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Great Lakes Monitoring and Research Strategy

Environmental Monitoring and Assessment Program

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ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM (EMAP) GREAT LAKES MONITORING AND RESEARCH STRATEGY

Environmental Research Laboratory
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EMAP-GREAT LAKES MONITORING
AND RESEARCH STRATEGY

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1. Introduction

1.1. Content and Organization of Research Strategy

The research strategy for the Great Lakes component of the Environmental Monitoring and Assessment Program (EMAP) is organized into ten chapters. A general introduction to the EMAP - Great Lakes (EMAP - GL) research strategy components, their focus and objectives, followed by a summary of the approach for meeting each of these objectives, is described in this chapter. Each successive chapter provides additional levels of detail about specific aspects of the approach such as design, indicators, or information management, ending with planned 1992 field activities. The sections of the research strategy are:

- Chapter 1. Introduction - provides a general introduction to the focus and objectives of subsequent chapters;
- Chapter 2. Overview of Approach - provides an overview of all aspects of EMAP - GL;
- Chapter 3. Monitoring Network and Field Sampling Design - contains a detailed description of the sampling design and site selection;
- Chapter 4. Indicator Development and Evaluation - discusses selection of indicators, their intended use, and the process of continual improvement in achieving descriptions of ecological condition for the Great Lakes;
- Chapter 5. Estimation and Analysis - describes the proposed procedures for the estimation and analysis of the current status, extent, changes, and trends in the condition of the Great Lakes;
- Chapter 6. Logistics Approach - outlines issues related to conducting a field program;
- Chapter 7. Quality Assurance Program - provides the approach and procedures for ensuring that the quality of the data collected meets program objectives;
- Chapter 8. Information Management - describes data management procedures;
- Chapter 9. Coordination - explains the approach for integration of information within EMAP - GL, with other components of EMAP, and with programs outside of EMAP;

- Chapter 10. Fiscal Year 1992 Field and Analysis Activities - outlines the specific objectives for the field activities and data analysis activities that have been planned;

- Appendix A. Glossary of EMAP Terms - provides standard definitions for terminology specific to EMAP - GL and the EMAP program; and

- Appendix B. Indicator Fact Sheets - provides further detail and references for the indicators examined for use in EMAP - GL.

1.2. An Overview of EMAP

Both the incidence and scale of reported environmental problems have changed over the past two decades. The public is increasingly concerned that the resources upon which they rely for recreation, quality of life, and economic livelihood remain sustainable. Scientists are increasingly concerned that the impact of pollutants now extends well beyond the local scale: global climate change, acidic deposition, deposition of air toxics, ozone depletion, nonpoint source pollutant and sediment discharges to waterways, and habitat alteration threaten our ecosystems on regional and global scales. Unfortunately, the current status of our environment on regional and global scales is often not well documented. While we believe that our policies and programs are improving the quality of our environment, we often cannot demonstrate improvement with available data.

In 1988, the US Environmental Protection Agency's (EPA) Science Advisory Board recommended implementation of a program within the EPA to monitor ecological status and trends, and to develop innovative methods for anticipating emerging environmental problems before they reach crisis proportions. The Environmental Monitoring and Assessment Program (EMAP) is part of the EPA Office of Research and Development's response to the Science Advisory Board's recommendation. To meet this need, EMAP was developed around the following objectives:

- estimate current status, extent, changes, and trends in indicators of the condition of the nation's ecological resources on a regional basis with known confidence;

- monitor indicators of pollutant exposure and habitat condition, and seek associations between human-induced stresses and ecological condition; and

- provide annual statistical summaries and periodic interpretive reports on ecological status and trends to resource managers and the public.

These objectives pose a challenge that cannot be met without a commitment to environmental monitoring, research, and assessment on long-term regional and national scales. Furthermore, this challenge cannot be met efficiently without drawing on the experience and expertise within other organizations that share responsibility for maintaining environmental quality or sustaining our resources.

EMAP is designed around six primary activities:

- strategic evaluation, testing, and development of indicators of ecological condition, pollutant exposure, and habitat condition; and protocols for collecting data on these indicators;
- design and evaluation of a comprehensive and versatile integrated monitoring framework;
- nationwide characterization of the extent and location of ecological resources;
- demonstration studies and implementation of integrated sampling designs;
- development of data handling and quality assurance, as well as spatial analysis and statistical procedures for efficient analysis and reporting on status and trends data; and
- assessments of the probable causes of environmental conditions and trends.

To facilitate monitoring of the condition of the nation's ecological resources, the program has been organized into seven basic resource groups: lakes and streams, inland and coastal wetlands, forests, agroecosystems, estuaries, arid lands, and the Great Lakes. In addition, there are groups responsible for coordination of indicators, statistical design and analyses, landscape characterization, integration and assessment, quality assurance, information management, geographical information systems, and logistics. The Great Lakes resource group is the newest resource group of EMAP, with planning initiated in 1990.

1.3. Legislative Mandate for Great Lakes Protection

The Great Lakes basin is one of the largest freshwater ecosystems in the world and the most intensively used freshwater resource in North America. Great Lakes water quality issues have been identified as: point and nonpoint source nutrient control, toxic substance control, remedial programs, inadequate information, science policy and allocation of research resources, and recommitment to an ecosystem approach (Dworsky and Allee 1988). This ecosystem has been the focus of environmental policies and legislation for almost thirty years. Four of the five Great Lakes are regulated by legislation developed in Canada and the United States, whereas the fifth, Lake Michigan, lies entirely within the US. The management, protection, and development of the Great Lakes is under the jurisdiction of two federal governments, the province of Ontario and eight US states, along with numerous municipal, provincial, state, federal, regional, and international agencies. Current legislation relies on water quality objectives which have been limited to specific pollutants. Initial efforts and activities, sponsored by the United States and Canada, for defining ecosystem objectives are also underway. The ecosystem objectives endeavor to protect the water quality while incorporating the effects of interactive ecosystem components. The geographic, natural, and social components of the Great Lakes ecosystem play important roles in the development of water quality management activities.

Prior to 1972, the United States operated under the statutes of the Federal Water Pollution Control Act (FWPCA). In 1972, a state-oriented system of ambient water quality standards based on water-use criteria was established (Findley and Farber 1988). Amendments to the FWPCA, in 1972, adopted goals of fishable and swimmable waters by 1983 and total elimination of pollutant discharges to navigable waters by 1985. The FWPCA was amended again in 1977 and henceforth is referred to as the Clean Water Act (CWA). The focus on a water quality approach to controlling pollutants was emphasized in the federal Water Quality Act of 1987 (Bascietto et al. 1990). This amendment to the CWA requires national assessments of trophic status and trends, and nonpoint source controls, in addition to assessing those waters not meeting established standards for priority toxic pollutants.

The United States and Canada initiated a combined major effort in the 1970's to manage environmental quality in the Great Lakes through the Great Lakes Water Quality Agreement (WQA). The Great Lakes WQA was signed in 1972 by the governments of the United States and Canada, primarily in response to eutrophication in Lakes Erie and Ontario which led to efforts to reduce the phosphorus load. Revisions to the Great Lakes WQA, signed in 1978, included proposals for addressing toxic chemical control in addition to a continued concern over phosphorus discharge. The goal of the Great Lakes WQA is to "restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes Basin Ecosystem" (IJC 1989). The International Joint Commission (IJC) was assigned the role of assisting in the implementation of the Great Lakes WQA. Subsequent revisions, signed in 1987, include annexes to address airborne toxic inputs, non-point source input, Remedial Action Plan development to clean up severely polluted sites, and development of ecosystem health objectives.

The Great Lakes Critical Programs Act of 1990 (US Public Law 101-596, 104 Stat. 3000) is the first US legislation which specifically refers to the Great Lakes WQA and the associated role of the IJC (Chandler and Vechsler 1991). The legislation requires the EPA to publish proposed water quality guidance for the Great Lakes system which is at least as restrictive as the provisions of the Great Lakes WQA.

The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (Title I of US Public Law 101-646, 104 Stat. 4761) addresses the prevention and control of exotic species in the Great Lakes on the part of multiple US agencies and directs consultation with the Government of Canada in developing an effective international prevention program (Chandler and Vechsler 1991). This law was in response to growing concerns over the introduction of nonindigenous species, particularly the zebra mussel, into the Great Lakes and the potential for extensive damage to Great Lakes ecosystems.

Amendments to the Clean Air Act in 1990 (US Public Law 101-549, 104 Stat. 2399) contain provisions which will affect the Great Lakes Basin. The EPA is charged with assessment of the extent of atmospheric deposition of hazardous contaminants in the Great Lakes, development of an atmospheric deposition network, and assessment of pollutant loadings and their effects in accordance with the specific objectives of the Great Lakes WQA (Chandler and Vechsler 1991).

1.4. Great Lakes Monitoring Programs

An understanding of agency involvement is critical to the water quality management process. Multiple agencies need to work together to achieve common long-term ecosystem goals while working towards diverse short-term goals. The dimensions of this challenge can be appreciated with an understanding of the structure and function of the institutional system. Colborn et al. (1990) provide a discussion of "the institutional ecosystem" that wrestles with challenges as diverse as habitat rehabilitation versus dredging and disposal in support of lake-shipping requirements, to implementation of lifestyle changes in order to reduce stress on the ecosystem. At each level of organization, ranging from federal to municipal, there are a multitude of agencies that have responsibilities in regard to environmental legislation.

Prior to 1964, water quality studies on the Great Lakes were conducted largely by individual universities and state and provincial pollution control and fisheries agencies (Beeton and Chandler 1963). There was little coordination among these institutions or their studies. As a result, much of the data was incompatible due to dissimilar objectives, data collection methods and sampling designs, and analytical methods. The 1972 Great Lakes WQA outlined a set of common goals for surveillance and monitoring programs. By 1975 it was clear that coordinated efforts to gather data for evaluating the condition of the Great Lakes were not in place (IJC 1973, 1975). The IJC Water Quality Board recommended the development of the Great Lakes International Surveillance Plan (GLISP) to provide the framework for coordinating, in a bilaterally comprehensive and cost-effective manner, the various surveillance and monitoring activities initiated under the Great Lakes WQA. GLISP was developed over the period 1974-1980 to track phosphorus reductions and the subsequent impacts. The 1978 Great Lakes WQA shifted the focus to toxic contaminants. Subsequently the issues which GLISP attempted to address included eutrophication, toxic contamination, microbiological contaminants, radiological elements, and biological community and habitat. The common programs of GLISP have produced long-term trend data for phosphorus and toxic contaminants based on selected, fixed stations in the offshore areas of the lakes. An integrated program to assess overall ecological condition has not yet been institutionalized in the Great Lakes.

1.5. Societally Important Great Lakes Values

To be effective, the information from a Great Lakes monitoring and assessment program must prompt action when it is required. This means that the information produced must be related to perceptions regarding aquatic health and represent issues of concern to the public, aquatic scientists, and decision makers. In ecological risk assessment, these perceptions are called endpoints. Suter (1990) and Hunsaker and Carpenter (1990) defined ecological endpoints as the environmental entity of concern and the descriptor or quality of the entity. Such endpoints represent concepts that are societally important but that tend to be nebulous or abstract and do not lend themselves to direct measurement.

Historically, these endpoints for surface waters, including the Great Lakes, have been expressed as designated uses, which have included habitat for aquatic life, fishability, swimability, navigation, and drinking water supply. The attainment of some of these uses depends directly on ecological condition. For others, it is less directly dependent on ecological condition, although attainment may be indirectly associated with the consequences of degraded ecological condition. As currently expressed in the CWA, physical, chemical, and biological integrity embody a societal concern and desire that the Great Lakes be unimpaired and healthy. In particular, increasing attention is drawn to the biological condition of ecosystems, or biological integrity, defined by Karr and Dudley (1981) as "a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats in the region." This is similar to one current concept of biological diversity defined as the diversity of life and its processes which have functional, structural, and compositional attributes at the genetic, species, community, and ecoregion levels of organization.

In addressing the ecological condition of the Great Lakes, the focus for EMAP - GL is on biotic integrity. However, not all the societal concerns about the condition of the Great Lakes fall neatly under the biotic integrity umbrella. For example, many Great Lakes sports fisheries are managed through the introduction of non-native game species. These introductions are intended to support sport and commercial fishing rather than to maintain or restore the biotic integrity of the lake ecosystems. Thus, attaining the societal value of fishability may conflict with attaining the societal values of biotic integrity.

There is also considerable public interest in the trophic condition of the Great Lakes. The desire for lakes with clear water may conflict with the desire for lakes which support a productive fishery or a diverse fish and wildlife fauna. Given multiple societal concerns or values, EMAP - GL proposes to evaluate the condition of the lakes with respect to trophic condition and biotic integrity.

1.6. Specific Objectives of EMAP - GL

The objectives for EMAP - GL parallel the EMAP program objectives. The data collected for EMAP is intended to describe current conditions (status) and to detect trends using a set of ecological indicators at the lakewide scale of resolution. Objectives of EMAP - GL are to:

- estimate the current status and trends in indicators of the ecological condition of each of the Great Lakes with known confidence;

- monitor indicators of pollutant exposure and habitat conditions within the Great Lakes and seek associations between stressors and condition that identify probable causes of adverse effects;

- evaluate the long-term change in condition of the Great Lakes as a result of management and regulatory programs; and

- publish annual statistical summaries on the extent and the status of indicators of ecological condition of the Great Lakes and periodic interpretive reports on the status and trends of indicators of ecological condition in the Great Lakes to the EPA Administrator, decision makers, and the public.

Examples of the types of questions that are intended to be addressed by EMAP include:

- What proportion of the Great Lakes have degraded benthic communities?

- What proportion of the sediments of the Great Lakes are contaminated by toxics?

- Is the trophic status of the Great Lakes changing over time?

- What is the current extent and ecological condition of Great Lakes coastal wetlands?

EMAP is not designed to be a site-specific, compliance-oriented, monitoring program nor is it designed to provide information on specific, local scale issues. Questions at the local scale can be addressed more effectively by existing or locally designed monitoring networks. However, EMAP - GL seeks to determine the additive effects of all management activities and environmental stresses at lakewide scales of resolution.

1.7. Focus and Purpose of the Research Strategy

This research strategy presents the rationale, objectives, approach, and plan for establishing a monitoring and assessment program to document the status and trends in ecological condition of the Great Lakes. The current document is not intended to

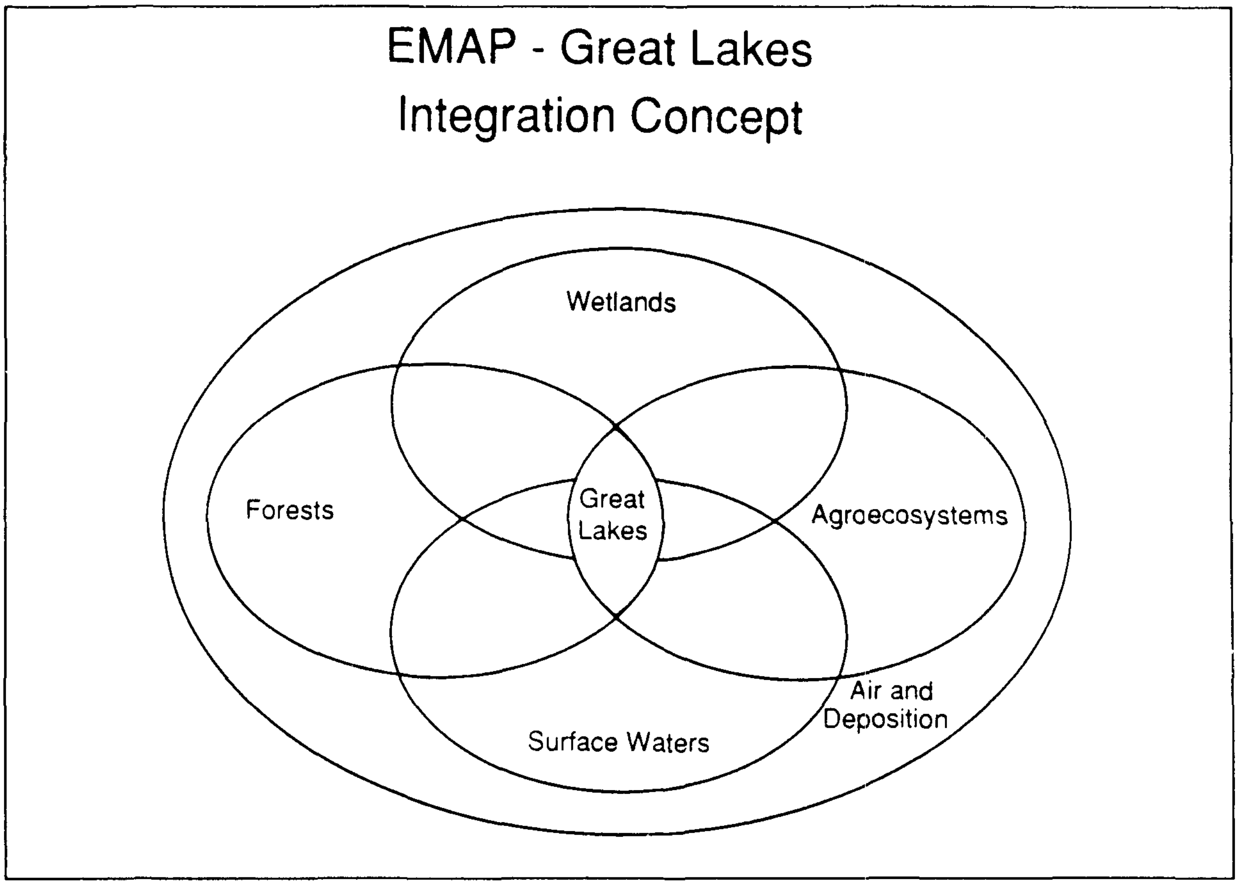


Figure 1.1 Conceptual representation of the EMAP concept for a regional characterization of *ecological resources.*

be a final plan for establishing these monitoring programs but rather part of a continually evolving process. The immediate objective is to inform potential EMAP clients of the approach proposed for describing and monitoring the condition of the Great Lakes, and to elicit input from the scientific, management, and regulatory communities. It is recognized from the outset that no one agency or group has the expertise to develop a program of this magnitude independently. The participants in preparing this strategy include representatives of EPA's Environmental Research Laboratory - Duluth (ERL-Duluth) and Great Lakes National Program Office (GLNPO), the US Fish and Wildlife Service (USFWS), the International Joint Commission, the University of Minnesota, Computer Sciences Corporation, and AScI Corporation. Coordination with additional organizations including the National Oceanic and Atmospheric Administration (N0AA) Great Lakes Environmental Research Laboratory (GLERL), Environment Canada National Water Research Institute (NWRI), and academic institutions around the Great Lakes is underway.

2. Overview of Approach

2.1. Introduction

This chapter provides an overview of the EMAP approach in the Great Lakes and the major questions that must be resolved as the program is implemented. Greater detail is presented in succeeding chapters ending with a discussion of planned activities for 1992.

The strategy for implementing EMAP - GL requires the resolution of major questions of statistical design and selection of indicators. Because long-term monitoring has been conducted in the Great Lakes for a limited number of indicators, the following approach is being taken:

- identify the research and monitoring needed to meet EMAP objectives;
- coordinate with ongoing research and monitoring programs to identify monitoring gaps and issues;
- conduct pilot studies to address the major outstanding questions;
- implement demonstration monitoring networks to evaluate lakewide indicators, design, and logistics; and
- implement monitoring and assessment networks on a lakewide basis.

2.2. EMAP - GL Design Approach

Meeting the EMAP - GL objectives outlined in Chapter 1 requires a design that is capable of:

- estimating, with known certainty, the status of the ecological condition of the Great Lakes at regional scales;
- establishing baseline data leading to rigorous detection and description of trends in the condition of the Great Lakes;
- identifying associations among measured attributes to hypothesize possible causes of impaired condition; and
- responding quickly to new issues and questions.

For the Great Lakes, the individual lakes have been established as the regional scale of resolution. These lakes are all individually large enough to be influenced by regional events and each has unique physical, chemical, and biological characteristics that affect their response to stress. Additional important requirements and features of the design include:

- explicit definitions of the classes within the Lakes to be sampled (i.e., offshore, nearshore, harbors and embayments, coastal wetlands);
- identification or listing of all potential sampling units within each class (i.e., geographic descriptions of areas constituting offshore and nearshore classes, lists of harbors and embayments and coastal wetlands);
- probability sample site selection for each class;
- flexibility to accommodate a variety of classes and problems, some of which may not yet have been specified; and
- a hierarchical structure that permits sampling at various levels of resolution.

The proposed EMAP design strategy is based on a tiered concept (Figure 2.1) that begins with a permanent national sampling framework. This framework consists of a hexagonal plate containing a triangular grid of approximately 12,600 points placed randomly over the conterminous United States. Those points that fall on the Great Lakes constitute the Tier 1 level of intensity for EMAP - GL. For much of EMAP, Tier 1 activities are intended to estimate the extent and geographic distribution of the ecological resources being studied. However, within the Great Lakes resource, the boundaries of the lakes and the locations of the harbors and embayments are known. Great Lakes coastal wetlands, in contrast, have been little studied and poorly mapped. Thus, Tier 1 activities for EMAP - GL will be focused on attempting to define the extent and distribution of coastal wetlands associated with the Great Lakes.

Tier 1 grid locations will also be used by EMAP - GL to define the intensity of the base grid for sampling and estimates of ecological condition. The activities associated with estimates of condition are Tier 2 in the hierarchical scheme. A suite of biological, chemical, and physical measurements will be obtained from each of these sites and the information aggregated to make statements about the conditions of the lake or a class within a lake. It is at this tier where most of the EMAP - GL monitoring and assessment activities will be focused (Figure 2.2 and Chapter 10). An important aspect of the EMAP design is the temporal and spatial interpenetrating nature of the site characterization and field visits. Whereas the sampling grid consists of points distributed across the Great Lakes, only one-fourth of these will be visited each year. Thus, over a four-year cycle, each grid point will be visited.

Because each class (i.e., offshore, nearshore, harbors and embayments, coastal wetlands) within a lake is likely to have a different level of homogeneity, sampling to characterize the condition of classes may require different spatial densities. The triangular nature of the EMAP grid design provides for the ability to increase or decrease the density of the grid by three-, four-, or seven-fold as well as by multiples

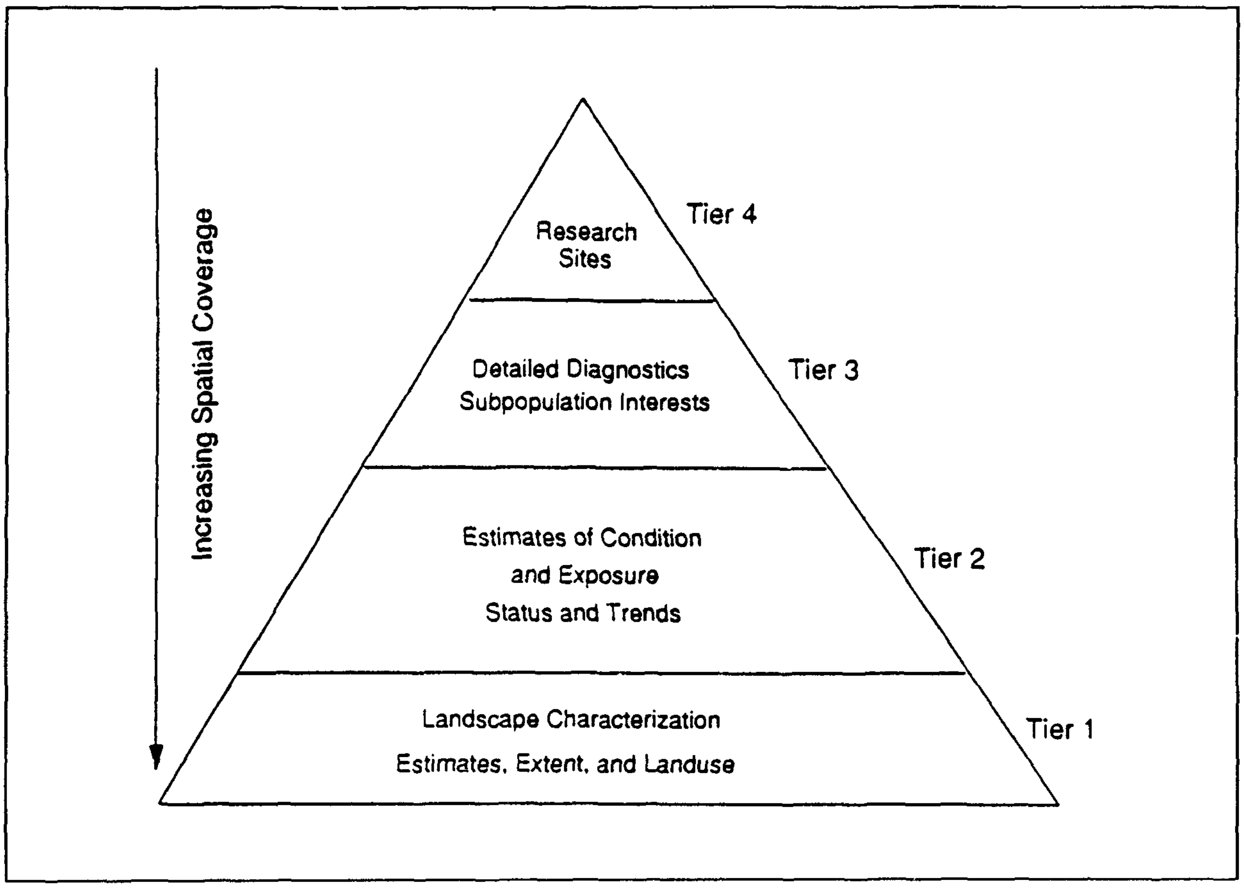


Figure 2.1 Concept of a four-tiered approach in EMAP. Spatial coverage is maximized in lower tiers while temporal coverage increases at the higher tiers.

of these values. Further discussion of this concept applied to the resource classes of Tier 3 of EMAP is intended to include activities related to the further diagnosis of problems within a lake or to evaluate a subclass within a lake that is not adequately covered using the existing sampling framework. In the Great Lakes, the designated Areas of Concern and the associated Remedial Action Plans might be considered for inclusion as Tier 3 EMAP - GL activities.

The final level (Tier 4) of activity potentially associated with EMAP - GL involves research within the Great Lakes that compliments the activities at the other tiers. This level is the link between EMAP and ecological research. At this time, EMAP - GL will not be establishing new research sites but will rely on existing programs. This does not mean that research will not be a component of EMAP - GL but rather that we will continue to keep abreast of and utilize the ongoing research that various agencies and institutions are conducting. The research that EMAP initially will be participating in relates most directly to Tier 2 needs (see Chapter 10.)

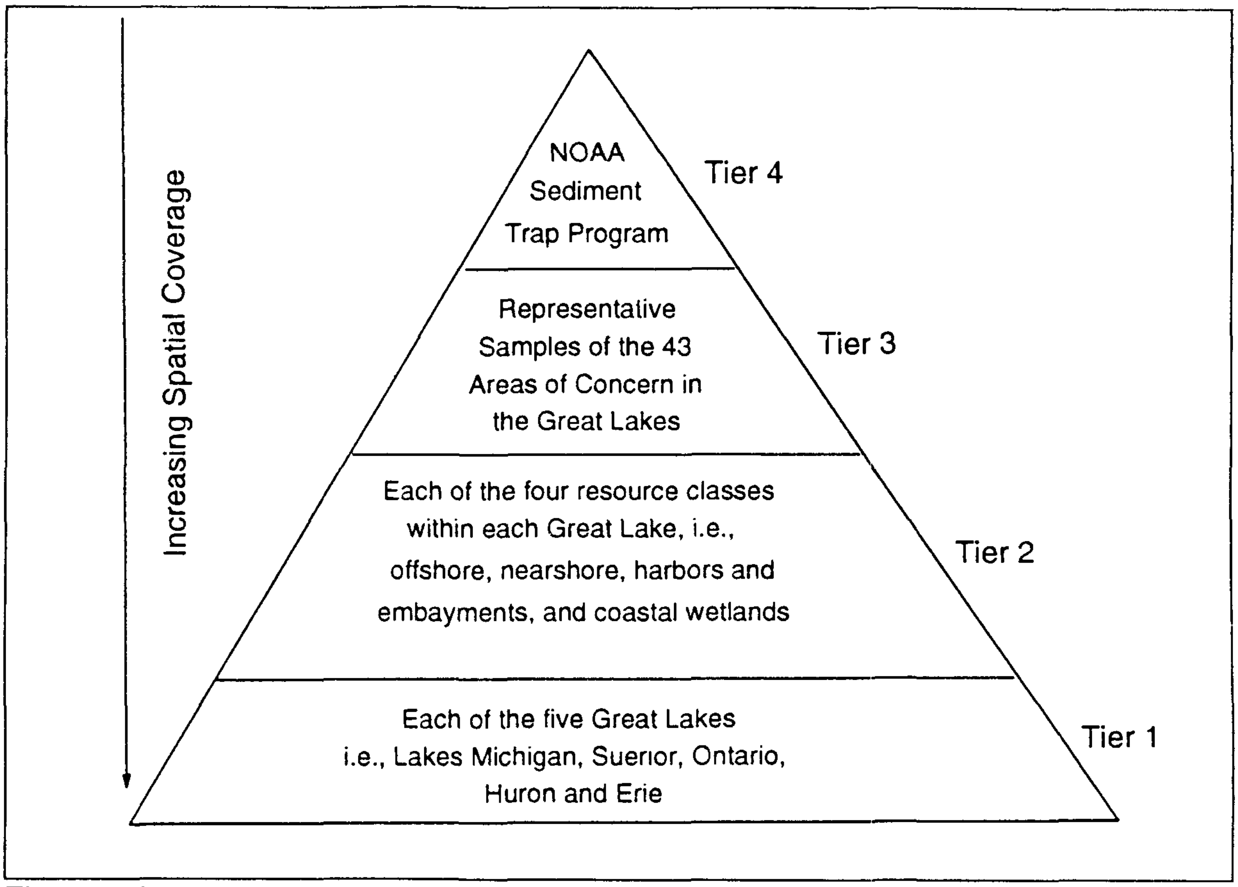


Figure 2.2 Concept of the EMAP four-tiered approach as applied to EMAP - Great Lakes.

2.3. EMAP - GL Indicator Approach

Traditionally, environmental monitoring programs have focused on individual chemical or biological species on a local scale. The concentration or response of these individual species was assumed to be related to a gradient of poor to good environmental conditions. Individual chemicals and organisms, however, do not exist in isolation but rather interact with other physical, chemical, and biological factors to produce ecosystem response. In addition, we have learned over the last two decades that continuing, persistent, and cumulative pollution is occurring not only at the local scale but also on a regional, continental, and global scale. In some instances, regulatory programs at the local scale have aggravated or contributed to problems on a regional scale. The concept of regional and national scale impacts requires a new approach to environmental monitoring, both in terms of what we measure and where we measure it. Instead of focusing on problems that receive the greatest media or public attention, we need to focus on problems that pose the greatest risk to the environment. In "Unfinished Business: A Comparative Assessment of Environmental Problems" (US EPA 1987), the EPA considered the highest potential risks to ecosystems to be global warming and stratospheric ozone depletion followed by regional problems of habitat alteration, nonpoint source pollution, and risks from criteria air pollutants.

Because environmental problems are becoming increasingly complex (i.e., cumulative effects from multiple pollutants at multiple scales), traditional monitoring approaches and indicators alone are insufficient to assess ecological condition. EMAP is being designed with a "top down" approach in a risk assessment framework. This top-down approach focuses on the endpoints of concern rather than the environmental perturbations or stressors.

Indicators selected by EMAP - GL must relate to the assessment endpoints of biotic integrity and trophic status and are characterized into four conceptual categories: response, exposure, habitat, and stressors (Chapter 4). Definitions of these four indicator types are:

- Response Indicator: A characteristic of the environment measured to provide evidence of the biological condition of a resource at the organism, population, community, or ecosystem level of organization.

- Exposure Indicator: A characteristic of the environment measured to provide evidence of the occurrence or magnitude of a response indicators contact with a chemical or biological stressor.

- Habitat Indicator: A physical, chemical, or biological attribute measured to characterize conditions necessary to support an organism, population, or community in the absence of pollutants. Examples include salinity or substrate type.

- Stressor Indicator: A characteristic measured to quantify a natural process, an environmental hazard, or a management action that affects changes in exposure and habitat.

EMAP will collect data on response, exposure, and habitat indicators at its field sampling sites. Stressor indicators will be primarily assembled from other sources. Within EMAP, indicators are identified through the development of conceptual models of ecosystems. These models may be based primarily on how current and anticipated stresses affect ecosystems, or from a perspective of the structural, functional, and recuperative features of "healthy" ecosystems.

Selection and development of indicators for EMAP - GL must be considered a long-term process (Figure 2.3). Some indicators may be ready for implementation on a regional basis, others require modification, and still others have been used only in isolated instances and require demonstration of their regional applicability. A multi-phase process has been identified to guide the selection of indicators and future development:

Phase 1 - identification of issues (environmental values and apparent stressors) and valued ecosystem attributes (assessment endpoints);

Phase 2 - development of a set of candidate indicators linked to the identified endpoints and responsive to expected stressors;

Phase 3 - screening of the candidate indicators based on a set of indicator evaluation criteria, selecting as research indicators those that appear to fulfill key requirements, rejecting those that clearly do not, and holding in a state of evaluation those candidate indicators that may, in the near future, advance to research status;

Phase 4 - quantitative testing and evaluation of the expected performance of research indicators on regional scales, to identify the subset of developmental indicators suitable for regional demonstration projects;

Phase 5 - regional scale demonstration of the sensitivity, reliability, and specificity of response for development indicators; and

Phase 6 - implementation of a core set of indicators in a full EMAP program with statistical summaries, and periodic reevaluation of indicators.

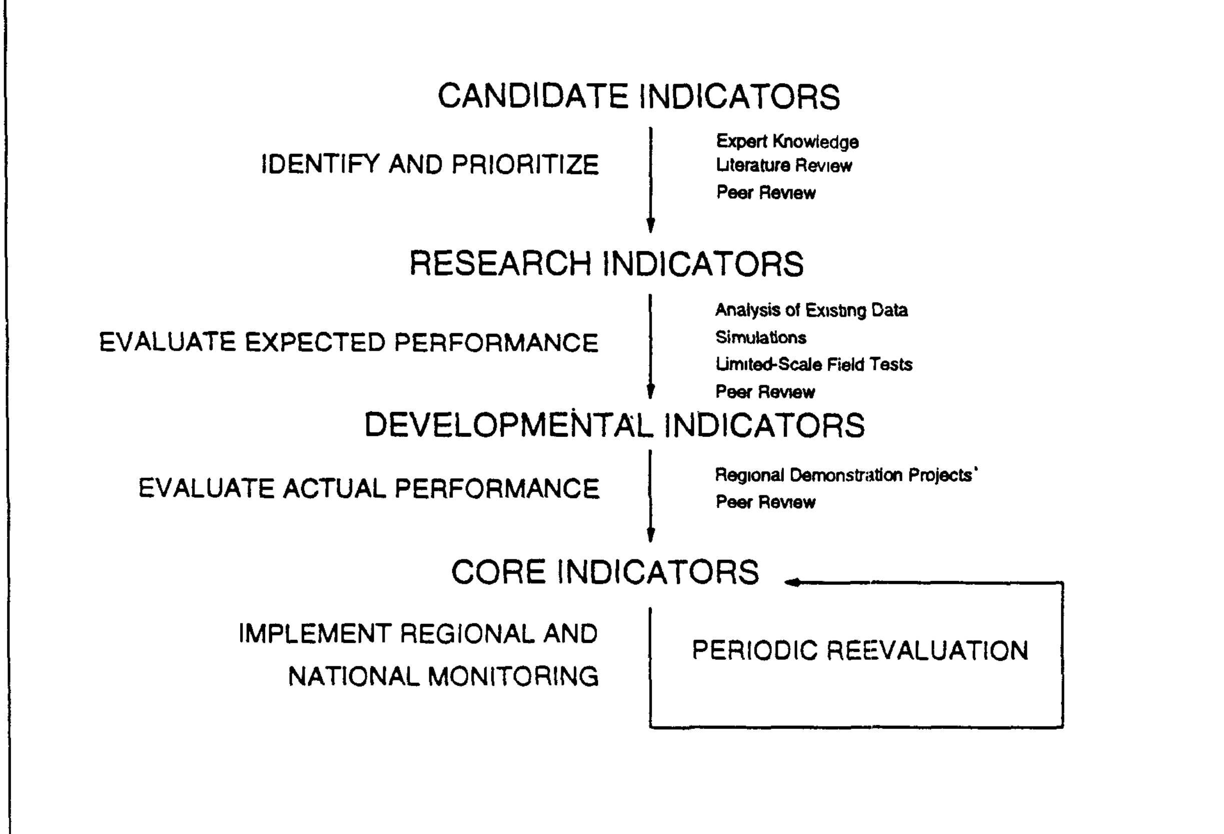


Figure 2.3 General approach for selection and development of indicators for EMAP.

Selection of assessment endpoints and indicators requires consideration of public values, policies, current threats to the Great Lakes, and an understanding of biological and chemical processes. The selection of biotic indicators of condition is driven by our understanding of biological communities, their interactions and the impact of various stresses on the chemical and physical habitats in which the organisms exist. It is equally influenced by the endpoints or values of concern. These endpoints, and thus the indicators representing them, must be sufficient to motivate change in policy when poor conditions are found.

In addition to determining the ecological condition of the Great Lakes, it is important to determine the likely causes of poor condition. In EMAP, diagnosis will be achieved through correlations between response indicators and the exposure, habitat, and stressor indicators as defined above. In limited situations, the response indicators themselves may shed some light on the likely causes of current conditions or trends. Statistical associations between the occurrence of poor conditions as defined by response indicators and values for the exposure, habitat, and stressor indicators will be used to infer the most likely categories of probable cause. Correlative analyses of these types cannot prove causality but will narrow the range of likely explanations for observed regional patterns and lead to the generation of hypotheses which can be investigated.

To meet the objectives of the EMAP - GL monitoring and assessment program, a series of indicators are proposed (Table 2.1 and Chapter 4) which are representative of the biological condition of the Great Lakes ecosystems, responsive and sensitive to a broad array of potential stressors, produce results with an acceptable sample variability, and are cost effective. The selection of indicators, however, is an evolving process as data become available, as new indicators are developed, and as the joint US-Canada workgroups complete their work in proposing indicators for the Great Lakes ecological objectives.

2.4. EMAP - GL Data Quality

An essential complement to the careful design and indicator strategies outlined in this section is consideration of data quality. Production and assurance of quality data should be an integral part of any program that intends to produce useful information. EMAP is committed to producing data for the intended purposes. To meet this objective, it is necessary to have a process for identifying the quality of data required. The following discussion represents a process that has just begun for EMAP - GL and will be ongoing during the early stages of implementation.

Data quality objectives (DQOs) are statements of the level of uncertainty a decision maker is willing to accept in results derived from environmental data. DQOs are generated in a multistage process. Stage 1 involves defining the major questions or problems of concern. At this stage, the focus is on the decision maker or data user. Information needs are identified based on an understanding of how the environmental data to be collected will be used. Also, resource and time constraints are identified and the consequences of Type 1 and Type 2 errors are examined. A Type 1 error results in a false positive (e.g., data indicate adverse ecological effects when no such effects exist), while a Type 2 error results in a false negative (e.g., data indicate no adverse ecological effects when they actually exist).

Table 2.1 Indicators being considered for EMAP - GL.

<u>Response Indicators</u>
Fish pathology
Aquatic vegetation
Lake trout recruitment
Forage fish populations
Lake trophic status index
Lake trout/walleye populations
Diporeia/Hexagenia abundance
Chlorophyll composition in water
Diatom abundance in sediment cores and traps
Benthic macroinvertebrate community structure
<u>Exposure Indicators</u>
NP and Si:P Ratios
Contaminant residues in fish
Zebra mussel/exotics abundance
Sediment toxicity to *Hyallela azteca*
Water column toxicity to *Ceriodaphnia*
Contaminants in sediments from cores and traps
<u>Habitat Indicators</u>
Sediment physical characteristics
Water column optical characteristics
Temperature, pH, routine water chemistry
<u>Stressor Indicators</u>
Resource management
Human population densities
Atmospheric deposition rates
Landuse and landcover surveys
Agricultural chemical application rates
Point and nonpoint source pollutant loading

Stage 2 involves defining the information needed to answer the question or make the decisions identified in Stage 1. This process includes developing pertinent subordinate questions that may need to be answered in order to fully address the problem. Also, at this stage, the population of interest should be clearly defined. There should also be an identification of specific design constraints, i.e., the desired confidence in the results. Finally, Stage 2 should examine existing data and confirm the need for new data, in cases where data do not exist, to provide the necessary information.

Stage 3 involves determining a scientific approach to data collection and the data quality requirements for that approach. This process includes considering as many approaches to collecting the necessary data as possible, along with considering the levels of data quality required to meet the constraints specified in Stage 1 and Stage 2. Stage 3 should also serve to identify research activities needed to meet the requirements of Stages 1 and 2.

Throughout the process, there is continuous feedback and communication at all levels involving the decision makers, the scientists identifying specific information needs, and those individuals collecting the data necessary to provide this information. EMAP is committed to the DQO process as a means of optimizing the allocation of limited resources and assuring that data collected in the program provides the information needed to meet program goals.

2.5. EMAP - GL Expected Outputs

EMAP must effectively convey its scientific results to decision makers and the public. If the original scientific objectives have been established in close consultation with decision makers, then communicating useful information on a wide range of environmental issues will be far easier and more meaningful. Although EMAP cannot fully anticipate this interpretation and communication process until actual results are available, Chapter 8 illustrates some of the potential users, questions, information flows, and outputs.

In general, EMAP will produce four types of products:

- Verified and/or aggregated data
- Annual statistical summaries
- Single-resource assessments
- Multi-resource integrated assessments

Many clients desire access to the data being collected by EMAP either as the individual, verified sample data or aggregated by assessment unit. There currently is no information database that includes regional and national ecological data on multiple ecological resources. Consequently, data are likely to be one of the early products from EMAP.

The current goal of each EMAP resource group is to have a statistical summary of the response, exposure, and habitat indicators monitored by that group within nine months of the last date of field-data collection. These summaries will contain descriptive statistics such as means, medians, distributions, ranges, and standards deviations for the various indicators monitored within the sampling frame or for selected indices computed from these data.

EMAP will produce regional and multiple-region/national assessments that will address either 1) the condition of particular resource or 2) the condition of all resources that occur in a region (or megaregion). EMAP will produce two general types of assessment reports: single-resource interpretive assessments and multiple-resource integrated assessments.

Single-resource assessments will be produced by resource groups and task groups composed of regional assessment specialists. Integrated assessments will be produced by the Integration and Assessment group with assistance from resource and task groups. Integrated monitoring data and interpretive reports on these data will be provided regularly to environmental decision-makers, Congress, and the public. These reports, or assessments, will be designed to contribute to informed decisions about which risks should receive the greatest scrutiny. In producing these assessments, EMAP scientists will incorporate relevant data from existing monitoring programs (of EPA or other agencies).

EMAP must reach varied audiences: Congress, environmental groups, news media, as well as the scientific community and other groups. These audiences will include many who do not have the background in ecology, sampling statistics, and other areas needed to fully understand EMAP's results. To improve communication with decision makers and the public, EMAP will use focus groups to critique proposed presentation material for clarity, simplicity, and conciseness. The focus groups will be composed of members representing the scientific community, environmental decision makers, policy makers, and the public.

2.6. EMAP - GL Program Limitations

It is equally important in understanding EMAP - GL to describe not only what the program will attempt to do but also its limitations. The program is not intended to describe all components of an ecosystem or resource type. It will not describe how systems function. It will, however, provide information about condition as measured by specific indicators during an index period as a "snapshot" of the overall condition of a system.

EMAP - GL has not been designed to directly address specific stressors such as chemical contamination. EMAP is not intended to be compliance monitoring and will not replace the need for such activities. In general, EMAP - GL is intended to provide a common sampling frame within which to assess the condition of the Great Lakes at a broad scale so that the relative magnitude and geographical location of various problems can be assessed and mitigation and research priorities can be made more objectively. The monitoring program is not intended to be truly anticipatory, but rather to provide an ongoing monitoring framework within which new variables can be added or modifications be made so that the magnitude and extent of emerging issues can be more quickly evaluated.

2.7. Questions to be Addressed

Throughout this strategy, there are questions which arise that should be addressed before EMAP - GL can be fully implemented. It will not be possible to obtain answers to all of these questions in one or even a few years. Because EMAP - GL is an evolving and flexible program, the monitoring and assessment activities are intended to change as new answers, indicators, and problems become apparent. At this time, the major questions include the following:

Design Questions

- Are the base and enhanced grid proposals adequate to describe condition of the offshore and nearshore classes of the Lakes?
- What boundary should be used to distinguish offshore from nearshore classes?
- How should harbors and embayments be selected for sampling at Tier 2?
- What is the number, location, and extent of Great Lakes coastal wetlands?
- How should the connecting channels be incorporated into the EMAP - GL design?
- How should wildlife populations be sampled?

