographic Reference Database for GIS coverages or links to the OEI (EPA's Office of Environmental Information) GIS library and the EROS Data Center

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A future focus of EMAP's WWW site will be to develop and provide the necessary algorithms for key data analysis. This will allow agencies and the public to routinely use EMAP data to answer questions. As the public and their management agencies become increasingly sophisticated this will become a greater component of EMAP Information Management.

EMAP Data Links - Two other EPA information management systems are directly linked to EMAP. These are the Office of Water's STORET and ORD's Environmental Information Management System (EIMS).

STORET - EPA Regions and many state agencies operate local copies of the STORET Oracle database that they use to house regional and local data. States will soon be able to choose to load their EMAP data into STORET. As STORET has been undergoing a recent revision, EMAP and STORET information managers have been working closely to enhance STORET's capabilities to store EMAP indicator and probabilistic survey data. This should be completed soon, and will allow EMAP data to be stored and accessed directly through EPA's STORET system.

EIMS - In ORD the EIMS stores information about ORD (and other) data (e.g., what data exist, where they can be found, etc.). The EMAP Data Directory is periodically uploaded to the EIMS. EIMS makes the existence of EMAP data sets more widely known. EIMS is also available to use as a directory for the myriad of non-EMAP data used in our geographic assessments. Any EPA Region, state, or ORD laboratory can make EIMS directory entries for these external (non-EMAP) data sets and have them labeled as part of the larger study. The linkage between EMAP and EIMS is ongoing.

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