Indicator Questions

- What are the appropriate indicators for EMAP - GL wetlands?
- Can nominal conditions for EMAP - GL indicators be determined?
- Can the individual indicator measurements be combined to describe overall condition of the lakes and their classes?
- What indicators of fish populations are most efficient and effective in describing their ecological condition?
- Are diatoms representative of phytoplankton populations within the Great Lakes?

- How many sediment cores are needed to describe the historical status and trends of the phytoplankton populations of the offshore class of the Lakes?

- What is the variability of diatom population abundance collected with sediment traps as a function of depth and spatial distribution?

- Will the spatial distribution of samples at one time of year be sufficient to make statements about indicators of water chemistry?

- What contaminants should be measured in sediments and biota?

- What protocol should be followed in sampling and measuring contaminants in zebra mussels?

- Is there a method for measuring zooplankton populations that provides temporally integrated data to account for the expected large temporal variations?

- What indicators are available to measure wildlife?

- Do process measures provide information that is necessary to make statements of ecological condition that cannot be inferred from other indicators?

Logistical Questions

- Who will actually conduct sampling once implementation is underway?

- Is a lake-specific logistical plan the most efficient way to sample the lakes?

- Are there sufficient numbers of trained Great Lakes scientists to undertake and maintain the monitoring and assessment program over the long term?

- Is there sufficient qualified analytical capability in the Great Lakes basin to conduct the needed chemical analyses?

2.8 Questions to be Addressed in 1992

Some of the questions listed above will begin to be addressed during 1992. For a variety of reasons, the initial sampling effort will focus on Lake Michigan. The answers to some questions will be applicable to all the lakes, while others will need to be addressed in each lake. The following are questions proposed as primary 1992 activities. These will be discussed in greater detail in Chapter 10.

Design Questions

- Questions over the density of the base grid for offshore areas in Lake Michigan will be addressed by evaluating existing data and collecting additional data for the trophic status and sediment related indicators.

- Lists and areal extent of the harbors and embayments of Lakes Michigan and Superior will be determined from USGS maps using the definitions described in Chapter 3.

- Available information regarding the extent of coastal wetlands of Lake Michigan will be identified.

Indicator Questions

- Recommendations for wetland indicators will be developed through a workshop of Great Lakes wetland scientists.

- Investigations into the definition of nominal conditions for sediment indicators in the nearshore of Lake Michigan will be conducted in conjunction with Canadian studies on the remaining four Lakes.

- The selection of appropriate indicators for fish will be explored through analysis of existing data and consultations with Great Lakes experts.

- Evaluation of existing data for Lakes Michigan and Superior, along with some sampling activities, will investigate the use of diatoms as representatives of Great Lakes phytoplankton populations, the use of sediment cores for historical trends analysis of diatom populations, and the exploration of sediment traps as an integrative measure of annual diatom population abundance and distribution.

- An evaluation of index periods for trophic status in the offshore resource class will be conducted by comparing spring and summer data in Lake Michigan.

2.9. Implementation Plan

The proposed timelines for implementation of EMAP - GL are presented in Table 2.2. Pilots are activities designed to test various aspects of the system, such as indicator evaluation or sampling and logistic constraints. Site selection for pilot activities need not be constrained to the EMAP - GL sampling grid. Demonstrations are activities in which parts of the system continue to be tested. A key aspect of the demonstration is the use of the sampling grid to provide policy relevant information for some subset of the indicators. The demonstration may incorporate additional sampling to evaluate indicator performance or examine components of variability for indicators of interest.

The timeline proposed in Table 2.2 represents an extremely optimistic time frame. It assumes adequate and timely resources to acquire and train the needed staff for program planning, implementation, and data analysis.

Table 2.2 EMAP - GL implementation schedule.

Year	Resource Class	Michigan	Superior	Ontario	Huron	Erie
1992	Wetlands					
	Harbors					
	Nearshore	Pilot				
	Offshore	Pilot	Pilot			
1993	Wetlands	Pilot				
	Harbors	Pilot				
	Nearshore	Demonstration	Pilot			
	Offshore	Demonstration	Demonstration			
1994	Wetlands	Demonstration	Pilot	Pilot		
	Harbors	Demonstration	Pilot	Pilot		
	Nearshore	Implementation	Demonstration	Demonstration		
	Offshore	Implementation	Implementation	Demonstration		
1995	Wetlands	Implementation	Demonstration	Demonstration	Pilot	
	Harbors	Implementation	Demonstration	Demonstration	Pilot	
	Nearshore	Implementation	Implementation	Implementation	Demonstration	Pilot
	Offshore	Implementation	Implementation	Implementation	Demonstration	Pilot
1996	Wetlands	Implementation	Implementation	Implementation	Demonstration	Pilot
	Harbors	Implementation	Implementation	Implementation	Implementation	Pilot
	Nearshore	Implementation	Implementation	Implementation	Implementation	Demonstration
	Offshore	Implementation	Implementation	Implementation	Implementation	Demonstration

Pilot phase to test major outstanding design, indicator or logistics questions

Demonstration phase to test use of the sampling grid to provide information

Implementation of monitoring

3. Monitoring Network and Field Sampling Design

3.1. Introduction

The broad EMAP objectives and the more specific Great Lakes components of those broad objectives have been discussed in previous sections. Meeting these objectives requires a design capable of:

- estimating, with known certainty, the status and health of each Great Lake;
- describing baseline data leading to rigorous detection and description of trends in status and health of each Great Lake;
- identifying associations among attributes, both within and among resources, to establish possible causes of impaired condition; and
- responding quickly to emerging issues and questions.

Important requirements and features of the design that are described in this section include:

- explicit definition of target populations and their sampling units;
- explicit definition of a frame for listing or otherwise representing all the potential sampling units within each target population;
- use of a probabilistic design on well-defined sampling frames to rigorously estimate population attributes through randomization and use of probabilistic methods for sample unit selection;
- flexibility to accommodate a variety of resource types and a variety of problems, some of which have not yet been specified;
- hierarchical structure that permits sampling at a coarser or finer level of resolution than the general grid density, giving flexibility at global, national, regional, or local scales; and
- ability to focus on subpopulations of potentially greater interest (e.g., specific resource classes within a lake).

A general overview of the EMAP design was introduced in Chapter 2; greater detail about the design can be found in Overton et al. (1991). The remainder of this chapter describes how the general EMAP design will be used in the Great Lakes component of EMAP. A description of how sample units will be selected to meet the design objectives of EMAP is provided. Some decisions have been made regarding pieces of the design puzzle; for other pieces, various options under consideration will be briefly presented.

3.2. Physical boundaries

It is important to define the physical boundaries of EMAP - GL because the design is based on the requirement to sample the lakes (i.e., the response, exposure, and habitat indicators), not land associated with the lake or tributaries to the lake (i.e., the stressor indicators). The program will be relying on additional data sources within the Great Lakes to provide information on stressors. Therefore, the following is offered as a working definition of the boundaries for EMAP - GL:

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 above is meant to be a natural, physical definition of the entire resource. It is recognized that human-induced changes have altered and will continue to alter the boundaries of the system. Thus, the presence of a dam makes it obvious where the human-induced boundary for the river is located, while that same boundary defines the maximum extent of lake influence. The same is true for filled areas and artificially maintained shoreline.

Although EMAP has begun as a US program, the status of the Great Lakes cannot be determined without sampling in Canadian waters with the cooperation of Canadian agencies. The boundary between the two countries must not be a restriction to determining the quality of the shared resource. Therefore, EMAP - GL intends to include the nearshore zone, harbors and embayments, and coastal wetlands of the entire Great Lakes and will engage the Canadians in discussions regarding access and participation.

3.3. Regionalization

The EMAP - GL regionalization scheme 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 as is shown from the dimensions in Table 3.1. The connecting channels tend to have some basic characteristics of their upstream lakes but are physically unique (Table 3.2). In its initial phases, EMAP - GL will monitor status and trends in the five lakes. Decisions on how to incorporate the connecting channels have not been made, but they may be treated as a separate class for the lakes.

Table 3.1 Physical and geographical characteristics of the five Great Lakes (adapted from MSU bulletins).

	Michigan	Ontario	Superior	Huron	Erie
Length (km)	494	311	563	331	338
Breadth (km)	190	85	259	294	92
Depth (m): Average	85	86	149	59	19
Maximum	282	245	407	229	64
Volume (km^3)	4920	1640	12230	3540	483
Surface area (km^2)	57750	18960	82100	59500	25657
Drainage basin area (km^2)	118100	60600	127700	131300	58800
Shoreline length[1] (km)	2670	1168	4385	6157	1400
Retention time (yrs)	99	6	191	22	2.6
Population: US	8709907[2]	2657432	474150	1606518	9183347
Canada	----	4616070	155675	941300	1742805
Landuse (% of total)					
Agricultural	44	39	3	27	67
Residential/Industrial	9	7	1	2	10
Forest	41	49	91	68	21
Other	6	5	5	3	2

[1] Includes islands; [2] Does not include ~5 million residents of the Chicago metropolitan area who depend on Lake Michigan for drinking water and domestic supplies but do not live in the Lake Michigan drainage basin.

3.4. Primary Resource Classes

3.4.a. Offshore and Nearshore Areas

The primary resource classes for the Great Lakes include the offshore, nearshore, harbor and embayment areas, and coastal wetlands. A clear definition for delineating each of the resource classes is needed for sample allocation and for defining the appropriate indicators to be used. For example, the variability of any indicator is expected to be substantially greater in the nearshore waters than in the offshore waters which tend to be homogenous. Some indicators, either by their nature or because of the current status of the Great Lakes, are only appropriate for specific resource classes (refer to Chapter 4).

There are many potential definitions of the offshore and nearshore boundary in the Great Lakes (Rathke 1984). In general, a simple physical definition is preferred, especially one that can be applied to all the Great Lakes. Two definitions were

Table 3.2 Watershed characteristics of the Great Lakes connecting channels.

	St. Mary's R.	St. Clair R.	L. St. Clair	Detroit R.	Niagara R.****	St. Lawrence R.****
Inlet	L. Superior	L. Huron	St. Clair R.	L. St. Clair	L. Erie	L. Ontario
Outlet	L. Huron	L. St. Clair	Detroit R.	L. Erie	L. Ontario	Atlantic Ocean
Length (Area)*	101-121 km	64 km	1115 km^2	51 km	59	240
Elevation Fall (m)*	6.75	1.5	--	1.0	--	--
Flow m^3/sec x 1000***						
Minimum	1.2	3.0	--	3.2	--	--
Average	2.2	5.2	--	5.3	5.8	7.2
Maximum	3.7	6.7	--	7.1	--	--
Average flow vel. m/s*	0.6-1.5	0.6-1.8	0.02-0.08	0.3-0.6	--	--
Depth (m)*	Shallow-30	9-21	3.4 avg. 8.2 max.	6-15	--	--
Width (km)*	0.3-6.4	0.25-1.2	39	0.66-3.0	--	--
Retention Times	~2 days	21 hrs	2-9 days	21 hrs	--	--
Controlled Flow	Y	N	N	N	--	--
Land Drainage Area** km^2 x 1000 (cum. total)	49.3	146.6	159.0	160.9	--	--

* Limno-Tech 1985, unpublished manuscript; ** David Cowgill, US Army Corps of Engineers; *** US EPA and Environment Canada 1988; Limno-Tech. 1985; and **** Environment Canada. 1991.

considered in detail for the Great Lakes component, distance from shore and depth contour. In describing the distance and depth relationship, Schelske (1980) states that "physical processes in the nearshore are distinct from the offshore, currents are stronger and effects of waves and currents, particularly relative to interactions with the sediments, are greater." Schelske defines the nearshore zone "as that area lying within the 30-meter contour line." He further notes that, except for Lake Erie, this definition corresponds approximately to a nearshore strip 20 km wide. Distance from shore would be convenient if it were a good approximation of depth contours. However, bathymetric data for Lake Michigan show that the distance from shore corresponding to the 30-meter depth contour can vary from 3 - 22 km depending on location in the lake. In terms of physical processes and sediment interactions and because of variability of the distance parameter, depth contour is proposed as the appropriate physical definition for delineating between the offshore and nearshore areas. A number of depth contour proposals have been used for research and monitoring efforts in the Great Lakes. The percent of lake surface area for the nearshore resource class varies given different depth contour definitions for the offshore and nearshore zones (see Table 3.3).

A proposed strategy for an *a priori* definition of offshore and nearshore zones is to select zones in a conservative manner to protect the integrity of zones. This strategy provides a low probability that a given zone would influence another. Such influence could impact data representation and statistical interpretation. The conservative definition proposed is that the boundary between offshore and nearshore areas is the

Table 3.3 Percent of Lake Michigan surface area for the nearshore resource class as defined by depth contour.

Depth Contour (m)	% Nearshore Surface Area	Reference
0-30	22%	Schelske 1980
0-40	26%	White 1991
0-50	28%	Surveillance Work Group 1986
0-85	34%	Bennet 1974; Simons 1980

depth contour equal to the mean depth of the lake. As seen in Table 3.3, the definitions of the nearshore zone for Lake Michigan can range from 30 - 85 m in depth and from 22 - 34% of the lake area. The conservative properties of the 85 m division may be illustrated by examining how cumulative distribution functions (cdf) change as the division moves further inshore. In a relatively homogeneous region, such as the offshore waters of Lake Michigan, one would expect the cdf to approximate that of a normal distribution (i.e., a symmetrical "S" shape). Figures 3.1 and 3.2 present cdfs for two parameters, total phosphorus and chlorophyll-a, from Lake Michigan measured in regions delineated by 85 m, 50 m, and 30 m depth contours. For both parameters, as more of the lake is included, the probability of picking up extreme values associated with the nearshore increases, and, as a result, the upper tail of the cdf becomes extended. The 85 m separation results in a cdf which closely approximates a normal distribution and therefore, is indicative of the more homogeneous offshore environment.

It should be noted that all of the current Lake Michigan offshore monitoring stations from GLISP are in depths greater than 85 m (the shallowest station is approximately 100 m deep). The representativeness of the 0 - 85 m depth contour for nearshore areas in Lake Michigan will be investigated during the 1992 pilot study (refer to Chapter 10). This investigation will primarily involve historical data analysis but will also include interpretation of 1992 field collected data.

Delineation of an additional, transition zone will be addressed during 1992 through analysis of benthic community composition in Lake Michigan (White, unpublished data). A transition zone has considerable merit because it would decrease the size of the nearshore zone and consequently, the number of samples required for characterization. Such a zone would reduce any potential diluting effect of the nearshore results.

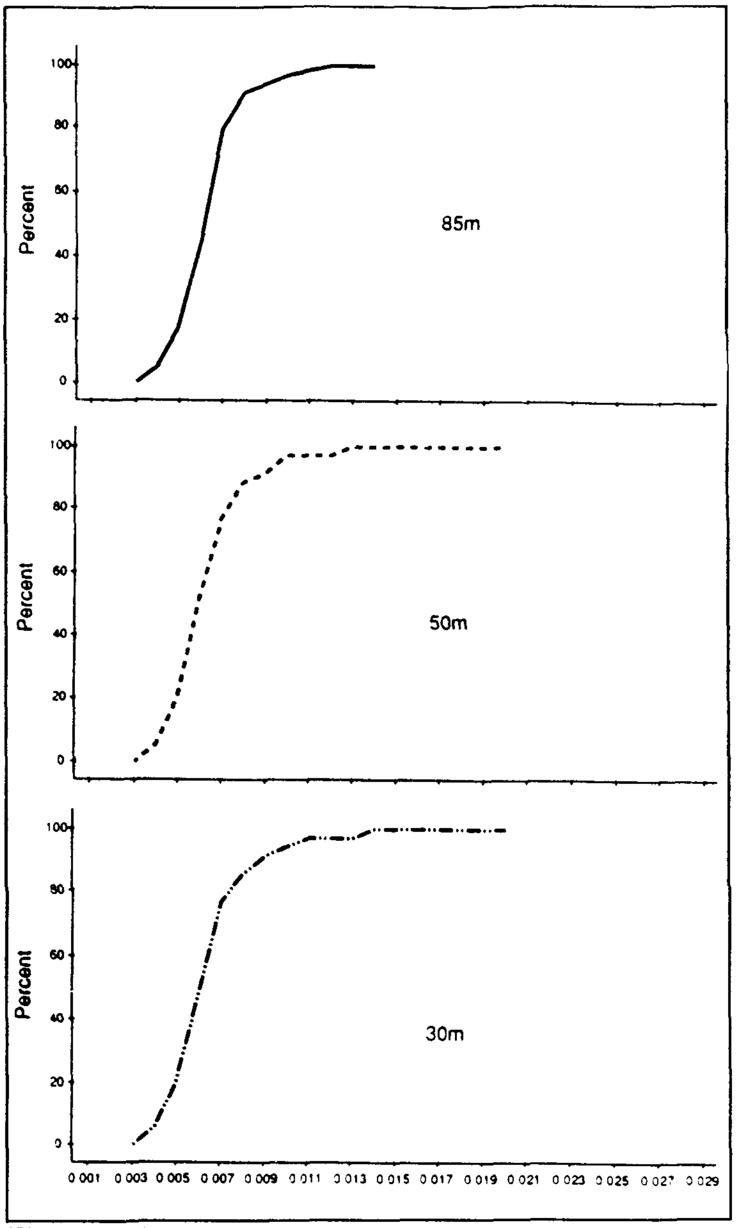


Figure 3.1 **Total phosphorus concentration (mg/L) (Lake Michigan) measured at 85 m, 50 m, and 30 m.**

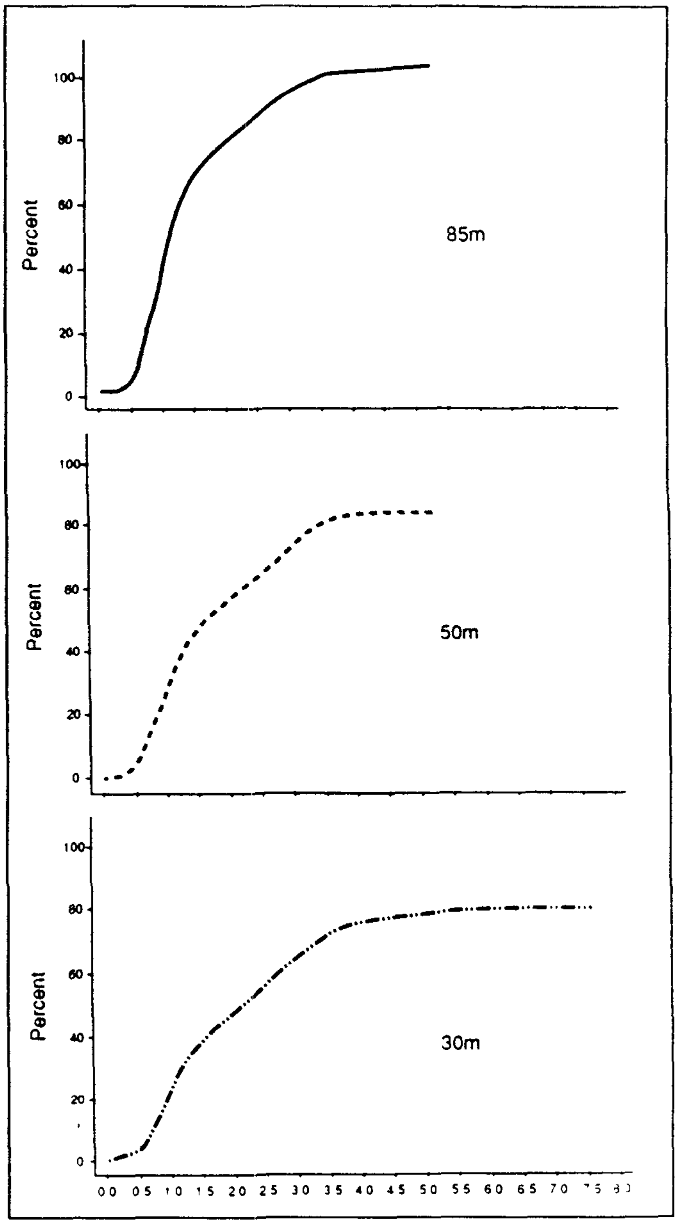


Figure 3.2 **Total chlorophyll-a concentration (µg/L) (Lake Michigan) measured at 85 m, 50 m, and 30 m.**

3.4.b. Harbors and Embayments

Harbors and embayments will be treated separately for two reasons. First, many embayments are formed by tributaries which 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 are more likely to be sources of nutrients and contaminants to the rest of the nearshore zone and to offshore waters.

It should be noted that many harbors and embayments often 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 have elected to 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. It is suggested that the "Geneva Convention on the Territorial Sea and the Contiguous Zone" be used because it provides a clear definition of bays in Article 7 (Hodgson and Alexander, manuscript). The following paragraph is a summary of this definition (see also Figure 3.3).

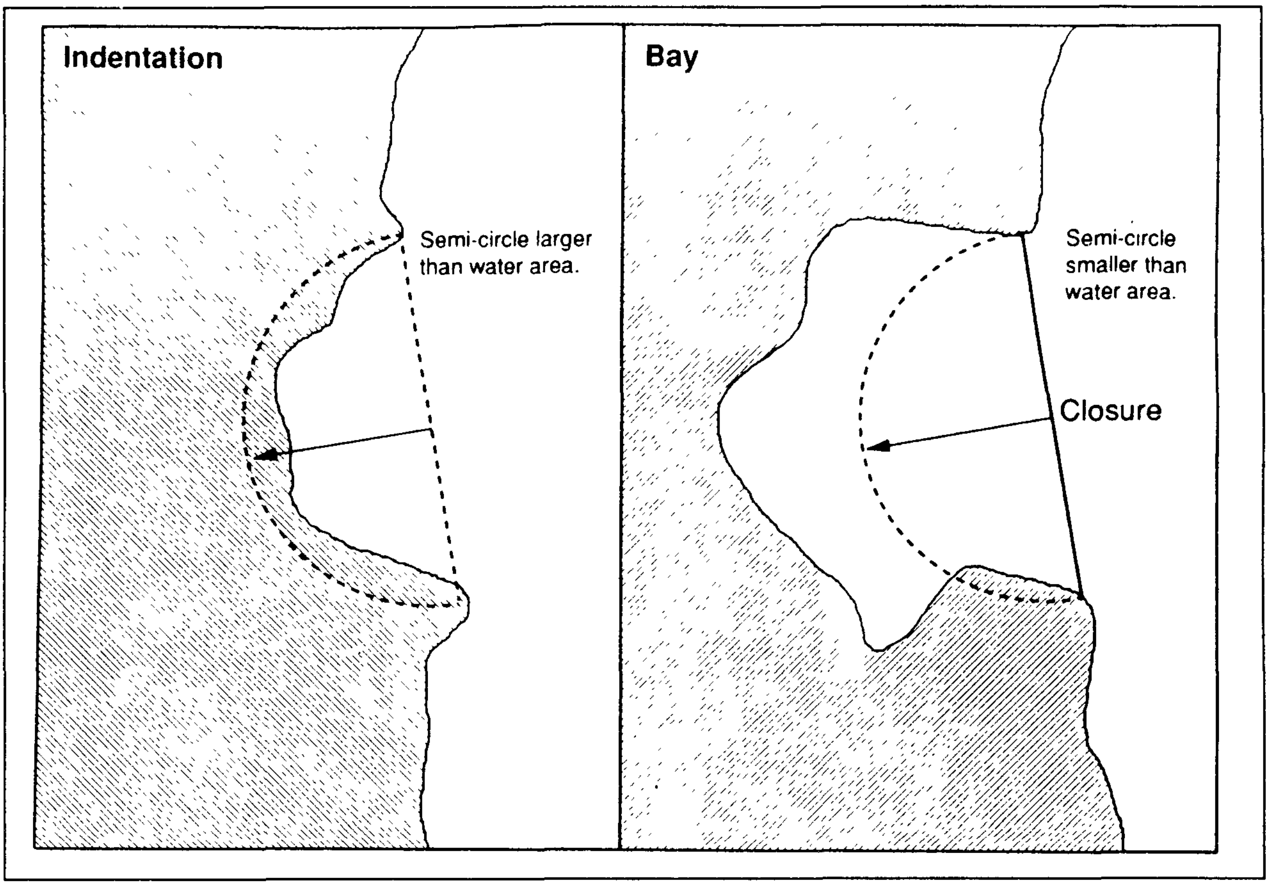


Figure 3.3 Definition of embayments for EMAP - GL (Hodgson and Alexander, manuscript).

"A bay is a well-marked indentation whose penetration is in such proportion to the width of its mouth as to contain landlocked waters and constitute more than a mere curvature of the coast. An indentation shall not, however, be regarded as a bay unless its area is as large as, or larger than, that of the semi-circle whose diameter is a line drawn across the mouth of that indentation.

For the purpose of measurement, the area of an indentation is that lying between the low-water mark around the shore of the indentation and a line joining the low-water marks of its natural entrance points. Where, because of the presence of islands, an indentation has more than one mouth, the semi-circle shall be drawn on a line as long as the sum total of the lengths of the lines across the different mouths. Islands within an indentation shall be included as if they were part of the water area of the indentation."

The lateral extent of the 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 will include to 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, will be treated as part of the general nearshore class.

Embayment minimum size will be determined from the GIS application during FY93. Preliminary examination of maps for three areas (Green Bay, southern Lake Michigan, and the Straits of Mackinac) was conducted to address this question. All of the map scales were 1:24,000 or better. Preliminary work leads to the conclusion that use of a minimum area, rather than a minimum distance across the mouth of a harbor or bay, may be appropriate. This approach would be best defined with the aid of GIS.

Evaluation of nearshore, wetland, and embayment resource class overlap will be further evaluated once these resources have been identified through the GIS application. The idea that an embayment containing an embayment would be considered in the nearshore class is just one possible outcome of our definition and not a rigid rule. Other possibilities within our definition include:

1) An "embayment" could include all resources classes - i.e., offshore, nearshore, harbors, and wetlands. Georgian Bay in Lake Huron may be such a case.

2) An "embayment" could include some nearshore area and several harbor/embayment areas. Green Bay and Saginaw Bay are good examples of this. For each of these, one of the specified harbor/embayment areas would be the major tributary mouth that is located at the head of the embayment, e.g., Fox River or Saginaw River.

3) An "embayment" could be defined as just a succession of two or more harbors/embayments in the EMAP - GL sense. In other words, a large "embayment" may be broken into several smaller harbors and/or embayments to be included in our list frame. A good example of this would be the Bay of Quinte in Lake Ontario, although Big Bay de Noc may qualify in Green Bay.

4) Some "embayments" would just be considered one harbor/embayment for our purposes. These would probably include Hamilton Harbor and Sandusky Bay.

3.4.c. Coastal Wetlands

The coastal wetland monitoring activities under EMAP - GL will be coordinated with the EMAP - Wetlands group. Wetland classification will closely follow the protocols used by EMAP - Wetlands. The general definition of a wetland provided by Cowardin et al. (1979) will be used:

> "Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. Wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soils; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of the year."

EMAP - GL will adopt the same criteria for the target population of wetlands to be monitored, that is wetlands with greater than 30% wetland vegetation cover that can be identified using 1:40,000 aerial imagery. EMAP - Wetlands are a subset of the jurisdictional wetlands as defined by the recent wetland identification criteria (Federal Interagency Committee for Wetland Delineation 1989).

The EMAP - Wetlands program has adopted a hierarchical classification of wetlands based on the Cowardin et al. (1979) system; the EMAP - Wetlands system differentiates tidally influenced wetlands with significant salinity (estuarine) from non-tidal, substantially freshwater wetlands (palustrine). Wetlands exhibiting salinity less than 0.50 ppt during average annual flow and that are not affected by tides are placed in the palustrine category and would include all Great Lakes wetlands. The palustrine category includes palustrine, lacustrine, and riverine wetlands of Cowardin et al. (1979). The EMAP - Wetlands classification system includes water source modifiers (lacustrine, riverine, and basin) and water regime modifiers, as well as vegetation classes (Leibowitz et al. 1991).

For purposes of defining the wetlands for monitoring under the EMAP - GL program, wetlands contiguous to the lakeshore and wetlands that lie within 305 m of the lakeshore will be included following Herdendorf et al. (1981). This definition recognizes the dynamic relationship between coastal wetlands and the Great Lakes; wetlands may be cut off from direct surface connection to the adjacent lake by bar or dune formation or by low lake level, but subsurface connections may be maintained and lake level may control aspects of the hydrology of nearby wetlands. Hydrologic connections with a Great Lake may extend upstream along rivers; exchanges caused by seiches and longer-period lake level fluctuations will influence riverine wetlands. Wetlands under substantial hydrologic influence from Great Lakes waters will be included in the EMAP - GL monitoring scheme.

3.5. Frame Development

In order to develop the frame for EMAP - GL, it is necessary to list the sample units for each of the primary resource categories. Depending on the spatial distribution of the resource class, either a map or a list frame will be used.

3.5.a. Offshore and Nearshore

The offshore and nearshore areas of the lakes will be determined from bathymetric maps from NOAA that have been digitized on a 2 km grid (except for Lake Superior which is available only on a 4 km grid) and are available in a Geographic Information System (GIS) format.

3.5.b. Harbors and Embayments

Harbors and embayments will be identified from United States Geographical Survey (USGS) quad maps (and the Canadian equivalent) using the definition as described previously.

3.5.c. Coastal Wetlands

A comprehensive inventory of Great Lakes wetlands is not currently available, however, Herdendorf et al. (1981) provide a catalog of wetlands along the US shoreline. Individual state and provincial efforts may have incorporated Great Lakes coastal wetlands into regional inventories. Frame development efforts in this area will continue during 1992-93 in cooperation with EMAP - Wetlands.

3.5.d. Issues

The previous discussion of approach points out issues that need to be resolved in regard to frame development. A primary question involves whether harbors and embayments should be sampled on a list frame or with an enhanced grid. Once this question is resolved, determination of where the site should be located within the bay or harbor needs to be considered. Considerable effort will need to be expended to answer these questions and it is proposed that exploration of historical data, in conjunction with GIS analysis, be conducted prior to any field work. Similarly, sampling wetlands will require an understanding of their distribution. Investigations will be conducted on the degree to which available inventories will be suitable for frame development.

There are also issues for the offshore and nearshore classes that relate to sampling for fish. Because fish populations are not fixed spatially, it may not be practical to sample fish at the same locations as the rest of the offshore and nearshore indicators. For example, if lake trout spawning success is found to be a necessary indicator of ecological condition, sampling may be conducted only at known spawning reefs. A detailed review of sampling options for fish as indicators of ecological condition will be conducted during 1992.

3.5.e. Quality of Frame

Generally, the quality of the frame is good to excellent, with the exception of the coastal wetlands. The main variable for offshore and nearshore definitions is water depth and, for the purposes of resource classification, it is obtained from bathymetric maps. USGS maps can be used to identify harbors and embayments. Some small-scale wetland inventories exist for states or provinces, but there is no current comprehensive effort for the Great Lakes basin. Until such inventories are available, the quality of the wetland frame will be uneven.

3.6. Monitoring Network Design

3.6.a. Tier 1 Sampling

The primary resource classes (offshore, nearshore, harbors and embayments, and coastal wetlands) are the Tier 1 resources for EMAP - GL. Tier 1 samples are intended to provide a frame for the Tier 2 samples as well as the scope, extent, and spatial distribution of the primary resources.

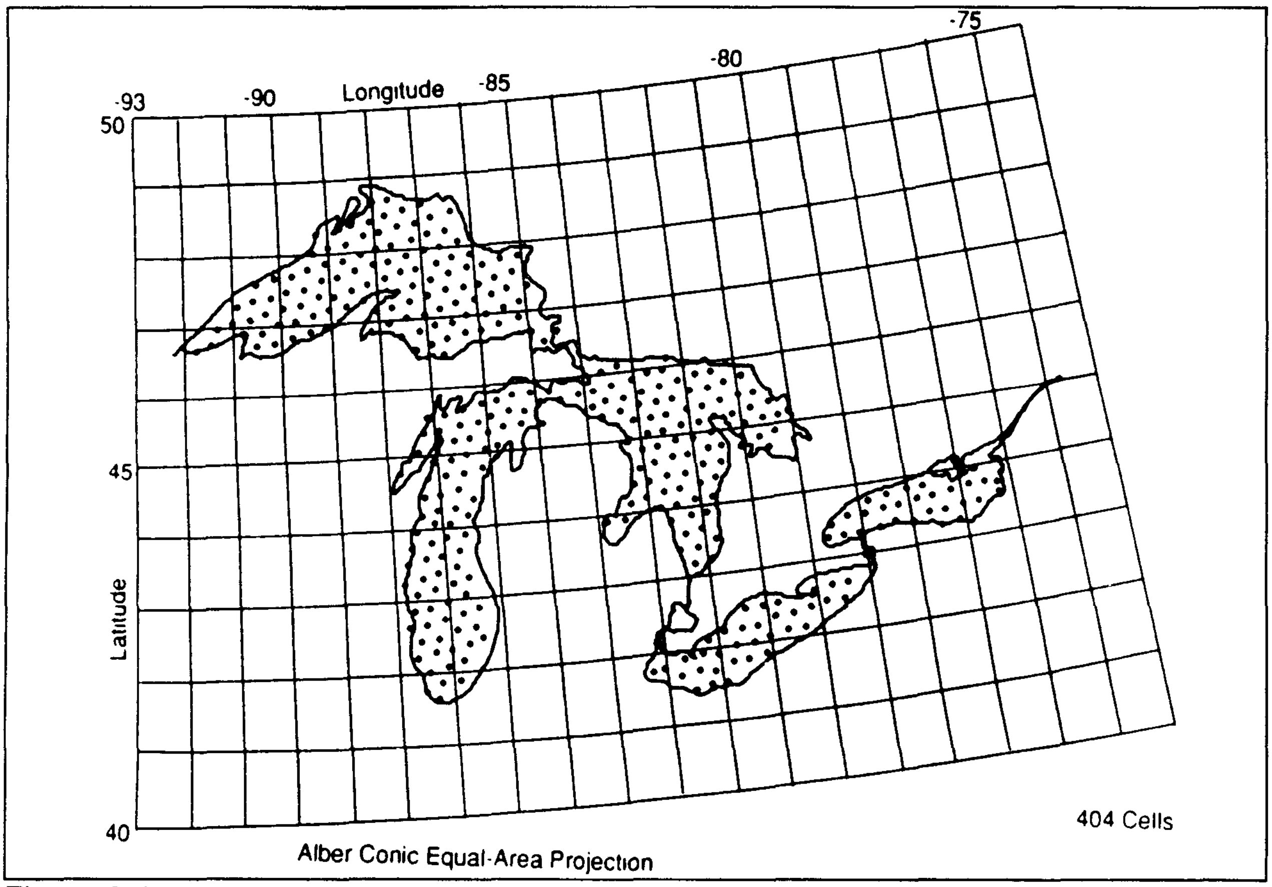


Figure 3.4 EMAP base grid cells within the Great Lakes.

Because the resources of the Great Lakes are well defined, the extent and distribution of the primary resource groups are well documented. The obvious exception is coastal wetlands. The primary uses of the Tier 1 sampling units will be to provide the frame for subsamples that are measured annually (Tier 2 samples).

3.6.b. Tier 2 Sampling

The Tier 2 sample is a subsample of the resource occurrences identified at Tier 1. For each sample frame, a methodology for sample site selection must be specified. As discussed under frame development, maps will be used to locate the appropriate resource class. In addition, association rules to determine where actual samples will be collected within the grid point will be needed for sediment and biota sampling. Figure 3.4 presents the EMAP base grid for the Great Lakes. For wetland sampling, site selection methodology will be developed in conjunction with EMAP - Wetlands. The site selection methodology for sampling in the offshore and nearshore resource classes is presented in the following sections. Sampling methods for harbors and embayments and coastal wetlands have not yet been determined.

Table 3.4 Summary of sampling grid points for the nearshore zone using the base grid, 3-fold, 4-fold, and 7-fold enhancement.

Number of nearshore grid points Lake Michigan	
Base Grid	45
3-Fold Enhanced Grid	127
4-Fold Enhanced Grid	145
7-Fold Enhanced Grid	272

3.6.c. Offshore Samples

Figure 3.5 is an overlay of the 85-m contour for Lake Michigan on the base grid. Forty-three grid points fall outside of the 85-m contour and thus, lie in the offshore resource class. Because of the rotating and interpenetrating nature of the EMAP design, a Tier 1 grid point is sampled every four years. This corresponds to 10 or 11 samples per year. This degree of sampling intensity corresponds well with the current GLISP offshore network which consists of eleven stations (Figure 3.6). As will be discussed in Chapter 10, a comparison of data between the existing GLISP stations and the proposed EMAP - GL offshore network will be initiated with studies conducted in the spring and summer of 1992.

In addition, historical data on extensive limnological surveys conducted in the Great Lakes will be investigated to determine if 10-11 samples are adequate to characterize the offshore areas. Because it is expected that insufficient data will be available for all

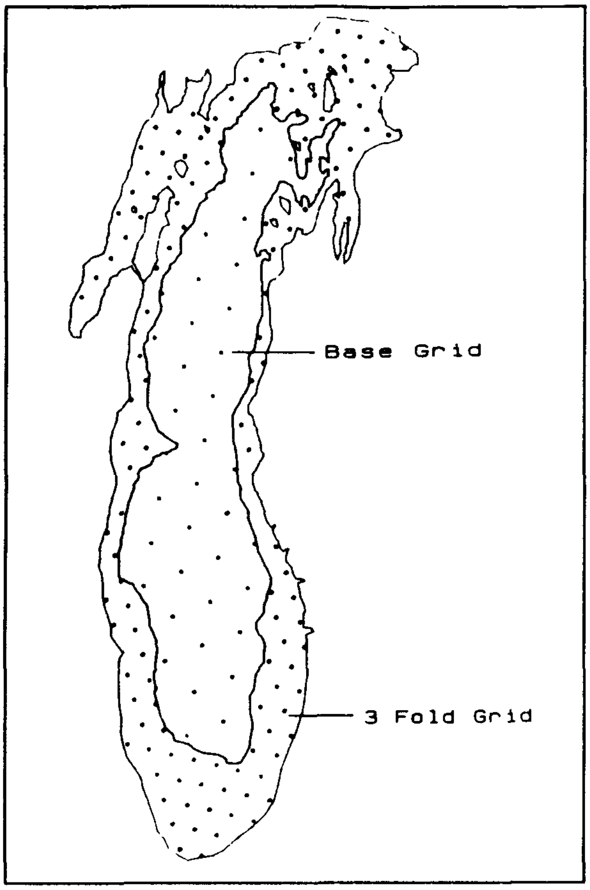


Figure 3.5 Eighty-five meter depth contour for Lake Michigan with EMAP base grid for offshore zone, 3-fold grid for nearshore zone.

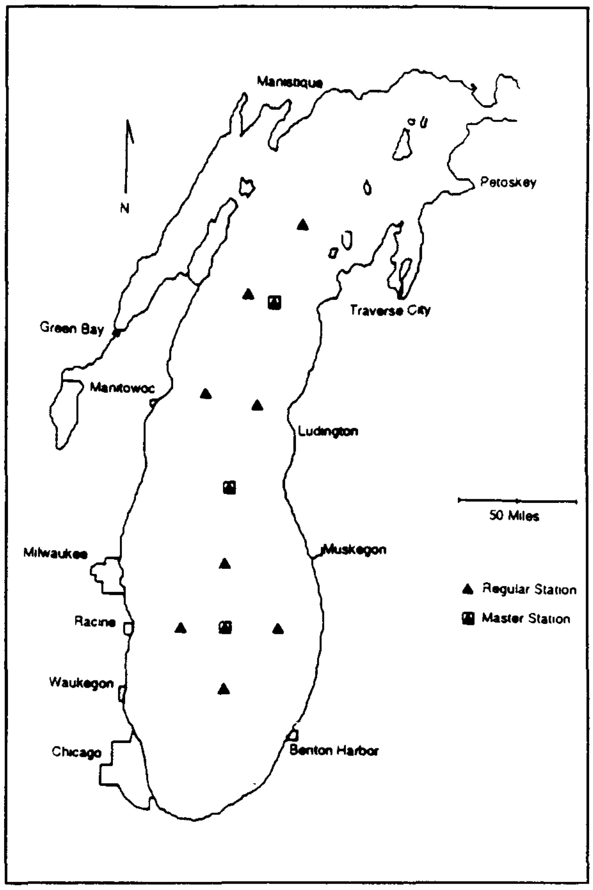


Figure 3.6 GLISP surveillance stations for Lake Michigan.

the lakes (and all indicators), more extensive sampling will probably be necessary to determine whether the base grid and rotating design will be sufficient. These studies would be initiated as part of the 1993 demonstration in Lake Michigan and the 1993 pilot in Lake Superior.

3.6.d. Nearshore Samples

The remaining base grid points (45), Table 3.4, are in water less than 85 m and would be considered nearshore sampling locations. However, with the higher spatial variability and the diverse nature of the nearshore zone, this sample size (11 per year) would not be adequate for characterization of the resource. Therefore, grid enhancement in the nearshore area is believed to be necessary. Using an enhanced grid, either 3-fold or 4-fold, would result in 30 to 40 samples per year (Figure 3.5). The next highest enhancement (7-fold) would probably result in too many sample sites in the nearshore zone. To the extent possible, existing data will be used to characterize the variability in nearshore indicators and to determine the appropriate degree of enhancement necessary to characterize the nearshore portion of the lakes.

The issue of adequate sampling intensity will continue to be investigated as EMAP - GL extends to the rest of the Lakes.

3.6.e. Harbors and Embayments

Because harbors and embayments are unevenly and widely distributed, this resource class is not sampled adequately by the base grid. There are two options being considered for this class to obtain a reasonable sample size:

Option 1 - Develop an association rule for the enhanced grid that would select harbors and embayments for Tier 2 sampling.

Option 2 - Develop a list frame of harbors and embayments and, by systematic random sampling, select a subset as the Tier 2 sample.

3.6.f. Coastal Wetlands

Because wetlands are unevenly and widely distributed, this resource class is not sampled adequately by the base grid. There are two options being considered for this class to obtain a reasonable sample size:

Option 1 - Develop an association rule for the enhanced grid that would select wetlands for Tier 2 sampling.

Option 2 - Develop a list frame of wetlands and, by systematic random sampling, select a subset as the Tier 2 sample.

3.6.g. Tier 3 for EMAP - GL

As discussed in Chapter 2, most of the emphasis for the early stages of EMAP in the Great Lakes will be placed on the Tier 2 level of sampling. Tier 3 is intended to represent activities resulting in the detailed diagnostics of subpopulations of interest (Figures 2.1 and 2.2). The Great Lakes region has, however, a subpopulation already identified that would logically fall into the Tier 3 category. Through international agreements, some 43 Areas of Concern (AOC) on the Great Lakes have been identified as locations with special problems (see Figure 4.2). Federal, state, provincial, and local groups are responsible for establishing Remedial Action Plans (RAPs) for each of these areas. Establishing a monitoring program to determine the improvements that result from implementing these RAPs is an essential component of the plan. We propose that including RAP monitoring activities into EMAP Tier 3 would be a logical umbrella to both put the RAP monitoring plans into a larger lakewide context and to provide a component of continuity between RAP sites. Thus, EMAP would assist other agencies in coordinating monitoring activities at AOC locations by establishing a consistent design and some key indicators to be measured at all sites.

3.7. Field Sampling Design

Because EMAP emphasizes regional coverage, the program has adopted an index sampling regime. Index sampling targets one (or a very few) sampling times within each lake, limiting temporal coverage to maximize spatial coverage with available resources. The spatial coverage is important because EMAP is interested in the regional pattern of indicators rather than conditions at individual sites. An ideal index period occurs when the values of the indicators are relatively stable, when indicator biota are present and measurable, and during a season of maximum stress. Because multiple indicators will be used, it will not be possible to select an index time that is optimal for all indicators and possible stresses. Indicators that integrate over annual cycles (or some other critical period) would be most desirable.

Index sampling should not be confused with indicator indices which are calculations of a metric from basic indicator measurements. Measurement of indicators and the use of indicator indices will be discussed in Chapter 4.

4. Indicator Development and Evaluation

4.1. Introduction

The process of indicator development and evaluation addresses the issues of selecting and using a set of measurements to assess the ecological condition of each of the Great Lakes. The process is defined by the goals of EMAP - GL which emphasize regional assessments of the ecological condition of the Great Lakes. This section encompasses a wide range of topics, including what organisms and chemical or physical features to target for each resource class, when to sample, and how to convert the measurements into meaningful assessments of ecological condition.

This overview of EMAP - GL indicators includes selection criteria, currently proposed indicators, and a strategy for the continuing process of selecting, developing, evaluating, and using indicators. The initial results of analyses of existing data which begin to tie the design features to the indicators are presented. Before any field work is performed, operations manuals (laboratory and field methods, quality assurance, field implementation) will be prepared.

4.2. Conceptual Framework for Indicators of Condition

Assessments of the Great Lakes condition must relate to values and problems of present or potential concern to society. These issues are referred to as endpoints of concern, and are reflected in the ways the Lakes are managed. For EMAP - GL, these values or endpoints are trophic state and biotic integrity.

The development and evaluation of indicators for EMAP - GL can take advantage of several existing features of research and monitoring in the Great Lakes. First, a great deal of ecological assessment work has been conducted on the Great Lakes in the past, and the basic physical, chemical, and biological characteristics are fairly well known, particularly in the relatively homogenous offshore waters of the upper Great Lakes (Superior, Michigan, and Huron). For example, fish species diversity, which has been used as an indicator in many inland lakes and streams, would be much less useful in the offshore waters of the Great Lakes due to the low rates of emigration and immigration and the resultant low diversity. Therefore, fish community indicators which focus on individual species, particularly top predators, on certain trophic levels (e.g., forage fish), or on discrete species assemblages, would be more directly applicable to the Great Lakes.

Second, in the Great Lakes, much of the framework for assessing ecological condition using indicators has been established. The concept of using indicators as "top-down" measures of ecological condition or integrators of ecosystem health is not new to the Great Lakes. Revisions to the Great Lakes WQA in 1978 emphasized a broad ecosystem approach to managing the Great Lakes and mandated the development of specific biological and chemical objectives which would aid in restoring and

Table 4.1 Indicators being considered for EMAP - GL.

Response Indicators
Fish pathology
Aquatic vegetation
Lake trout recruitment
Forage fish populations
Lake trophic status index
Lake trout/walleye populations
Diporeia/Hexagenia abundance
Chlorophyll composition in water
Diatom abundance in sediment cores and traps
Benthic macroinvertebrate community structure
Exposure Indicators
N:P and Si:P Ratios
Contaminant residues in fish
Zebra mussel/exotics abundance
Sediment toxicity to *Hyallela azteca*
Water column toxicity to *Ceriodaphnia*
Contaminants in sediments from cores and traps
Habitat Indicators
Sediment physical characteristics
Water column optical characteristics
Temperature, pH, routine water chemistry
Stressor Indicators
Resource management
Human population densities
Atmospheric deposition rates
Landuse and landcover surveys
Agricultural chemical application rates
Point and nonpoint source pollutant loading

maintaining balanced, stable oligotrophic and mesotrophic ecosystems (Cairns et al. 1991). Indicator development related to this objective has focused on the development of surrogate organisms, that is, species which integrate physical, chemical, and biological properties of the ecosystem (Ryder and Edwards 1985). Surrogate organisms have been proposed for both oligotrophic (Edwards et al. 1990, Ryder and Edwards 1985) and mesotrophic (Edwards and Ryder 1990) waters of the Great Lakes. The indicator development and evaluation process for EMAP - GL has relied heavily on this past work and embraces the tenet of the ecosystem approach under which the work was conducted.

Nearshore waters have comparatively less information and coastal wetlands are poorly known. It is recognized that only a few studies have examined the aquatic animal or plant community composition, or chemical, physical, and biological functions of coastal wetlands on the Great Lakes. Coastal wetlands are dynamic systems, changing in area and configuration with long-term Lake levels. Aside from the areal dynamics of these systems, very little is known about their general ecology or linkages to either adjacent uplands or pelagic waters. The general lack of information on Great Lakes coastal wetlands confounds the easy choice of indicators of system condition. Indicator development for wetlands will necessarily lag behind that of other resource classes.

EMAP has defined four types of indicators: response, exposure, habitat, and stressor. It is important to understand that these categories provide a conceptual framework which acts as a tool to guide the process of selecting, evaluating, and implementing the actual measurements used to assess ecological condition. These categories are not meant to be rigid boxes in which each measurement type may serve only one function. The definitions are:

- Response indicators are derived from measurements that describe the biological condition of organisms, populations, communities, or other components or processes of the aquatic ecosystem as they relate to the endpoints of concern (trophic state, biotic integrity). Response indicators are the focal points upon which the health of the Great Lakes will be assessed. The measurements should be amenable to quantifying the integrated response of the ecological resources to individual or multiple stressors. Response indicators should clearly relate to aspects of the environment valued by the public, including the scientific community. Response indicators may also be chosen to identify problems, such as accelerating eutrophication or decreasing recruitment in fish populations.

- Exposure indicators are intended to serve a diagnostic function when measured in conjunction with response indicators. They are used to identify the likely causes of impaired conditions as detected by the response indicators. The exposure and habitat indicators are characteristics of the aquatic environment that give evidence of the occurrence and magnitude of a response indicator's contact with a physical, chemical, or biological impact. Historically, Great Lakes monitoring has primarily evaluated water quality, i.e., measures of physical and chemical characteristics of surface waters. These assessments have largely relied on what we have called exposure indicators.

- Habitat indicators are attributes that describe the physical conditions of the environment that are necessary to support the integrity of the biological community.

- Stressor indicators quantify a natural process, environmental hazard, or management activity causing change in exposure or habitat. They can be thought of as characterizing the sources of exposure. Some examples include landuse and landcover, pesticide application rates within the watershed, human population densities, and export of pollutants. Sources of information for stressor indicators proposed for EMAP - GL include: landuse and landcover surveys, human population density, atmospheric deposition rates, agricultural chemical application rates, point source pollutant loading, presence of introduced species, and stocking and harvest records.

The primary role of exposure, habitat, and stressor indicators within EMAP is to identify the probable causes for impaired conditions. In addition, habitat indicators may be used to normalize response indicators. For further discussion of the use of ecological indicators in EMAP refer to Hunsaker and Carpenter (1990). Table 4.1 presents indicators currently being considered for use in EMAP - GL.

4.3 Strategy for Indicator Development and Implementation

Given the spatial, temporal, and ecological enormity and complexity of EMAP - GL, it is essential to have a basic strategy that defines a process and a set of goals and criteria by which to evaluate whether the steps have been successfully completed. Each phase in the general strategy can be expanded to include as much detail as needed to assure achievement of its goals. The following strategy has been modified from the overall EMAP indicator strategy (Hunsaker and Carpenter 1990).

The indicator development strategy (Figure 4.1) does not propose a linear process. Instead, there may be considerable branching and feedback to previous steps. Some indicators may progress relatively quickly to full implementation, while others may progress slowly for many years. There are six basic phases:

- Identify environmental values and apparent stressors.

- Develop a set of candidate indicators which are linked to endpoints of concern and responsive to expected stressors.

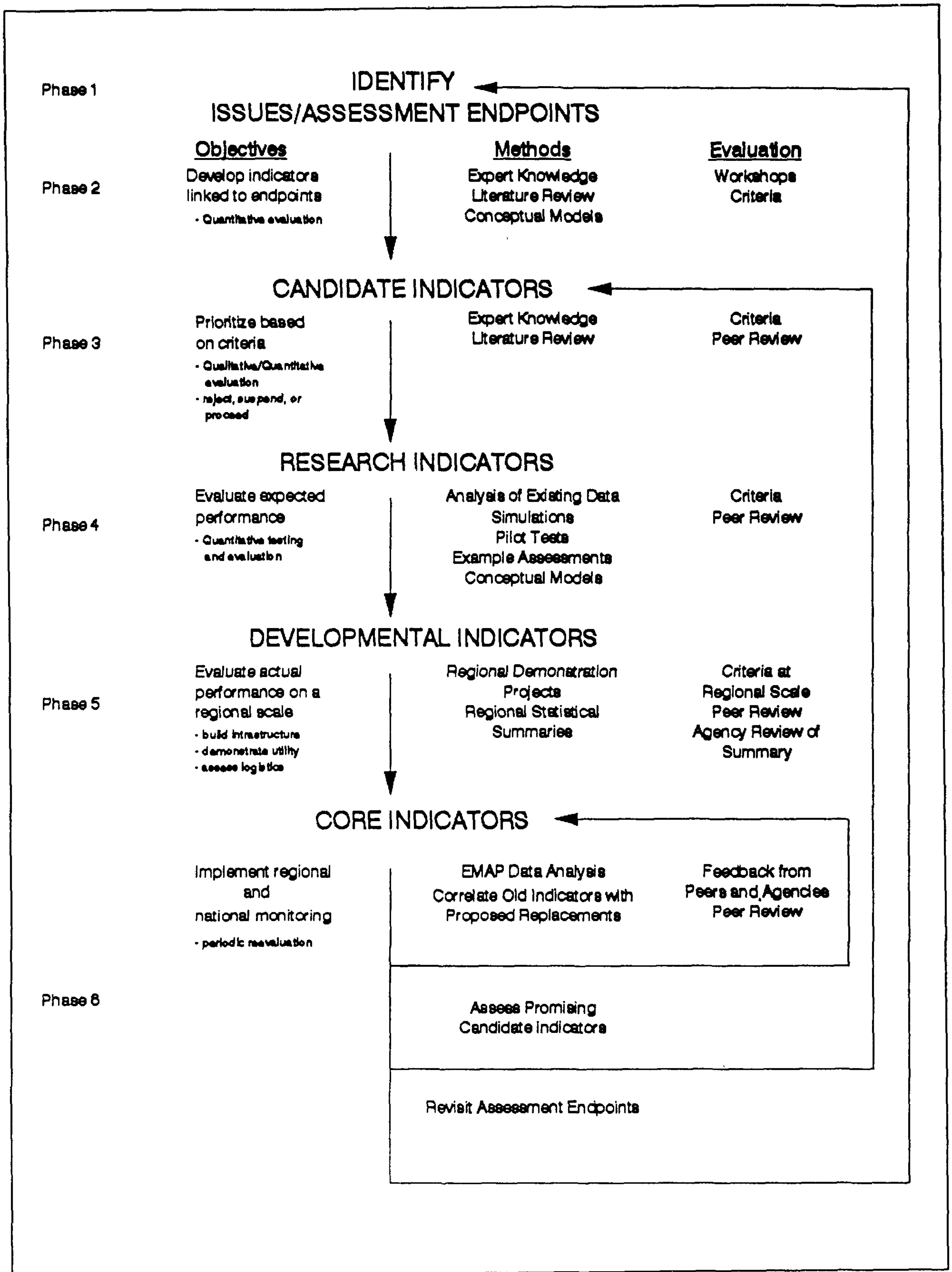


Figure 4.1 Indicator selection, prioritization, and evaluation approach for EMAP (Hunsaker and Carpenter 1990).

- Screen candidate indicators to select research indicators with reasonably well-established databases, methods, and responsiveness.

- Quantitatively evaluate expected regional scale performance of research indicators to identify developmental indicators for regional demonstrations.

- Demonstrate developmental indicators on a regional scale, using the sampling frame, methods, and data analyses intended for full (core) implementation.

- Implement core indicators with annual sampling and data analyses, and periodic reevaluation of indicators.

The first two phases are meant to generate ideas for endpoints and indicators. These two phases encourage broad-scale, lateral thinking, with a focus on breadth rather than depth of coverage, and may be revisited at any time. Essentially, EMAP - GL has completed the first pass through phases 1 and 2, using a series of meetings, informal literature reviews, and exploratory data analyses.

Phases 3 to 5 are oriented toward critical evaluation and integrative filtering of the candidate indicators down to a defensible, practical set of core indicators. Where phases 1 and 2 are inclusive, these three phases focus on excluding indicators that are currently not feasible within EMAP and on documenting the value of those selected.

As noted earlier, the development of indicators for Great Lakes coastal wetlands will lag behind other resource classes; the dynamic nature of coastal wetlands and general lack of comprehensive information on the hydrologic, chemical, and biological features of these systems require careful consideration. The EMAP - Wetlands program has suggested candidate wetland indicators for measuring long-term response and exposure. The general classes of indicators include: wetland extent, landscape indicators, hydrologic indicators, sediment characteristics, community composition and abundance of vegetation and animal biota, chemical contaminants, bioaccumulation in tissues, and nutrients in sediment or plant tissues (Leibowitz et al. 1991). The list of EMAP - Wetlands candidate indicators will be used as a starting point to identify appropriate indicators for Great Lakes coastal wetlands. A panel will be convened to consider ways to tailor this list of candidate indicators and discuss new indicators that are appropriate to the needs of the EMAP program for monitoring Great Lakes coastal wetlands. The panel will be drawn from academic and governmental scientists having experience with Great Lakes coastal wetlands, including water quality, sediment, vegetation, wildlife, hydrodynamics, and landscape ecology. The panel will also identify ways that Great Lakes coastal wetlands can be partitioned by functional type, facilitating a cyclic sampling of representative wetlands.

4.3.a. Establishing Nominal Condition

The process of selecting and implementing indicators cannot be separated from the problem of how the data will be used to make statements about the ecological condition of the lakes. The question is one of establishing the criteria that can be used to separate nominal from subnominal. In other words, determining the value of an index or metric score below which a region is considered to be in an unacceptable condition, relative to a particular endpoint of concern. Some of the approaches to establishing these criteria include selecting and assessing reference sites, using ecological models, and basing the criteria on the empirical distribution of indicator values.

EMAP - GL will interpret ecological condition based on a combination of these approaches, relying on a series of regional reference sites (Hughes et al. 1986, Hughes 1989) and historic condition as described through paleolimnological reconstructions, benthic surveys, commercial catch records, and other applicable data. This will allow integration of professional judgement, an understanding of historical or pristine conditions, and knowledge of current ecosystem research to select the least disturbed (most natural) but typical sites of a region. If reference sites can be identified, the response indicator values, and the statistical variability found can be used to develop the nominal conditions for the region. It will also be useful to examine the range of stressors impinging on the Tier 2 sites and to purposely select additional sites to ensure that the model of severely impaired systems is well defined.

Another option for determining whether a system is impaired is through one or more ecological models. Models may be based on field data for a variable or set of variables, complex ecosystem studies, or laboratory toxicity tests. Empirical models that identify relationships are an effective tool for establishing criteria. Habitat classification models should be useful for assessing exposure and habitat indicators. As EMAP - GL progresses, models that are applicable to these systems will be incorporated into the data interpretation process and used to refine criteria.

In many respects, the definition of acceptable conditions is a social, as well as a scientific one. Our intent in EMAP - GL is not to defend any specific value as the one and only value but rather to participate in the discussion on how to objectively establish this criterion. EMAP will produce data that can provide the foundation for the assessment and take part in the technical discussion on establishing scientifically and socially desired boundaries.

4.4. Response Indicators

The process of selecting indicators has been complex, governed by EMAP's emphasis on ecological response and on broad scale assessments. It has been guided by consultations with other professionals in aquatic ecology, and examination of available databases and the scientific and management literature. Table 4.2 lists a chronology of EMAP indicator development for the Great Lakes. Much of the effort has been placed on response indicators, which address the first of the EMAP objectives. The discussions below are not intended to be a review of existing literature but rather a summary of plans to use various taxa and indicators. Appendix B of this report provides detailed indicator fact sheets for EMAP - GL.

EMAP - GL has several general criteria for evaluating the usefulness of response indicators. The response indicators should be biological and incorporate elements of ecosystem structure and function; the selected indicators should correlate with changes in other unmonitored biological components; they must have clear connections with the endpoints of concern and must be responsive to a broad array of potential stressors. An ideal indicator is applicable in lakes of similar productivity in each of the Great Lakes; sensitive to varying levels of stress; cost effective, providing considerable information in a limited amount of sampling time; easily implemented; and provide reproducible results with low sampling variability.

Table 4.2 Chronology of EMAP indicator development for the Great Lakes.

*	April 1991. EMAP - GL Research Planning Committee formed from specialists in fields related to indicator development.
*	April-May 1991. Weekly conference calls of the Research Planning Committee. Potential indicators suggested and a list of potential indicators developed.
*	May 1991. First Indicator Development Workshop. List of potential EMAP - GL indicators modified and discussed. Literature reviews and development of indicator fact sheets developed out of this workshop.
*	May-August 1991. Weekly conference calls of the Research Planning Committee.
*	August 1991. Second Indicator Development Workshop. Following literature reviews and discussion between Research Planning Committee members and experts in fields related to the proposed indicators, selection of candidate indicators finalized.
*	August 1991 - Present. Weekly conference calls of the Research Planning Committee. List of candidate indicators reviewed and updated following consultation with experts. Sampling logistics and schedules for the pilots on Lakes Michigan and Superior in FY92 suggested and discussed.

4.4.a. Fish Indicators

Fish indicators will be used as indicators of biotic integrity, providing information on population abundance, recruitment, pathology, forage base, and average condition of individuals.

This section presents a highly simplified outline of the changes in the composition of some Great Lakes fish stocks during the last century. More detailed information for all of the lakes can be found in Christie (1974), Hartman (1988), and Rathke and McRae (1990); and for each lake individually in Christie (1973; Lake Ontario), Hartman (1973; Lake Erie), Wells and McClain (1973; Lake Michigan), Berst and Spangler (1973; Lake Huron), and Lawrie and Rahrer (1973; Lake Superior).

The Great Lakes contain the largest and most valuable assemblage of freshwater fish resources in the world (Hartman 1988). Yet the fish communities in the Great Lakes today are drastically different than those found around 1800, before intensive settlement began in the basin (Ryder 1972). Ryder and Edwards (1985) characterize today's Great Lakes fish communities, relative to those of the distant past, in the following manner:

> "...as a generalization, the fish communities of the Great Lakes today are of smaller mean size, comprised of species more dependent on the pelagic zone and lacking large species that formerly were abundant in rivers and near-shore zones, including large terminal predators and benthic feeders."

Historically, the upper Great Lakes supported a coolwater salmonid community, including salmonines (salmon, trout, chars), a large benthic predator (the burbot), and a coregonine complex (whitefish, ciscoes, chubs) that consisted of perhaps eleven species in Lake Michigan (Koelz 1929) and slightly fewer species in Lakes Superior and Huron. The species complex of prime importance was that of the lake trout. Many different lake trout stocks, including several river-run stocks (Loftus 1958), occupied much of the basins of these lakes where they preyed primarily on a complex assortment of coregonine taxa, as well as on other fish species and invertebrates (Eschmeyer 1957, Goodier 1981).

Lake Erie is distinct from the upper Great Lakes in that it has a shallower basin and much higher levels of natural nutrient loading. Consequently, in its pristine state it was probably mesotrophic rather than oligotrophic in nature (Beeton 1961, Ryder 1972). As a result, percid species including the walleye, blue pike, sauger, and yellow perch dominated the Lake Erie fish community, particularly in the western and central basins. Lake trout were moderately abundant at one time in Lake Erie, particularly in the deeper eastern basin (Applegate and Van Meter 1970). However, it is likely that only one stock of lake trout existed in Lake Erie due to a low level of environmental heterogeneity (Ryder and Edwards 1985). Lake Erie has historically sustained the most productive commercial fishery in the Great Lakes, with its yield generally exceeding the combined yields of the other lakes (Baldwin et al. 1979).

Like Lake Erie, Lake Ontario also has a relatively high level of natural nutrient loading relative to the upper Great Lakes (Beeton 1965). The indigenous fish community of Lake Ontario somewhat resembled that of the upper Great Lakes, except for the presence of euryhaline marine species, notably the Atlantic salmon and American eel, which became established due to the lake's natural connection with the Atlantic Ocean (Christie 1972).

The presettlement environments of many of the larger bays in the Great Lakes were probably similar to that of the eastern basin of Lake Erie today (i.e., late oligotrophic or early mesotrophic), with some being more oligotrophic (e.g., Thunder Bay and Keweenaw Bay of Lake Superior) or more mesotrophic (e.g., Saginaw Bay in Lake Huron, the Bay of Quinte in Lake Ontario). Fish communities in these large bays ranged from a typical coldwater salmonid community (similar to that found in the Upper Lakes) to a coolwater, mesotrophic percid community (Ryder and Edwards 1985). Naturally eutrophic conditions and their typical warmwater centrarchiddominated communities were probably relatively rare in much of the Great Lakes proper except for some tributaries to Lake Erie and their deltas, or along sheltered shorelines in small bays.

The appearance of the sea lamprey in the upper Great Lakes in the 1940's and 1950's (Table 4.3) sequentially reduced the already over-exploited stocks of lake trout to virtual extinction in Lakes Huron and Michigan and to near extinction in Lake Superior. Lake trout stocks in Lakes Erie and Ontario were well on their way to collapsing by this time, primarily due to uncontrolled fishing effort and overharvest. Burbot stocks were also decimated by the sea lamprey. Elimination of these top predators resulted in an explosion of various forage species, particularly those comprising the coregonine complex, which radiated from their former predation refugia and spread to areas of the upper Great Lakes where they did not traditionally occur in high abundance (Ryder and Edwards 1985). In the absence of predation pressure, many of these coregonine stocks began to interbreed, losing their identity and creating an ever-changing assemblage of forage species. Further complications arose with the introduction and invasion of two exotic species, the rainbow smelt and the alewife (Table 4.3). These two species quickly became abundant in most areas of the Great Lakes and eventually came to dominate the forage fish assemblages in all of the lakes. Four species of Pacific salmon (coho, chinook, pink, kokanee) were stocked beginning in the mid-1960's, partly in response to the tremendous forage base provided by the alewife and smelt. These stockings were in addition to numerous introductions of two non-native trout species, the rainbow and brown trout, which had been stocked over the years in the Great Lakes. All of these introduced salmonines, except perhaps the kokanee, have reproduced to some extent in some of the Great Lakes, but populations of Pacific salmon are still maintained through large stocking programs. Other species of fishes continue to be introduced or invade the Great Lakes (Table 4.3). The ruffe, a European percid, has been established in the St. Louis River estuary (Lake Superior) since at least 1987 (Pratt 1988) and the white perch, a European percicthyid, has become established in parts of Lakes Ontario, Erie, Huron, and possibly Superior (Hartman 1988).

Table 4.3 Chronology of first appearance of certain exotic species in the Great Lakes.

Lake	Rainbow Smelt	Sea Lamprey	Alewife[1]	White Perch	Ruffe[5]
Ontario	1929[2]	1850[3]	1860	1950	--
Erie	1932[4]	1921[1]	1931	1953	--
Huron	1925[2]	1932[1]	1933	1980	--
Michigan	1923[2]	1936[1]	1949	--	--
Superior	1930[2]	1946[1]	1954	--	1986

[1] Christie (1974), [2] Van Oosten (1937), [3] Lark (1973), [4] Trautman (1957), [5] Pratt (1988)

It is apparent from the above discussion that the present fish communities in the Great Lakes are highly dynamic, astatic assemblages (Ryder and Kerr 1978, Ryder et al. 1981). These characteristics create special problems in the development of fish community indicators for EMAP - GL. A goal of restoring Great Lakes fish communities to a pre-settlement state, for example, is not attainable because exotic species such as the alewife, smelt, and Pacific salmon have come to dominate their trophic levels in many areas, and extinct species, such as the blue pike in Lake Erie and the Atlantic salmon in Lake Ontario, represent gene pools which can never be re-established.

Table 4.4 Proposed oligotrophic fish community metrics for EMAP - GL.

*	Number of fish of a given species or group per trawl tow
*	Catch per unit effort with various sampling gear
*	Target biomass for certain species or groups
*	Mean weight of individual fish at capture
*	Mean condition factor (W=weight; L=length; W'=weight predicted from historical regression): a. Standard Condition Factor (K): $K=W/L^3$ b. Relative Condition Factor (K_n) $K_n=W/W'$
*	Percentage of native juvenile lake trout caught in assessment gear
*	Percent occurrence of external tumors (gross external pathology)
*	Production/Biomass ratios
*	Species ratios
*	Commercial yields
*	Sport fishing yields
*	Age/size structure of populations

The proposed oligotrophic fish community indicators for EMAP - GL (Table 4.4) focus on the lake trout. An extensive evaluation of the lake trout as an indicator was performed under the auspices of the IJC and the Great Lakes Fishery Commission by the Work Group on Indicators of Ecosystem Quality (Ryder and Edwards 1985). The rationale for using the lake trout as an indicator was cited by the work group, some of which is summarized below.

1) During the early days of settlement in the Great Lakes Basin, lake trout were widely distributed in Lakes Superior, Michigan, Huron, Ontario, and the eastern basin of Lake Erie; an area that represented about 95% of the total surface water of the Great Lakes Basin.

2) In general, lake trout move extensively throughout the aquatic system of the Great Lakes Basin and consequently, are exposed to a multitude of natural stresses found in oligotrophic systems.

3) The lake trout is an excellent integrator of oligotrophic biota by virtue of its function as the major terminal predator over most of the Great Lakes Basin.

4) The environmental requirements of lake trout (e.g., temperature, dissolved oxygen, habitat) are widely documented in the Great Lakes.

5) Lake trout, as top predators, may be expected to bioconcentrate certain toxic substances that may appear at levels too low to detect in lower trophic levels. Subdetectable concentrations of toxic organic substances in the environment may eventually be back-calculated on the basis of lake trout tissue analysis (Connolly and Thomann 1982, McNaught 1982, Rodgers and Swain 1983).

6) The reproductive and early life history stages of the lake trout are especially vulnerable to environmental stresses. The inability of lake trout to produce or to sustain progeny to fishery recruitment stages provides both an early-warning and a retrospective indicator of ecosystem impairments.

7) Historic data series exist on the abundance of the lake trout in each of the Great Lakes in the form of commercial catch statistics. Some of these data series extend well back into the 1800's. Recent commercial data series combine catch and effort statistics as an index of abundance, demographic characteristics of lake trout stocks and fecundity and food habits. Other studies detail reproductive success, location and quality of historic spawning grounds, incidence of sea lamprey attack, movements, stock diversity, genetic characteristics, and contaminant burdens.

8) There are ongoing programs of lake trout sampling by federal government agencies in both the United States and Canada, by several states and the province of Ontario, which are coordinated by the Great Lakes Fishery Commission and the IJC. These programs assess lake trout abundance, recruitment, feeding habits, movements, contaminant burdens, spawning location and behavior, and many other factors important to the maintenance of healthy stocks.

The proposed mesotrophic fish community indicators for EMAP - GL focus on the walleye. The suitability of walleye as an indicator of mesotrophic ecosystem health was evaluated by the Mesotrophic Indicators Work Group under the auspices of the IJC (Edwards and Ryder 1990). It is within these geographic regions where the use of the walleye as the principal fish community indicator is proposed.

The notion of harmonic fish communities was first developed from empirical data on several unperturbed mesotrophic lakes in the boreal forest region (Ryder and Kerr 1978). In this region, in which the community structures were assumed to be similar to those immediately following glaciation, the fishes were found to be highly similar in both kind and proportion from lake to lake. The term "harmonic community" implies high integration among species, high levels of stability, effective resilience to exogenous stresses and appropriate complexity, as well as moderately constant community composition and Production/Biomass ratios. The harmonic community concept was used by the Mesotrophic Indicators Work Group to develop desirable characteristics of harmonic components (walleye, yellow perch, northern pike, white sucker) for use as indicators of ecological condition in mesotrophic regions of the Great Lakes (Edwards and Ryder 1990). Table 4.5 presents those properties of harmonic mesotrophic fish communities identified by the IJC workgroup.

Tumor incidence may be an important indicator for harbors and embayments. These areas (particularly AOCs) are considered to be among the most contaminated by persistent chemicals, and tumors in fish are a highly visible indicator to the general public. There are, however, a number of technical issues related to sampling and interpretation of results. The difficulties of sampling fish have previously been discussed. A sampling program specifically for tumors is particularly difficult because incidence is almost always very low, even in contaminated areas. The problem encountered when investigators are unable to collect fish from specified locations is especially difficult to reconcile. If toxic chemicals are present at toxic concentrations, exposed fish might die or otherwise avoid an area.

A negative response in a tumor survey is also difficult to interpret because the exposure history of the sampled fishes cannot be determined. While fish movements occur in generalized species-specific patterns, estimating the quality or quantity of an exposure is impossible without the use of some other measure of exposure. Nonetheless, the investigation of abnormal pathology has been included in the EMAP - Estuaries program (Weisberg et al. 1991). While the overall incidence of abnormal pathology was low, they have found greater incidence in small estuaries than in other classes sampled particularly with bottom dwelling fishes. Thus, this indicator, coupled with measures of sediment toxicity, was useful in interpreting the relative condition of classes within EMAP - Estuaries as well as in suggesting chemical contamination as the cause of degradation.

The use of acoustic techniques for enumerating fish populations is potentially useful in an EMAP - GL context. Hydroacoustic techniques have been used, fairly successfully, to enumerate pelagic planktivores in Lake Michigan (Brandt et al. 1991). However, the selection of appropriate fish community indicators for EMAP - GL has not been finalized, and until indicators are selected, it is difficult to assess the applicability of acoustic enumeration techniques. In addition, there are many limitations associated with present-day acoustic technology which may preclude its immediate use in EMAP - GL. These include: little or no sampling capability near the bottom and surface, and uncertainty of target strength values (Brandt et al. 1991; Thorne 1983). Present day technology is such that all fishes in a mixed-species assemblage must be assumed to have a particular fish length to acoustic-scattering relationship. Until these relationships are established for individual species in the Great Lakes, the use of hydroacoustics for species-specific enumeration will only be possible when considered in concert with ground truth data obtained by traditional sampling methods (i.e., bottom trawling).

Because of the extensive activity in the Great Lakes to measure fish populations, it is proposed that decisions on the indicators to be selected for EMAP - GL be delayed until a more comprehensive evaluation of existing data can be made during 1992 (refer to Chapter 10). The applicability of concepts such as the harmonic community and the indicators listed in Table 4.1 (i.e., lake trout/walleye populations, lake trout recruitment, forage fish populations, and gross pathology) should be considered very tentative until this evaluation is completed.

We will also actively coordinate our work on fish indicators with the expertise and ongoing programs of the U.S. Fish and Wildlife Service and the Great Lakes Fisheries Commission. These programs include surveys of non-game fish populations. The ability to use existing information or modifications of existing approaches will be fully considered before any additional sampling efforts are initiated by EMAP - GL. We do not want to unnecessarily add new monitoring of fish populations in the Great Lakes.

Table 4.5 Ecological properties of harmonic fish communities and astatic assemblages in mesotrophic waters of the Great Lakes (from Edwards and Ryder 1990).

Ecological Property	Harmonic Community	Astatic Assemblage
Integration	High degree of integration among indigenous species	Random and loose linkage, particularly when exotics present
Stability	Retains semblance of steady-state	Highly variable
Resilience	Rapid returns to steady-state following topological distortion	Descriptive identity not possible over time
Identity (Persistence)	Retains species identity following topological distortion	Descriptive identity not possible over time
Species ratios	Moderately constant	Changing
Production/Biomass community ratio	Circa 0.3	0.1-1.0 (variable)
Yields	Predictable and constant	Highly variable
Resistance to invasion	Moderately resistant under natural regime	Prone to invasion
Size composition	Slight overlap of niche	High levels of space contention along some niche dimensions
Complexity	Optimal biotic complexity	Biotic complexity suboptimal or uneven
Resource utilization	Maximal	Variable and unpredictable

4.4.b. Targeted Invertebrate Populations

In addition to fish community indicators, EMAP - GL will also use indicator organisms occupying mid-levels in the food web. In oligotrophic regions, abundance of the amphipod crustacean, *Diporeia*, is proposed as an indicator. *Diporeia* responds to a variety of stresses and its level of response may be easily quantifiable in terms of absolute or relative abundance (Ryder and Edwards 1985). For example, when cultural eutrophication occurs in an ultra-oligotrophic system, *Diporeia* first increases in abundance as a general response to increased nutrient levels and then decreases when its nutrient optimum is surpassed. This observation is readily made through the use of standardized sampling methods for *Diporeia*, which assess standing stocks in terms of numbers and biomass (e.g., Alley and Anderson 1968, Freitag et al. 1976, Marzolf 1964).

In mesotrophic regions, abundance of the burrowing mayfly, *Hexagenia*, is proposed as an indicator. The use of *Hexagenia* as a benthic indicator would complement walleye as a pelagic indicator. This mayfly is an important food item for both subadult and adult walleyes. It is strongly indicative of healthy surficial sediments with adequate levels of dissolved oxygen in the overlying water column. Mayfly abundance is easily quantified and historical datasets (e.g., Manny et al. 1988, Hiltunen and Manny 1982) exist detailing past levels of abundance. *Hexagenia* occupies an integrative node in mesotrophic ecosystems in that it tends to reflect the effects of interactions at the sediment-water interface.

4.4.c. Benthic Community Structure

Sediments in lakes often contain elevated levels of nutrients, metals, organics, and oxygen demanding substances as the result of anthropogenic input and deposition. Sediments and the anthropogenic substances associated with particles are also subject to resuspension, transport, and redeposition. In particular, many of the problems in the Great Lakes are the result of sediment contamination. At the same time, the invertebrate communities within and on these sediments are important in the food web as intermediaries between decomposers, primary producers, and fish. Thus, they are critical components of the biotic integrity of the lakes.

Benthic macroinvertebrate community structure has been used extensively as a biomonitoring tool in the Great Lakes (Schneider et al. 1969, Nalepa 1987). These communities generally form stable associations that integrate and reflect environmental conditions over long periods of time. However, while extensive sampling of benthic communities has occurred in some portions of the Great Lakes, there have been no sustained long-term programs with a regional scope.

There is probably no best period to sample macroinvertebrates because the various taxonomic groups mature and emerge at different times throughout the growing season. Thus, any index period will miss some species present at other times. As with fish, the complexity of possible substrate types and lake zones makes selecting standardized sampling methods difficult. Sampling is proposed with a combination of several methods including handpicking from natural substrates, Ekman® or Ponar® grabs, and box core analysis. Comparisons between various sampling methods exist (Nalepa 1987) and will be utilized in decisions on the techniques to be used.

There are newly developed indices of biotic integrity for macroinvertebrate assemblages in the Great Lakes but they require field validation (Edwards and Ryder 1990). Considerable research is needed to develop these indices, to modify applications for different ecological zones of the Great Lakes, and to determine the sensitivity of species to various stressors. Candidate indices and metrics include:

taxa richness, number and proportion of indigenous families to the total, and diversity indices compared to historic estimates.

4.4.d. Primary Producers/Lake Trophic Status

Primary producers have long been used to indicate the status and trends of ecosystem condition. Primary producers reflect and respond directly to ambient water quality, are sensitive to water quality changes, are the first or among the first trophic levels to respond to changes, and form the basis of the food chain which impacts each successively higher trophic level. In general, trophic status is synonymous with, or associated with, primary producer assemblages and related exposure and habitat indicators. There are five prominent methods for monitoring and assessing primary producer assemblages or trophic condition: 1) algal species composition and abundance; 2) chlorophyll-a concentrations; 3) Secchi disk transparency; 4) primary productivity using radiolabelling; and 5) ambient phosphorus concentrations and annual phosphorus loading.

Phytoplankton are the most important primary producers in large freshwater systems such as the Great Lakes. Algal assemblages and particular species have often been used as indicators of water quality and trophic status (Rawson 1956, Hutchinson 1967, Palmer 1969, Stoermer 1978, Van Landingham 1982). The study of phytoplankton was considerably accelerated during the 1960s and 1970s on a national basis due to the eutrophication of waterways, reservoirs, and lakes. Symptoms associated with eutrophication were taste, odor, and filter-clogging problems at municipal water supplies, excessive oxygen depletion in lakes, and a deteriorated aesthetic condition. Investigations were conducted on the role of point and nonpoint sources and specifically the input of phosphorus as it related to phytoplankton biomass and secondarily, to floristic composition changes during nitrate and silica depletion episodes (Dillon and Rigler 1974, Schelske 1975, Rhee and Gotham 1980, Smith 1982, Bierman et al. 1984, Grover 1989). The implementation of phosphorus loading strategies successfully improved water quality in regard to eutrophication in the Great Lakes.

In many cases, primary producer-nutrient relationships have been established. However, phytoplankton assemblages and chlorophyll-a typically exhibit a great deal of seasonal variation due to physico-chemical changes. Within this seasonal timeframe, populations may fluctuate dramatically on an hourly-, daily-, and weekly basis. These factors present challenging problems in the assessment and monitoring of primary producers, as they relate to the objectives of EMAP - GL.

4.4.d.1. Trophic Status Index

Lake trophic status indices directly address the trophic issues of the Great Lakes. The classic indicator for lake trophic status is chlorophyll-a, as a reflection of phytoplankton biomass. Chlorophyll-a has been extensively used as a trophic index in the Great Lakes (Dobson et al. 1974, ULRG 1976) and elsewhere (Sakamoto 1966, USEPA 1974, Wetzel 1975, Brezonik 1976;1984, Rast and Lee 1978). Similar trophic classification systems have been developed for Secchi disk transparency (Dobson et al. 1974, ULRG 1976, Carlson 1977, Rast and Lee 1978), ambient phosphorus concentrations (USEPA 1974, Vollenweider 1976, Brezonik 1976, Rast and Lee 1978), primary productivity (Shannon and Brezonik 1972, Vollenweider et al. 1974, Likens 1975, ULRG 1976), and phosphorus loadings (Vollenweider et al. 1974, Rast and Lee 1978), due to their relationships with phytoplankton biomass. In many cases, these variables are used interchangeably or used in a composite index.

It will be appropriate, however, to determine the most representative single- or multi-variable index for the Great Lakes. Certain indices may only be appropriate for certain lakes and may require further delineation for offshore and nearshore waters. Comparison of the results of different indices must be conducted for the Great Lakes. For EMAP - GL, Secchi disk transparency, chlorophyll-a, and total phosphorus will be measured allowing an inspection of single- and multi-variable indices. These parameters have been routinely measured in the Great Lakes for many years. Nearshore (<85 m) trophic status will be assessed via the Composite Trophic Index (CTI), a multi-variable index (Gregor and Rast 1979).

4.4.d.2. Diatoms (Bacillariophyceae)

Diatoms have been extensively used as indicators of a wide array of water quality conditions. It has been recognized that species and assemblages exhibit sensitivities and tolerances to different water quality variables (Kolkwitz and Marsson 1908, Hustedt 1930, Patrick and Reimer 1966;1975, Hutchinson 1967, Cholnoky 1968, Lowe 1974). Because the siliceous valves of diatoms are retained in lake sediments, ecological relationships have been applied to the reconstruction of paleoecological histories from the examination of diatom microfossils in sediment cores (Pennington 1943, Reid 1961, Stockner and Benson 1967, Stoermer and Yang 1968). During the past decade, application of this technique has significantly accelerated in the reconstruction of paleoecological/paleolimnological lake histories, particularly regarding trophic state (e.g., Agebeti and Dickman 1989, Anderson et al. 1990, Whitmore 1991, Wolin et al. 1991), lake acidification (e.g., Dixit et al. 1988, Charles et al. 1989, Birks et al. 1990, Dixit et al. 1992), and other water quality variables (e.g., Tuchman et al. 1984, Bradbury 1986, Smol 1988, Kingston and Birks 1990). This approach also has the resolution to detect the reversibility and recovery of lakes in response to management strategies (Fritz and Carlson 1982, Battarbee et al. 1988, Anderson et al. 1990, Wolin et al. 1991).

Diatom populations are important floristic components of phytoplankton assemblages in both marine and freshwater systems. In the Great Lakes, diatoms have historically been the dominant phytoplanktonic group. Prior to 1955, every Lake Michigan investigator indicated that diatoms were the dominant phytoplanktonic group. Ahlstrom (1936) reported that diatoms dominated all samples during all seasons, but deemed Lake Michigan as a "Dinobryon lake", as this chrysophyte was still regarded as a protozoan. Davis (1966) suggested that the deep-water Great Lakes should be more properly classified as "chrysophyte lakes" where diatoms taxonomically reside as a class in the Division Chrysophyta. With improved optics, staining techniques, and a greater use of electron microscopy over the past two decades, soft-bodied flagellates and picoplankton have received considerably more attention and their importance in ecosystem productivity has been recognized (Munawar and Munawar 1975, Stoermer and Sicko-Goad 1977, Fahnenstiel et al. 1986). On an annual basis, however, diatom populations constitute the dominant portion (number and biovolume) of phytoplanktonic assemblages in the majority of areas in the Great Lakes.

Phytoplankton and particularly diatoms have been the subject of study in the Great Lakes for 150 years. The earliest, traceable published account of Great Lakes diatoms was by Bailey (1842) from collections made during the summer of 1839 in northern Lake Huron. Within this timespan, lakewide studies and studies encompassing large expanses of the Great Lakes have been conducted (Stoermer 1967, Vollenweider et al. 1974, Stoermer et al. 1975, Munawar and Munawar 1976;1982, Stoermer and Kreis 1980, Kreis et al. 1985, Makarewicz 1988). Generally, Lakes Michigan and Erie are associated with the greatest bodies of phytoplankton literature, followed by Lake Ontario, and then Lakes Huron and Superior. The early research was concentrated in Lake Erie, due to the onset of noticeable eutrophication symptoms (e.g., Beeton 1961;1965), and some long-term, qualitative and quantitative records at certain localities exist (Davis 1964;1965, Hohn 1969, Verduin 1964, Nicholls et al. 1980).

Phytoplankton investigations in Lake Michigan have a long history and contain a large amount of diatom literature, many of which are classic accounts. Prior to 1960, collections were primarily restricted to nearshore regions due to the inaccessibility of offshore waters (Ehrenberg 1854-56, Briggs 1872, Forbes 1883, Kofoid 1896, Ward 1896, Chase 1904, Leighton 1907, Eddy 1927;1934, Skvortzow 1937, Daily 1938, Damman 1941, Lackey 1944, Griffith 1955, Vaughn 1961;1962), with the exception of the deep-water study by Ahlstrom (1936). As accessibility to the offshore zone increased, studies on larger expanses of the open waters ensued (Stoermer and Kopzynska 1967, Stoermer 1968, Holland 1969;1980, Stoermer et al. 1971;1972, Holland and Clafkin 1975, Schelske et al. 1976;1980;1983, Stoermer and Stevenson 1979, Stoermer and Tuchman 1979). Additionally, a number of studies in Lake Michigan include historical examinations and long-term records (Thomas and Chase 1887, Damman 1945;1960;1966, Stoermer 1967, Stoermer and Yang 1969;1970, Williams 1972, Bowers et al. 1986, Makarewicz 1988). Unfortunately, most of these monitoring programs have not been sustained for a variety of reasons. At present, the longest, continuing monitoring programs on Lake Michigan are at the Chicago and Milwaukee municipal water supplies; however, most recent data are not available in the open literature.

A number of paleoecological studies of diatom microfossils have been conducted in the Great Lakes: Lake Superior (Reid 1961, Thayer et al. 1983, Stoermer et al. 1985c), Lake Michigan (Parker and Edgington 1976, Glover 1982, Stoermer and Wollin 1990, Stoermer et al. 1992), Lake Huron (Stoermer and Yang 1968, Wolin et al. 1988), Lake Erie (Peterson 1975, Frederick 1981, Harris and Vollenweider 1982, Theriot and Stoermer 1984, Stoermer et al. 1987), and Lake Ontario (Duthie and Sreenivasa 1971, Stoermer et al. 1985a;1985b;1985c;1989, Wolin et al. 1991). The greatest number of studies have been conducted on the lower Great Lakes (Ontario, Erie) with the emphasis exclusively on the impact of eutrophication on diatom species composition and abundance. Certain studies have examined the impact of trophic state changes on diatom valve morphology. Wolin et al. (1991) suggests that the recent recovery of Lake Ontario, as indicated by diatom assemblages, is in response to phosphorus loading reductions.

Based on the extensive phytoplankton studies in the Great Lakes, several conclusions can be drawn. Extant assemblages can be used to assess the ecological condition and trophic status of the Great Lakes, in regard to nutrient enrichment. Certain assemblages and their abundances indicate classic extremes in trophic status. Seasonal and spatial variability, however, are great. As a result of changing conditions and disturbance, shifts in abundance and species composition become more intense and temporally would require more intensive monitoring.

The use of diatoms in sediment cores offers a distinct advantage in monitoring these changes over time. This advantage is due to the integrated, unbroken record they provide where trophic status can be assessed by species composition and the abundance of microfossils. Diatoms in dated sediment cores have provided insights which could only be inferred from phytoplankton collections. The onset of cultural influences ensued at different times in the Great Lakes and progressed northward. These initial changes were observed in diatom species composition and abundance, and also indicate that cultural activities have affected each lake with differing intensities. At the onset of nutrient enrichment, oligotrophic species are stimulated in abundance; however, sustained nutrient input decreases their relative abundance and increases species which are more tolerant of enriched conditions. In the extreme, certain species are greatly reduced or possibly extirpated and replaced with tolerant taxa (e.g., *Cyclotella* flora replaced by *Stephanodiscus* flora). Although the autecology of many species and the diatom flora of the Great Lakes is moderately well-known (Stoermer and Kreis 1978), a single, sentinel species indicative of ecological condition cannot be applied universally to the Great Lakes. Although certain species can be associated with different trophic states (Table 4.6), assemblages are more appropriate in assessing conditions.

As described further in Chapter 10, EMAP - GL will be investigating the application of paleoreconstruction of diatom populations from dated cores as a means of identifying historical population composition and distribution within the lakes. However, the use of cores is likely to be too inaccurate to measure conditions and trends on an annual basis. An alternative approach to determining annual conditions is through the use of sediment traps. These traps can be positioned in the lakes to collect sedimented material over an entire annual cycle. Thus, quantifying the diatoms present in the collected material would represent an integrated annual collection of the diatom community. This technique has not been investigated sufficiently at this time and will also be addressed in the pilot activities conducted during 1992 (refer to Chapter 10).

Table 4.6 Apparent tolerances of Great Lakes diatoms to trophic conditions.

Oligotrophic:	**Eutrophic:**
Cyclotella comta (Ehr.) Kutz.	*Actinocyclus normanni* fo. *subsalsa* (Juhl.-Dannf.) Hust.
Cyclotella kutzingiana Thw.	*Diatoma tenue* var. *elongatum* Lyngb.
Cyclotella ocellata Pant.	*Fragilaria capucina* Desm.
Cyclotella operculata (Ag.) Kutz.	*Melosira granulata* (Ehr.) Ralfs
Melosira italica subsp. *subartica* O. Mull	*Stephanodiscus binderanus* (Kutz.) Kreig.
Rhizosolenia eriensis H.L. Sm.	*Stephanodiscus tenuis* Hust.
Meostrophic:	**Eurytopic:**
Cyclotella comensis Grun.	*Asterionella formosa* Hass.
Cyclotella michiganiana Skv.	*Fragilaria crotonensis* Kitton
Cyclotella stelligera (Cl. & Grun.) V.H.	*Stephanodiscus niagarae* Ehr.
Melosira islandica O. Mull.	*Tabellaria fenestrata* (Lyngb.) Kutz.

Two Great Lakes studies have been identified in regard to sediment traps. Both studies were conducted in Lake Michigan (NOAA and University of Wisconsin), and neither study has published results. Additionally, these studies do not appear to be described in data reports nor are they contained within a computerized database. A study of this nature has also been conducted in Jellison Hill Pond in Maine (Sweets 1983), which examines diatoms in plankton, sediment traps, and surficial sediments. There may be a limited number of studies conducted in inland waters and possibly in the marine environment. Data from these studies will be pursued and examined as part of the pilot study to determine applicability to EMAP - GL, and literature will be searched for other similar studies in the Great Lakes and elsewhere.

The primary task for specific diatom studies is the development of a comprehensive workplan based on literature, ongoing studies, and best available technology. The workplan will be used for implementation of diatom studies for the entire EMAP - GL program and will be coordinated with similar studies in the National EMAP Program. Aspects regarding diatoms include: collection methods, sample preparation, replication of cores, replication of intervals, replication of sediment traps, and variability assessments from the above examinations. These will be used to develop spatial, temporal, and sample number needs as well as to identify any weaknesses that will require further examination. Other aspects in the workplan will include: quality assurance, taxonomic and enumeration aspects, inter-laboratory comparisons, documentation, verification, archiving, data analysis and reporting, and statistical methods. Additional discussion of these factors will be incorporated in the 1992 pilot study activities.

The workplan will require the completion of several tasks conducted during the 1992 pilot and beyond. Tasks consist of: 1) development of the paleolimnological and sediment trap approaches for diatoms, 2) examination of sediment trap samples from the NOAA sediment trap recovery planned during fall, 1992, 3) examination of the previously conducted Lake Michigan sediment trap diatom data, and 4) may require the analysis of limited sediment cores for diatom populations. Please refer to Chapter 10 for additional information.

Questions to be addressed for diatom populations in sediment traps include:

- What is the temporal resolution required in sediment trap samples (yearly, quarterly, etc.) to relate to the functional and operational resolution of diatoms in sediment cores?

- What are the primary depths that should be targeted in sediment trap placement as it relates to diatoms in sediment cores?

- Is there evidence of diatom dissolution when comparing trap and core samples?

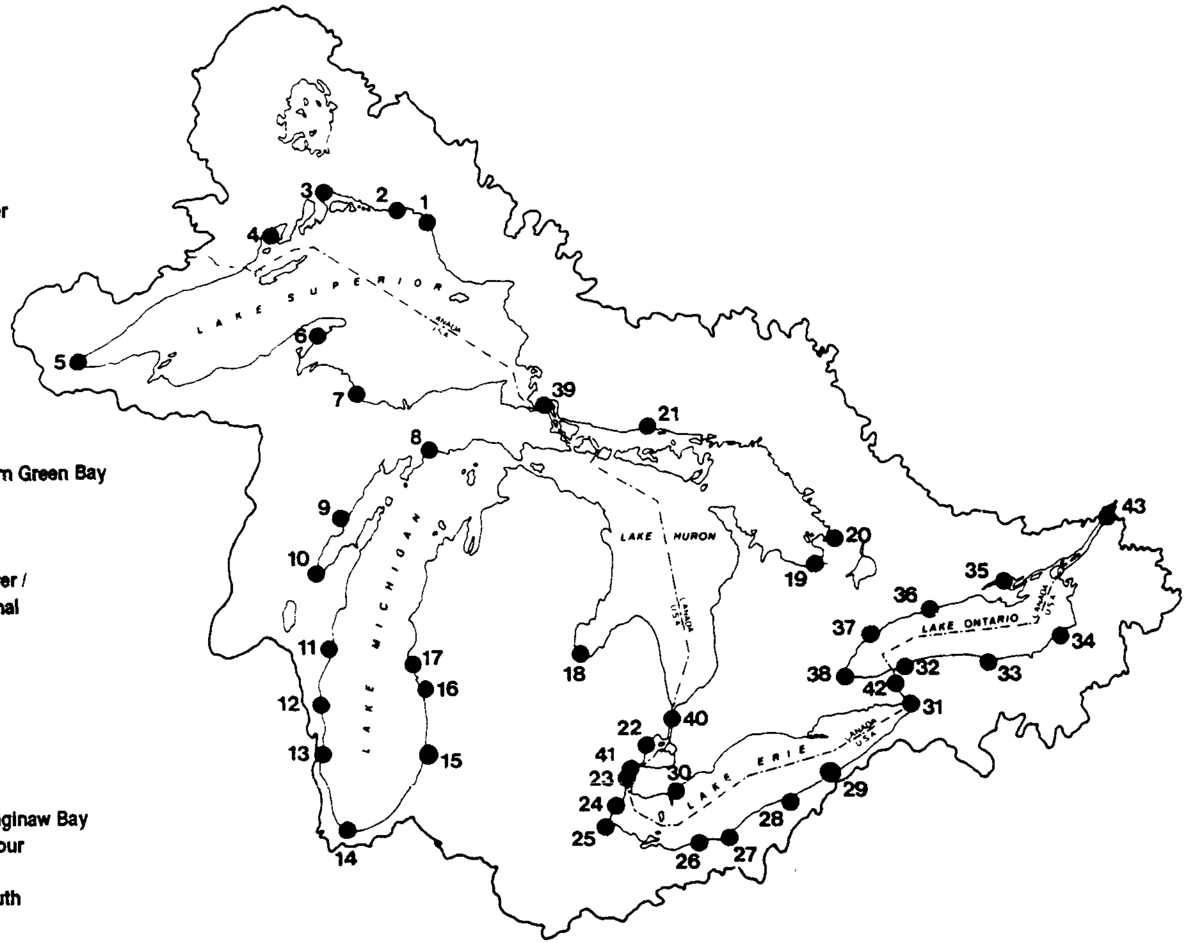
- How reproducible are diatom populations in replicate sediment trap samples?

4.5. Exposure and Habitat Indicators

Exposure and habitat indicators are intended to serve a diagnostic function when measured in conjunction with response indicators. The exposure and habitat indicators will be used in association with response indicators to develop hypotheses of potential causes of impaired ecological condition. Analysis of the exposure and habitat indicator data should help to characterize the physical, chemical, and biological conditions that support healthy ecosystems.

As of 1985, the IJC had designated 42 Areas of Concern (AOCs) for the Great Lakes, one more was recently added to the list (Figure 4.2). These AOCs primarily consist of bays and harbors and often where tributaries discharge to the Great Lakes. The variety of types of problems existing in these areas suggest that the Great Lakes are susceptible to all the traditional categories of exposure and habitat alterations (Table 4.7). One of the significant unknowns at this time is the contribution of air deposition to the Great Lakes. Based on data existing for Lake Superior and Green Bay (Lake Michigan), the airshed above the lakes appears to be an important pathway for the distribution and loading of air toxics into the lakes (IJC 1987). Research and monitoring on air toxics deposition will be expanded as the result of the new Clean Air Act of 1990 and should provide valuable data on potential exposure and sources of persistent chemicals.

Forty-three Areas of Concern Identified in the Great Lakes Basin



Lake Superior

1 Peninsula Harbour
2 Jackfish Bay
3 Nipigon Bay
4 Thunder Bay
5 St. Louis Bay / River
6 Torch Lake
7 Deer Lake - Carp Creek / River

Lake Michigan

8 Manistique River
9 Menominee River
10 Fox River / Southern Green Bay
11 Sheboygan River
12 Milwaukee Estuary
13 Waukegan Harbor
14 Grand Calumet River / Indiana Harbor Canal
15 Kalamazoo River
16 Muskegon Lake
17 White Lake

Lake Huron

18 Saginaw River / Saginaw Bay
19 Collingwood Harbour
20 Severn Sound
21 Spanish River Mouth

Lake Erie

22 Clinton River
23 Rouge River
24 River Raisin
25 Maumee River
26 Black River
27 Cuyahoga River
28 Ashtabula River
29 Presque Isle Bay
30 Wheatley Harbour

Lake Ontario

31 Buffalo River
32 Eighteen Mile Creek
33 Rochester Embayment
34 Oswego River
35 Bay of Quinte
36 Port Hope
37 Metro Toronto
38 Hamilton Harbour

Connecting Channels

39 St. Marys River
40 St. Clair River
41 Detroit River
42 Niagara River
43 St. Lawrence River (Cornwall / Massena)

Figure 4.2 Great Lakes Areas of Concern (Minister of the Environment 1990).

Table 4.7 IJC Areas of Concern: Summary of Use Impairment Identified by the Jurisdictions in Areas of Concern and Whether or not Problem Definition and Description of Causes is Complete

Area of Concern	Restrictions on fish and wildlife consumption	Tainting of fish and wildlife flavor	Degradation of fish and wildlife populations	Fish tumors or other deformities	Bird or animal deformities or reproduction problems	Degradation of benthos	Restrictions on dredging activities	Eutrophication or undesirable algae	Restriction on drinking water consumption, or tast and odor problems	Beach Closings	Degradation of aesthetics	Added costs to agriculture or industry	Degradtion of phytoplankton and zooplankton populations	Loss of fish and wildlife habitat	RAP reviewed by IJC	Based on IJC Review, problem definition and description of causes is complete
Penninsula Harbour	●		●			●	●							●	N	
Jackfish Bay	●		●			●	●		□		●			●	N	
Nipigon Bay	●	●	●			●	●	□	●		●			●	N	
Thunder Bay	●		●			●	●			●	●			●	N	
St. Louis Bay/River	●		L	O	O	●	●	L		L	●	L	O	●	N	
Torch Lake	●			●		●									Y	N
Deer Lake-Carp Creek/River	●				●										Y	N
Manistique River	●					●	●								Y	N
Menominee River	●		●			●	●			●				●	●	Y
Fox River/Green Bay	●	O	●	●	●	●	●	●		●	●		●	●	Y	Y
Sheboygan River	●		●		L	●	●	●				●	O	●	Y	Y
Milwaukee Harbor	●		●	●		●	●	●		●	●		●	●	N	
Waukegan Harbor	●					●	●								N	
Grand Calumet River Indiana Harbor Canal	●	●	●	●	L	●	●	●	●	●	●	●	●	●	N	
Kalamazoo River	●														N	
Muskegon Lake	●														Y	N
White Lake	●														Y	N
Saginaw River/Bay	●				●	●	●	●	●				●		Y	N
Collingwood Harbour	●		L		L	●	●	●		●	●		L	●	Y	N
Severn Sound	●		●			●	●	●			●		●	●	Y	Y
Spanish River	□		□			□	●					□		□	N	
Clinton River			●			●	●								Y	N
Rouge River	●		●	●		●	●	●			●				Y	N
River Raisin	●					●	●								Y	N
Maumee River	●		●	●		●	●	●	●	●	●		L	●	N	
Black River	●		●	●	O	●	●	●		●	●		L	●	N	
Cuyahoga River	L		●	●	O	●	●	●		●	●		●	●	N	
Ashtabula River	●		●	●	O	●	●						L	●	N	
Presque Isle Bay							●			●					N	
Wheatley Harbour				□		□	●	□		□				●	N	
Buffalo River	●	L	L	●	L	●	●	L		●	●		O	●	Y	N
Eighteen Mile Creek															N	
Rochester Embayment	●		●	L	O	L	L	L	L	L	●		L	●	N	
Oswego River	●	O	●	L	L	●		●		O			L	●	Y	N
Bay of Quinte	●		●		□	●	●	●	●	●	●		●	●	Y	
Port Hope						●	●								Y	Y
Metro Toronto	●		●		L	●	●	●		●	●		●	●	Y	N
Hamilton Harbour	●		●	●	●	●	●	●		●	●		L	●	Y	Y
St. Mary's River	●		●	□		●	●	●		●	●		O	□	N	
St. Clair River	●		□	□	●	●	●		●	●	●	●		□	N	
Detroit River	●			●		●	●		●	●	●			□	N	
Niagara River*	●		●	●		●	●						●		N	
St. Lawrence River* (Cornwall/Massena)	●	□	●	●	□	●	●	●	●	●	●	●	□	●	N	
St. Lawrence River (Cornwall/Massena)	●		L	L	L	L							O	●	N	

Symbols Used:

Blank - Data confirm no use impairment
● - Beneficial use impaired
O - No data available
* - Use impairments identified by Ontario
□ - Under assessment
L - Likely impaired
Y - Yes
N - No

Physical habitat quality characterizes physical conditions that may limit biological components from reaching the full potential expected for an ecological zone within a lake. In some cases, the physical habitat limitations are natural, in others, human-induced. In either situation, physical habitat information is needed to fully interpret the response indicator data. For all the resource classes, the structural characteristics of the sediment will be determined as a physical habitat indicator. Additional features will undoubtedly be included for wetlands as these indicators are developed.

The habitat most important for aquatic species is the surrounding water. Thus, conventional water quality parameters can be considered as habitat indicators. In EMAP - GL, these parameters include nutrient status, ionic strength, redox status, and optical characteristics. Nutrient status addresses the supply of chemical compounds that often limit the growth of algae and macrophytes. Total nitrogen, total phosphorus, and silica will be determined. Ratios of these nutrients have been used to determine unfavorable conditions for diatoms (Holm and Armstrong 1981, Smith 1983). Ionic strength (e.g., Na, K, Mg, Ca, SO_4, NO_3, Cl,) indicates the association between water quality and soil weathering processes, and some anthropogenic disturbances. The redox status of waters (assessed by D.O., pH, temperature, Mn, and Fe) is a major factor in the solubility, mobility, and toxicity of many chemicals including nitrogen and toxic heavy metals. Specific conductance and Secchi disk transparency will also be measured.

Indicators of exposure are intended to measure possible stress on the biota in response to toxic chemical contaminants. Measurement of the concentrations of toxic chemicals in the water column of the Great Lakes was not considered to be a practical approach for EMAP - GL. Water concentrations of critical contaminants are usually extremely low and may be quite variable due to intermittent inputs and the movement of water masses within the lakes. Because the sediments are a sink and potential source of contaminants in the lakes, exposure indicators for EMAP - GL are focused on measures within the sediment component of the lakes.

The sediment exposure indicators currently proposed are sediment toxicity tests and measures of critical contaminants in bulk sediment. Both will be conducted with sediments collected at the same time and location as benthic community structure to allow comparisons between these indicators. Sediment toxicity tests will address possible biological exposure to toxic materials accumulated in sediments. EMAP is not designed to pinpoint toxic "hotspots", but should be able to characterize, on a lake basis, the degree to which contaminants are associated with biotic integrity.

Toxicity may be demonstrated by several adverse responses shown by test organisms (e.g., mortality, impaired growth, reduced reproduction). In addition, there are several possible methodologic choices, such as which test species to use, type of exposure (solid-phase, pore water elutriate), acute vs. chronic, and test duration. Other questions relate to the variability of laboratory operation, the representativeness of the collected sediments, and how to define "reference" sediments. EMAP - GL will conduct 10-day acute solid-phase bioassays with *Hyalella azteca* and also *Chironomus tentans* solid-phase chronic assays (Giesy et al. 1990, Ingersoll and

Nelson 1990, Borgman et al. 1989, Rosiu et al. 1989, Nebeker et al. 1984). Overlying, clean water will be used in all tests. Mortality is a measurement endpoint for both tests. Growth is an additional endpoint used only with the *Chironomus* test.

In addition to measurements on sediments, chemical contaminants in fish will be determined to assess the exposure to chemicals that fish have experienced. This indicator expresses a potential health hazard for humans, as well as the biota. As such, this indicator may be considered to be both a response indicator and an exposure indicator (as is true for trophic state and sediment toxicity). Because EMAP emphasizes ecological response, chemical contaminants in fish fits best as an exposure indicator. The contaminant monitoring effort will be closely coordinated with the US FWS National Contaminant Biomonitoring program.

Currently, proposed analytes for fish or sediments include the IJC Critical Pollutant List and additional persistent toxic chemicals identified in the Great Lakes (Table 4.8). Appendix 1, Hazardous Polluting Substances, and Appendix 2, Potential Hazardous Polluting Substances, of the Great Lakes WQA (IJC et al. 1989) contain information on additional chemicals identified in the Great Lakes Basin. Because each of the lakes differs in the types of contaminants present or expected, not all analytes would be measured in each lake.

Table 4.8 IJC Critical Pollutant List[1] (GLWQB 1987) and additional persistent toxic substances in the Great Lakes[2] (Minister of the Environment 1990).

Benzo(a)pyrene[1]	ΣDDT[1]	DEHP[2]	As[1]	Cr[2]
Chlordane[2]	Dieldrin[1]	Methoxychlor[2]	Cd[1]	Cu[2]
Heptachlor[2]	Endrin[2]	PCDDs[1]	Hg[1]	Se[2]
Hexachlorobenzene[1]	Lindane[2]	PCDFs[1]	Pb[1]	Zn[2]
PAHs[1]	Mirex[1]	PCP[2]		
PCBs[1]	α and γ hexachlorocyclohexane[1]	Toxaphene[1]		

Although sediment exposure indicators will be the focus, harbors and embayments may be a resource class where water column contaminants are sufficiently high in concentration and occurrence to warrant measurements. Rather than measure concentrations directly, a water column toxicity test may be utilized as a measure of exposure. The test proposed is the standard *Ceriodaphnia dubia/affinis* seven-day static renewal test (Weber et al. 1989, ASTM 1988, Mount and Norberg 1984). This test uses survival and reproduction as endpoints and has been extensively used in effluent toxicity evaluations.

An additional measure of exposure and habitat condition is the measurement of the presence of the zebra mussel, *Dreissena polymorpha*. This invading species has become widespread in the Great Lakes basin and has the potential for serious disruption of existing habitat. Because this is a new invader, with numerous agencies and scientists conducting research, it is not apparent at this time whether existing programs to monitor its spread are sufficient to meet EMAP goals. This will be investigated further over the next year.

At this juncture, it appears that zebra mussels can only be examined in the nearshore and harbor/embayment resource classes. EMAP - GL and NOAA Mussel Watch have had preliminary discussions on the collection and analysis of zebra mussels for use in both programs. The use of zebra mussels as an indicator of biotic integrity or trophic status, however, presents difficulties due to our current state of knowledge. Because the zebra mussel problem is new and potentially significant, a large number of research projects have been initiated through other EPA programs as well as through other agencies. Tracking increases and decreases in abundance may be useful as an indicator of the status and trends of their distribution. There are several programs actively developing methods for this purpose outside of EMAP. We are following these developments through coordination with the zebra mussel program at the ERL-Duluth laboratory as well as by other agencies through interagency coordination committees.

Other potential uses as a stressor are unclear because of the limited knowledge of the role of zebra mussels. For example, the rates of removal of abiotic and biotic solids, nutrients, and contaminants from the water column as mediated by zebra mussels are unknown and fluxes to the sediment of these parameters are unknown. More importantly, the actual effects of the above processes are unknown but have many implications, e.g., higher concentrations in the sediment, greater productivity, and greater contamination of benthos and bottom-feeding fishes. These effects are currently under study. The use of zebra mussels as an exposure indicator appears to be one of the most likely candidates due to their widespread occurrence. Discussions between EMAP - GL and NOAA Mussel Watch will continue and may lead to zebra mussel collections in Lake Michigan at some point. Samples could potentially be analyzed for contaminant body burden concentrations. In addition, appropriately conducted studies may lead to a greater understanding of the processes and effects which then may trigger the use of zebra mussel as an indicator.

4.6. Stressor Indicators

As described in Chapter 2, stressor indicators will be used (along with the exposure and habitat indicators) to investigate associations with impaired conditions. Presumably, the stressor indicators will address the "ultimate" cause of impairment rather than the proximal causes. For example, industrial discharges are an ultimate source of stress that show up as chemical contaminants in toxic sediments (exposure indicators) and impact biota (response indicators). This section will describe stressor indicators only in the broadest view because the highest EMAP priority for development and implementation goes to the response indicators first and then to the exposure and habitat indicators.

Currently, none of the data needed to assess the stressors are planned for field sampling. Instead, these data will be collected from a variety of existing data sources including maps, and management and regulatory agency reports and databases.

Landuse and landcover characterizations will be the most general stressor indicators. Landuse will describe the most prevalent types of human induced stress. For example, agricultural landuse tends to be associated with increased nutrient and sediment loading and increased pesticide levels. Urban landuse is associated with increased toxic materials and nutrient loading. A representation of existing landuse on a very coarse scale is presented in Figure 4.3.

Population density will describe the general level or intensity of human-induced activity. Shifts in population density may change potential for stresses imposed on the lakes. Figure 4.4 depicts the population distribution around the Great Lakes as of the 1980 census.

Pollutant loadings can be assessed by analyzing current pollution discharge permits, both municipal and industrial. These records will further describe the kinds and intensity of nutrient, chemical, and thermal stresses. On the US side of the lakes, data sources include National Pollutant Discharge Elimination System (NPDES) permits and compliance records which are available through state or regional offices and through EPA databases stored at the National Computer Center.

Flow and channel modifications can be assessed from the landscape characterizations, and regulatory agency records (e.g., Army Corps of Engineers). Normally, channelization removes a great deal of the habitat diversity and also may create new avenues for invasion by non-native species.

Stocking, harvesting, and species introduction records provide information about the biological stresses in aquatic ecosystems. Management practices which are designed to enhance fishability often result in a degradation of biotic integrity. Increased stocking activities may indicate that the waterbody cannot currently maintain the desired harvest levels. Introduced species (intentional or otherwise) have considerable potential for decreasing biotic integrity, as is evidenced by the pervasive influence of the sea lamprey, alewife, and rainbow smelt in the Great Lakes.

4.7. Relationship of Indicators to Assessment Endpoints

As discussed in Section 1.5 (Societally Important Great Lakes Values), the two assessment endpoints proposed for EMAP - GL are biotic integrity and trophic status. The purpose of selecting indicators is to allow the quantification of attributes that provide descriptions of the assessment endpoints. For the most part, it is the response indicators that will be used in this process.

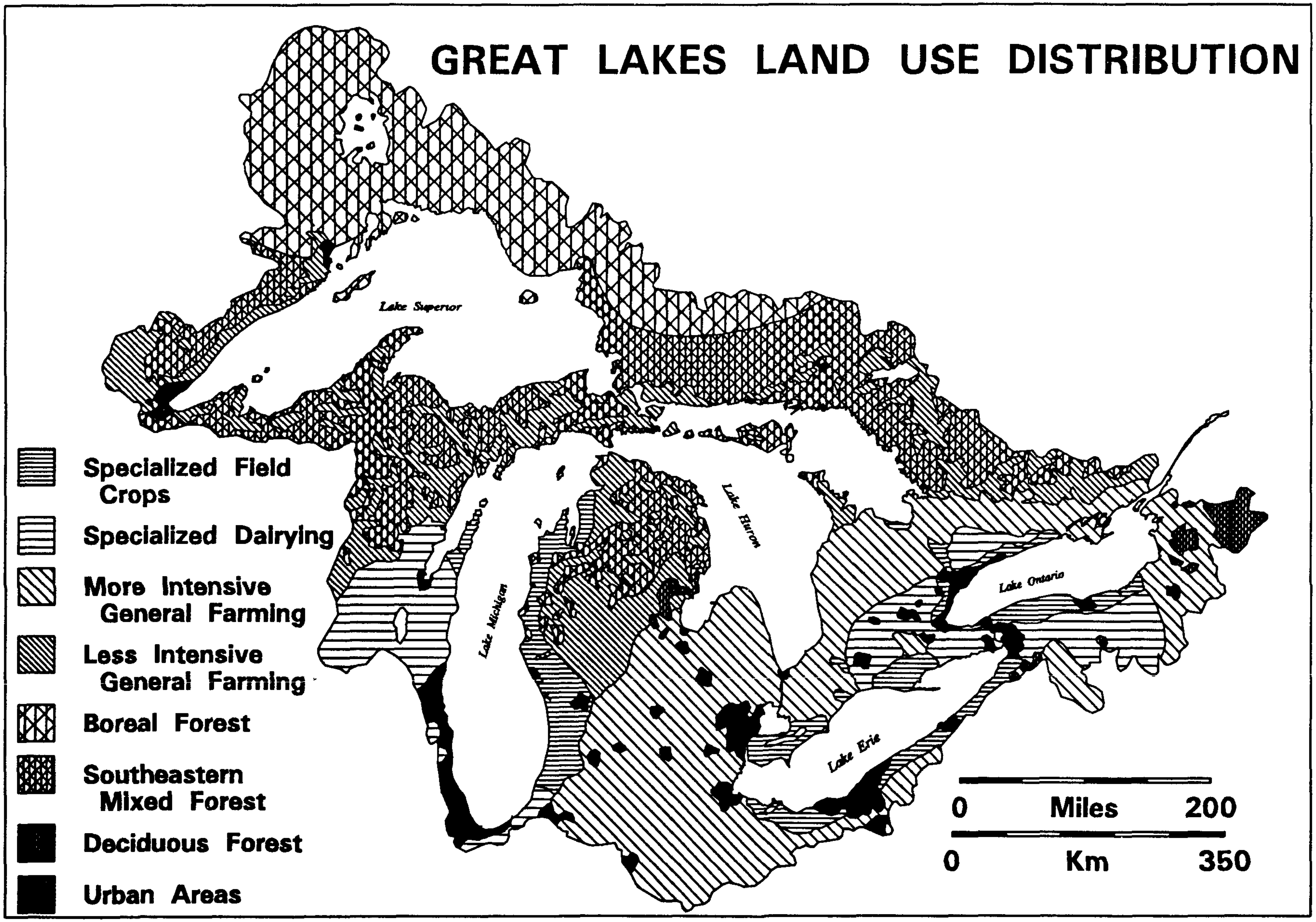


Figure 4.3 Great Lakes land use distribution (US EPA and Environment Canada 1988).

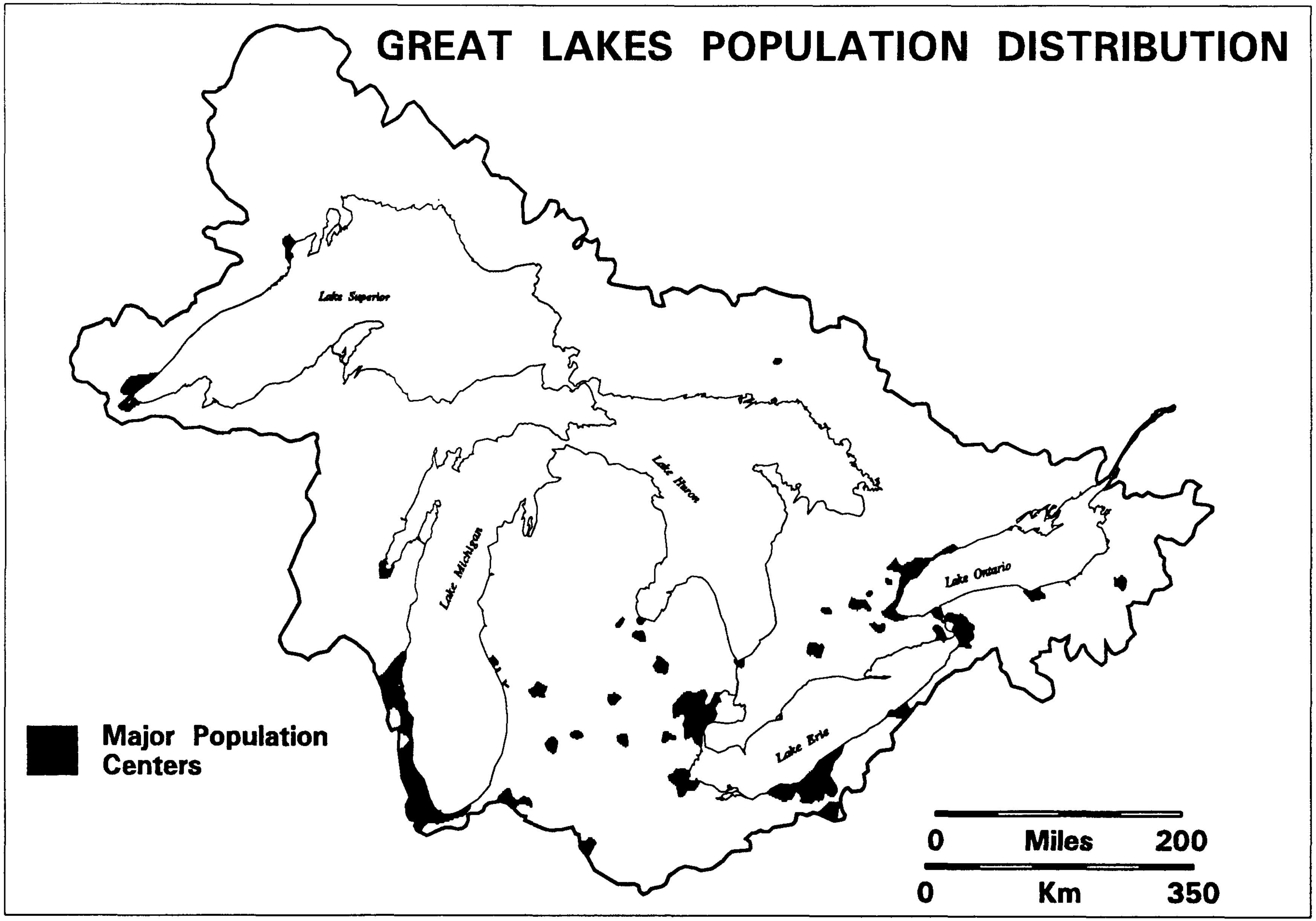


Figure 4.4 Great Lakes population distribution (US EPA and Environment Canada 1988).

4.7.a. Biotic integrity

Biotic integrity has been defined by Karr and Dudley (1981) as "a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats in the region". At this time EMAP - GL has focused on structural components of ecosystems as its measure of biotic integrity (Table 4.1). Quantitative measures of integrity under this definition could include descriptions such as the number of species, population abundances and age/size structure, the distribution and associations of populations, and the presence and abundance of keystone or surrogate species. As previously discussed, the comparison of indicators to expected nominal conditions is inherent in judgements of biotic integrity. At the present time, we believe it is not possible to quantify the biotic integrity of an entire Great Lakes ecosystem. While we believe this is a goal to work toward, we propose to initially work with particular components of the ecosystem and measures of their condition (status and trends). As our understanding of ecosystem organization continues to expand, we will work toward improving our ability to quantify what must now be considered the concept of overall biotic integrity.

Our approach has been to identify what we consider to be the major structural components that make important contributions to the overall functioning of the Great Lakes ecosystems. The following discussion outlines how we believe our proposed indicators contribute to measures of integrity in the Great Lakes. We have addressed major structural components and attempted to apply our previously described criteria for indicator development.

- Microbes. The microbial community is essential to the cycling and movement of materials through aquatic ecosystems. Because their role in material cycling is best described through process rates, we did not consider species lists and population abundances as appropriate descriptors of the condition of this group of organisms. Techniques to measure processes such as nitrification and carbon utilization have been used to a limited extent in the Great Lakes. The work that has been conducted has shown that some estimates of nominal and subnominal conditions can be detected at a site-specific level. The implication of subnominal processing rates of materials to overall ecosystem condition, however, is not well understood. At the present time, we have not proposed indicators for EMAP - GL that describe microbial processes. However, we are aware of ongoing efforts in other programs within the Agency to investigate these processes more fully in the Great Lakes. As these efforts become better developed, the microbial community will be evaluated as potential indicators for EMAP.

- Phytoplankton. Phytoplankton represent the major carbon fixation pathway within the Great Lakes proper. Because phytoplankton populations display temporal variability, we have focused on diatom species distribution and abundance determined from sediment cores and sediment traps as surrogates for the entire phytoplankton community. In addition, diatoms are, in general, the most common type of phytoplankton under the historical oligotrophic and mesotrophic conditions of the lakes.

- Aquatic vegetation. Inclusion of macrophytes and periphytic community organisms will be discussed with Research Planning Committee members and invited scientists in this field. Preliminary discussions with Dr. Martin Auer (Michigan Technological University), Dr. Jay Bloomfield (NY State Department of Environmental Conservation), and Mr. John Madsen (U.S. Army Corps of Engineers) have provided the following perspectives:

  - Macrophytes as indicators of biotic integrity would perhaps work best based on community structure (density and diversity) measurements. It seems likely that presence/absence measurements would be variable due to influences of light availability, wave action, nutrients, and general substrate-related considerations. While reappearance of macrophyte communities may signal an improvement in environmental quality, it has been difficult to relate these observations to the environmental conditions which influence their occurrence.

  - *Cladophora glomerata* could be an excellent indicator of trophic condition via evaluation of standing crop (abundance), distribution, or nutrient (phosphorus) indicators. Each of these parameters have limitations which are outlined below:

    Standing crop varies dramatically over the growing season due to stochastic, wind-driven, sloughing events. This detachment phenomenon makes comparison of standing crop measurements among sites or among years valueless from a status and trends perspective.

    Distribution of *Cladophora* is highly sensitive to light availability and can provide misleading information with respect to nutrient status, e.g., a reduction in water level may expose shoal areas to light and foster growth.

    Nutrient content, especially phosphorus, has routinely been observed at elevated stored levels in *Cladophora* proximate to a point source of nutrients. The analysis of stored phosphorus content itself is straightforward, although some effort would be required to develop sampling protocol which addresses the seasonality in stored phosphorus content.

  Plans for using aquatic macrophytes as indicators of the condition of harbors, embayments, and wetlands will also be discussed through a workshop on "Indicators of Coastal Great Lakes Wetland Condition", to be held in early 1993.

- Benthic invertebrate communities. Benthic invertebrate communities that contribute to material cycling are a major source of food to predators and play a significant role in the movement of contaminants through bioturbation of sediments and food web transfer. Our descriptors of the condition of benthic communities depend on measures of the numbers and abundance of species, the associations among species, and the abundance of key species (e.g., *Diporeia*) that have been proposed as surrogate indicators of ecological condition. As described in Chapter 10, we propose to participate in ongoing efforts to describe nominal conditions for benthic community structure in the Great Lakes.

- Zooplankton. Zooplankton function, in part, as an intermediary between phytoplankton and fish within the Great Lakes. While their ecological significance is unquestioned, the temporal dynamics of zooplankton populations make them particularly difficult to characterize without extensive time dependent sampling. Some monitoring of zooplankton on a spatial scale has been conducted by GLNPO in their surveillance program. In addition, research is underway by several investigators to evaluate the ability of hydroacoustic sounding devices as a means of quantifying zooplankton communities (as well as fish). As these research data become available, they will be included as part of the continuing study to assess the application of zooplankton monitoring to the EMAP program.

- Forage fish. Forage fish are the food base for top predators (see below) that existed historically or that have been stocked into the Great Lakes. As discussed previously, forage fish populations have changed dramatically over the past hundred years both as a result of invasions of new species and from changing predation pressure due to stocking of Pacific salmonids. The fisheries management practices related to sport fish (top predators) make forage fish population fluctuations difficult to interpret. Monitoring of forage fish populations is currently conducted in the Great Lakes but the intensity and time period for which data is available is uneven across the lakes. This data and its application to EMAP objectives will be investigated as part of the overall fisheries analysis.

- Top predators (fish). An extensive discussion of the rationale for selecting top predators as representatives of the fish community and as integrators of the ecosystem as a whole has been presented earlier in this chapter. As stated in that discussion, we are not prepared at this time to select specific measurements for top predators. A detailed analysis of how EMAP can complement existing monitoring of fish populations in the Great Lakes will be conducted as part of the next year's activities.

- Wildlife. We use this term as an aggregation of those mammals and birds that depend on the Great Lakes for their survival. Due to their position in the food web, they have been found to be sensitive to contamination from persistent organics (e.g., DDT). The bald eagle has been proposed as an integrative species to monitor overall condition of the lakes (Minister of the Environment 1990). In addition, herring gull populations have been monitored as part of existing Great Lakes programs (Minister of the Environment 1990). As a group, wildlife are integral to the organization and function of the Great Lakes ecosystems but pose particularly difficult problems for monitoring through the EMAP framework.

- Humans. The measurement and evaluation of the condition of human populations around the Great Lakes is not an objective of EMAP. However, human beings are an important component of the overall biological organization of ecosystems and are undoubtedly the most significant source of loadings to the lakes. The relationship between the Great Lakes and human health can be included in the evaluation of contaminant residues in fish. Residues will be included not only as part of the monitoring of fish populations but also can be used to determine the risk associated with their consumption by both wildlife and human beings. Residues in sport and commercial fish will be compared to existing fish consumption advisories as well as data on recommended "safe" levels for wildlife. In addition, the human population density and distribution around the Great Lakes will be an important stressor indicator included in the periodic reports that will attempt to interpret the relationships between response, exposure, habitat, and stressor indicators.

- Process rates. As discussed above, EMAP - GL is focusing on structural measures of biotic integrity rather than functional characteristics. It is recognized that processes are what make the ecosystem function and this recognition has led to the selection of measures of structure representative of major functional groups. The principal approach of EMAP in emphasizing spatial distribution presents limitations on measures that require repeated visits to the same site. It is possible, however, that some measures of process rates can be incorporated into the program. For example, nitrification and respiration rates of sediment microbes could be determined from sediment samples collected during one site visit. Similarly, primary production estimates have been made using spatially distributed surveys for collecting water samples and then conducting onboard measures of carbon fixation. EMAP - GL will continue to investigate the feasibility of incorporating such measures into its sampling framework.

4.7.b. Trophic Status

Trophic status is an indication of the degree of nutrient enrichment and the resultant degree of productivity. Nutrient concentrations within a lake are the result of loadings from point sources such as municipal wastewater treatment discharges, nonpoint runoff from landuse activities such as agriculture, atmospheric deposition, resuspension of sediments, and other recycling processes. While lake trophic status ...ually a continuum of possible conditions, it is usually conceptualized as either ...igotrophic (low nutrients levels, low productivity), mesotrophic (moderate nutrient levels, moderate productivity) or eutrophic (high nutrients, high productivity). Historical data indicate that the Great Lakes could be characterized as predominantly oligotrophic, with mesotrophic conditions occurring in the shallower bays and nearshore areas prior to European settlement. Conditions within many portions of the lower Great Lakes became much more eutrophic with the industrial revolution and accompanying growth of the human population around the Great Lakes. One of the success stories of the environmental era of the 1970's and 1980's was the reduction in nutrient inputs and the subsequent degree of recovery of many portions of the lakes. There are still, however, areas that exhibit anthropogenic nutrient enrichment and this is still a major concern within the Great Lakes basin (Figure 4.5).

There have been a variety of measurements that have been used to quantify lake trophic status and that are often combined into a trophic status index. These indices generally utilize a combination of chlorophyll-a (an indication of phytoplankton mass), total phosphorus or total nitrogen, and Secchi disk (as an indication of water transparency). As discussed previously in this chapter, we are proposing to use the Composite Trophic Index (CTI) of Gregor and Rast (1979) that combines chlorophyll-a, total phosphorus, and Secchi disk measurements during the period of spring mixing. The application of the CTI to EMAP objectives will be investigated, as well as the individual components of the index. Estimates of phytoplankton populations determined from sediment cores and sedimentation traps will also be evaluated.

4.8. Application of Indicators to Resource Classes

Because the four resource classes (offshore, nearshore, harbors and embayments, coastal wetlands) have different physical, chemical, and biological characteristics, some of the indicators proposed and eventually selected may not be appropriate for each subclass. Table 4.9 presents a tentative listing of indicators proposed for offshore, nearshore, and harbors and embayments. As has been stated several times, this listing is tentative until further research and data analysis have been conducted. No indicators for Great Lakes coastal wetlands are proposed at this time but will be the subject of future workshops and discussion.

4.9. Sampling Index Period

Nutrient and major ion concentrations in the offshore waters appear to be vertically homogeneous during spring isothermal conditions in all the lakes, except Lake Erie (Rosa 1987, Nielson and Stevens 1987, Stevens et al. 1985, Bartone and Schelske 1982, Scavia and Bennett 1980, Shiomi and Chawla 1970). Open lake nutrient trends based on GLISP sampling have been reported using spring isothermal data for 15 years. The other time period for which long-term data are available is mid to late summer. However, due to uncertainties related to spatial and temporal representativeness, trends based on this time period have not traditionally been reported. Nearshore waters and harbors and embayments have not been studied as extensively and there is no historically determined index period for nutrients and major ions. Further analysis of existing data will be conducted during FY92 to determine whether there is an optimal index period for the nearshore and harbor and embayment waters.

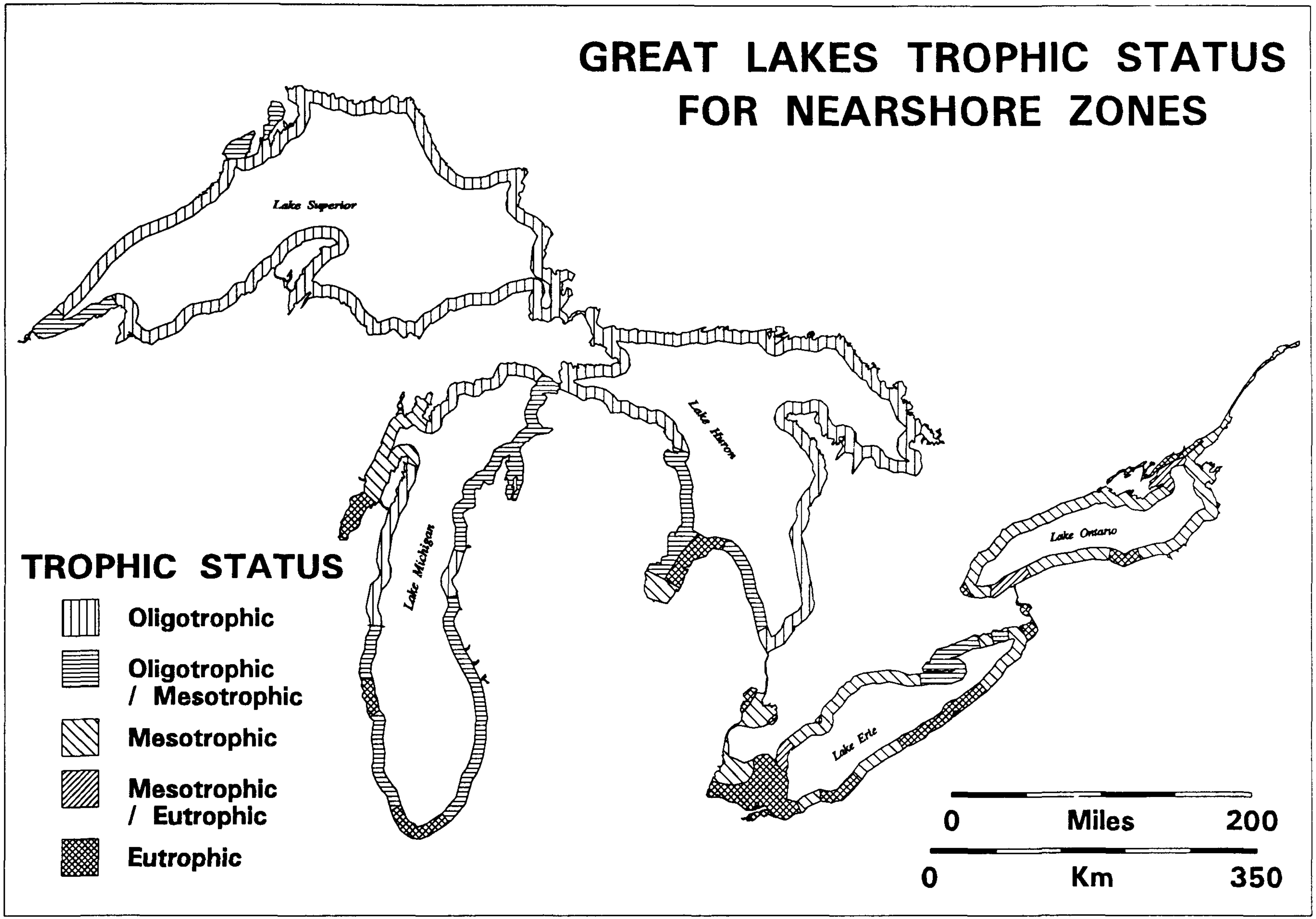


Figure 4.5 Trophic status of the Great Lakes (US EPA and Environment Canada 1988).

Table 4.9 Proposed indicators, by resource class, of ecological condition for EMAP - GL.

Indicators	Resource Classes*		
Response	Offshore	Nearshore	Harbors and Embayments
Benthic macroinvertebrates	XXX	XXX	XXX
Diporeia/Hexagenia abundance	XXX	XXX	XXX
Forage fish population	XXX	XXX	XXX
Lake trout/walleye	XXX	XXX	XXX
Lake trout recruitment	XXX	XXX	
Fish pathology			XXX
Diatom assemblages	XXX	XXX	XXX
Chlorophyll-a composition	XXX	XXX	XXX
Trophic status index	XXX	XXX	XXX
Aquatic vegetation		XXX	XXX
Exposure			
Sediment toxicity		XXX	XXX
Sediment contamination	XXX	XXX	XXX
Fish contamination	XXX	XXX	XXX
N/P and Si/P ratios	XXX	XXX	
Water column toxicity			XXX
Exotics abundance	XXX	XXX	XXX
Habitat			
Sediment physical characteristics	XXX	XXX	XXX
Water column optical characteristics	XXX	XXX	XXX
Temperature, pH, etc.	XXX	XXX	XXX

* Wetland indicators to be evaluated during FY93.

Due to the mixing of the offshore waters during spring isothermal conditions, the surface layer (0 - 1 m) of the lakes may be adequate for chemistry measurements. As with the index period discussed above, open lake nutrient trends based on GLISP sampling at 1 m depths have been reported for several years. Examples of various statistical tests using historical data to verify the adequacy of this will be included in the assessment of the Lake Michigan pilot (refer to Chapter 10). Historical data available from summer sampling and data collected from EMAP - GL offshore sites during the summer of 1992 will also be analyzed to evaluate the representativeness of samples at different depths. For nearshore zones, and harbors and embayments, the surface value will probably not be as stable.

The proposed sediment sampling includes several indicators: sediment physical characteristics, chemistry, toxicity, and benthic populations. In order to ensure that the majority of benthic species with a non-aquatic life history phase will be present in the aquatic community, sampling should occur in the fall (late August to early October). Index periods and sampling locations for wetlands will follow EMAP - Wetlands procedures, adjusted for conditions in the Great Lakes, if necessary.

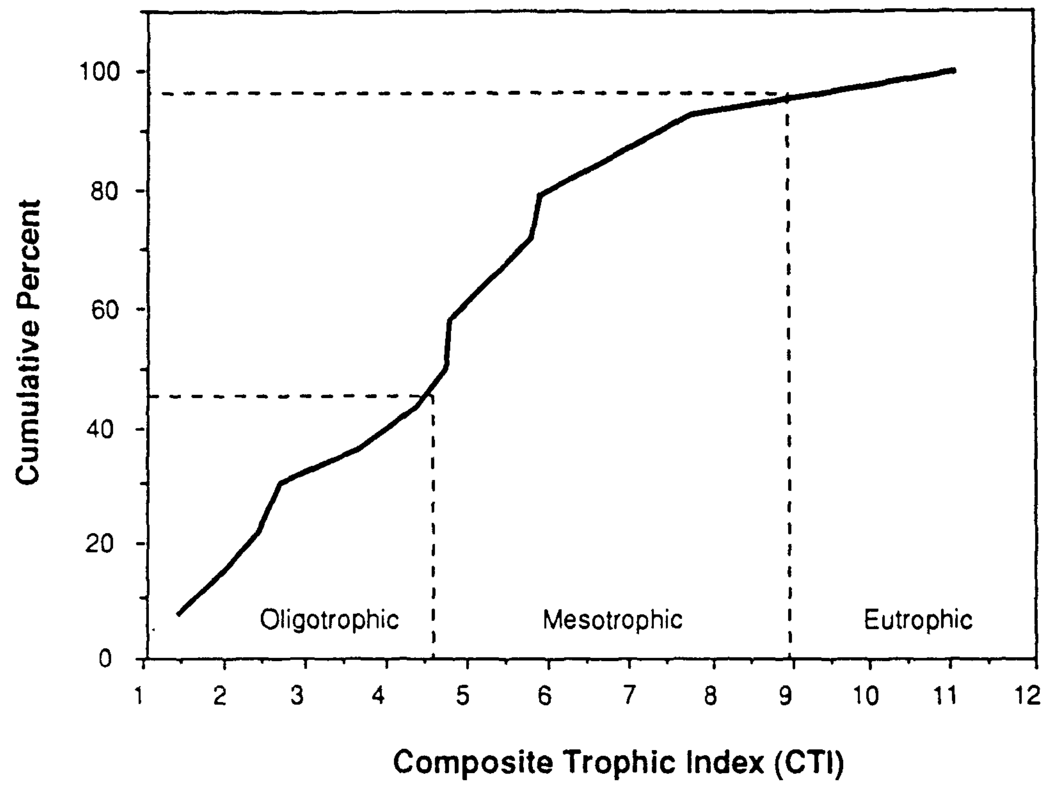


Figure 4.6 Cumulative Frequency Distribution of the Composite Trophic Index (CTI) calculated for the nearshore zone of Lake Michigan, Spring 1976.

4.10. Analyses of Existing Data

This section will present results of preliminary analyses conducted on a portion of a water chemistry database from Lake Michigan. The analyses are far from comprehensive, but do illustrate some of the problems and concerns which often arise when dealing with Great Lakes data.

Secchi depth, chlorophyll-a, and total phosphorus data for Lake Michigan were retrieved from STORET for the period of record (1976-1990). The retrieval consists of data collected by ten different agencies and groups, including federal, state and academic institutions, over a generally discontinuous time interval (Table 4.10). This same dataset was used in Chapter 3 to illustrate differences in cumulative distribution functions of these three parameters using differing definitions of the offshore boundary.

Table 4.10 Summary of Lake Michigan Database Retrieved from STORET and Used to Calculate Composite Trophic Indices (CTIs).

		Parameters Sampled		
Agency	Sampling Years	Total P	Secchi	Chlor a
ACOE[1]	84-86, 89	x		
GLNPO[2]	76,77,80,81,83, 84-89	x	x	x
USGS[3]	76-79,82,84, 86-88	x	x	x
EPA Lake Survey	76,79,80	x	x	x
Illinois EPA	76,77,84-88, 90	x		x
EPA Reg. V	76,77,79,81-90	x	x	x
IN Bd Health	80,81	x		
Michigan DNR[4]	76-90	x	x	x
WI DNR[4]	76-90	x	x	x
University of Michigan[5]	76-77	x	x	x

[1] ACOE = Army Corps of Engineers, Chicago; [2] GLNPO = Great Lakes National Program Office, US EPA; [3] USGS = United States Geological Survey; [4] DNR = Department of Natural Resources; [5] Univ. Mich. = University of Michigan, Ann Arbor in cooperation with GLNPO.

The three parameters mentioned above will be used to assess trophic status in the nearshore zones through use of the Composite Trophic Index (CTI) (Gregor and Rast 1979). Figure 4.6 illustrates how these data will be used in an EMAP context. Certain values of the CTI correspond roughly to trophic status. It is evident that the majority of the nearshore stations in spring 1976 were oligotrophic and mesotrophic in nature with only a few (< 5%) in the eutrophic category. Although the data used to generate the CTI has not undergone extensive quality control procedures, the cumulative distribution function of the CTI will eventually be used to determine subnominal thresholds relating to the trophic status endpoint. Sampling stations in historically mesotrophic areas of the Great Lakes will have a higher threshold CTI than historically oligotrophic nearshore areas.

5. Estimation and Analysis

5.1. Introduction

Measurements of the indicators for EMAP - GL will be made with known precision and confidence. The next step is to provide analysis and interpretation of status and trends. In general, status will be portrayed through descriptive statistics, visual displays of spatial patterns and estimates of the proportion of the resource class in various categories using classification and cumulative distribution functions (cdf). Yearly statistical summaries will be combined to develop more comprehensive statements and interpretations of the status of the Great Lakes. As the database grows over the years, trends of indicators will be estimated by examining changes in statistical descriptors including changes in proportions in various categories and the cumulative distribution functions.

At each site selected for sampling, a series of indicators will be measured to give a representation of the overall health of the Great Lakes primary resources. These indicators were designed to address three major attributes of concern: 1) response indicators to describe the biotic condition of the aquatic ecosystem; 2) habitat indicators for describing the physical condition of the environment; and 3) exposure indicators that characterize the impaired condition of the habitat.

5.2. Sampling Design

The use of probability-based sampling permits inferences about the condition of the resource population, i.e., the Great Lakes resources. The sampling design allows the flexibility to define and to refine classification schemes (e.g., nominal and subnominal) through estimates of the proportion of the total area sampled. We can make these predictions with measurable confidence and we can increase the level of confidence in the estimate if necessary. The strict adherence to an overall sampling design allows assessment of the spatial and temporal variation within each primary resource class. We are also assured that information on status gathered over time can be used to measure trends and change of the resource classes and that EMAP - GL information can be interfaced with other EMAP programs (e.g., forests, lakes, wetlands, etc.) for more inclusive statements on ecological health or condition over larger spatial scales.

Boundaries of two resource classes are well defined (refer to Chapter 3) and are not expected to be changed during the next five years. A grid sample will be used for the nearshore and offshore resource classes. Sampling design and frame have not been established and are under development for the harbor and embayment and coastal wetland resource classes.

Indicator selection for EMAP - GL has progressed to a tentative list of primary measurements (see Table 4.1). Based on these primary measurements, we can calculate secondary indices, e.g., Composite Trophic Index as described in Chapter 4.

We may eventually attempt to combine all of our indicators and indices into an overall assessment of the health of the Great Lakes as discussed below (refer to section 5.6).

5.3. General Statistical Overview

The analysis will follow the general model described in "Design Report for EMAP" (Overton et al. 1991) and "EMAP Sampling Design Implementation, Perspectives and Issues" (Stevens et al. in press). The general model is presented in terms of the Horvitz-Thompson (HT) estimator (Horvitz and Thompson 1952). The HT estimator can be used with any finite population probability sample, and requires only specification of the inclusion probabilities. First order inclusion probabilities are the probabilities with which the individual sampling units are included in the sample. The HT estimator requires that every unit in the population have positive first order inclusion probability; however, the actual values need only be calculated for each unit that is selected for sampling. These are designated by the symbol π_i referring to the i^{th} sampling unit. Second order, or pairwise, inclusion probabilities are the probabilities with which two specific sampling units are included in the sample. These are designated as π_{ij}, referring to the probability of simultaneously including units i and j. Pairwise inclusion probabilities are necessary to calculate the variance of the HT estimator. Design features such as stratification, methods of randomization, sample selection methods, and sample size are required to determine π_{ij}.

The HT estimator of a total is given by:

$$\hat{T}_y = \sum_{i \in S} \frac{y_i}{\pi_i} \qquad (1)$$

where y is any attribute, T_y is the total of that attribute over any specific identified population, and "^" denotes the estimator as opposed to the population parameter. The summation is restricted to the specific set of units, S, in the sample or any subset of the sample defined by a specific population. If the units in the sample are numbered from 1 to n, where n is the sample size, (1) takes the form

$$\hat{T}_y = \sum_{i=1}^{n} \frac{y_i}{\pi_i} \qquad (2)$$

In some instances, interest will focus on totals; in other cases, there is more interest in means or proportions. An estimate of the mean is obtained by dividing $\hat{T}$ by N, the number of units in the population or its estimator $\hat{N} = \sum_{i=1}^{n} \frac{1}{\pi_i}$:

$$\bar{y} = \begin{cases} \dfrac{\hat{T}_y}{N}, \text{ population size known} \\ \dfrac{\hat{T}_y}{\hat{N}}, \text{ population size estimated} \end{cases} \tag{3}$$

Estimators of proportions are obtained using indicator functions. For example, to estimate the proportion of the population with attribute A, set $y_i = 1$ if sample unit i has attribute A, and set $y_i = 0$ otherwise, and apply (5.1). Then $\frac{\hat{T}_y}{N}$ provides the desired estimator. More generally, a comprehensive characterization of the populations is by the estimated cdf for the variable of interest. The cdf of a variable Y, written $F_Y(y)$, represents the proportion of the population that has value of the variable Y less than or equal to the number y. For example, if Y were the concentration of chlorophyll a (c.a.), then $F_{c\,a}(2) = 0.30$ would mean that 30% of the target population has a value of c.a. less than or equal to 2.

The HT estimator of $F_Y(y)$ is

$$\hat{F}_Y(y) = \frac{\sum_{i=1}^{n} \frac{I(y_i \le y)}{\pi_i}}{\sum_{i=1}^{n} \frac{1}{\pi_i}} = \frac{\sum_{\substack{i=1 \\ y_i \le y}}^{n} \frac{1}{\pi_i}}{\sum_{i=1}^{n} \frac{1}{\pi_i}} \tag{4}$$

where $I(y_i \le y) = \begin{cases} 1, y_i \le y \\ 0, y_i > y \end{cases}$.

The Yates-Grundy estimator of variance for (1) is given by

$$\hat{V}[\hat{T}] = \sum_{i=1}^{n} \sum_{j>i}^{n} \left(\frac{\pi_i \pi_j - \pi_{ij}}{\pi_{ij}}\right)\left(\frac{y_i}{\pi_i} - \frac{y_j}{\pi_j}\right)^2 \tag{5}$$

Basic population parameters are estimated by some form of (1), and so are strict HT estimators. The variance estimator (5) is unbiased if all pairwise inclusion probabilities are positive and known exactly. However, systematic random designs, such as EMAP's grid based design, have some joint inclusion probabilities that are zero. Moreover, even the non-zero joint inclusion probabilities can be difficult to calculate exactly. These design features will require approximations in calculating joint inclusion probabilities. The approximation developed by Overton (1987b) is used in most instances. The approximation is derived under the assumption that the population is randomized between draws. This assumption does not hold for most EMAP samples, but simulation studies (Overton and Stehman 1987, Stehman and Overton 1987a;b) have demonstrated that this approximation along with the variance estimator (5.2) performs well in EMAP-like sampling circumstances. A convenient computational form of the pairwise inclusion probability approximation is given by

$$\pi_{ij} = 2(n-1)\pi_i \pi_j/(2n - \pi_i - \pi_j):$$

The use of this approximation in conjunction with the Yates-Grundy variance estimator in EMAP - GL amounts to assuming that the grid-based sample is nearly a simple random sample. The grid-based sample should provide more precise estimates that simple random sampling, so the (5) will provide conservative estimates of precision. Variance estimates that account for the systematic design effect, such as generalizations of the Yates successive difference estimators (Yates 1953), are being investigated by the EMAP Statistics and Design Team.

The Yates-Grundy variance estimator is not an appropriate estimator for use with a systematic design because of the failure of the assumption that $\pi_{ij} > 0$ for all i,j. The variance approximation we propose using is derived from the YG estimator by replacing π_{ij} with $2(n-1)\pi_i\pi_j/(2\,n - \pi_i - \pi_j)$. The variance estimator then becomes strictly a function of π_i and π_j. Moreover, if in addition $\pi_i = \pi$, a constant, for all i (as for a uniform grid), and the HT estimate of the population size is used, then the variance approximation for the mean collapses to $(1 - \pi)s^2/n$, where s^2 is the usual SRS based estimate of the population variance. The factor $(1 - \pi)$ can be thought of as a finite population correction factor.

We regard this as a working approximation that needs to be refined. Several refinements are being investigated by the EMAP Statistics and Design Team. In particular, most (all?) popular variance estimators for systematic samples are derived for finite populations. The continuous population analogues need to be derived and their properties investigated. Along the same lines, we are investigating variance estimators that utilize the spatial structure of the population.

These general forms specified in the EMAP design protocol can be used with any probability sampling design, including those with unequal probabilities of selection or extensive stratification. They are presented here to demonstrate the ties between EMAP - GL and the overall EMAP. However, under equal probability sampling as is used for Great Lakes primary resource classes (open water and nearshore), the general forms simplify to more familiar forms for estimates of the usual descriptive statistics and their variance estimates.

5.4. Analysis for Biotic Integrity

The assessment of status of the biological resources in the Great Lakes will require the systematic and complete analysis of response, habitat, and exposure indicators. For the strategy document, we will demonstrate our approach for statistical analysis of a hypothetical dataset. We have assumed that chlorophyll-a was collected from 11 offshore sites around Lake Michigan. Chlorophyll-a is an indicator of algal biomass, therefore it can be used as a measure of nutrient level and overall water quality. The chlorophyll-a measurements are grouped so that cumulative distributions can easily be calculated.

5.4.1. Descriptive Statistics/Visualization

The mean chlorophyll-a content in Lake Michigan open water was calculated for our hypothetical dataset. The mean chlorophyll-a level as calculated from the dataset is 1.6 μg/L, with a standard deviation of 0.22 μg/L. The coefficient of variation (standard deviation/mean) gives a relative measure of the variability of the different resource indicators within the lake. For chlorophyll-a the coefficient of variation is 14%. A small coefficient of variation would suggest that the resource is uniformly distributed. The coefficient of variation for chlorophyll-a would suggest that the offshore regions of Lake Michigan are homogeneous in regard to this indicator. Refer also to Chapter 3 for discussion of chlorophyll-a distributions.

5.4.2. Classification/Cumulative Distribution Functions

As discussed in Chapter 4, one of the desired goals of the assessment phase of EMAP - GL would be to classify the responses into nominal and subnominal conditions. This classification process will be based on a set of rules but the decision points that separate each resource class into different groups will be flexible and subject to modification as our expertise and knowledge grows. Determining proportions of a class, e.g. offshore area, in nominal and subnominal groups can be accomplished through the use of the cumulative distribution functions. However, the decision points or indicator values that separate groups and therefore define the proportions in the groups can be changed to accommodate new information or new regulatory decisions. Because cumulative distribution functions represent the complete distribution of values, the proportion of values that are above or below any reference value can be estimated visually and the effect of changes in nominal and subnominal boundary values on results can be evaluated without reanalysis of the data. For example, the ecological objective workgroup to the IJC recommended an objective of annual lake trout production greater than 0.38 kg/ha as determined using mortality rates for Lake Superior. If we were to use lake trout production as an indicator, we could initially use this a classification of nominal/subnominal for Lake Superior. As the database on lake trout production in Lake Superior improved, some other number may be determined to be a better delineation of the quality of the fish community. This approach allows some initial classification but maintains the flexibility for future descriptions.

Assuming we can define degraded conditions based on single or multiple indices, we can describe the status of each major resource class within the Great Lakes on an areal basis. For instance, we could describe the trophic status of offshore areas either by percent or actual area (km^2). The degree to which these change over time would be the measure of trends.

Using the hypothetical data for chlorophyll discussed above, we can assume that offshore sites with chlorophyll values greater than 2 µg/L are eutrophic. This would mean that 27% of the offshore area is subnominal or eutrophic. If we assume that the sampling grid is equivalent to a simple random sample, we can calculate 90% confidence limits around this proportion (θ), i.e.,

$$(\theta) = x/n$$
$$\text{variance}(\theta) = (\theta)*((1-(\theta))/n$$
$$\text{90\% Confidence Limits} = \theta \pm [\text{t-value}*\text{S.D.}(\theta)]$$

Where x = 3, the number of sample sites with chlorophyll-a greater than 2 µg/l
n = 11, the number of sample sites
t-value = 1.80

Our 90% confidence limits are derived from the t-distribution, mean, and standard deviation for θ, where n=11. The 90% confidence limits for the proportion 0.27 are (0.04-0.50). The same procedure can be used to develop confidence limits around the cdfs for the proportion of the population that is above or below a specified value of chlorophyll-a. The confidence limits that were calculated for the cdf are based on an assumption of a random sample. These confidence limits are conservative and, in the future, the statistical support team will investigate alternative estimators of the variance.

In addition to single variable (indicator or index) statistics, multivariate analysis, e.g., principal component or discriminant analysis will be used to find a linear combination of indicators and indices that describe or discriminate between research sites for each resource class. The multivariate approach will complement our other statistical methods.

5.4.3. Estimates for Combined Resource Classes

The nearshore and offshore portions will be sampled with different density grids, so that the inclusion probability densities will be different for the two resource classes. If a combined estimate is desired for a common indicator, it could be obtained via the general variable probability estimators. However, the general forms can again be simplified by making them specific to the two resource classes. Let A_{ow} be the area of offshore waters and A_{ns} be the area of nearshore waters. If $\bar{y}_{ow}$ and $\bar{y}_{ns}$ denote estimates of some quantity for the offshore and nearshore classes, respectively, then a combined estimate is given by

$$\bar{y}_{total} = \frac{A_{ow}\bar{y}_{ow} + A_{ns}\bar{y}_{ns}}{A_{ow}+A_{ns}} \qquad (6)$$

i.e., the composite estimate is given by combining the individual estimates with weights proportional to their respective areas.

5.5. Analysis of Change and Trend

EMAP places emphasis on detection of change and trends in ecological condition. We plan on extensive analyses of data using a variety of statistical techniques ranging from classical techniques based linear model theory to non-parametric techniques to techniques that are still under development that draw upon the theory of spatial statistics and sampling theory. Some of these approaches are described in more detail below.

5.5.1. Linear Model Analysis of Trend

Linear model techniques, such as analysis of variance and regression, are used with various assumptions regarding spatial and temporal variance components, statistical independence, explanatory variables, nature of trend, and nature of change. A linear model to evaluate the effect of having some annual observations in the interpenetrating design might begin with the model

$$y_{ij} = \mu + \Theta t_j + a_i + b_j + e_{ij}$$

where μ is the average value at time 0, Θ is the slope over time (fixed, linear trend), a_i is the effect of the i^{th} site, b_j is the effect of the j^{th} year, and e_{ij} is zero mean random error with standard deviation σ_e. The site and year effects are random, with standard deviations σ_a and σ_b, respectively. Under this model, σ_a describes inherent population variation, σ_b describes the variation from year to year, and σ_e represents the composite variation from all other sources: local spatial, high frequency temporal, measurement, field crew, analytical, and so on. The model assumes that all sites are subject to the same trend, and that there is no correlation between site effects and that the year effect is the same for all sites. These assumptions can be modified by a suitable choice of correlation structure, or identification and inclusion in the model of explanatory variables.

Urquhart et al. (1991) have used a similar linear model to compare two classes of sampling designs that have been used or suggested for long-term ecological monitoring: a rotating panel design (Duncan and Kalton 1987) and a serially alternating design (Overton et al. 1991) as is used in EMAP. The rotating panel design prescribes that a set of sites will be visited for several consecutive years, and then dropped from future consideration. As a set is dropped from the monitoring program, it is replaced with a new set of equal size, which then remains in the survey for a number of years. The basic arrangement for a rotating panel is for the total sample to be split into the same number of equal-sized sets as the number of years a set remains in the sample. Thus, for example, with a 4 year rotation, one fourth of the sample is replaced every year. The serially alternating design again splits the total sample into several equal-sized sets, but only one set is visited each year. A set is not revisited until all other sets have been visited, and the serial revisiting is continued indefinitely. The basic serially alternating design does not prescribe any replacement or annual revisits. Both designs can be augmented by adding a set of sites that are visited annually for the duration of the monitoring program.

Urquhart et al. (1991) used a general linear model to compare the relative efficiency of these two designs. The linear model they used gave them sufficient flexibility to consider the estimation of both status and trend, and to explore various levels of population variation, measurement error, and inter-annual variation, and to incorporate some correlation between years, and between sites measured at different times. Their conclusions were that the serially alternating design is almost always more efficient than the rotating panel, and, over the wide range of possibilities that they investigated, was never less than 99% as efficient. Moreover, they concluded that the augmented serially alternating design offered a substantial advantage in ability to make estimates for subpopulations, since more sites are visited sooner than with the rotating panel.

The approach used by Urquhart et al. (1991) can also be used to gain insight into the power of the design to detect change, since an output of their model is the precision of a trend estimate. In order to assess that power, estimates of the several components of variance and correlations are needed. For some indicators, these may be available from existing data, or they may be obtained from pilot experiments.

5.5.2. Non-Parametric Method for Trend Detection

The Mann-Kendall (Mann 1945, Kendall 1975) test has been used to detect trends in water quality (Hirsch et al. 1982) and has been recommended for use in more general environmental applications (Gilbert 1987, Loftis et al. 1989). The Mann-Kendall test statistic is $S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k)$, where $sgn(x_j - x_k) = \begin{cases} 1, & x_j - x_k > 0 \\ 0, & x_j - x_k = 0 \\ -1, & x_j - x_k < 0 \end{cases}$, and $\{x_1, x_2, ..., x_n\}$ is a sequence of observations at a single fixed site. The applications have been primarily concerned with evaluating trend at a single site, although both Gilbert (1987) and Loftis et al. (1989) suggest approaches to the multiple site situation.

A chi-squared test was used in the Phase II Eastern Lake Survey to examine population distributions for evidence of change (Overton 1987a). The test can be applied to both successive independent samples from a population, and to remeasurements on successive occasions. In the independent sample case, the test is carried out by using the cdf of the pooled samples to define classification criteria (for example, quintiles of the combined population) and doing a chi-squared test of homogeneity. A pair of such tests, classifying first by the median and then by quintiles of the pooled distribution, provide sensitivity to changes in shape as well as changes in location of the distribution function. For the remeasurement or paired sample case, the test is carried out by classifying according to the sign of the differences and to percentiles of the cdf of the sum. Both versions can be extended to multiple years.

5.5.3. Power to Detect Change and Trend

An important consideration in the selection of techniques for change and trend detection is the sensitivity of the tests, or, in statistical terms, the power of the tests. Statistical power is the probability that a test of an hypothesis is rejected given that the hypothesis is false. Generally, power increases with increasing departure from the hypothesis, that is, a large change is more likely to be detected than a small change. A statistical test of a particular hypothesis can be characterized by specifying the size of the test (probability of rejecting a true hypothesis) and its power function (probability of rejecting a false hypothesis as a function of degree of departure from the hypothesis). Where choices among alternative methods of change and trend detection exist, the more powerful test is preferred.

Power will be used to evaluate the adequacy of the design, and to determine the sample sizes needed for specific subpopulations. The evaluation is in terms of describing the probability of detecting a change or trend of a given magnitude. If the magnitude of change that is detectable with, say 80% probability, is unacceptably large for some subpopulation, then the sample size for that subpopulation may have to be increased. Provisions for doing so are incorporated in the general EMAP design. The EMAP-Statistics and Design Team is actively conducting studies of the power of proposed tests for change and trend using simulation studies based on realistic data.

An important aspect of EMAP's interpenetrating design is that it will achieve its full potential power to detect change only after repeat visits to all sites, that is, after two complete cycles. Repeat visits to a site permit a paired analysis which essentially eliminates the component of population variation. Thus, ability to detect change will increase greatly in years 5 through 8 of the sampling. Similarly, the power to detect a persistent trend will continue to increase as more years of data become available.

5.5.4. Associations

One of the objectives of EMAP - GL is to seek associations between ecological condition, as determined from response indicators, and exposure and habitat indicators. Associations among indicators will be evaluated using a suite of correlation techniques including both parametric and non-parametric tests. Categorical and logistic regressions are the techniques that will probably be more successful. The statistical analysis to be selected will depend upon the characteristics of the data for each indicator and the specific question to be answered by each analysis.

This approach will be applied to each of the resource classes to evaluate associations that might be masked by combining all classes into one analysis. For example, harbors are likely to be subject to different stresses than the offshore class of the lakes. The amount of data obtained for each class must be sufficiently large to ensure that uncertainty associated with conclusions is not unacceptably large. Thus, this is another factor to consider in evaluating the density of the proposed sampling network.

5.6. Great Lakes Ecological Condition Index: A Conceptual Proposal

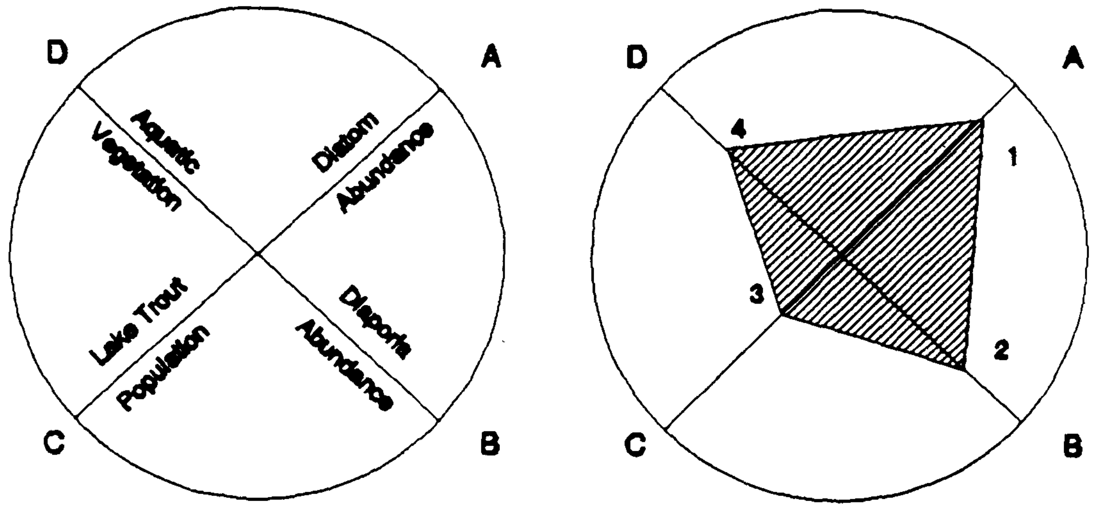
Any program that professes the goal of describing the ecological condition of the Great Lakes faces the difficulty of integrating a variety of indicators into an overall statement of condition. One goal of EMAP is not only to describe the status and trends of specific indicators but also to integrate these measurements into statements that can be used by scientists, decision makers, and the general public. The scientific community has attempted such integration through the use of indicators that integrate overall ecosystem condition (Edwards et al. 1990) and through the use of indices. Indices have been developed and used to describe various types of diversity (i.e., Shannon-Weaver index) or the biotic integrity of certain groups of organisms (i.e., Index of Biotic Integrity for freshwater fishes). There is a great deal of literature devoted to both proposing such indices and to pointing out the difficulties, errors, or limitations for their use. We do not intend to review all such literature in this report. However, in the spirit of continuing to make attempts to provide an integrative framework, the following discussion focuses on yet another approach. This approach, still in its infancy, is derived primarily from some approaches being taken in Europe and described in Rojanschi et al. (1991) and ten Brink et al. (1991).

The basic premise associated with this proposal is that indicators which are selected:

- can be measured quantitatively and accurately;
- are susceptible to human influence;
- have some indicative value for the condition of the systems; and
- have some social and political value.

It is our intention in the selection of EMAP - GL indicators (as previously discussed in Chapter 4) to meet these criteria. In addition, there must be knowledge, information, or decisions on what is the desired (nominal) state for each of the indicators. The definition of nominal, of course, is not an *a priori* decision that can be made through science alone. As also discussed in Chapter 4, some determination of nominal values may be possible through the use of historical data, reference sites, and ecological models. However, societal values are also a significant component.

Assuming indicators have been selected and nominal (desired) values for those indicators are chosen, there remains the question of integration. The proposal is to take a two-dimensional shape (we will use a circle for an example) with each indicator represented as a radius of the circle. The point at which the indicator radius intersects with the circle is defined as the nominal value. In other words, the length of the radius is (by definition) quantified into units of the indicator with the circle connecting the radius for each indicator (Figure 5.1). The center of the circle represents the zero point for the indicator, that is, the indicator is not present. In essence, the radius (in the case of a circle) represents the axis of a quantified indicator measurement. An alternative approach would be to characterize the nominal condition of an indicator as 100% of the length of the radius representing that indicator. In either case, the actual measured value for each indicator is plotted against its radius. The measured points are connected and a new interior shape is created (Figure 5.1). The index of overall condition is thus described as a percent area of the nominal area (the whole circle). Thus, the status of the ecosystem can be described, for example, as 50% of nominal and trends in either direction can be reported and graphically displayed.



Example diagram with four indicators. "A-D" represent the nominal condition for each indicator. Assumes equal weighting and no correlation between indicators.

Example diagram with "1-4" representing actual measured values for the four indicators. The shaded area divided by the total area would equal the index of overall condition.

Figure 5.1 Great Lakes ecological condition index: A conceptual proposal.

As with any idea, there are a number of difficulties that quickly arise from what seems like a simple concept. The formation of a circle, for example, assumes that each indicator has equal value. In contrast, if weighting indicators is desired, the appropriate shape may not be a circle but rather some other geographic shape. This would result from having the line representing the nominal condition of the indicators consist of different lengths depending on their relative weight. For example, some individuals might argue that top predator fish have more value to society and should be weighted more heavily than a particular species of benthic invertebrate. Society or regulations might dictate that endangered species should have more weight in such an analysis than a common species. While weighting might result in different geographic shapes, the basic analysis of overall condition would follow the same process as described above.

Another difficulty is that the basic shape of the nominal condition graph depends on the distance separating the indicator axis. If all indicators are equally weighted and have no correlation between them, the spacing of the indicator axis would be different (and therefore forming a different shape and area) than if the indicators were correlated. The degree of correlation would need to be known. Some techniques for defining appropriate shapes based on the degree of autocorrelation have recently been developed in the mathematics of graph theory and may be applicable to this problem.

As described above, this approach to simplifying the analysis and display of complex interactions is clearly in the preliminary phases of thought and discussion. The reactions and ideas of many scientists will be solicited to determine if there is any value added (or lost) in attempting to develop such an index and if so, to help develop both the concept and the mechanics of its construction.

6. Logistics Approach

6.1. Introduction

This section describes the logistics approach for implementing EMAP - GL. It includes a summary of requirements for the logistics plans, a discussion of the major logistics issues, a field operations scenario, and a proposed organizational structure.

6.2. Logistics Implementation Components

Implementing the EMAP - GL program will require detailed, comprehensive logistics planning. Logistics considerations include coordination and oversight of all implementation support activities and the actual data collection activities. A logistics plan must be developed prior to start of implementation of field activities to assure that the goals of the program are met. The logistics plan should include all elements given in Table 6.1 as specified by US EPA (1990a).

Table 6.1 EMAP Logistical Elements for Implementation of Great Lakes Monitoring Programs.

1.	Overview of Logistical Activities	9.	Procurement / Inventory Control
2.	Staffing	10.	Training
3.	Communications	11.	Field Operations
4.	Sampling Schedule	12.	Laboratory Operations
5.	Site Access	13.	Data Management Activities
6.	Reconnaissance	14.	Quality Assurance
7.	Waste Disposal Plan	15.	Logistics Review/ Recommendations
8.	Safety Plan		

Element 1. Overview of Logistical Activities--Summarize the types of activities required to complete the project. Maintain a timeline showing all critical path milestones, e.g., project design, indicator selection, site selection, reconnaissance, procurement, methods selection, development of standard operating procedures, and resolution of specific quality assurance issues.

Element 2. Staffing and Personnel Requirements--Describe the number of personnel and the organizational structure necessary to accomplish project objectives. Define who is responsible for staffing and interagency and teaming mechanisms. Consider work schedules to determine whether extra positions should be created or whether existing personnel should work overtime. Create a contingency plan for replacing staff members when necessary. Identify key personnel and provide plans for retaining them.

Element 3. Communications--Address communications among field crews, laboratory crews, and supervisory personnel, and between EMAP participants and any local organizations who should be informed of EMAP field activities. Also include plans for tracking samples, data, crews, equipment, and supplies. Discuss how field crews should interact with the public or with the media. Explain how approved changes in standard operating procedures will be documented and communicated for implementation.

Element 4. Sampling Schedule--Based on project, indicator, and statistical design or other program requirements, devise an efficient schedule for field activities. Consider geographical sampling windows within geographical areas and other factors such as climate and site access constraints.

Element 5. Site Access--Address issues related to gaining access to sampling sites including scientific collection permits, if required. Develop a list of local contacts to discern property ownership, jurisdiction, and the best site access methods. Address plans to obtain appropriate access permission and applicable collection permits. Consider how to coordinate activities in the same area of more than one resource task group. Discuss ways to arrange long-term access rights, track changes in ownership of private sites and management of public sites, notification of owners and managers before revisiting the sites for future monitoring, and provide contingency plans in case of future failure to obtain access permission.

Element 6. Reconnaissance--Define criteria for selecting base operation sites (take into consideration personnel and technical support requirements), geographical location with respect to sampling sites, and time constraints imposed by sampling design or climate. Sampling sites identified as having potentially difficult physical or legal access should be visited during field reconnaissance. Additional resources needed for sampling should be identified if the access problem is due to physical conditions.

Element 7. Waste Disposal Plan--Explain how chemical and biological wastes will be stored, transported, and disposed of safely and legally. Address what permits will be needed for storage, transport, and disposal of wastes.

Element 8. Safety Plan--Discuss how emergency situations will be evaluated and handled. Determine which emergency services will be available in the field. Explain what procedures will be used to initiate search and rescue operations. List the training or other preventive measures required to conduct field operations safely. Indicate how this field safety plan will be developed in conjunction with laboratory, processing, and materials handling safety plans.

Element 9. Procurement and Inventory Control--Identify equipment, supply, inventory control and resupply, and service requirements of the field program. Consider the shipping requirements for chemical and biological materials. Determine what analytical or other services will be needed and the best mechanisms for acquiring them. A procurement schedule should be provided for all items.

Element 10. Training Program--Describe who will prepare, review, and revise the field training and operations manual and the procedures for field measurements, sampling, sample handling shipment, data recording, quality control, safety, waste disposal, and communications. Outline a schedule for the completion of these items. Describe training needs and identify who will conduct and review training. Address how personnel will be evaluated to ensure competency.

Element 11. Field Operations--Indicate the organizations that will perform each of the daily field activities. Describe how and when the daily field activities will be performed. Discuss and schedule the major events within field operations (i.e., mobilization, demobilization, and phase changes in sampling activities). Consider contingencies such as back-up personnel in the event of sickness. Require real time evaluation to identify and resolve problems.

Element 12. Laboratory Operation--Indicate what organizations will be responsible for each type of sample preparation or analysis and for formulating each laboratory operations manual. If EPA conducts the activities directly, provide a development plan for providing appropriate laboratory facilities.

Element 13. Information Management--Describe any data management activities that might be affected directly by field operations. Establish guidelines for the timely and responsive transferral of information from field personnel to data managers. Indicate the groups that will be responsible for preparing and reviewing field data forms; provide a schedule for the completion of these forms. Develop a schedule for completion of the information management plan by the information management group.

Element 14. Quality Assurance--Describe who will provide input to the QA plan on field sampling, sample handling and preparation, sample shipment, sample disposition, and data management. A schedule for completing the QA plan should be provided to the logistics team and included in the logistics plan. QA activities should be coordinated with other resource groups using similar methods. This effort should identify common methods and standards when possible.

Element 15. Logistics Review and Recommendations--For each year of study within each resource group, summarize logistics activities. Discuss how personnel will be debriefed to identify and resolve problems. Discuss pilot studies and associated methods evaluation experiments; present logistics data summaries within the full-scale project.

Field activities will start in 1992 with pilot programs in Lake Michigan and Lake Superior. Additional Great Lakes will be phased into the program in each of the following years.

6.3. Logistics Issues

The complexity of this program poses a number of logistics issues; overlooking or ignoring apparently minor issues or details will eventually jeopardize the success of the program. These issues will be addressed fully in each of the logistics plans prior to the full implementation of field activities. A brief discussion of the major issues (staffing, access, and data confidentiality) is provided in the following sections.

6.3.a. Staffing

Due to the type of field data needed for indicator evaluation (Chapter 4), field personnel will require a nigh degree of expertise. They must have knowledge of fish, macroinvertebrate, and diatom taxonomy, field sampling methods, and sample handling. Various state resource agencies, EPA regional offices, other federal agencies, and universities have large pools of experienced personnel. Long-term agreements with these agencies and institutions to provide key personnel during the field season may provide a solution to this issue. To accomplish this, EMAP will have to demonstrate its utility to the other organizations by providing additional data and information addressing their problems. A concerted effort to inform these organizations of the goals and objectives of EMAP, and getting these organizations involved in the early planning phases of the programs are initial steps being taken.

6.3.b. Access

Obtaining access information and permission to visit sampling sites involves public or private authorization. If land is publicly owned, approval must be obtained from the appropriate authority. If land is owned privately, each landowner will have to be contacted and written access permission will have to be obtained. For the most part, access is only a potential problem for the wetland class of EMAP - GL. The other classes will most frequently be sampled by ships in the lakes themselves.

Gaining access permission and knowledge of access routes will require reconnaissance. The amount of time devoted to sampling may be dependent upon the physical access conditions.

6.3.c. Data Confidentiality

Data confidentiality is an issue of particular concern to EMAP. Many landowners may be reluctant to permit access from their property because they fear regulatory and enforcement actions. As with obtaining access, data confidentiality is only a potential problem with the wetlands component of EMAP - GL. Access is not a design constraint, and any denials by landowners could affect population estimates. EMAP data may have to be aggregated in such a way that individuals cannot be identified to assure landowners and cooperating agencies that site-specific data will not be used against their interests. Agreeing to withhold certain information, however, is in direct conflict with the Freedom of Information Act and EPA's policy on data confidentiality. This issue will have to be resolved in the near future. The EPA Office of General Counsel is currently being consulted in this matter.

6.4. Field Operation Scenario

The following field operation scenario is presented to demonstrate that the proposed field activities are logistically feasible within the allotted time frame. This scenario is only one of many that could be developed at this time. It is strictly hypothetical and does not necessarily include all proposed indicator parameters or the order in which activities would take place when the program is actually implemented. Indicators are being evaluated and developed for pilot programs; the actual protocols will be solidified in the future.

6.4.a. General Logistics Scenario

(1) The index periods will be immediately after ice-out in the spring and late July through September.

(2) The number of Tier 2 sites sampled per year will be approximately 10-20 per lake for the offshore zones and 40-80 per lake for the nearshore zones. It will take four years to sample all Tier 2 sites.

(3) Site selection is completely random and does not consider site access.

(4) Distance between sites will be one-quarter the density of the Tier 2 sites, or approximately 150 miles for the offshore sites.

(5) Research vessels will be the primary sampling platform.

(6) Samples requiring immediate laboratory analyses will be shipped to the appropriate laboratory by overnight courier the day after collection or analyzed on board.

6.5. Organizational Structure

The long-term success of EMAP is dependent on the development of an interorganization program with common goals for the monitoring of the ecological condition of the environment. Great Lakes monitoring will involve numerous agencies and academic institutions. As EMAP evolves, agreements will have to be established to define responsibilities. These organizations have highly experienced field personnel, and it is anticipated that personnel from these agencies will participate in field activities, analyses, and interpretation.

7. Quality Assurance Program

7.1. Introduction

The quality assurance (QA) program for EMAP - GL will be designed to ensure that the type, amount, and quality of data collected will be in accordance with the data quality objectives established for the program. Quality assurance programs are mandated by the EPA for all data acquisition activities which it sponsors or in which it participates (Stanley and Verner 1985). The EMAP - GL plan is based on ongoing work and publications by the EMAP - Estuaries and EMAP - Surface Waters resource groups.

Related to the spatial and temporal scales of implementation of data collection activities is the number of participating groups. The participation of Federal and State agencies, contractors, private consultants, analytical laboratories, and scientists from universities or other research institutions is expected. Existing monitoring programs considered for integration into the EMAP framework may have QA requirements that are initially incompatible with those established for the Great Lakes component, or EMAP as a whole. Differences in sampling and analytical methodology, whether among participating groups, among regions, or as a result of new technologies over the life of EMAP, must be monitored and assessed in order to quantify and minimize their impact on the interpretation of the observed status and trends of ecological condition.

In developing information of known quality consistent with data quality objectives, emphasis will be on consistency in implementation, quality control, prompt corrective action, and continuous improvement. This approach will identify and correct problems as soon as possible, to minimize their impact on data quality. Appropriate guidance, training, technical support, and tools (e.g., performance audit materials, quality assurance documentation) will be provided to all participants to implement QA programs that are consistent with the data quality requirements of the Great Lakes component, and EMAP as a whole. While the emphasis of the QA program is to provide guidance and support, there must also be the means to deal with instances of poor performance, if necessary, to avoid compromising data quality.

The following subsections outline the general approaches, conceptual rationale, and guidelines proposed for designing and implementing the overall QA program for EMAP - GL.

7.1.a. The Data Quality Hierarchy

Data quality exists at several levels. Measurement data quality includes attributes such as precision, accuracy, representativeness, comparability, and completeness associated with the measurement of environmental variables. At the next level, it also includes the uncertainty associated with the methods used to assimilate these measurement data into an assessment (i.e., provide information from the data). For

EMAP, this can be perceived as "indicator quality", since the indicators are those tools used to provide information about specific aspects of ecosystem condition. Factors affecting quality at this level comprise not only measurement data quality, but also sampling design and statistical data analysis. At the next level, these indicators are aggregated into an overall assessment of system condition. The uncertainty associated with each indicator must be included in an estimate of the overall certainty of this aggregate assessment. This uncertainty will then be compared to ecosystem-level quality objectives to assure that data collection and interpretation activities are consistent with program objectives in terms of the quality of the information provided. Finally, EMAP intends to integrate information across ecosystems in order to make regional-scale assessments of ecological condition. Again, the uncertainty associated with each component of the evaluation (i.e., individual ecosystem assessments) must be incorporated into an estimate of overall uncertainty for the assessment and compared to cross-ecosystem quality objectives. The Data Quality Objective (DQO) process requires that sources of variability be identified at each level and that all relevant sources be considered in generating estimates of uncertainty at any level of the hierarchy.

7.1.b. The Role of DQOs in EMAP

The EMAP mission provides the Stage 1 input to initiate the DQO process. The EPA perceived a need within the Agency and in other client groups for information regarding the current extent of various ecological resources (i.e., how much of each resource exists), the current status or condition of those resources, and some indication of trends in extent and condition over time. The need for environmental information has been stated in very qualitative terms at this level.

At this point in the process, the tools necessary to measure extent and define condition within each of these ecosystems are being developed. This, in turn, will allow policy and decision makers to articulate the requirements for data quality in more quantitative terms. The program is now in Stage 2, with extensive feedback to Stage 1, and the process may require several iterations.

In Stage 2, each resource group within EMAP must develop a series of indicators that, in aggregate, allow for an overall assessment of ecosystem condition. Quantitative "logic statements" must be developed describing the data to be collected for each indicator and the way in which that data will be used to provide information on system condition. These statements should include critical values above which the system is in an acceptable or marginally impacted condition (i.e., nominal) and below which the system is significantly impacted (i.e., sub-nominal). This critical value must be scientifically defensible. Where possible, these statements should also relate each indicator to endpoints of societal interest or concern, so the ramifications of changes in system condition can be understood and appreciated by a variety of client groups.

In addition to developing these logic statements, a series of error constraints must be developed that identify all known sources of error or uncertainty associated with the indicator. These will include measurement error (the difference between sample values and *in situ* true values). Measurement error can be further divided into analytical error (error associated with the measurement process) and error from other sources such as sample design, collection, handling, storage, preservation, etc. Sampling error is a function of natural spatial and temporal variability and sampling design. Wherever possible, estimates should be provided for each source of uncertainty. In this way, factors that contribute significantly to the overall variability of the indicator are identified and the effectiveness of various options in resource allocation can be evaluated. For example, if spatial variability is the major factor in the overall uncertainty associated with an indicator and measurement error is small by comparison, it may be judicious to use a less precise and less costly method of analysis and invest more resources in increasing the sampling density within a region to reduce the overall uncertainty in the data.

Early in the program, individual indicators will be used to make discreet assessments of condition. Tools for making aggregate ecosystem assessments and cross-ecosystem assessments will be developed over time. The DQO process should provide the framework for this development, assuring that assessment tools at all levels provide information of sufficient quality to meet program objectives.

7.2 Data Quality Requirements

In all data collection activities, data quality requirements will be specified in five areas: precision, bias, comparability, completeness, and representativeness (Stanley and Verner 1985; Smith et al. 1988). In addition (when appropriate), minimum tolerable background levels of chemical constituents will be established. These levels represent the maximum concentrations of constituents that can be contributed by the sample collection and measurement process. In cases of trace-level analyses, limits of detection will be monitored and assessed.

Ideally, data quality requirements will be developed based on the overall data quality objectives. In some cases, the requirements established will be qualitative; in others, quantitative. The requirements will also be reviewed periodically throughout the program, and revised as necessary in response to improved capability, additional knowledge, or technological or resource limitations.

Data quality requirements, constrained by sampling, measurement, or logistical considerations, will determine the choice of appropriate methodology. Criteria required for initial selection of appropriate chemical and biological methodologies are presented in Table 7.1. Choice of these criteria is based primarily on the approach advocated by Hunt and Wilson (1986), with the addition of criteria relevant to the design of a data management system.

Table 7.1 Criteria for Selection of Appropriate Sampling and Analytical (or Measurement) Methodology (based on Hunt and Wilson 1986).

Criteria	Comments
Range of values of interest	May need to be tailored for different regions or different projects
Lowest value of interest (values below this will probably have uncertainties > 100%); or, in case of trace-level analyses, the required limit of detection	Chemical: Used to determine appropriate limit of detection Biological: May help define the minimum effort required in obtaining data (e.g., at least 100 organisms in a benthic sample are needed for determining species composition and relative abundances)
Maximum tolerable measurement error (random and systematic)	Defined on basis of sample collection and measurement only Additional error components of interest can be defined in terms of short-term or long-term (e.g., within-day or within-batch vs. among-day, among-batch, or among-group) Should be expressed in both absolute and relative terms: Absolute: M equal to lowest value of interest Relative: M some specified percentage of true or most probable value "known value" = Absolute/Relative; Represents value at which absolute error equals relative error
Standard reference on which method is based	Describe any required modifications
Required frequency of sampling or collection	Requirements based on sampling plan; used to estimate variance components of interest
Collection, analytical, or measurement constraints	Site selection criteria, special equipment requirements; use of hazardous reagents, etc.
Sample handling considerations or measurement conditions	Appropriate holding times Operational: May be based on data reporting time requirement Maximum: If greater than operational, point at which sample is no longer considered representative of conditions at a time of collection containers/preservation techniques
Reporting requirements	Type of variable (numeric coded, character, categorical, etc.) Reporting units (mg/L, μeq/L, number of individuals, etc.) Number of significant figures desired, and maximum number of decimal places In addition to being used to select method of appropriate sensitivity, information is needed to design database, also for collection forms (hard copy or electronic)
Data reporting time	Time period between collection and incorporation of validated data into database for use in analysis and reporting

7.2.a. Precision and Bias

Precision and bias are estimates of random and systematic error in a measurement process (Kirchner 1983, Hunt and Wilson 1986). Collectively, they provide an estimate of the total error or uncertainty associated with an individual measurement, or set of measurements. In theory, random and systematic errors can be determined at any point in a collection and measurement process. Estimates of the various error components will be accomplished primarily through the use of replicate sampling; such sampling can be modified to address and control major sources of variability. The statistical design and sampling plan should act to minimize systematic errors in all components except measurement error (σ^2_{meas}). Systematic errors in these components will be minimized by using documented methodologies and standardized procedures, and evaluated using samples of known composition that can be subjected to the entire collection and measurement process. Variance components of the collection and measurement process (e.g., among analytical laboratories or among individuals identifying biological specimens) should be estimated periodically so that quality assurance efforts can be allocated to control major sources of error.

The precision and bias requirements will be used to define criteria to monitor collection and measurement activities and to maintain them in a state of statistical control (i.e., the distribution of individual measurements have a stable and predictable over time (Taylor 1988). Estimates of precision and bias are also necessary to evaluate the other three data quality indicators (comparability, completeness, and representa-tiveness).

In general, data from one or more measurements of variables will be combined (and possibly transformed or categorized) into metrics; one or more metrics will be incorporated into an indicator, and one or more indicators will be used to provide an estimate of the ecological health (as "nominal" or "subnominal") of a population.

7.2.b. Comparability

We also need to be cognizant of data comparability external to EMAP - GL, i.e., 1) with other EMAP ecosystems group (e.g., surface waters, forests, and wetlands); 2) with other environmental datasets, data from existing monitoring programs being incorporated or integrated into EMAP - GL; and 3) the comparability of data collected now to data that will be collected in the future, whether as part of EMAP itself, or other monitoring efforts that may develop in the future. In these cases, comparability would need to be evaluated with respect to the QA and QC data available. The degree of comparability required will depend on the intended use of the data (trend detection, associative analyses, etc.)

7.2.c. Completeness

For EMAP - GL, the requirements for completeness will be based on the amount of data required to make conclusions pertinent to the program (or project-specific) objectives.

7.2.d. Representativeness

Representativeness is defined as "the degree to which the data accurately and precisely represent a characteristic of a population parameter, variation of a property, a process characteristic, or an operational condition" (Stanley and Verner 1985, Smith et al. 1988). Representativeness can be affected by problems in any or all of all the other indicators of data quality, as well as by issues such as the location of a sampling site, the time of sampling, and the statistical selection of sampling sites. More specific to a quality assurance program is the representativeness of samples or procedures used to control and assess data quality as compared to the range of conditions being sampled.

7.2.e. Tolerable Background Levels

Background is operationally defined as the amount of contamination due to collection, handling, processing, and measurement. It is most relevant to those chemical constituents present in the environment in very low concentrations. Requirements for tolerable background limits will be determined based on the lowest concentration of interest that is required to assure representativeness or completeness requirements are not compromised. Careful adherence to sample collection, handling, and processing protocols will minimize background levels. Blank samples of various types will be used to provide estimates of background levels.

7.3. Organization and Staffing Requirements

Overall responsibility for implementing consistent and adequate quality assurance programs within EMAP as a whole is the responsibility of EMAP QA coordinator. The design and implementation of the QA program for the Great Lakes component is the responsibility of the QA Officer. The QA Officer will be assisted by one or more coordinators in implementing the large-scale annual sampling operations.

7.4. Quality Assurance Documentation

Prior to the implementation of field sampling operations, a number of different documents will be prepared (or existing documents utilized) as part of the QA program. These documents are described in Table 7.2.

Primary guidance for implementing the QA program will be provided by the EMAP Quality Assurance Program Plan (QAPP) (US EPA 1990b). The policies, organization, objectives, and functional activities that pertain specifically to the QA program for the Great Lakes component will be detailed in a Quality Assurance Project Plan (QAPjP).

The Great Lakes QAPjP will be used as guidance in preparing QAPjPs for special studies, be they regional or local in focus. In general, the QAPjP for any specific data collection activity will detail the quality control and quality assessment activities (summarized in the following subsections) that will be used to ensure the data meet the data quality requirements established for the project. Additional QA documentation that may be appropriate in specific instances include guidance documents or QA program plans for other federal or state agencies and facilities, provided they meet or exceed the requirements set forth in the EMAP QA Program Plan and Great Lakes QAPjP.

QA documentation pertaining to EMAP - GL will be reviewed periodically, and revised as necessary to reflect changes based on previous performance, or other modifications to either the QA program or to EMAP in general. Changes in various aspects of the QA program should also be incorporated into revision of standard operating procedures related to sample collection and measurement.

7.5. Quality Control Guidelines

Quality control is applicable to all stages of a data acquisition process, from design through sampling and analysis, data management, and interpretative reporting. Each stage in the process represents a point at which quality control measures can be implemented (if necessary or desirable to monitor those aspects that are most subject to error or inconsistency).

Those stages conducted after the commencement of field operations also represent points where assessments of data quality can be made. In some cases, such assessments are necessary to monitor sources of error to optimally allocate control measures among points in the process where they are most needed.

General activities to maximize the success of quality control program include:
(1) documentation of procedures related to design, sampling, measurement, information management, data analysis, reporting, and quality assurance;
(2) standardized training programs to ensure a minimal level of competency in all aspects of the project; (3) maintenance schedule for all sampling and analytical equipment and instrumentation; and (4) periodic site visits by knowledgeable members of the QA or management staffs to ensure that sampling and measurement activities are being conducted appropriately, to recommend corrective actions as necessary, and to assist on-site personnel with addressing QA-related issues.

Where appropriate, collection and measurement processes will be monitored through the use of frequent quality control checks using samples of known composition, or through replicate measurements. Control charts will be maintained whenever possible. Use of these tools allows for rapid identifications and resolution of problems related to sample collection or measurement, and provides documentation that the process is being maintained in a state of statistical control. Specific examples of quality control activities are provided in the following subsections.

Table 7.2 Quality Assurance Related Documentation of EMAP - GL.

- EMAP Quality Assurance Program Plan (QAPP)

  Describes philosophy and QA policies of EMAP, and provides guidance for designing and implementing QA programs within EMAP

- Great Lakes Quality Assurance Project Plans (QAPjP)

  Details the quality control and assessment activities that will be used in the QA program for Great Lakes

- Field Operations Manuals

  Standard operating procedures for sample collection, handling, and processing, collection of field data, and data management activities (including QA and QC procedures). Also describes other logistical procedures (e.g., sample shipping, waste disposal, communications, safety, etc.) conducted in the field.

- Analytical Methods Manuals

  Standard operating procedures for sample analysis (including QA/QC procedures).

- Training Plan

- Quality Assurance Project Plans from EMAP Support Groups

  Information Management

- Other QAPPs and appropriate QAPjPs for other participating groups (agencies, laboratories, principal investigators, etc.)

It is important to recognize that the utility of quality control measurements will be constrained (especially in the field) by the relatively brief index period each year (approximately 2.5 months), by the turnaround time between collection of samples and subsequent analysis (especially for complex analyses such as organic compounds or fish tissue analyses).

7.5.a. Biological Measurements

When possible, some type of control criteria will be established to ensure an adequate sampling effort has been conducted at each site to collect a representative index sample. In cases where this is not feasible, some type of replicate sampling, repeated measurement, or additional effort sampling program will be conducted at a subset of sites to provide an estimate of sampling efficiency or precision. Such estimates can subsequently be used to develop control criteria as the program will be conducted at a subset of sites to provide an estimate of sampling efficiency or precision. Repeated sampling and measurement strategies will be designed in conjunction with the sample replication scenarios presented in Chapter 3. Repeated or independent checks on sample processing and taxonomic identifications will be conducted on a subset of samples collected. Reference collections of biological specimens will be developed and maintained by participating groups during the course of the program. Such collections will be eventually archived at a permanent collection facility (e.g., museum) for future use.

7.5.b. Chemical Measurements

Quality control activities for chemical measurements are well-documented (e.g., Hunt and Wilson 1986, Taylor 1988). Table 7.3 summarizes these activities. Specialized collection and handling procedures may be required for certain types of water samples (e.g., those being analyzed for organic constituents) to minimize contamination and prevent changes in composition between collection and analysis.

In the laboratory, appropriate types of control samples (and control charts) will be used to monitor and evaluate statistical control of the analytical process. For inorganic analyses, at least one check standard (at a concentration near the middle of the calibration range) will be analyzed periodically with routine samples. Additional standards may be necessary to determine detection limits for analytes present in low concentrations. For organic analyses, internal standards may not be available; matrix spikes or duplicate analyses on a subset of routine samples will be required to monitor random and systematic errors.

When possible, Standard Reference Materials (SRMs) or Certified Reference Materials (CRMs) will be used periodically as non-blind samples to assist laboratories in maintaining statistical control. Such materials will be of most use for analyses of sediment chemistry, and possibly for some organic analyses, and for analyses of compounds in fish tissue. Such materials are currently being used by the Near Coastal component of EMAP, and this program should provide information related to feasibility, cost, and preliminary performance data that can be utilized in the QA program for the Great Lakes. It would be advantageous to subject such reference samples to the entire collection and measurement process, rather than just to the analytical phase. This would assist in monitoring potential errors (random and systematic) associated with sample collection and field processing. The feasibility of implementing such an approach as a quality control tool will be investigated as part of the QA program for the Great Lakes.

7.5.c. Habitat Quality and Site Characterization Measurements

Quality control activities associated with the landscape characterization measurements being conducted in support of the EMAP Great Lakes component will be documented in a separate quality assurance plan. For those measurements being collected as part of the EMAP Great Lakes effort, the most critical quality control activities (once standardized methods are implemented) are the development and use of standardized codes and categories. For measurements collected from maps, an independent check of the measurements conducted periodically by a second person (or group) would serve to detect and correct errors on a timely basis. For data being collected during a site visit, proper calibration of instruments (e.g., calibration of an electronic depth

Table 7.3 Quality Control Activities Associated with Chemical Measurements.

Field:

- Calibration checks of instrumentation using independent standards of similar composition to environmental samples. Use of control charts to monitor performance.
- Preventative maintenance program for all equipment and instrumentation.
- Standardized procedures for collecting, handling, and processing samples. Procedures to minimize potential of contamination during collection, handling, or processing.
- Proper preservation and labeling of samples.
- On-site review of recorded data and other information.
- Periodic use of field blank samples and audit materia to check for effect of collection and processing.

Laboratory:

- Standardized procedures for preparation, calibration, and analysis.
- Preventative maintenance program for analytical instrumentation.
- Routine use of control samples (blanks, check standards, matrix spikes, etc.) and control charts to monitor statistical control of analytical process.
- Periodic use of reference material (Standard Reference Materials, Certified Reference Materials) or other sample of known composition as internal standards to check for systematic errors in analysis.
- Review of analytical data immediately after analysis and before entry into database.

finder against a calibrated sounding line), and repeated measurements by a second person on a subset of sites would be used as the primary means of minimizing errors. Such repeated measurements also provide estimates of the magnitude of measurement errors.

It would be desirable to implement methods to monitor for systematic errors in collecting these data (whether they result from a particular method or from different crews that utilize a method).

7.5.d. Samples and Specimens

Archival activities will involve samples for chemical analyses, the curation of biological specimens (fish, invertebrates, and slides of diatoms from sediment cores), and validated databases. For chemical samples, samples of water and sediment will generally be archived during a particular index period in case some type of reanalysis is warranted. Such samples (or a subset) may be preserved and archived for longer periods to permit future analyses of constituents other than those initially determined. An example might include more detailed analyses of samples when the results of bioassay experiments indicate possible toxicity.

Such long-term storage may be feasible for some inorganic constituents, but may not be feasible for organic compounds. Samples of fish tissue may be placed in a specimen bank, such as that established by the National Institute of Standards and Technology (NIST) for possible analyses in the future.

Voucher specimens of fish and invertebrates will be collected as part of the routine quality control program. Periodically, such specimens will be placed into a permanent collection. Possible options for curation include the establishment of a specimen banking and curation system specifically for EMAP, or to make arrangements with regional facilities (e.g., national museums, university museums, or state biological survey agencies) to incorporate specimens collected as part of EMAP into permanent collections. The archival of specimens would be reported in the appropriate summary or interpretative reports.

7.6. Data Review, Verification, and Validation

This aspect of the QA program overlaps with the QA program that will be established for the information management program (Chapter 8). Operationally, QA for Great Lakes information management can be considered as two separate elements. One element, data review, verification, and validation ensures that all information which is ultimately entered into a database is accurate. The second component, which is addressed in Chapter 8, deals with maintaining the security and integrity of validated databases once they have been archived and made available for use in data analysis, reporting, or distribution to users outside of the Great Lakes component, or outside of EMAP. Of primary concern here is the prevention of deletion, alteration, or irretrievability of information stored in databases.

The general approach in minimizing data-related errors prior to archival will be to emphasize the review of information at the point of collection or measurement as soon as possible after the sample or measurement has been obtained. Where feasible, data recording will be done electronically, with standardized recording forms being used as backups. In the field, data logging devices (hand held computers that display screens similar to manual field forms) are being tested by other EMAP task groups. Use of data logging devices would reduce the time required for data entry, and will automatically check for erroneous data as it is entered (e.g., range checks on numeric data, misspellings, or invalid codes). Similar types of devices may also be utilized for laboratory measurements.

The review process will be automated to the extent possible, but not to the exclusion of a manual review by qualified and knowledgeable people. In order to complete the review, verification, and validation process as quickly as possible, a substantial investment in sources and personnel required for data entry and data review and verification will be required.

Data review will initially involve a check of raw data (e.g., what is recorded on data forms) before entry into an electronic database. In the field, forms should be reviewed by a second person before leaving a site. A subsequent review should occur immediately after data entry by comparing the entered data to the raw data. Data from quality control samples or measurements, and reviewing control charts, can be used to determine if reanalysis (or remeasurement) is required before data are entered.

The data verification process is largely an automated one, and serves to check that entered values are correct and (when possible) internally consistent within a sample (or set of measurements). Examples of verification procedures include range checks, checks for duplicate entries, frequency checks of coded variables to identify inappropriate codes, and format checks to ensure data has been entered in the correct format. Quality control data from check samples, blacks, or replicate samples, or use of redundant measurements for critical parameters (e.g., field versus laboratory pH) can be used to determine if there are problems with sample collection or measurement. Internal consistency checks include ion balance and conductivity calculations for inorganic chemical constituents. For biological samples and measurements, internal consistency checks include summing species proportions in samples to ensure they do not total to more than 100 percent, checks for missing taxa, evidence of "container effects" in bioassay experiments, and the taxonomic accuracy of species identifications.

Once the entered data are verified as being accurate, they are validated by examination against regional expectations to identify and explain outlier samples or sites. Validation may involve comparison with historical data, or through the use of association and multivariate analyses.

7.7. Assessment of Data Quality

The assessment of data quality for the Great Lakes component of EMAP will occur within a lake and among sampling cycles. Qualitative assessments include documenting methods, using a sampling design that ensures unbiased and representative samples, and site visits to ensure consistency among participating groups. Quantitative assessment will attempt to estimate errors associated with sample collection and measurement that are important in either the interpretation of indicators, or to optimize the QA program through time (to adjust the effort and intensity of quality control to areas where it is needed the most).

The primary means of assessing error and uncertainty will be through carefully designed performance evaluation studies. These studies will test hypotheses related to data quality requirements for random and systematic errors.

The design will be based on consideration of Type I and Type II errors, and will attempt to provide estimates of: (1) total measurement error for use in data interpretation activities; and (2) important components of variance within measurement error that can be used to determine which steps in the collection and measurement process require more (or less) quality control emphasis. The sample sizes and frequency of measurement will be optimized to provide the necessary answers in the required reporting period.

Performance evaluation studies could be conducted using performance audit samples for chemical analyses, reference samples for biological measurements, and "round-robin" studies using natural samples (either chemical or biological). For water column chemistry, appropriate performance audit materials are available for most inorganic constituents. Depending on the constituent, appropriate materials for organic analyses may or may not be currently available. Materials for sediment chemistry and fish tissue chemistry may be limited in their availability and appropriateness.

As mentioned previously, an important issue in the program is the impact that using different methodologies, or modifying or changing methodologies over time, will have on data interpretation, particularly in the detection of trends in ecological condition. The QA program for the Great Lakes component will provide standard guidelines for implementing a new methodology. Performance evaluation studies will provide some information on methods comparability, but comparability studies should be a more intensive effort designed to test specific hypotheses related to the comparability with a previous methodology. Such a comparability study must be conducted, evaluated, and approved before new or modified methods can be implemented.

7.8. Quality Assurance Reporting

In addition to the documentation described in Chapter 2, other types of reports will be produced periodically as part of the QA program. These include: (1) summary reports of site visits and audits; (2) performance evaluation (or method comparisons) summaries; and (3) assessments of data quality. Summary reports of site visits will serve to identify and track issues and subsequent corrective actions, and provide information to update other QA documentation.

The results of performance evaluation studies will be reviewed and returned to participants within a short time after submission. Evaluation summaries of QA-related data and other appropriate information will be prepared and included in the appropriate Great Lakes reports.

8. Information Management

8.1. Overview of EMAP - GL Information Management

During the development and implementation of the EMAP - GL program a great volume of raw data of diverse origins will be collected, analyzed, and reported. The resulting information[1] will be utilized to evaluate the current status, extent, changes, and trends in the condition of Great Lakes ecological resources. The capability provided by an EMAP- Information Management System (IMS) to manage and disseminate such information in a timely and cost-effective manner will be a major determinant of the success of the program. The IMS will provide the information management functions of data collection, validation and verification, storage, analysis, retrieval and reporting, and archiving. This section describes the information management objectives of EMAP - GL and the operational approach to be used to accomplish those objectives.

The EMAP - GL program will utilize historical datasets generated by other monitoring programs currently or previously operational. Such datasets will contain usable information in differing formats, and in various states of quality assurance. The EMAP - GL IMS will have the capability to quality assure and incorporate historical datasets into standard dataset formats.

EMAP - GL data will be summarized, compared, aggregated, and reported, using a variety of statistical and spatial analysis techniques, to satisfy multiple levels of EMAP users. Other EMAP resource groups, federal, state, and local agencies, academic institutions, and other researchers will need timely access to EMAP - GL data and information. The EMAP user community is illustrated in Figure 8.1. One established goal of EMAP - GL is the production of statistical summaries within nine months after the completion of data collection. The EMAP - GL IMS will have the capability to process a variety of analyses and produce timely outputs.

The EMAP - GL IMS will integrate with and utilize the extensive datasets generated by different monitoring programs within the Great Lakes region. The IMS must integrate the data processing activities which simultaneously occur, within different sampling programs, over broad geographic scales. An effective project management system is a necessary component of the IMS.

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1 The relationship of information to data may be summarized by the following 'processing' function

$$\text{information} = f_{\text{processing}}(\text{data})$$

which simply states that processing converts data into information in a defined, consistent manner.

The ultimate goal of EMAP - GL data management is the timely and cost-effective production of pertinent quality-assured data readily accessible to a broad-based, scientific user community.

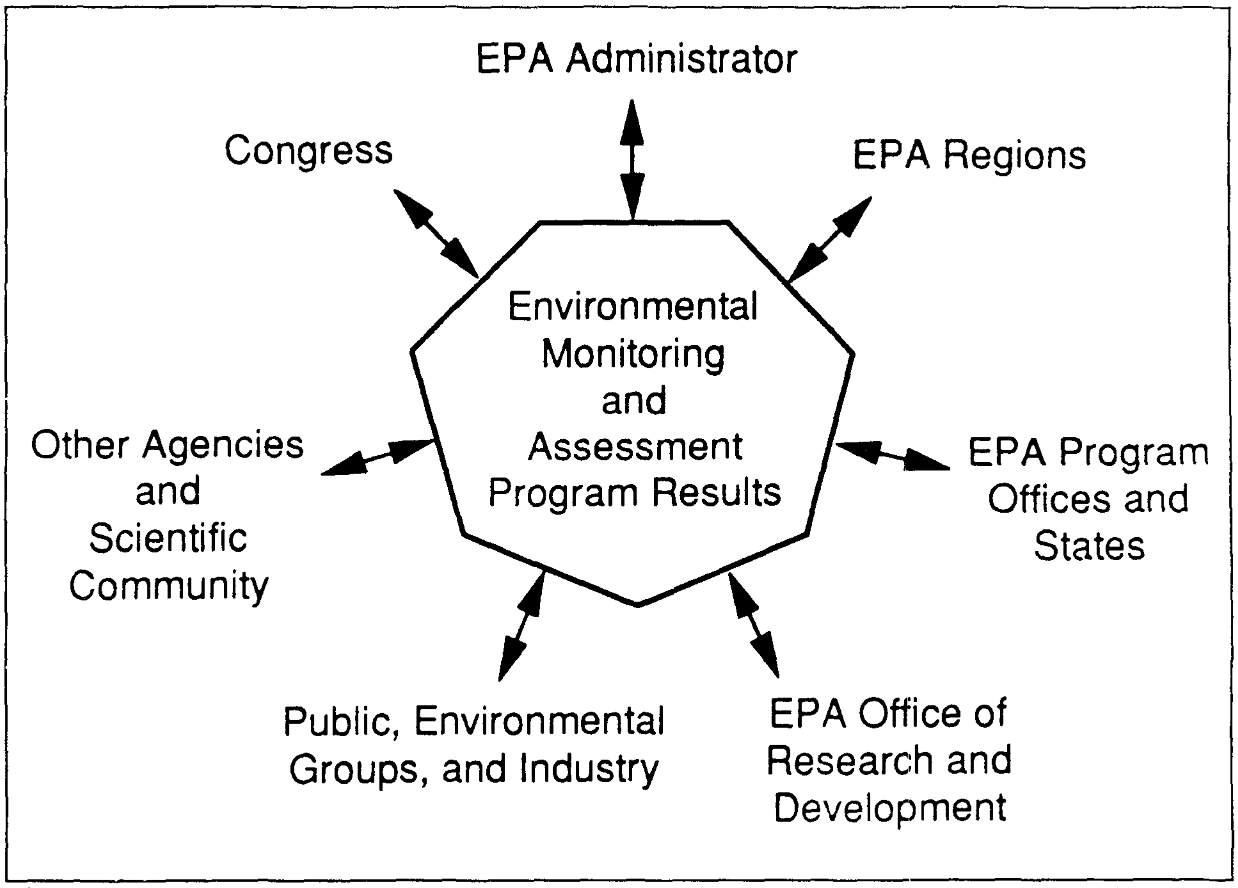


Figure 8.1 EMAP user community.

8.2. Objectives of EMAP - GL Information Management

The overall objectives of EMAP - GL information management are to:

- provide state-of-technology IMS design and development within the guidelines of the Office of Information and Resource Management (OIRM), the EMAP Information Management Committee (IMC), and other applicable guidelines;

- incorporate recognized, and stated, agency, program, and task group standards of Quality Assurance and Documentation (including a Data Management Plan) into all phases of IMS design and development, and into data management activities within the EMAP - GL program;

- provide for the wide-spread availability of EMAP - GL data within the EMAP - Great Lakes Resource Group user community and incorporate, into IMS design, data interoperability on a program scale;

- produce and disseminate compilations of EMAP - GL information, both periodic and special interest, in a timely manner and, specifically, produce annual statistical summary reports within nine months after completion of data collection;

- ensure the statistically sound integration of all usable data from on-going programs and historical data sources, from sources within, and external to, the EMAP - GL program and from all appropriate levels of data aggregation;

- incorporate an adaptability to evolving program needs, and to the state of technology, into the IMS design, and into the EMAP - GL information management perspective; and

- develop and maintain a cost-effective and efficient IMS, responsive to defined user requirements, utilizing to the extent possible, existing resources.

8.3. Mission Needs Analysis

Information Resources Management policy specifies Mission Needs Analysis as the first phase of the system development process. The IRM Mission Needs Analysis results in the development of three products: a matrix of potential system users and information uses, a process flow diagram, and an Initial System Concept.

8.3.a. System Users and Information Use

The definition of EMAP - GL system users is embedded within a program definition of EMAP users and within an IMC definition of users groups, defined in terms of their data requirements.

The EPA OMMSQA overview (EPA 1990b) defines the following user classes:

> "The program will serve a wide spectrum of users:
>
> - decision-makers who require information to set environmental policy;
> - program managers who must assign priorities to research and monitoring projects;
> - scientists who desire a broader understanding of ecosystems; and
> - managers and analysts who require an objective basis for evaluating the effectiveness of the Nation's environmental policies."

Also identified are 'Congress, the EPA Administrator, private environmental organizations, The EPA Science Advisory Board, the public, other agencies, Regional offices, states, and the international community'.

The IMC has produced a general classification of users based upon their function within the EMAP program and the EMAP data category they need to access. The following five classes are defined:

(1) EMAP - GL Core Research Group: Includes those individuals and groups charged with designing and implementing the IMS, and interpreting the data from the field sampling programs.

Requirements - The EMAP - GL Core Research Group will need access to sampling measurement data, raw, verified, and validated, in all stages of summarization and aggregation. This group will also need access to sampling support data concerned with sample and shipment tracking, logistics, quality assurance/quality control, and project management. in various media; electronic, reports, maps.

This group also requires access to the data on as close to a real time basis as possible. Raw data used by this group will not be quality assured. This group needs access to all data described in the other categories.

(2) EMAP - GL Team - This group includes individuals and groups involved in the EMAP - GL effort, but are not involved in the day-to-day field operations. These participants include outside participating agencies, logistical support personnel, GL QA/QC personnel, program reviewers, and EPA Headquarters personnel.

Requirements - This group requires access to summary information regarding logistics and project management as well as validated data. They will require access to only those files that have validated and verified. They do not require real time access, nor do they need to have access to a comprehensive data set.

(3) EMAP Program - Includes all researchers directly involved in the design, implementation, and analyses of the national EMAP program. These individuals include members of other task groups, members of the Synthesis and Integration Team, and personnel in other agencies directly involved in EMAP.

Requirements - This group requires final summaries regarding logistics and project management. They will require access to only those files that have been validated and verified. They do not require real time access, nor do they need to have access to a comprehensive dataset. They need data in a context which can be integrated with data from other disciplines. Document summaries with interpretation and graphic outputs will be most useful.

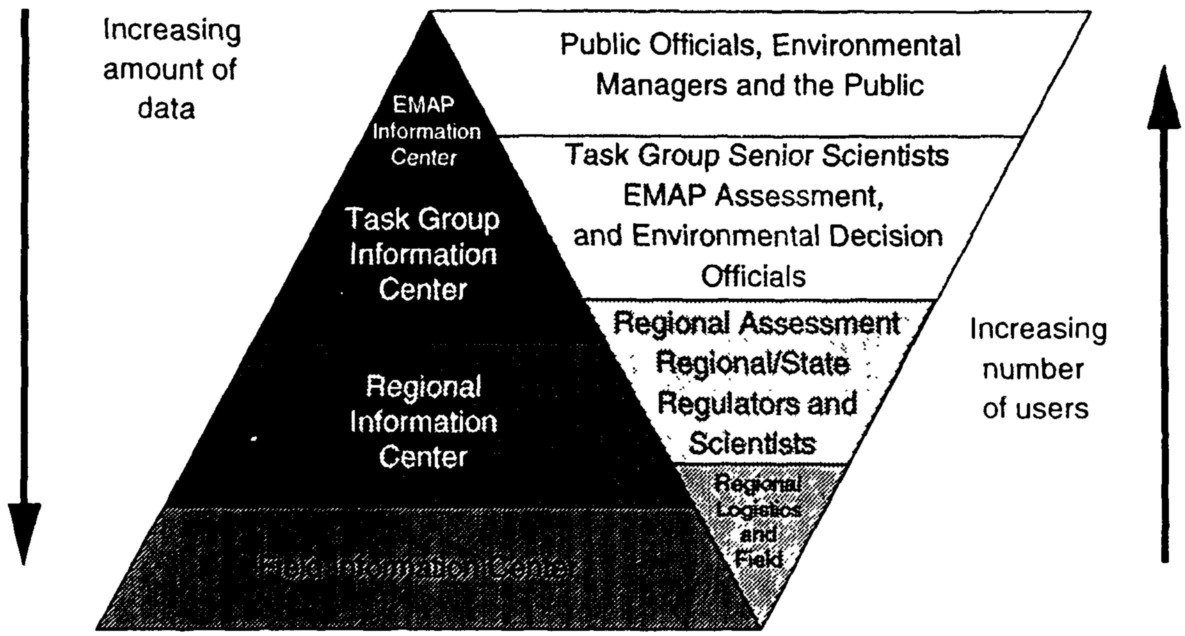
(4) Legislators and Environmental Managers -

Requirements - This group will need summarized and interpreted data. They will not require any data regarding logistics or project management. This group of users will be best served by published reports, maps and an on-line summary system.

(5) The General Public -

Requirements - This group will need summarized and interpreted data. They will not require any data regarding logistics or project management. This group of users requires published reports, maps, and an on-line summary system.

The classes of EMAP users and data are illustrated in Figure 8.2.



Relationship of classes of EMAP users and data.

Figure 8.2 Relationship of classes of EMAP users and data.

8.3.b. Process Flow Diagram

As utilized in IRM's Mission Needs Analysis, Process Flow Diagrams depict the interconnected flow of information work processes from input origins to output products, 'plotted' against a vertical axis of involved system organizations or individuals. This document is currently being developed by EMAP - GL.

8.3.c. Initial System Concept

The Initial System Concept is the end product of IRM's Mission Needs Analysis. It is a concise depiction of inputs, processes, and outputs. This document is currently being developed by EMAP - GL.

8.4. EMAP - GL Processing Environment

The EMAP - GL program is embedded within a national EMAP program which, ultimately, will integrate the IMSs of all participating Task Groups, into a single decentralized EMAP IMS, capable of providing complete national data interoperability. The EMAP - GL program is also a member of an international community of Great Lakes monitoring agencies. Finally, the EMAP - GL program will function autonomously on a Task Group level, developing and maintaining an independent IMS. The IMS will be a distributed information management system consisting of a central EMAP processing node and remote information centers which will function as regional data coordination centers for field collection and laboratory processing data. Remote information center sites will be located at existing computing facilities proximal to the region of data collection. The EMAP - GL information management program will consist of the following components:

- a distributed IMS resident, utilizing an Agency-standard hardware/software configuration, on a central EMAP node and multiple remote processing nodes;
- developmental and operational personnel; and
- policies and Standard Operating Procedures (SOPs).

The above components should not be considered static entities, capable of being defined once for the lifetime of the Great Lakes EMAP program. An effective Great Lakes EMAP program will result only if the above-listed program components are allowed to remain in a continuing state of adjustment to the forces of evolving EMAP user needs and state of IMS technology.

8.4.a. Distributed EMAP - GL IMS

A hybrid multi-platform system has been proposed which links the EMAP - GL IMS as a node in a Wide Area Network (WAN) of Task Group Information Centers and Research Triangle Park (RTP). The proposed IMS will realize of the concepts of system decentralization and data interoperability evolving in the EMAP program. The EMAP - GL node will provide database management, IMS development, GIS capabilities, and communication. To the extent possible, the proposed configuration will utilize existing EPA computing resources. All additional hardware and software resources needed in the course of IMS development will be acquired by approved Agency procurement. The proposed node configuration and networking, local and internode, is diagrammed in Figure 8.3.

The hardware configuration and suite of software utilized by EMAP - GL is determined by agency and program standards. Hardware and software needs will be defined by an IRM-required Essential Elements of Information document, EEI-2, " Preliminary Design and Option Analysis". Currently, all database development and statistical analysis is performed using the Statistical Analysis System (SAS). All GIS analysis will be performed using ARC/INFO. The use of a Relational Database Management System (RDBMS) to facilitate IMS development is proposed. Should a RDBMS be adopted to serve IMS database functions, SAS will continue to be utilized as the statistical analysis tool. The use of Computer Aided Software Engineering (CASE) tools is also proposed as a means of standardizing development.

EMAP - GL will utilize existing compatible hardware configurations at remote node processing sites, while software and peripherals will be Agency-approved.

8.4.b. Developmental and Operational Personnel

Developmental personnel requirements of an EMAP - GL information center can be fairly well defined in consideration of immediate needs. The work efforts necessary to develop and support an IMS integrated with multiple Great Lakes agencies, however, can be only roughly estimated. The following personnel list is, accordingly, preliminary.

- Great Lakes Task Group Information Manager (TGIM): The TGIM is responsible for planning, coordinating, and facilitating information management activities within the task group. The TGIM serves as the liaison to the EMAP Information Center and other EMAP resource and task groups.

- Great Lakes Database Manager (DBM): The DBM is responsible for the design, development, and administration of a Great Lakes IMS that best meets the evolving needs of EMAP users, is fully interoperable with other EMAP IMSs, and adheres to applicable Information Management Committee (IMC) and agency standards.

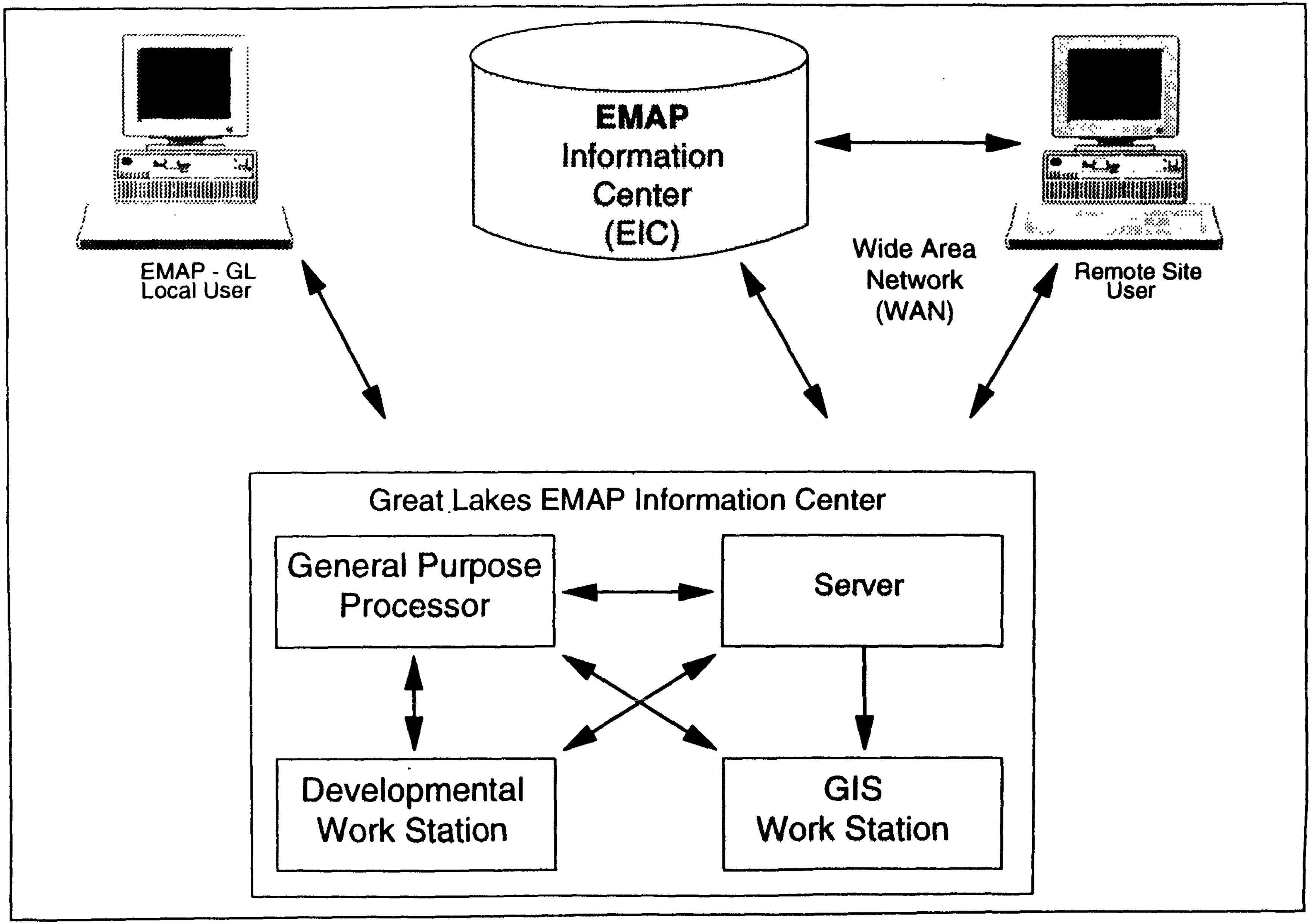


Figure 8.3 EMAP - GL node configuration and networking.

- Programmer/Analyst: The Programmer/Analyst provides specified systems analysis, application programming, testing, documentation, and user support.

- Geographic Information System (GIS) Specialist: The GIS Specialist is responsible for the development of descriptive and analytical GIS functions.

- Data Clerk/Librarian: The responsibilities of the Data Clerk/Librarian include data entry and maintenance, the documentation of Great Lakes datasets of various origins, processing approved data requests and transfers, and monitoring and reporting the "state of the database".

Remote information processing nodes will utilize computing facility staff.

8.4.c. Policies, Standards, and Standard Operating Procedures

Information management at EMAP - GL is embedded within a hierarchy of policy levels, some well-defined, others in a nebulous state. The acquisition, development, and management of all agency information technology is governed by an umbrella of OIRM policies (US EPA 1987). Chapter 4 of the IRM Policy Manual, "Software Management", establishes the Agency Software Management Program, one section (4.5.h) of which states:

> "The development of all application systems will conform to the Agency's system development life cycle methodology."

The life cycle methodology was issued under a separate cover, in three volumes (US EPA 1989). The objective of this document is "to provide guidance, assistance, and only when necessary, controls" in the design, development, maintenance of application systems. The EMAP - GL program is governed by IRM policy, and the IMS will be developed in accordance with the requirements established by the guidance document.

While an EMAP IMC information management policy document does not yet exist, the prospect of a decentralized national EMAP system with data interoperability strongly supports the establishment of, at least, some standards (e.g., data structure, variable naming). EMAP - GL will fully cooperate in the establishment of inter-Task Group standards and conventions that promote the national sharing of EMAP information.

Standards dealing with VAX system security and data confidentiality are an inherent part of any ERL-Duluth laboratory system development. These standards are consistent with those of other ORD laboratories. Also, ERL-Duluth is defining Automated Data Processing standards and policies, beginning with Information System Quality Assurance, to be applied to all IMS development.

Policies and SOPs will be developed to guide and govern all aspects of information management for EMAP - GL and its remote information centers. The policies and

SOPs formulated will be consistent, in intent and content, with those policies, outlined previously, which apply to the EMAP - GL program.

Some areas of future policy development are:

- data confidentiality issues involving the sometimes conflicting objectives of promoting the widespread use of collected data and assuring the confidentiality of proprietary data;

- data accessibility issues arising from the need to assure EMAP - GL users ready access to desired data and information, while maintaining system security and data integrity;

- data processing responsibilities and restrictions in remote information centers;

- QA/QC expectations and responsibilities of the various IMS functions within the EMAP - GL IMS; and

- issues involving the interagency and international cooperation in the collection, processing, and dissemination of data.

The necessary SOP documents will be formulated to serve as a guide to the discrete operations involved in the collection, verification, validation, analysis, and aggregation of EMAP data and information. Each SOP should define the objectives of the SOP, describe the data, operations, and methodologies involved, define pertinent criteria, and establish contingencies. All EMAP - GL SOPs will be permanently stored in a readily accessible file.

8.5. Operational Components

This section describes the EMAP - GL IMS at the operational component level. The systems described are in a planning and design phase at the time of writing; more detailed descriptions of the operational components of EMAP - GL IMS will be published as the program develops. The following major operational components can be identified at this time: Sample Collection System; Sample Tracking System; Logistics Information System; Historical Data Processing; Indicator Development Data Management; Data Retrieval System; Data Reporting System; Data Dictionary System and Documentation, Data Archival, Geographic Information System (GIS) Applications, Quality Assurance; and Project Management.

8.5.a. Sample Collection System

The EMAP - GL field sampling program will concurrently operate a computerized field data entry system and a manual field data entry system in order to evaluate the cost and effectiveness of both types of system. When EMAP - GL is fully operational, Portable Data Recorders (PDRs) will be used with the field computer system to enter field data directly into field computer files, with computer entry screens duplicating the manual entry field forms. PDR entry screens will have integral data verification processing (e.g. numeric range checks, code field checks, duplicate entry verification). Sampling measurements, as well as site information, will be stored in sample measurements files, linked to sampling event and station files. A hierarchical (station, sampling event, sample measurements) spatial and temporal indexing is created which uniquely identifies any, and all, sample parameters. The use of a unique sampling index assures non-duplication of sample records. Hierarchical indexed samples will be correlated with an independent sample numbering system, which allows samples to be tracked within the Sample Tracking System. If resources permit, bar code readers will be used to improve the efficiency and accuracy of the sample number entry and identification. Bar coding assures an objective anonymity of sampling station and facilitates sample processing checks. The use of pre-numbered sample labels for sample containers and data recording media will reduce incorrect sample identification.

Field data SOPs will provide a guide for the proper collection and entry of field data. All field data will be archived on a periodic basis. Initially, a backup manual field system will be retained should the computerized field system fail.

The Sample Collection System will be interfaced or, in some instances, integrated with, the existing sample collection programs of those Great Lakes monitoring programs cooperating with the Great Lakes EMAP program.

8.5.b. Sample Tracking System

A critical component of the IMS will be a Sample Tracking System which uniquely identifies the three levels of field sampling structure (sample stations, sampling events, and individual samples taken), interrelates data from these hierarchical levels, and tracks individual samples from collection through all processing and analyses. The Sample Tracking System will link Field Measurements Files, Lab Measurements Files of Lab Analysis Systems, Station, Event, and Shipment files by means of a Sample Status file. Simplistically, the Sample Tracking System is a set of files indexed by variables cross-referenced to the Sample Status file. The Sample Status File is, therefore, a file of cross references to other data files, presently including:

- Station Id: Index of the Station file, links a sample to one station (may be implicitly defined by the Event Id);
- Event Id: Index of the Event file, links a sample to one sampling event, at one station;
- Sample Id: The index of the Sample Status file, this mnemonic variable must contain all necessary components to uniquely designate a given sample. The necessary components vary, but normally includes spatial and temporal components, as well as components to specify the type of sample or member of a sample series;

- Date: A YYMMDD field that may or may not be a part of the Sample Id;

- Ship Id: The index of the Shipment file, links a sample to one shipment which may include a multiple events or stations;

- Field Id: The index of a Field Data file (including a file identifier, if multiple field data files exist), links a sample to field measurement(s);

- Data Id: The index links sample data to a particular media location where the data resides. Because various types of sample data exist (e.g., raw, textual, QA), more than one type of Data Id may be necessary;

- Team Id: The index links the sample to a Data Collection Team file, identifying personnel, equipment, and other pertinent collection information; and

- Process Id: The index links the sample to a Processing Plan file, which contains processing and analyses specifications. The index will operate with an associated field containing the current processing status.

From the above descriptions it is obvious that the Sample Status file is the hub of access to all sample information. This architecture provides for growth of the Sample Tracking System. Additional types of sample information may be added to the system simply by adding another spoke (index variable) linking the hub to the data file containing the new type of sample data.

The Sample Tracking System should accomplish the following functions:

- identify, uniquely, by Sample Id, all field samples, linking field samples to sampling events, (and, thence, to sampling stations), and to sample shipments, and to all subsequent sample processing steps;

- report the status and location of any given field sample;

- summarize the processing status of a specified group (e.g. station set, bar code sequence, indicator dataset) of samples in report format;

- display the processing status of groups of samples, by station, using an interface to the GIS system;

- automatically report incomplete sample sets at processing points (e.g., receipt of samples for lab analysis); and

- Provide sample anonymity to all subsequent sample analyses, thereby facilitating processing checks, using duplicate samples.

Bar coding of sample collections will be used, if economically feasible, to facilitate use of PDRs and a sample entry system by sampling crews. A bar code sequencing scheme will be used; Sample Id values may be used directly or blocked ranges of cross-referenced values to collection of data. Samples will bar coded prior to sampling.

8.5.c. Field Logistics System

A Field Logistics System will be developed to provide support information for field sampling. Indexed by Station Id, the system will supply critical resource information to sampling crews. The location and means of contact for transportation facilities, supplies and equipment locations, medical facilities, communication centers, fuel suppliers, and other important resources proximal to sampling stations will be referenced in the Logistics database. An Itinerary database will store specific planned and actual sampling trip information. A Boat/Crew file will contain information on personnel and equipment utilized; this file can be linked to the Itinerary database by a Trip Index.

The Field Logistics System will provide, at least, the following:

- an itinerary of sampling sites to be visited, by a specified boat and crew, with a sampling event schedule for each station;
- a log of actual sampling activities and sampling trip information, such as resource utilization (and cost);
- a report of critical resources (described previously) available, proximal to each sampling station, for the entire sampling trip; and
- summary reports, and displays using GIS, of sampling activities such as, cost and percent success of sampling trips or types of sampling.

The Field Logistics System will be interfaced with the Sample Collection and Sample Tracking Systems.

The EMAP - GL program will utilize sampling data collected by other on-going monitoring programs, which have Logistic Systems supporting their sample collection. Every effort will be made to utilize and interface with those Logistic Systems currently functional.

8.5.d. External Dataset Processing System

Data useful to EMAP - GL will often reside in datasets other than those generated by EMAP-initiated sampling programs. While important to the EMAP - GL program, such data sources require special quality assurance and data confidentiality considerations, and often special processing. External data sources that may be utilized by EMAP - GL include:

- sampling programs from other agencies, at all levels of government (e.g., federal, state, county, municipal);

- sampling programs conducted by institutions, private industry, and environmental organizations; and

- sampling programs carried out by functions in foreign governments, by institutions, industry, or organizations in other countries, or by multinational organizations.

The above-mentioned sampling programs may be currently active or they may have concluded in the past.

Data contained in the datasets may be at various levels of aggregation and various stages of quality assurance.

Beyond containing data valuable to Great Lakes resource assessment, external datasets must satisfy criteria which determine their functionality within the EMAP - GL IMS. The necessary SOP documents establishing criteria for inclusion of external datasets into IMS will be formulated. Some of the fundamental questions to be addressed by these SOPs are:

- Is the dataset acquirable (or accessible), either through the dataset's owner or administrator? Do data confidentiality issues restrict the acquisition of subsets of interest of the dataset?

- Is the dataset of EMAP-compatible (or of readily convertible or massageable) format and level of aggregation?

- Was the dataset produced by sampling design protocol comparable with that of EMAP - GL sampling protocol?

- What restrictions are placed on the use and distribution of data, in the dataset, or on information generated from the data?

- If the dataset is active, will EMAP - GL be assured of access to future dataset updates?

- While perhaps not a standard SOP criteria the cost-effectiveness of the acquisition of external datasets and their future updates will be a primary factor in their use.

To assure the efficient incorporation of applicable data into the IMS, the External Dataset Processing System must perform the following functions:

- conduct a comprehensive search of current and past Great Lakes sampling programs, producing a list of datasets (and their administrators) whose data content is potentially applicable to the development of defined EMAP - GL indicators;

- evaluate the list of potentially usable datasets in terms of defined criteria; appropriate efforts will be made to acquire the qualified datasets;

- for each acquired dataset: formulate quality assurance, and if necessary, data conversion SOP(s); archive original dataset; qualify original dataset to produce a subset of potential EMAP - GL data; quality assure potential EMAP - GL subset; and, if necessary, convert the quality-assured dataset to EMAP - GL standard format datasets;

- integrate the resulting converted dataset into the IMS. The processing provides an interface with the Indicator Development Management System and is highly variable; and

- thoroughly document, for each dataset, all processing from acquisition to conversion to IMS standard dataset format and produce archives of all important stages in the dataset incorporation not readily reproducible. All incorporated datasets will be automatically updated in the Data Inventory System.

Segregated work areas for each stage of dataset conversion (e.g., original data, qualified data, quality assured data) will be established for all datasets. Access to external datasets resident in the work areas will be determined by the data confidentiality policies of EMAP - GL and the dataset's administrator.

8.5.e. Indicator Development Data Management System

Initially, all processed raw data files, field and lab, as well as all historical data files will be stored in SAS data sets. The acquisition and use of a Relational Data Base Management System (RDBMS) is anticipated; at that time SAS data sets will be converted to the RDBMS format. Statistical analyses of data will continue using SAS. The field/lab and historical SAS data sets comprise the entry data sets of the Indicator Development Data Management System (IDDMS). Both field/lab and historical data sets will have been extensively quality assured using data verification and validation SOPs. Indicator data sets will be generated from IDDMS entry data sets by analysis and aggregation and further analysis of indicator data sets will result in overall assessments of resource conditions. From the information perspective, this process, the IDDMS, will be accomplished by SOP-mediated processing operating upon data structures.

The IDDMS data sets will be segregated into indicator libraries and each data set development thoroughly documented. Data archives of the stages of the quality assurance process will be produced.

8.5.f. Data Dictionary System and Documentation

An inventory system of data libraries, files, and elements provides important information about the nature, location, and inter-relationships of data elements in the EMAP - GL IMS and is essential to system maintenance and documentation.

The core of the DDS will consist of two data sets, developed and maintained in SAS; a Data Set Index, and a Data Dictionary. The two data sets are hierarchical and are linked by the data set index variable.

The Data Set Index will contain one record for each data set in the EMAP-GL IMS and will include, at least, the following information:

- a general description of the data set information content;
- the purpose of the data set, the indicator(s) development with which it is associated;
- information on the location of the data set and how it may be accessed;
- information on humans associated with the data set; who is responsible for the data set, its origin, scientist(s) currently working with the data set. This data set can be linked to an indexed Relevant Humans Data Set;
- information on hierarchical relationships with other data sets; and
- information on the quality of the data contents, restrictions, and data confidentiality.

The Data Dictionary will contain one record per data element in the EMAP - GL IMS. Each record will be related to a Data Set Index data set by a data set index variable. The cardinality of the relationship of Data Set Index records to Data Dictionary records is one-to-many. The Data Dictionary will contain, at least, the following information:

- a description of the data variable (element);
- the data type and format;
- the range of valid values, if numeric, or the set of valid values, if alphanumeric; and
- the location (data set and library) and distribution of the variable (other data sets in which it is located).

The DDS will have two main applications, which require it to be accessible to users of a wide range of sophistication:

- System documentation, interactive with system configuration maintenance: EMAP - GL core staff responsible for modifications to data structures in the IMS must have current data inventory information.

- IMS Information Content reports: A variety of potential EMAP-GL users will need current listings, by categories of information, to construct retrievals from EMAP - GL IMS.

The need for current, reliable data set index and data dictionary information requires that any modifications to the GLIMS data structures generate an instantaneous system update of the Data Inventory System. All structural modifications will be made within an interactive system utility which automatically updates the data dictionary (a possible CASE application).

The EMAP - GL IMS will ultimately be data interoperable with other Task Group IMSs and may be part of a decentralized national EMAP system. It is, therefore, mandatory that the current state of the DDS be available to all prospective users. Furthermore, data interoperability implies at least some variable conventions and standards be adopted. To that end, system configuration maintenance will be interactive with a Standards file and review function.

The development of the EMAP - GL Data Dictionary System (DDS) must be considered in context of EMAP IMC Dictionary/Catalog/Directory (D/C/D) Work Group's efforts to develop a program-wide dictionary system. Also, the adoption of a RDBMS may involve considerations of any integral or active data dictionary the management system may contain.

Complete system design and development documentation is mandated by IRM's data management policy, specifically the generation of the set of Essential Elements of Information (EEI) documents over the life cycle of the EMAP - GL IMS. The EEI documents address mission needs, design, procedural, managerial, and operational documentation needs. Additional documentation (e.g. data and processing SOPs, data set profiles, user logs) will be developed and maintained.

8.5.g. Data Archival System

The capabilities of the Data Archival System are determined by IMS policy (at all levels) assuring data integrity. All data archival will be performed in accordance with data archiving SOPs. All data archiving should be performed from within the IMS and as automated as possible. For instance, if processing creates a new dataset, which requires archiving, that processing should also automatically create an archive of the new dataset.

The Data Archival System will be capable of archiving both data and procedural files. Specific files to be archived will be established by Archival SOPs. Some examples of files which will be archived are:

- raw data files from field sampling or lab analysis;
- original historical datasets;
- quality assured (verified and validated) datasets;
- important data exception files to the quality assurance process;
- any permanent dataset that represents the end product of an analysis of a dataset;
- any data file condition that is not readily recreatable from an existing static file and existing processing; and
- any data file to be transferred out of the IMS.

Initially, active files should be archived at all unrecreatable times of change. Problems of redundant archiving can be analyzed and solved as they become recognized.

The frequency of archivals will also be established by SOPs. The frequency of archival depends on the activity of the file; at the least, archive such that no file activity will be lost or that no file condition can not be recreated.

A minimum of two on-site copies of all files should be archived, and at least one archive copy stored off-site. Any file characterized by much update activity should maintain a historical set of archives, the number of archives composing the set to be determined by the amount of file activity.

While data archiving will be system maintained to the greatest degree possible, human initiation of some data archives is inevitable. When human initiation is necessary, memory aids ("tickler files") will be utilized in the system.

8.5.h. Geographic Information System (GIS) Applications

EMAP - GL will have access to the GIS system located at the ERL-Duluth. The system currently uses a Data General AVIION Model 410 dual processor, with 32 MB of memory and 2GB of disk storage. Accessories include a CalComp plotter and CalComp Digitizer. The GIS system at ERL-Duluth uses the 6.0 version of ARC/INFO, currently in Beta test.

The EMAP GIS Task Group is currently developing procedures and standards for the use of all Task Groups. EMAP - GL will utilize the extensive spatial analyses and display capabilities of ARC/INFO to produce base maps and overlays depicting Great Lakes sampling and the results of indicator analyses.

8.5.i. Quality Assurance

Data QA is not the responsibility of any single system component, instead it pervades the entire IMS. While IMS QA is comprised of data verification and validation SOPs and processing (applied SOPs), of procedures and practices that help ensure data integrity, design perspective remains the motive force.

Data verification SOPs provide the basis for developing data entry and data review verification. Several types of data verification processing will utilized:

- Range checks on numeric data: Field and laboratory numeric data entry will be checked against valid range definitions. Data that falls outside of the acceptable range will be written to an exception report for review by QA personnel.

- Valid code checks on coded data: Coded field entries will be compared with the set of valid code values established by the scientific personnel and information management to assure compliance.

- Duplicate record checks: Indexing of datasets establishes a means of checking for duplicate (or missing) records.

All data entry validation will include error message display with contingency options.

8.5.j. Project Management

The integration of a number of complex database management systems, combined with the timely, cost-effective production of processed data and the efficient utilization of many varied resources makes the need for a Project Management System imperative. Additionally, the EMAP - GL IMS will serve a program whose duration will ensure change in outputs, technology, and methodologies. These changes will, almost certainly, be manifested in structural and processing changes within IMS. A Configuration Management System with the following components has been suggested:

- Configuration identification: definition and identification of items subject to configuration control;

- Configuration control: evaluation, coordination, and approval or disapproval of proposed changes to controlled items;

- Configuration status accounting: recording and monitoring of changes to controlled items;

- Data management: maintenance of official correspondence records, configuration management records, and controlled documentation; and

- Configuration auditing: verification that controlled items are what their documentation states they are and that they meet their assigned requirements.

8.6. Resource Utilization

All information system development and management is accomplished by the utilization of resources which may be acquired in two ways; the authorized use of or access to appropriate existing capabilities, or the procurement, by approved Agency procedure, of new resources. The EMAP - GL program will make use of existing and planned resources compatible with the EMAP - GL program, to the extent possible, and only acquire additional resources where needed. Agency resources which may be accessible to the EMAP - GL program include current programs, data sources, staff, and equipment. Similar resources may be available through other agencies, institutions, contractors, and other governments.

Valuable guidance in the development of the IMS is provided through several sources. The EPA OIRM within the Office of Administration and Resource Management (OARM) provides a model which serves as guide to all Agency system design and development. The IMC provides a forum for the cooperative resolution of problems and the sharing of ideas and expertise, as well as guidance to the long term integration of Task Group information systems. Most important, in practical terms, other Task Groups have willingly shared their IMS development experiences, solutions to problems, and design products. EMAP - GL will continue to utilize these available resources to expedite IMS development.

The EMAP - GL program will be cooperating with several agencies that have implemented broad-scale, long-term monitoring programs in the Great Lakes region. The resources provided by this cooperative effort, e.g., equipment, human resources, methodology, and experience, are essential to the success of Great Lakes EMAP program.

The EMAP - GL program will make use of the ADP resources available at the ORD Laboratories. The Information Manager will work with their ADP coordinators and laboratory directors to plan and obtain approval for the utilization of these resources by EMAP - GL.

The EMAP - GL Information Management will, also, identify and utilize an ADP Coordinator at each location within the program. Each ADP Coordinator will be an existing local resource whose responsibilities include assisting the Information Manager in development of the EMAP - GL ADP resources and plans.

9. Coordination

9.1. Introduction

The focus of this section is coordination, both among components within EMAP and between EMAP - GL and other state and federal programs.

In developing a complex program such as EMAP, a wide range of issues must be acknowledged and addressed throughout the early phases. The coordination of activities and analyses must occur at multiple levels both within the program and across other programs. For example, within the Great Lakes component of EMAP, there is the need to integrate water quality monitoring activities in the Great Lakes Basin. Equally important is the need to integrate categories within EMAP. Outside of EMAP itself are a host of programs which, although they cannot adequately address the objectives of EMAP by themselves, can complement the information from EMAP to provide a clearer view of current status trends in indicators of condition of surface waters and diagnosis of conditions.

9.2 Within EMAP

An important aspect of EMAP is the inclusion of all ecological resources within the program. From the National perspective, this provides the opportunity to evaluate the relationships between conditions and problems in each resource category, their impacts on one another and the potential to more effectively evaluate comprehensive ecological resource management strategies. The achievement of these potentials requires extensive coordination in the selection of indicators, methodologies, and design.

Within EMAP, the focus to date has been the design and evaluation of programs to identify status, trends, and probable cause of conditions within each ecological resource group. Discussions to enhance the integrative aspect of the program have been gradually increasing and will be the focus of the EMAP Integration and Assessment Team. Coordination between ecological resource groups has been facilitated by the coordination teams within EMAP (i.e., statistics and design, indicator development, integration and assessment, information management, quality assurance, and logistics). The activities sponsored by these teams currently provide the framework to ensure our future ability to more fully integrate the information from each aspect of the EMAP. Workshops have been held by the Indicator Development coordinator to facilitate discussion between the ecological resource groups to ensure that they take into account, in the development of their programs, information needs of other groups that they might be able to supply or that might be supplied for them. Coordination is also taking place in simply defining the specific resource categories (e.g., wetlands from lakes) and in ensuring that all ecological resources are considered.

The Integration and Assessment team, in conjunction with the statistics and design team, and the ecological resource groups began efforts during FY91 to evaluate design alternatives that might maximize the ability to integrate information from various ecological resource groups. These efforts can be coupled with the design and pilot activities of each resource group to evaluate long-term options for the program.

9.3. Other Federal Agencies

Almost every federal agency that has a mandate or jurisdiction over some natural resource has an interest in Great Lakes resources. We firmly believe that EMAP should be a multi-agency program. It is the concept of the program that is important, not the location within any particular agency. If aspects of the program objectives are being met through activities in other agencies, then there is no need to duplicate that aspect of the program.

While efforts will be needed to coordinate with each of the groups, we targeted our early efforts toward those federal entities maintaining active Great Lakes monitoring programs. This led to early interaction with the US Fish and Wildlife Service and the National Oceanographic and Atmospheric Administration. Programs maintained by each of these agencies were discussed in Chapter 1. Our intent here is to describe potential interactions. Discussions have been taking place between EMAP - GL and each of these agencies but no firm commitments have been achieved.

9.4. International Activities

Implementing monitoring activities within the Great Lakes will not likely be successful without the cooperation of the Canadian government. They currently share responsibilities with GLNPO for implementing GLISP. They also conduct a wide variety of additional monitoring and research on the lakes. The initial contacts for joint activities between EMAP - GL and the Canadians have been at the scientist level within the Canadian Center for Inland Waters. As described in Chapter 10 which addresses 1992 activities, a joint study on sediment indicators is currently being proposed. In addition, there have been preliminary discussions of conducting comparisons between offshore data on trophic status at the Canadian sites with data obtained by them at proposed EMAP - GL offshore sites. Discussion at the management level are underway with the goal of developing an integrated monitoring program for ecological condition throughout the Great Lakes.

9.5. Research Organizations

As described in Chapter 1, research organizations such as universities and state and federal research centers are important groups with which EMAP - GL needs to interact. The research needed to allow EMAP to reach its potential will come from these groups. Interaction with these groups during the developmental stages of

EMAP will provide the mechanism to ensure that the program is grounded in sound scientific principles. Existing field sites can provide locations for testing and developing indicators of ecological condition and an understanding of the relationships between our indicators of response and indicators of exposure, habitat and stress. In addition, the feasibility of engaging university consortia to conduct portions of the long-term program are being actively pursued.

9.6. Conclusions

The types of interactions and coordination which are needed to create a successful program which best serves the public interest have been presented. During the next year, EMAP - GL will be pursuing these coordination efforts and seeking to establish mechanisms to facilitate this coordination. We envision the need for a scientific advisory panel to ensure the sound footing of the program and an interagency coordination panel to facilitate the interaction and coordination needed among participating state and federal agencies.

10. Fiscal Year 1992 Field and Analysis Activities

10.1. Introduction

As summarized in Chapter 2, and discussed throughout this strategy, there are a number of questions that must be addressed before EMAP - GL can be fully implemented. As a first step in accomplishing the EMAP - GL objectives, a series of pilot activities will be conducted over the next year. The goals of these activities are to begin answering the following questions. Not all questions, of course, can be studied or answered in one year. Some will require extensive data collection, sampling, research, and evaluation before answers will be apparent. Monetary resources also restrict the number of questions that can be addressed in any given year. Therefore, EMAP - GL will be continuing to evolve even after monitoring and assessment activities have been started in all the Lakes. The following questions are planned to be studied in 1992:

Questions on EMAP - GL Design

- Questions over the density of the base grid for offshore areas in Lake Michigan will be addressed by evaluating existing data and collecting additional data for trophic status (Section 10.2.a.) and sediment related indicators (Sections 10.2.b. and 10.3.c.).

- Lists and areal extent of the harbors and embayments of Lakes Michigan and Superior will be determined from USGS maps using the definitions described in Chapter 3 (Section 10.4.).

- Available information regarding the extent of coastal wetlands of Lake Michigan will be identified (Section 10.5.).

Questions on EMAP - GL Indicators

- Recommendations for wetland indicators will be developed through a workshop of Great Lakes wetland scientists (Section 10.5.).

- Investigations into the definition of nominal conditions for sediment indicators in the nearshore of Lake Michigan will be conducted in conjunction with Canadian studies on the remaining four Lakes (Section 10.3.).

- The selection of appropriate indicators for fish will be explored through analysis of existing data and consultations with Great Lakes experts (Section 10.6.).

- An evaluation of index periods for trophic status in the offshore resource class will be conducted by comparing spring and summer data in Lake Michigan (Section 10.7.).

- Evaluation of existing data for Lakes Michigan and Superior, along with some sampling activities, will investigate the use of diatoms as representatives of Great Lakes phytoplankton populations, the use of sediment cores for historical trend analysis of diatom populations, and the exploration of sediment traps as an integrative measure of annual diatom population abundance and distribution (Sections 10.3.b. and 10.8.)

EMAP - GL pilot activities will begin on Lakes Michigan and Superior in 1992 (Tables 10.1 and 10.2). Spring cruises are planned for both lakes, while two additional cruises, one summer and one fall, are planned for Lake Michigan. Assessment of offshore trophic status and determining compatibility between data collected at EMAP grid sites and that collected under other sampling programs (e.g., GLISP) will be the primary focus of the spring cruises. The summer cruise in Lake Michigan will also include a sediment sampling component which will be used to examine variability in offshore benthic macroinvertebrate communities and the adequacy of the base grid sampling intensity. The fall cruise is part of a cooperative nearshore study with Environment Canada and NOAA which will collect sediment in unimpacted nearshore areas. Benthic macroinvertebrates in these samples will be enumerated and used to determine nominal conditions. The remainder of this chapter describes these field activities in greater detail. Great Lakes historical datasets (Table 10.3) will be compiled during the pilot project to evaluate design and analysis aspects of trophic status and sediment indicators.

10.2. *Investigations Within the Offshore Resource Class*

10.2.a. Application of the EMAP Offshore Design for Trophic Status

Of all the indicators suggested for EMAP, those associated with estimates of offshore trophic status are the closest to implementation (refer to Chapter 4). These measurements have been utilized at the lake scale for almost two decades. As part of the Great Lakes WQA, GLNPO has been monitoring offshore trophic status by sampling at 11 sites throughout Lake Michigan (refer to Chapter 3). These sites were selected to represent the offshore portion of the lake by investigating data from an intensive survey conducted during the 1970's. However, the GLNPO site selection process did not use a statistical approach that allows for statements of condition with known levels of certainty. The EMAP base grid that will be used for offshore EMAP monitoring has roughly the same density as the existing GLNPO monitoring sites (Figure 10.1).

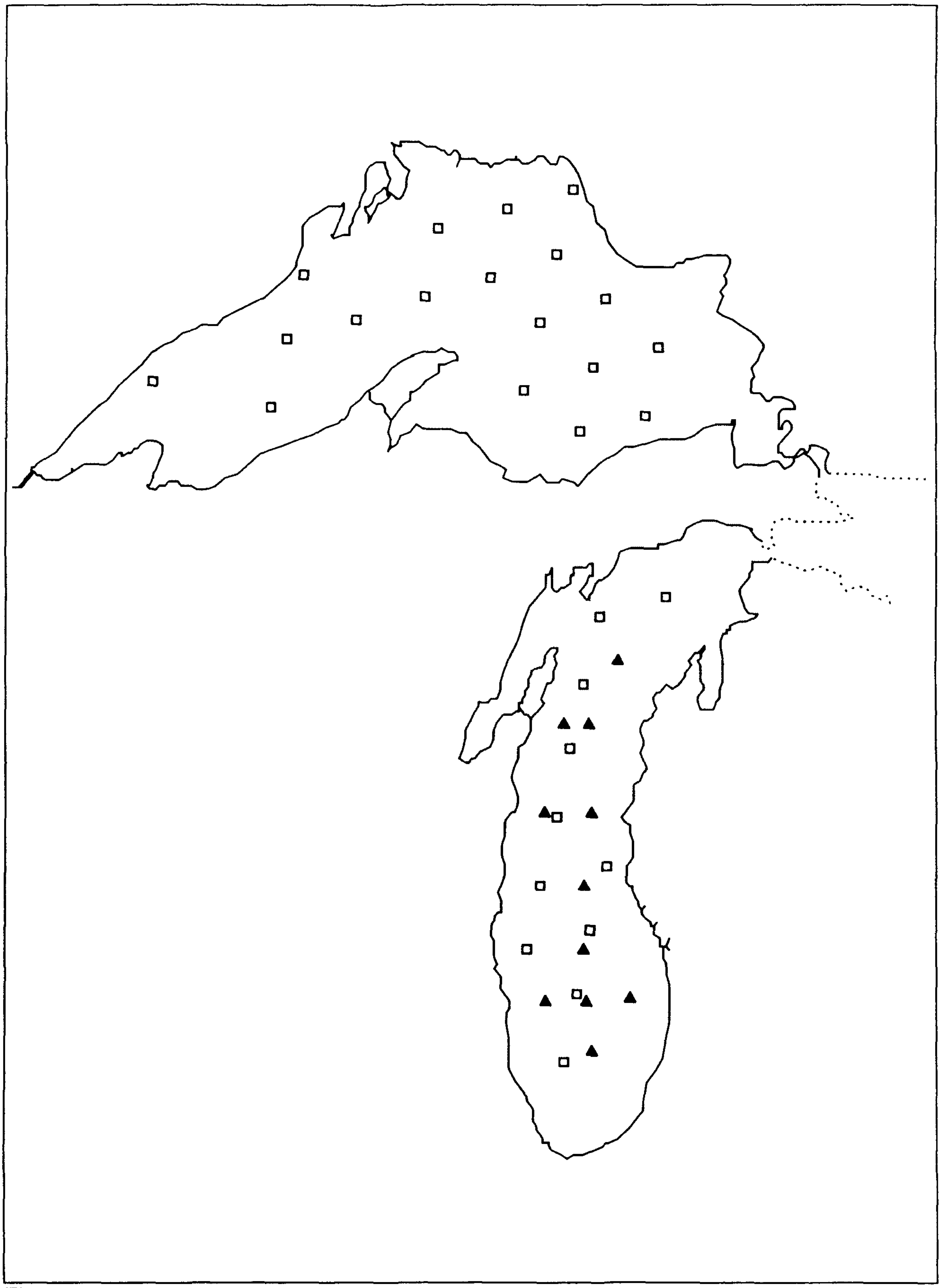


Figure 10.1 1992 EMAP(□) and GLISP(▲) sampling stations for Lakes Michigan and Superior.

Table 10.1 1992 EMAP - GL Field Pilot Activities

LAKE	RESOURCE CLASS	SAMPLING AGENCY	SAMPLING PERIOD	STATIONS	PARAMETERS SAMPLED	PURPOSE
Michigan	Offshore	EPA-GLNPO	April	10	Conventional Water Chemistry; Nutrients	Index Period, Indicator Research, Trophic Status, and Historical Data Compatability
			August	10	Conventional Water Chemistry; Nutrients; Sediment	Index Period, Indicator Research, Trophic Status, Historical Data Compatability, and Benthic Community Structure
	Nearshore	Environment Canada - CCIW	October	60	Sediment Communities, Toxicity; and Geophysical Characteristics	Nominal Conditions for Nearshore Benthic Communities
Superior	Offshore	EPA-GLNPO	May	18	Conventional Water Chemistry; Nutrients	Trophic Status and Historical Data Compatibility
		Environment Canada - CCIW	May	9	Conventional Water Chemistry; Nutrients	Index Period, Indicator Research, Trophic Status, and Historical Data Compatibility
			August	9	Conventional Water Chemistry; Nutrients	Index Period, Indicator Research, Trophic Status, and Historical Data Compatibility

Table 10.2 1992 EMAP - GL Design and Analysis Pilot Activities

Area of Interest	Current Activities	Long-Term Objectives
Benthic Community Structure	Historical data acquisition and analysis - Power analysis - Components of variance	- Determine required sampling intensity for macroinvertebrates - Determine small-scale spatial variability - Address "transition zone" between nearshore and offshore
Fish Indicators	Historical data acquisition Review of sampling techniques and field/laboratory protocols	- Development of fish-related indicators for EMAP - GL - Determine spatial/temporal variability associated with past sampling programs
Wetland Indicators	Identification of GIS/remote sensing wetlands datasets Determine status of wetlands inventory and availability of digital data Planning a Great Lakes wetlands workshop for spring '93	- Complete inventory of the number and extent of Great Lakes coastal wetlands
Trophic Status Indicators	Historical data analysis - Power analysis - Components of variance	- Determine required sampling intensity for trophic status indicators in offshore and nearshore - Examine sensitivity of the CTI to changes in nearshore trophic status - Develop an index for offshore trophic status
Harbors and Embayments	Identification of Great Lakes bays/harbors meeting the EMAP - GL definition Incorporation of digitized Great Lakes shoreline into the EMAP - GL GIS Comparison of frames (enhanced grid vs. list)	- Development of a bays/harbors sampling frame to be used in '93 pilot and demonstration activities

Table 10.3 Great Lakes Historical Datasets Compiled by EMAP - GL as of May 1992.*

Source	Year Collected	Geographical Scope	Resource** Class	Content	# Samples
USEPA - STORET[1]	76 - 89	Lake Michigan	O, N, H	Chlorophyll-a Secchi Total Phosphorus	> 13,000
NOAA[2]	80 - 81	Southern Lake Michigan	O, N, H	Macrobenthos Abundance and Biomass (Three Replicates each for Ponar and Peterson Grabs)	240
Murray State University[1]	75	Lake Michigan	O, N, H	Macrobenthos Community Structure	286
Illinois State[3] Geological Survey	75	Lake Michigan	O, N, H	Sediment Chemistry, pH, Eh, and Grain Size	286
Environment Canada - CCIW[1]	91	Lake Superior	N, H	Macrobenthos Community Structure	63
	87 - 89	Lake Erie	N, H	Benthic Community Structure from Eight Sampling Devices and Multiple Box Cores	Multiple Samples at One Station

1 = Unpublished Data
2 = Nalepa et al. (1985)
3 = Cahill (1981)

* Note: All data sets are spatially - indexed with latitude, longitude and depth.
** Resource Classes: O = Offshore, N = Nearshore, H = Harbors and Embayments.

The primary objective of the 1992 EMAP activities in Lake Michigan will be to assess the compatibility of data collected at EMAP grid locations to the data collected as part of GLISP. The results of this compatibility study will determine if 1) EMAP - GL can use data collected under GLISP in an historical context (e.g., for trend analysis) and 2) the EMAP base grid is of sufficient density to provide the ability to detect change. To minimize potential between-ship variability the EPA surveillance vessel will conduct sampling at the GLISP and EMAP sites, simply alternating its normal cruise pattern between these two networks during the spring sampling program. Comparable data will be collected at all stations and standard descriptions and operating procedures will be utilized (Palmer and Warren 1992). The resulting data will be initially stored in the shipboard computer system and subsequently transmitted electronically to the EMAP - GL information management network.

In addition, GLNPO will be extending its normal spring cruise to Lake Superior for the first time (Environment Canada has been responsible for surveillance in Lake Superior since 1968). Because GLNPO has not previously conducted water quality sampling in Lake Superior, the sample locations will be the EMAP base grid locations (Figure 10.1). The relative homogeneity of the offshore waters of Lake Superior should allow the use of the Environment Canada dataset for trend analyses. To assess the degree of offshore homogeneity, Environment Canada will add nine offshore EMAP grid sampling sites to their regularly scheduled cruise in May 1992 (Figure 10.1.). Although the sample size for comparison is small, differences detected between the GLNPO and Environment Canada data may point to the need for more detailed studies on between-ship variability.

10.2.b. Application of EMAP Offshore Design to Benthic Community Structure

Benthic community structure is one of the important response indicators for EMAP - GL. The spatial variability of this indicator in offshore sediments will be a significant factor in determining whether the proposed sampling density (EMAP base grid) is adequate. As part of the GLNPO summer cruise in Lake Michigan, sediment samples will be collected at the EMAP sites to determine 1) the variability of benthic community structure in the offshore area at the EMAP sites using the proposed base grid density and 2) the confidence intervals associated with the analyses. Methods of sampling are the same as described in section 10.3.

10.3. Sediment Indicators in the Nearshore Resource Class

Sediments are both the repository of many chemical contaminants and the substrate for many organisms critical to Great Lakes food webs. Many of the problems identified in the Great Lakes, including most Areas of Concern, are associated with sediment contamination. Because of the chemical binding properties of sediments and the fact that particle associated contaminants settle out onto sediments, they have often been considered as a sink for contaminants. We now realize that because contaminants do concentrate in sediments, they are a critical source of contamination often long after inputs of toxic materials have been reduced. Due to their critical role in Great Lakes ecosystems, many indicators tentatively selected for EMAP are related to sediments. However, while there are varying amounts of data on benthic community structure for the various lakes (e.g., Cook and Johnson 1974, Nalepa 1987, Nalepa 1991), the combination of benthic community structure, sediment toxicity tests, contaminant analyses, and physical characterization has rarely been attempted. The following is a joint study between Environment Canada's National Water Research Institute (NWRI), NOAA's Great Lakes Environmental Research Laboratory (GLERL), EPA's Great Lakes National Program Office (GLNPO), and EPA's Environmental Research Laboratory - Duluth (ERL-D).

10.3.a. NWRI Study on Sediment Indicators

The NWRI has completed the first year of a three-year study to develop biological sediment guidelines for the four Great Lakes with Canadian boundaries (Reynoldson and Day 1991.) The NWRI program is based on the fact that unperturbed systems support, for extensive periods of time, assemblages of species that are self-maintaining and resilient to normal environmental fluctuations. Such communities can be defined through the collection of physical, chemical, and biological data. The strategy of the EMAP portion of the study is twofold: 1) to help establish a reference database of clean sites and 2) to include Lake Michigan in the sampling program.

The overall objectives of the program are to:

- Classify benthic invertebrate community assemblages and toxicity test responses that represent different substrate condition (habitat).
- Develop a model to predict the benthic community and toxicity test response from habitat (sediment) characteristics.
- Establish nominal conditions for benthic communities and test responses.

A series of EMAP objectives will also be addressed through this study:

- Select key species and toxicity test endpoints that show the most robust predictive response for defining nominal sediment conditions and propose a framework for determining biologically significant direction changes in sediment conditions based on the invertebrate fauna and response.
- Examine annual and sampler variability in the approach by including a subset of sites previously sampled over a ten-year period by NOAA.
- Determine the relationship between community structure and bioassay assessments of sediment conditions.

- Determine the efficiency of incorporating measures of sediment chemical contaminants that might be used as a means of predicting future exposure to organisms higher up in the food web.

10.3.a.1. Site Selection

Two sets of sites will be selected: 1) a reference set for inclusion in a Great Lakes nearshore reference data matrix and 2) a subset for resolution of annual and operator differences.

The first and major set of sites will be selected for incorporation into the NWRI nearshore reference database. The reference sites to be sampled will represent, as best as is practicable, pre-contamination conditions. Therefore, sites are ideally required to be: less than 85 m deep, less than 3 k from shore, have more than 10 cm of accumulated fine grained sediment, have more than 1 ha of contiguous fine grained sediment, have an unexposed fetch, be away from outfalls, be away from development, and be accessible. Sampling sites will be located using a stratified approach with equal site distribution within a stratum. Sampling strata have been selected on the assumption that the potential for differences in reference communities will be maximal in varying physical habitats. For the Canadian sites, the sampling strata were defined by seventeen ecodistricts (Wickware and Rubec 1989) that encompass the Canadian Great Lakes shoreline; the ecodistricts are based on differences in geomorphology, geography, climate, soil type, and vegetation. To provide a data matrix of approximately 250 sites (required for model development), 15 sites were located in each ecodistrict. In the case of Lake Michigan, it is proposed to use the five ecoregions identified by US EPA and Environment Canada (1988) to locate 12 sites in each ecoregion. This would provide 60 sites that should be sufficient and comparable with the other Great Lakes (Table 10.4). The exact locations of sites within the ecoregions will be made from examination of land use maps, topographic maps, hydrographic charts, nearshore sediment maps, and the location of outfalls and intakes.

Table 10.4 Number of ecodistricts and sites in each Great Lake.

LAKE	ECODISTRICT	SITES
Superior	4	68
North Channel	3	51
Georgian Bay	3.5	59
Huron	2	34
Erie	2.5	42
Ontario	2	34
Michigan (proposed)	5*	60

* US Ecoregions (US EPA and Environment Canada 1987)

The large number of sites in the reference site data matrix precludes sampling to determine seasonal and annual variation. This variation is a concern particularly as it may affect the community assemblages. In the Canadian dataset, these issues are addressed by sampling a subset of stations (10%) over three years and at four stations sampling monthly for two years. In Lake Michigan, NOAA has sampled 30 sites over a ten-year period (Nalepa 1987). These sites will be sampled during the 1992-93 field season. Nine of these sites meet the depth requirement and will be included in the reference set. The remaining 21 sites will be used to test this approach for EMAP offshore application. Finally, a subset (5-10) of sites will be sampled by NWRI and NOAA to compare methods, the sensitivity of the collection and analytical methods, and sampler variation (see Section 10.3.b.).

10.3.a.2. Field Methods

Geophysical Parameters (Table 10.5): When onsite, precise latitude and longitude will be obtained from the Loran C system. The Loran C coordinates and the chain being used will be noted. Water depth will be noted and air temperature will be measured for later comparison with water temperatures. Also, comments on wind and weather will be noted. The distance from the shore will be calculated from charts.

Limnological Parameters (Table 10.5): A Van Dorn water sampler will be used to obtain a water sample 0.5 m from the bottom. A one liter sample will be drained off and stored for filtration. Dissolved oxygen, pH, and temperature will be taken on the remainder of the sample. Half of the 1 L sample will be passed through the filtering apparatus and divided as follows:

Table 10.5 Geophysical parameters measured at each site.

GEOGRAPHICAL	LIMNOLOGICAL	SEDIMENTOLOGICAL
Distance from shore	Temperature, surface and bottom	Water content
Latitude	Degree days	Particle size
Shoreline development	Thermocline depth	Loss on ignition
Slope	In bottom 0.5 m	TP, TOC, TON
Depth	Alkalinity, hardness	AVS
	pH	Metals, major ions in pore water
	Nutrients	Metals, major ions
	Oxygen	Nutrients

i) For total phosphorous, filtered water will be placed in a square 125 mL glass bottle containing 1 mL of sulfuric acid. The samples will be sealed, stored at 4°C and shipped to CCIW for analysis.

ii) Filtered water for nutrients will be placed in a round 125 mL glass bottle. The samples will be sealed, stored at 4°C and shipped to CCIW for analysis. Samples (500 mL) will be filtered through a 0.45 Millepore ® Sartorius filter. The first portion passed through the filter will be discarded. Clean glassware will be used and the filters handled with forceps only.

The remaining water from the 1 L will be divided as follows:

i) For total phosphorous, water will be placed in a square 125 mL glass bottle containing 1 mL of sulfuric acid. The samples will be sealed, stored at 4°C and shipped to CCIW for analysis.

ii) For alkalinity, water will be placed in a round 125 mL Nalgene® bottle. The samples will be sealed, stored at 4°C and shipped to CCIW for analysis.

Sediment Characterization (Table 10.5): Sediment samples (600 mL) for geochemistry will be taken from the upper 5 cm of the box core or from a Ponar® sample. The sediment will then be homogenized in a glass dish with a Nalgene® spoon. The sample will then be divided as follows:

i) Organic contaminants (approximately 125 mL into a hexane-prewashed glass bottle with hexane rinsed aluminum foil liner): Samples will be sealed and stored frozen (or at 4°C in the field) and shipped to ERL-Duluth for storage and analysis. Depending on other data, it is likely that only a subset of these samples will be analyzed.

ii) Particle size distribution (about 20 mL into a scintillation vial): Samples will be stored at ambient temperature in the field and shipped to CCIW for freeze drying and analysis.

iii) Metals and nutrients: samples for metals, LOI, AVS, TP, TOC and TN will be stored together in a Whirlpak® plastic bag. Samples will be stored at 4°C in the field and shipped to CCIW for freeze drying and analysis.

Pore Water Sampling and Processing: From each box core, a 10-cm core will be taken and sealed. Samples will be stored at 4°C in the field and shipped to CCIW for extraction by squeezing in a nitrogen atmosphere and subsequent analysis.

Community Structure: Samples will be taken from a box corer, or mini-box corer developed at CCIW for this project. As an alternative, a techops corer may be used; this device has been calibrated against the box corer and mini-box corer. The sampler to be used depends primarily on the research vessel used in the project. Box cores will be sampled by inserting five 10 cm Plexiglass® tubes (i.d., 5.5 cm) into the sample, an addition tube will be used for pore water characterization (below). Core tubes for community structure will be removed and each replicate will be placed into a Whirlpak® plastic bag and kept cool until sieved. Replicates will be sieved (250µ) in the field as quickly as possible. If sieving cannot be done in the field, the replicate samples will be stored in 4% formalin in the Whirlpak® bag and sieved as soon as possible thereafter. When replicates have a high sand content, they will be placed in a bucket and sieved (250µ) with water added. The replicates will be agitated and the slurry poured through a 250µ sieve. The process will be repeated three times to ensure that no invertebrates remain in the sediment. Sieved replicates will be placed in scintillation vials and preserved with 4% formalin. Replicates with large amounts of organic material will be placed in larger containers and preserved with 4% formalin. Vials and containers will be properly labeled and stored at ambient temperature. Formalin must be used as alcohol causes oligochaetes to deteriorate. After 26 h formalin will be replaced by ethanol.

Sediment Bioassays: If a box core (50 X 50 cm) is used for sampling, three subsamples will be taken after coring for community structure and pore water. Otherwise, three Ponar® grabs will be collected at each site and shipped to CCIW for bioassays. Each sample will be placed in its own plastic lined bucket and sealed. The buckets will be kept as cool as possible until shipped to CCIW.

Sample Labeling: Each sample will be labeled with a 12 digit number, e.g., 01/19/03/090991. The first two digits represent the ecodistrict, the next two the site number, the next two the replicate number, and the last six the date (month/day/year). Additional labeling to meet the needs of EMAP tracking will be added if necessary.

10.3.a.3. Laboratory Methods

Community Structure: All samples will be sorted and picked by hand using low power on a stereo microscope. Small amounts of material will be placed in a petri dish marked with a grid and scanned twice. Organisms will be identified to major group (family, class) and placed in ethanol in labeled vials (20 mL plastic scintillation vials) for identification. Oligochaetes and chironomids will be completed to the species level where possible. This will provide greater discrimination, and provide information not available if identifications will be only taken to lower levels. Taxonomic verification will be conducted by referral to recently published keys, reference collections, and consultation with recognized experts. A reference collection of all identified material has been established and all identifications will be confirmed by an acknowledged expert.

Bioassay: Four sediment bioassay organisms are being used at CCIW and will be used in this project: *Chironomus riparius, Hyalella azteca, Hexagenia limbata,* and *Tubifex tubifex.* Chronic tests will be conducted using reproduction and growth as endpoints. All test methods are described in a Standard Operating Procedure (SOP) document and will be referenced to internationally recognized test methods. Methods will always specify acclimation periods, dose level selection (for reference toxicants), dosing schedules, test duration, test endpoints, lifestage, age or size of test organisms, and test acceptability criteria. Water change rates (if applicable), loading rates (organism mass/L), and aeration rates will also be described. Mode of operation will always be stated, i.e., static or semi-static (renewal). Exposure verification by chemical analysis for reference compounds will be conducted.

The ability of laboratory personnel to obtain consistent, precise results will be demonstrated with reference toxicants (positive controls) before they attempt to conduct toxicity assessments with field samples. At least five toxicity tests with reference toxicants will be conducted for each species of organism to establish warning limits early in the program. Once consistent results (e.g., a coefficient of variation in the endpoint of less than 30%) are achieved, the frequency of reference toxicant tests will decrease to approximately once per month for each toxicity test.

Sediment samples for bioassays will be scheduled for analysis as soon as possible with the schedule dependent on the permissible holding times according to the SOP. All documentation and test results that will be stored electronically in computer files will undergo human verification against input errors and inadvertent program changes. There will be a back-up system to permit recovery of data lost due to hard disk failures or operator errors.

As the objective is to determine background responses to a variety of conditions, test organisms will not be fed. Because of the confounding effects of resident fauna, primarily predation and competition for resources, sediments will be sieved through 250μ mesh before testing.

10.3.a.4. Data Analysis

Data will be entered into one of three data matrices, these will be stored electronically and on hard copy. Electronic storage will use Lotus 1-2-3 data files. Community structure data will be entered into a two-way data matrix of columns (taxa) and rows (individual replicate samples from a site). Environmental data and bioassay data will be stored similarly with the columns being respectively: environmental variables and individual assay endpoints. Bioassay response and benthic communities will be classified using multivariate statistics. Assurances that these formats are compatible with EMAP data files will be made and the information will be electronically transferred to the EMAP information management system for storage and use.

Initial data examination will be by table arrangement. Data will be examined in its original form, as percent abundance, and using a similarity index. Sites will be classified using PCA (principal component analysis) or CCA (canonical correspondence analysis). *Two methods will be used to relate community structure* and bioassay response to environmental variables: CCA or MDA (multiple discriminant analysis). Both will be done in a stepwise fashion. The computer software packages TWINSPAN, DECORANA, and SYSTAT will be used.

10.3.a.5. Reporting

A report on the Lake Michigan portion of the project will be prepared within six months of sample completion. Tentative determinations of nominal conditions, a test of their sensitivity and, from the NOAA comparison, a test of temporal variability will be included in this report. The report will be based on the Lake Michigan data and 150 Canadian stations that will have been sampled. A more detailed and comprehensive report that will include detailed assessment of the importance of annual and seasonal variability to the prediction process and more extensive testing of the recommendations will be prepared. It will be based on the entire dataset on completion of the Canadian study and will include more than 250 Canadian stations. This more comprehensive report will be prepared for Environment Canada but will be coordinated with EMAP - GL and GLERL.

10.3.b. NOAA-GLERL Project Description for Use of Sediment Traps for Indicator Measurements

Sediment traps have been proposed as the most efficient means of collecting integrated diatom samples (see Chapter 4), but this approach has not been tested. This project (coordinated through an IAG with NOAA-GLERL) will test the hypothesis that diatom samples can be collected using long-term (one year) sediment traps in a vertical mooring configuration.

The test site is an established GLERL long-term monitoring site in southern Lake Michigan (100 m bottom depth, 26 km southwest of Grand Haven, MI; 43.04°N, 86.64°W). Seven autosequencing sediment traps were deployed in October 1991 in a single vertical mooring at 15, 35 (duplicate traps), 75, 90, and 95 (duplicate traps) meters depth. Each trap is programmed to collect 23 samples on a 15-day rotation, thus providing 161 samples over the course of approximately one year. In order to test the EMAP hypothesis, these traps will be retrieved between August and October 1992; the samples will be allowed to settle, and the overlying water will be siphoned off. Samples will be freeze dried and weighed and then split to provide a portion of each to the University of Michigan, responsible under a separate EMAP agreement for the diatom analyses (a FY94 project).

In addition, it is apparent that sediment and sediment trap samples are matrices that are believed to be important and useful to the goals of the EMAP - GL program. However, the importance of these matrices as environmental/ecosystem indicators (i.e., what do they indicate?) and the best methodology for application to EMAP's goals have not been well thought out. Much has been learned over the past 20 years about how to interpret sediment trap samples and the information stored in sediments. Since similar analyses would be made on both sediments and sediment trap samples, a unified or coordinated protocol should be developed during FY94. GLERL will convene a small workshop of selected experts to assess the importance, utility, and application of sediments and sediment trap materials to the goals of the EMAP - GL program and to develop a recommended sampling protocol for these media that meets the goals of EMAP, to develop a recommended sampling protocol for these media that meets the goals of EMAP, and to be technically defensible.

10.3.c. NOAA-GLERL Project Description for Benthic Survey and Methodology Comparison (Southern Lake Michigan)

The status and trends of the benthos in the Great Lakes have been identified as a primary environmental/ecosystem indicator (Chapter 4). For southern Lake Michigan, GLERL has compiled an extensive status and trends dataset for benthic organism communities at some 40 stations. These data cover the periods 1964-1967, 1980-1981, and 1986-1987. GLERL will resample these stations during the spring, summer, and fall of 1992, collecting Ponar® grab samples in triplicate at each station.

As part of the EMAP Lake Michigan pilot project, a subset of ten of GLERL's long-term trends stations will be selected, and two sets of triplicate samples will be collected at each of these stations during each of the three sampling dates (i.e., a total of 180 samples). One set of triplicates (90 samples) will be retained and processed by GLERL; the duplicate set of triplicates will be provided to Environment Canada for comparison between Ponar® grab sample methodology (used by GLERL) and the box core sub-cores methodology (used by EC). GLERL will provide taxa abundances to the lowest practical taxonomic level in each of the triplicate GLERL samples.

As part of the EMAP - GL Lake Michigan pilot project, the Great Lakes National Program Office (GLNPO) will collect 11 benthic samples from the open lake region during the summer of 1992. These samples will be processed (screened and preserved) by GLNPO and sent to GLERL during FY94. GLERL will identify and provide abundances of taxa in each of these samples.

10.4. Development of the Harbors and Embayments Sampling Frame

USGS quad maps for the shoreline of Lake Michigan will be obtained and the number, location, and area of the harbors and embayments (as defined in Chapter 3) will be determined. If not available in digital format, these maps will be digitized and entered into a GIS for future use and analysis.

10.5. Wetland Indicators

As discussed in Chapter 4, little research on indicators of Great Lakes wetland condition has been conducted. As an initial activity, we intend to hold a workshop of Great Lakes wetland scientists and EMAP - Wetland members to develop recommendations for appropriate measurements and indices. Although not actually a 1992 fiscal year activity, (October 1, 1991 - September 30, 1992), this workshop will probably be held in late fall 1992 or early winter 1993 before any further field work is planned. Scientists with expertise in Great Lakes coastal wetland and nearcoastal ecology (vegetation, benthos, fisheries, wildlife, hydrodynamics) and landscape ecology will be drawn from academic institutions and state, provincial, federal and tribal groups from the U.S. and Canada. The workshop will also bring in persons experienced with EMAP design from other resource groups, notably EMAP-Wetlands and EMAP - Near Coastal (Estuaries). Objectives of the workshop will include:

- identifying existing databases on biota and wetland functions at landscape and local scales;
- identifying gaps in information that will be pertinent to developing indicators specific for Great Lakes coastal wetlands;
- identifying ways that Great Lakes coastal wetlands might be grouped for comparative assessments;
- identifying whether the EMAP grid or a list frame will be most appropriate for selecting monitoring sites;
- review of the indicators previously identified by EMAP - Wetlands and EMAP - GL programs and developing recommendations for their use or improvement; and
- generation of a list of suggested reference sites for pilot and demonstration studies on each of the Great Lakes.

10.6. Fish Indicators

As suggested throughout this report, there are many issues that require further analysis of existing data before being addressed for EMAP - GL. Because of their high perceived social value and their position in the food web, evaluation of existing data on fishes will be a high priority.

There are several agencies that have responsibility for gathering data on the fishes of the Great Lakes including the measurement of chemical residues. Because this is such a significant issue and one that can involve substantial cost, a thorough evaluation of existing data and methods will be conducted. Specific concerns that will be looked at include dealing with the high proportion of exotic versus native species, variability of sampling techniques, the compatibility of existing sampling approaches to the EMAP - GL objectives, community versus population versus individual based indicators, inconsistencies in methodology and criteria for contaminants in fish tissue, and how to treat the tremendous numbers of sport fish which continue to be stocked into the Great Lakes.

10.7. Index Period for Trophic Status Indicators

The traditional season for collecting and reporting data on trophic status in the Great Lakes is soon after ice-out (early spring). This is the period when the lakes are generally well mixed and before biological activity has incorporated the nutrients associated with enrichment. However, for many of the other indicators, late summer is believed to be the most appropriate period to make measurements. GLNPO has been conducting summer cruises for several years, and the data is in the process of being evaluated regarding the relative information obtained at the two periods of time. As part of this year's study, GLNPO will also be visiting the EMAP - GL offshore sites during their summer cruise. This data, in addition to the existing data, will be used to help evaluate the two sampling periods as they relate to EMAP - GL objectives.

10.8. Investigations of Diatom Populations as Indicators of Trophic Status and Biotic Integrity

A major difficulty in monitoring and assessing primary producer assemblages is the great temporal variation in species composition and abundance observed in the water column. To meet the needs of EMAP - GL and reduce the amount of sampling that would be required to characterize phytoplankton populations from water sampling, diatom populations will be assessed using sediment cores and sediment traps. This dual approach will:

- provide the paleoecological history of the Great Lakes (sediment cores);
- develop information on nominal or reference conditions, as they pertain to diatom populations prior to European settlement in the Great Lakes Basin (sediment cores);

- provide a temporally integrated assessment of diatom species composition and abundance, both long-term (sediment cores) and annually (sediment traps);

- identify water quality trends and emerging trends based on sediment trap results;

- integrate population measurements from epilimnetic, hypolimnetic, or a mixture of waters dependent upon sediment trap placement; and

- offer various levels of temporal resolution, if desired, from both sediment traps and sediment cores.

For FY92, further development of the sediment core/sediment trap approach strategy will be necessary. The known literature regarding paleoecological investigations of diatoms in the Great Lakes and elsewhere will be summarized. In addition, the literature on diatom recovery from sediment traps will be summarized, as it preliminarily appears that little information is available.

To address the sediment trap aspect of the approach, a limited amount of sampling and analysis will be conducted in FY92 (refer to Section 10.3.b.) Sediment traps have been deployed by NOAA-GLERL at GLERL's "100 meter station" in southern Lake Michigan. Seven sequential sediment traps are positioned such that two are near the surface, two are near the lake bottom, and the other three are staggered at various depths. Upon retrieval, a quantitative portion of each set of deposited material will be analyzed for diatom assemblages. Analysis of these samples will begin to address issues regarding depth of trap placement and reproducibility of traps and samples. Other factors that will have to be examined in the development of this strategy include: an estimate of the number of sediment traps; the relationship of plankton in the water column versus those in the sediment traps; and the number of diatom analyses required to reduce the variability to an acceptable level.

Other factors which will be examined in strategy development will include: an estimate of the number and distribution of cores required, the number of samples required to reduce variability expected on spatially-correlated core intervals, resolution (time scale) required for core intervals, potential of dissolution effects, relationship between extant plankton and sediment cores (Battarbee 1981), and the relationship between diatoms found in sediment cores and sediment traps.

The descriptive metrics associated with diatom populations will be examined and metrics involving specific species, species diversity, evenness, and redundancy will be evaluated. Abundance expressions of biovolume and number/cm^2 will also be evaluated. The development of composite and similarity indices and those using other statistical methods, e.g., Canonical Correspondence Analysis, will also be evaluated for the Great Lakes (ter Braake 1986;1989, ter Braake and Barendregt 1986, ter Braake and van Dam 1989).

All methodological aspects of diatom studies will be coordinated with other national EMAP programs. All diatom samples will be cleaned with hydrogen peroxide and mounted on slides with a high-resolution, optical mounting resin. Preparation methods used will allow a quantitative estimate of the flora. Samples will be examined with a research quality, light microscope at a magnification of 1000X and 500 valves per slide will be enumerated. Standard quality assurance protocol requires 1 of every 10 slides to be replicated; within-slide variability will also be evaluated. Specimens will be taxonomically identified using the recognized reference literature. Light and electron micrographs will be used for documentation of the flora, where known taxa and unknown entities will be maintained in a catalogue with pertinent information. Slides will be ultimately stored in a repository such as the Philadelphia Academy of Sciences. Raw data sheets (count sheets) will be retained at all times. Raw data will be transferred to computer format and output methods will meet the different needs of EMAP - GL for reporting purposes.

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Appendix A.

EMAP Glossary (Draft)[1]

[1] Based on Baillargeon 1991.

A

accuracy: The degree of agreement between a measurement or set of measurements and the true value or an accepted reference value. A set of measurements may be accurate without necessarily being precise.

adaptive sampling strategy: A sampling approach which, by design, can be modified to meet changing objectives or circumstances.

analysis: A detailed examination of a problem or entity made in order to understand its nature or to determine its essential features or character.

Annual Statistical Summary: A document containing summaries of EMAP data collected on a single EMAP resource type for a given year. Summaries may include cumulative frequency distributions, estimates of the extent of nominal or subnominal condition, comparisons among regions, or comparisons of data through time.

anthropogenic: Referring to the influence of human activities on nature.

area frame: A method of defining the sampling frame based on units of land area that in aggregate comprise the total land area of a region of interest. The individual sampling units are defined with maps or other cartographic materials. (See frame.)

area sample: A sample from an area frame.

assessment: Interpretation of information, or the assignment of significance or importance to data, within the context of policy-relevant questions.

assessment endpoint: An explicit rule or set of rules that relates a specific resource sampling unit to each element of a sampling frame.

attribute: Any property, quality, or characteristic of a sampling unit or site. The indicators and other measures used to characterize a sampling unit or site are representations of the attributes of that unit or site.

association rule: An explicit rule or set of rules that relates a specific resource sampling unit to each element of a sampling frame.

auxiliary data: Data collected by a monitoring or sampling program other than EMAP. Such data may be on-frame (but not the EMAP frame) or off-frame data. The sampling methods and quality assurance protocols of auxiliary data must be evaluated before the data are used. The term is synonymous with he term "non-EMAP data."

B

baseline condition: The status of a resource of resources as determined by initial sampling events. Future samples are compared to baseline conditions to infer changes.

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

best management practices: Application of techniques targeted at minimizing specific anthropogenic disturbances, such as soil erosion, pollutant transport, storm water runoff, or similar land-use-related disturbances.

bias: Systematic error manifested as a consistent deviation (positive or negative) from the known or true value. It may be regarded as the difference between the conceptual weighted average value of an estimator over all possible samples and the true value of the quantity being estimated. An estimator is said to be "unbiased" if this difference is zero. Bias differs from random error, which shows no such consistent deviation and for which this difference is always zero.

bioaccumulation: A process by which chemicals are taken up by organisms from environmental media (air, water, soil, or food.)

bioassay: A laboratory or field test in which living organisms are used to detect the presence of or test the effect of a particular substance, factor, or condition. Results are compared to a standard preparation or control to determine the relative strength of the substance, factor, or condition.

biodiversity: The variety and variability among living organisms and the ecological complexes in which they occur. Diversity can be quantified as the number of different items and their relative frequencies. For biological diversity, these items are organized at many levels, ranging from complete ecosystem to the biochemical structures that are the molecular basis of heredity. Thus, the term encompasses expressions of the relative abundances of different ecosystems, species, and genes.

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

biological magnification (or biomagnification): The process by which the concentrations of certain substances (e.g., radioactive materials and persistent pesticides) in the tissues of living organisms become greater at higher trophic levels of a food web.

biomarker: A measurement of body fluids, cells, or tissues that indicates in biochemical or cellular terms the presence and magnitude of toxicants or of host response.

biomass: The amount of organic matter contained in all living organisms per unit area or volume. Because living organisms contain a large proportion of inorganic material (e.g., water and minerals), biomass is usually measured in terms of carbon content, and it is usually expressed as a density (mass per unit area or volume), such as kilograms of carbon per square kilometer or grams of carbon per cubic meter. It is sometimes convenient to express the mass as its energetic equivalent, such as kilocalories per square kilometer.

biome: A major class of ecosystem type possessing characteristic flora and fauna which have developed under and adapted to characteristic climatic regimes. Examples of biomes include tropical rain forest, tundra, northern boreal forest, or desert.

biosphere: That portion of the earth and its atmosphere that can support life.

bottom-up approach: A risk assessment methodology that uses first principles or experimental results to assess environmental condition. This is a more traditional form of risk assessment that moves from source(s) and source assessment, through exposure assessment, to effects assessment. For example, pollutant effects are related causally to pollutant sources by transport, fate, and dose-response models. (See top-down approach.)

C

candidate indicator: A potential EMAP indicator proposed for a given resource category or class, or as a cross-resource indicator, based on a combination of literature review, exchanges at expert workshops, and interviews with scientists and environmental managers. An indicator with candidate status is judged against specific EMAP criteria to determine its applicability/usefulness as a research indicator.

classification: The process of assigning a resource unit to one of a set of groups or categories defined by values of attributes measured on the resource units. For example, forest sites can be classified into forest types, depending on the species composition of the forest. The process also may be hierarchical - a stepwise partitioning of resource units into classes based on specified attributes of those units. For example, lakes can be distinguished by size - large lakes versus small lakes; small lakes can further be distinguished by hydrologic lake type - small seepage lakes versus small drainage lakes.

client: An organization, administrative unit, or other entity with whom EMAP interacts to determine policy-relevant assessment requirements, to conduct assessments, and to communicate assessment results. Clients may include other EPA administrative units, other federal agencies, Congress, state and local governments and their agencies, and private organizations.

cluster analysis: A statistical procedure for classifying data points by combining similar points for form small classes, then combining small classes into larger classes, and so on.

community: In ecology, a group of interacting populations co-occurring in time and space. Sometimes, a particular subgrouping may be specified, such as the fish community in lake or the soil arthropod community in a forest.

confidence interval: An interval within which a particular parameter (e.g., the population mean) lies with a specified degree of confidence. The interval is bounded by upper and lower confidence limits. A confidence interval is so termed because the confidence that the specified parameter lies within the interval can be expressly stated. For example, the confidence that the true population mean lies between 19.82 and 21.78 is 95%. Such statements require an assumption about the form of the underlying distribution (e.g., normal, binomial, multinomial) of the variable being measured.

coordination: A bringing into a common action, movement or condition; direction toward a common goal. Coordinated activities in EMAP include Integration and Assessment, Indicator Development, Information Management, Logistics, Total Quality Management, and Statistics and Design.

core indicator: EMAP indicator that is selected for long-term, ecological monitoring as a result of its acceptable performance in a regional demonstration project.

correlation coefficient: A measure of the degree to which two or more variables are related; its value always lies between -1 (strong negative relationship) and +1 (strong positive relationship.)

cumulative frequency distribution: A curve or distribution generated by some function, $F(x)$ represents the proportion of the population, expressed as units or area (e.g., proportion of stream reaches or proportion of estuary area) in the target population having a value for that variable that is less than or equal to *x*. An empirical cumulative frequency distribution, based on a probability sample, is an estimate of the population cumulative distribution function, or CDF.

D

data quality objective: Quantitative and qualitative statement of the level of uncertainty one is willing to accept with regard to a given variable being measured. A data quality objective may include goals for accuracy, precision, and limits of detection. It may also include goals for completeness, comparability, and representativeness. Data quality objectives are established before sampling is begun and may influence the level of sampling effort required.

demonstration project: A regional monitoring study undertaken to test the EMAP approach as implemented for a particular resource category. Demonstration projects are undertaken after a pilot project is completed and data quality objectives are established. (See pilot project.)

descending analysis: A method of calculating the upper confidence bound of a cumulative frequency distribution. A descending analysis provides the upper confidence bound on numbers of units possessing a particular value or values above it. An alternate method is ascending analysis.

design-based: Referring to inferences using methodology based on the sampling design. Such inferences derive their properties from the design protocols. (See model-based.)

developmental indicator: An EMAP indicator that has passed evaluation for expected performance (existing data analyses, simulations, and limited-scale field tests or pilot projects) and, with the concurrence of scientific peer reviewers, is deemed suitable for actual performance testing in a regional demonstration project. The term "probationary core indictor" is preferred to "developmental indicator" since the former is more descriptive of an indicator's status.

diagnosis: The process of associating exposure, habitat, and stressor indicators with indicators of ecological condition (i.e., response indicators) in order to identify environmental problems.

diagnostic indicator: A characteristic of the environment measured for comparison with indicators of ecological condition (i.e., response indicators) to determine possible explanations for subnominal, or poor or unacceptable, conditions; a collective term for any exposure, habitat, or stressor indicator.

discrete resource: A resource category or class that can be regarded as being spatially discrete or subdivided by boundaries. Examples of discrete resources might include small lakes or stream reaches. Designation of a resource as discrete is scale-dependent. (See extensive resource.)

distribution function: A mathematical expression describing a random variable or a population. For real-world finite populations, these distributions are knowable attributes (parameters) of the population and may be determined exactly by a census, or estimated from a sample. The general form is the proportion (or other measure, like number, length, or area) of the resource having a value of an attribute equal to or less than a particular value. Proportions may also be of the different possible measures, like number (frequency distributions), area (areal distributions), length, or volume. Distribution functions are a primary descriptive statistic of EMAP. (See cumulative frequency distribution.)

domain: In a spatial or geographic sense, domain refers to areal extent of a resource, that is to the region(s) occupied by a resource. In mathematics and statistics, domain refers to the set of values to which a variable is limited or the set on which a function is defined.

double sample: A sample of a sample. In EMAP, a larger (Tier 1) sample of resource attribute measurements can be obtained via remote sensing or cartographic materials than can be obtained via field sampling (Tier 2). Attributes measured on the Tier 1 sample can be used to guide selection of the Tier 2 sample, and therefore, the Tier 2 sample constitutes a double sample of the Tier 1 sample.

E

ecological indicator: A characteristic of the environment that, when measured, quantifies magnitude of stress, habitat characteristics, degree of exposure to a stressor, or ecological response to exposure. The term is a collective term for response, exposure, habitat, and stressor indicators.

ecological risk assessment: The process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors.

ecoregion: A geographic area which is relatively homogeneous with respect to ecological systems.

ecosystem: The biotic community and its abiotic environment.

ecosystem function: Attribute related to rates of change of structural components of an ecosystem; examples include primary productivity, denitrification rates, and species fecundity rates.

ecosystem structure: Attribute related to instantaneous physical state of an ecosystem; examples include species population density, species richness or evenness, and standing crop biomass.

ecotone: A habitat created by the juxtaposition of distinctly different habitats; an edge habitat; an ecological zone or boundary where two or more ecosystems meet.

effective sample size: A computed sample size for special circumstances in which the "normal" or original sample size is determined to be insufficient. The effective sample size is computed from known or preliminary statistical characteristics of the attribute(s) being sampled.

environmental indicator: A measurement, statistic or value that provides a proximate gauge or evidence of the effects of environmental management programs or of the state of condition of the environment.

environmental value: A characteristic of the environment that contributes to the quality of life provided to an area's inhabitants; for example, the ability of an area to provide desired functions such as food, clean water and air, aesthetic experience, recreation, and desired animal and plant species. Biodiversity, sustainability, and aesthetics are examples of environmental values.

eutrophication: A developmental or aging process undergone by some water bodies in which biological productivity increases through time. Eutrophic water bodies are characterized by high nutrient (nitrogen and phosphorus) concentrations and, as a consequence, by heavy growth of aquatic plants and algae. This in turn contributes to increasing production of organic matter and its subsequent decomposition by microbes. Lowered dissolved oxygen in the water caused by microbial activity results in increased release of nutrients from the sediments, further contributing to the eutrophication process.

Eutrophication is accelerated by human activities (sewage inputs, crop and lawn fertilization, etc.) that contribute nutrients to surface waters.

exposure: The co-occurrence of a stressor with one or more ecological components (ecosystems or their biotic components.) Stressors can be chemical, biological, or physical in nature.

exposure indicator: A characteristic of the environment measured to provide evidence of the occurrence or magnitude of a response indicator's contact with a chemical or biological stress.

extensive resource: A resource category or class covering a large geographic area and not subdivided by natural boundaries. Examples of extensive resources include grasslands or large marshes. Characterization of a resource as extensive is scale-dependent.

F

40-hex: A colloquial term for the landscape description hexagon or landscape sampling unit centered on each of the grid points in the EMAP sampling grid. The area of each hexagon is approximately 40 km^2. (The actual size of each hexagon is 39.7 km^2.)

found data: Data not collected by EMAP. Examples may include historical monitoring data or contemporary data collected by other monitoring programs. It is always necessary to establish the population represented by such data.

frame: An explicit representation of all units or elements of a target population or universe that is to be sampled. Examples include list frames and area frames. (See sampling frame.)

G

geographic information system (GIS): A computer system expressly designed for storing, manipulating, analyzing, and displaying data in a geographic context. A geographic information system is usually thought of as a software system, but specialized hardware, such as graphics display terminals and plotters, is required to take full advantage of the software.

grid: A systematic network of sampling points superimposed on a region of interest. In EMAP, the grid is a network of equilateral triangular structures with grid points 27.1 km apart. This network, superimposed on the conterminous U.S., establishes a base grid of approximately 12,600 points with approximately one grid point per 635 km^2. (See hexagon.)

grid enhancement: The process of systematically increasing the number of points in a sampling grid. Grid enhancement is one method of producing an augmented sample.

grid randomization: The process of randomly positioning the grid so that each (discrete) unit of area of fixed size is equally likely to contain a grid point. This process is the basis for the probability-sample designation for EMAP monitoring.

H

habitat indicator: A physical, chemical, or biological attribute of the environment measured to characterize conditions necessary to support an organism, population, or community in the absence of pollutants. Examples include salinity of estuarine waters or substrate type in streams or lakes.

hazard: The intrinsic ability of a stressor to cause adverse effects under a particular set of circumstances.

hazard indicator: A type of stressor indicator; a measure that reflects human activities that inadvertently affect ecological resources. Examples include measures of pollutant release, number of permits issued for construction activity, and rates of application of fertilizers to forests and crops that influence nutrient concentrations in adjacent streams.

hexagon: A regular six-sided polygon. The EMAP sampling grid is designed around hierarchical hexagonal shapes. A hexagonal face of a truncated icosahedron projected onto the United States is the main hexagon on which the EMAP sampling grid is based. Other hexagons are formed by the nature of the triangular grid: Each baseline grid point is bounded by six adjacent grid points that form a hexagon. These so-called baseline tessellation hexagons have an area of 634.5 km^2. Landscape sampling units (40-hexes) are smaller hexagons (1/16 the area of a baseline tessellation hexagon, 634.5 $km^2/16 = 39.7\ km^2$) centered on a sample grid point within each baseline tessellation hexagon.

I

icosahedron: Regular geometric solid with 20 equilateral triangular faces and 12 vertices. A modified icosahedron, referred to as a truncated icosahedron, is the basis for the baseline EMAP sampling grid.

implicit sampling frame: A set of rules or criteria used to select sampling units that cannot, *a priori*, be listed explicitly. In EMAP, the criteria are developed during landscape characterization activities to identify resource sampling units within each landscape sampling unit.

inclusion probability: The probability of including a specific sampling unit within a sample. Inclusion probabilities must be known in order to calculate sample statistics.

index: Mathematical aggregation of indicators or metrics; one example is the Index of Biotic Integrity, which combines several metrics describing fish community structure, incidence of pathology, population sizes, and other characteristics.

index period: The period of the year or sampling window when measurement of an indicator yields the most meaningful information. The index period may vary from one indicator or resource class to another.

index sample: A standardized form of judgment sample for which rules of selecting the sample are formally prescribed. In EMAP, index samples usually are acquired to facilitate interpretation of a probability sample.

indicator: A measurement that can be used to assess the status and trends of environmental quality, that is, to assess the ability of the environment to support a desired human or ecological condition.

integrated assessment: Periodic reports in which an evaluation is made of the significance of status and trends in response indicators in the context of policy-relevant questions. Integrated assessments focus on assessment of environmental condition in the context of multiple resource issues. They may include correlative analyses among frame data from within and among resource categories and auxiliary data, as well as relevant literature citations from outside EMAP that are used to support, explain, or be refuted by EMAP results.

integration: The formation, coordination, or blending of units or components into a functioning or unified whole. In EMAP, integration refers to the establishment of a cohesive approach to environmental monitoring, the coordination of monitoring efforts in multiple resource categories and the blending and analysis of ecological data in order to undertake interpretation and assessment. Integration in EMAP also includes coordination of EMAP with other monitoring programs and coordination of program activities to address the needs of constituent groups.

interpenetrating design: An aspect of monitoring design in which a new set of sampling units is selected each year through a cycle of successive years. Each subsequent cycle uses the same set of sampling units as the initial cycle. In a four-year cycle, for example, the set of sampling units sampled in year 1 would be resampled in years 5,9,13,..., those sampled in year 2 would be resampled in years 6,10,14,..., and so on.

L

landscape: The set of traits, patterns, and structure of a specific geographic area, including its biological composition, its physical environment, and its anthropogenic or social patterns. An area where interacting ecosystems are grouped and repeated in similar form.

landscape characterization: Documentation of the traits and patterns of the essential elements of the landscape, including attributes of the physical environment, biological composition, its physical environment, and its anthropogenic or social patterns. An area where interacting ecosystems are grouped and repeated in similar form.

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

landscape indicator: A measurement of the landscape, calculated from mapped or remotely sensed data, used to described spatial patterns of land use and land cover across a geographic area. Landscape indicators may be useful as measures of certain kinds environmental degradation such as forest fragmentation.

landscape pattern type: A geographic area throughout which a common set of ecological resources and land uses form a consistent pattern. Landscape pattern types are visually interpreted, classified, and delineated by analysis of remote imagery or maps. They are classified in terms of composition (i.e., component land use/land cover classes such as forest, grassland, agriculture, or urban) and the pattern in which the components are arranged (e.g., matrix, matrix/patch, mosaic.)

list frame: A method for defining the sampling frame based on a characteristic or attribute of the sampling units. The individual sampling units are defined by tables or lists of units are defined by tables or lists of units with common attributes. For example, all lakes greater than 4 ha in the southeastern United States can be found and listed by using U.S. Geological Survey maps or remote sensing (or some other standardizing method). Such a list constitutes a list frame.

long-range plan: A document setting forth, in general, the milestones, activities, and tasks that must occur to achieve some goal in a specified time frame. It is similar to an operating plan but is less detailed and covers a longer time frame. The time frame for long-range planning in EMAP is five years.

M

management indicator: Within EMAP, a type of stressor indicator; a measure reflecting human activities that intentionally alter an ecological resource to meet some management objective; for example, the dredging or filling of a wetland for the purpose of housing development.

management plan: A detailed program of action designed to achieve management objectives. A management plan may include regulations (e.g., restricted fishing) and policies (e.g., permit requirements.)

measurement endpoint: A measurable ecological characteristic that is related to the valued characteristic chosen as the assessment endpoint. Measurement endpoints are often expressed as the statistical or arithmetic summaries of the observations that comprise the measurement.

model: A description, analogy, or abstraction used to help visualize or conceptualize something that cannot be directly observed or measured; a system of postulates, data, and inferences presented as a mathematical description of an entity or a state of affairs.

model-based: Referring to inferences using methodology based on models. Such inferences derive their properties from the model assumptions. In some instances model-based inference is advantageous over design-based inference, given that certain assumptions hold. (See design-based.)

monitoring: The act of measuring indicators or characteristics or environmental condition through time.

monotonic: Characterized by a lack of reversals; that is, steadily increasing or decreasing without changes in direction.

N

natural process indicator: In EMAP, a type of stressor indicator; a measure reflecting phenomena that affect ecological condition, regardless of the presence of management actions or environmental hazards; examples include natural climatic fluctuations, predator-prey cycles, and insect and disease epidemics.

nearest resource unit: A step in the sampling process where a resource sampling unit is selected because of its proximity to the center of a landscape sampling unit.

network: A generic term for a collection of sites (i.e., subset of population units in a target population) where measurements are made "continuously" or periodically over time. The term usually is associated with trend studies or long-term research studies. Network sites include those obtained either (1) as a probability sample from a target population or (2) from an existing collection of sites, as "found" sites, or by subjective selection. In the second case, estimates of population characteristics may not be possible.

nominal: The state of having desirable or acceptable ecological condition.

nominal value: A standard established for a response indicator to represent desirable or acceptable (nominal) condition. Subnominal values are then those values that fall below the nominal value.

nonparametric statistics: Statistical approaches used when the sampled characteristics of populations cannot be described by a normal distribution or when the distribution is unknown. Such methods are also referred to as distribution-free methods.

O

off-frame data: Data acquired by a sampling approach that does not provide a probability sample. For example, data acquired by the National Acid Deposition Program are off-frame data.

on-frame data: Data acquired by a sampling approach that provides a probability sample. For example, the Surface Water Survey of the National Acid Precipitation Assessment Program produced on-frame data.

operating plan: A detailed program of action describing the procedures, practices, and actions to be undertaken to achieve specified ends in a specified time frame. An operating plan is similar to a long-range plan but is more detailed and covers a narrower planning time frame. In EMAP, the time frame for operational planning is three years.

P

parameter: An attribute or characteristic. The term is used in specific technical disciplines in various ways: In statistics, parameter refers to attributes of models or populations, and variable refers to attributes of sampling units. In chemistry, parameter often refers to the attributes of, for example, a water sample. Sometimes it is appropriate to refer to a particular attribute as a parameter in one context and variable in another; a parameter of the lake is a variable of the population of lakes.

pattern: The location, distribution, and composition of structural landscape components within a particular geographic area or in a spatial context; for example, a mosiac of patches.

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

policy: A definite course or method of action selected, in light of given conditions, from among alternatives to guide and determine present and future decisions.

policy analysis: The process of evaluating alternative prospective policies or the various components of those policies.

population: In statistics and sampling design, the term population refers to the total universe addressed in a sampling effort. An example of a population is the set of lakes between 10 and 2000 ha in the eastern United States. The term universe is often used interchangeably with population. In ecology, the term population refers generally to a group of individuals of the same species residing in close proximity to each other such that the individuals share a common gene pool.

population estimate: A statistical estimate or distribution of some characteristic that applies to an explicitly defined target population (category, class, or subclass), for example, the median acid-neutralizing capacity (or the cumulative frequency distribution of acid-neutralizing capacity) for all small lakes in the Northeast.

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

precision: The degree of agreement among replicate measurements of the same attribute. A set of measurements may be precise without necessarily being accurate.

probability sample: A sample chosen so that the probability of including each selected unit in the sample is known, and so that each population unit has a positive probability of selection. This implies that the target population is represented by the sample and that the target population is explicitly defined. Statistical estimates of characteristics of the population so sampled can then be made with known precision.

probationary core indicator: An EMAP indicator that has passed evaluation for expected performance (existing data analyses, simulations, and small-scale field tests) and with the concurrence of scientific peer reviewers, is deemed suitable for actual performance testing in a demonstration project.

program: An administrative entity (people operating in some management environment) created for the purpose of achieving some stated goal or end.

Q

quality assurance: The total integrated program for ensuring the reliability of environmental measurements and analysis. Quality assurance consists of multiple steps taken to ensure that all data quality objectives are achieved.

quality control: Specific steps taken during the data collection process to ensure that equipment and procedures are operating as intended and that they will allow data quality objectives to be achieved.

quantile: The value of an attribute indexing a specified proportion of a population distribution or distribution function. Quartiles (25th, 50th, and 75th percentiles), the median (50th percentile), and other percentiles are special cases of quantiles.

R

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

region: Any explicitly defined geographic area. Regions may be defined administratively (e.g., EPA Region III), politically (e.g., Texas), geographically (e.g., the Southwest), biogeographically (e.g., short-grass prairie), physiographically (e.g., Rocky Mountains), or by other means.

remote sensing: The collection and interpretation of information about an object without physical contact with the object. Satellite imaging and aerial photography are examples of remote sensing.

research indicator: A candidate indicator identified for an EMAP resource category which has been prioritized on the basis of several criteria (e.g., regionally applicable, integrates effects, monotonic, conducive to synoptic monitoring) and, following peer review, has been selected for further evaluation for use in EMAP as a possible probationary core indicator. An evaluation of the expected performance of a research indicator is made after existing data are analyzed, simulation studies are performed with realistic scenarios and expected spatial and temporal variability, and limited field tests are conducted.

residual: In statistics, the deviation of a data point from the value predicted by a regression equation. It is computed as the difference between the observed value and the predicted value.

resource: An ecological entity that is identified as a target of sampling, description, and analysis by EMAP. Such an entity is ordinarily thought of and described as a statistical population. A resource can be characterized as belonging to one of two types, discrete and extensive, that pose different problems of sampling and representation.

resource assessment: Periodic reports in which an evaluation is made of the significance of status and trends in response indicators in the context of policy-relevant questions. Resource assessments focus on assessment of individual resource categories. They may include correlative analyses among frame data from within a resource category and auxiliary data, as well as relevant literature citations from outside EMAP that are used to support, explain, or be refuted by EMAP results.

resource category: A group of general, broad ecosystem types or ecological entities sharing certain basic characteristics. Seven such categories currently are identified within EMAP: estuaries, Great Lakes, inland surface waters, wetlands, forests, arid lands, and agroecosystems. These categories define the organizational structure of monitoring groups in EMAP and are the resources addressed by EMAP resource assessments.

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

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

Resource Group: A group of scientific and administrative personnel, headed by a Technical Director, responsible for monitoring a given EMAP resource category. There are seven such groups in EMAP: Estuaries, Great Lakes, Inland Surface Waters, Wetlands, Forests, Arid Lands, and Agroecosystems.

resource sampling unit: An individual station or site of a particular ecological resource category or class; an individual unit of a target population (e.g., a stream segment, a forest stand, a wetland, an estuary) upon which indicator measurements are made. More than one resource sampling unit can occur in a landscape sampling unit.

response indicator: A characteristic of the environment measured to provide evidence of the biological condition of a resource at the organism, population, community, or ecosystem level of organization.

risk: The probability or likelihood an adverse effect will occur.

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

risk communication: The exchange of information about environmental risks among risk assessors, risk managers, the general public, news media, special interest groups, and others.

risk management: The process of evaluating alternative regulatory and non-regulatory responses to risk and selecting among them. The selection process necessarily requires the consideration of scientific, legal, economic, and social factors.

S

sample: A subset of the units from a sampling frame, for example, a subset of resource units from a population or set of sampling sites.

sampling design: The set of procedures associated with the inspection of the target population, population units, sampling frame, and measurements to be made on units for a specific survey (study) objective.

sampling frame: A list or spatial representation of explicit, clearly defined, mutually exclusive, ecological resource units containing all of the elements of a specified universe. (See frame.)

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

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

spatial statistics: Statistical methodology and theory that accounts for spatial structure in a dataset. Conventional population estimation does not normally account for spatial attributes, except perhaps for spatial identity of subpopulations.

strategic plan: A document setting forth the mission and objectives of a program, its goals, and the products it will ultimately provide. A strategic plan must also provide an overarching vision of how to achieve those ends.

stratified design: A statistical sampling design in which the target population is divided into groups (strata) because of some distinguishing characteristic(s); a probability sample is selected from each stratum.

stratum: A sampling structure that restricts sample randomizing/selection to a subset of the frame. Inclusion probabilities may or may not differ among strata.

stressor indicator: A characteristic measured to quantify a natural process, an environmental hazard, or a management action that can effect changes in exposure and habitat. Three types of stressor indicators are considered in EMAP: hazard indicators, management indicators, and natural process indicators. Examples include the incidence of fertilizer application, which can increase nutrient concentrations in lakes; incidence of dredging/filling, which can diminish availability of wetland habitat; and climatic fluctuations, which can promote damage by pathogens.

subnominal: Having undesirable or unacceptable ecological condition.

subnominal threshold: A value selected for a response indicator below which a resource is designated as subnominal with respect to a given assessment endpoint.

subpopulation: Any subset of population, usually having a specific attribute that distinguishes its members from the rest of the population, for example, lakes from a specified population that are above 1000 m in elevation. Subpopulations are important entities in the EMAP plan. Any defined subpopulation is subject to characterization via estimation of subpopulation attributes and comparison to other subpopulations.

suite: A group or collection of related, complementary objects. In EMAP, the term usually is used in the phrase "indicator suite," which refers to the complete array of indicators measured on a given resource category.

survey: The collection of data in order to examine, characterize, or analyze the condition or status of some aspect or aspects of an area.

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

T

target population: The total entity of set of entities addressed in a sampling effort. An example of a target population is the set of lakes between 10 and 2000 ha in the eastern United States. (See population.)

Task Group: A group of scientific and administrative personnel headed by a Technical Coordinator and charged with addressing specific cross-cutting, integrative issues in EMAP, such as Integration and Assessment, Indicator Development, Information Management, logistics, Total Quality Management, and Statistics and Design. (See Resource Group.)

tier structure: In EMAP, a set of hierarchically arranged levels or stages of monitoring/sampling effort.

Tier 1: The sampling level in which the landscape is described with information obtained through remote sensing, maps, and other information. The principal aims of the Tier 1 sample are to describe the extent of resource categories and classes and to describe landscape structure. Tier 1 efforts also includes development of sampling frame information for each resource category.

Tier 2: A more intensive level of sampling than at Tier 1, in which a probability sample drawn from the sampling frame information developed at Tier 1, that is, a double sample from the Tier 1 sample. Tier 2 is oriented to field monitoring of indicators to assess ecological condition of each resource category.

Tier 3: An augmented sampling effort within the same frame that Tier 2 sampling has been conducted, but with increased spatial or temporal resolution. A Tier 3 sample is undertaken on a given resource when assessment of the routine Tier 2 sample indicates that enhanced spatial or temporal resolution and/or a more complete suite of indicators is necessary to adequately evaluate that resource.

Tier 4: Specialized studies or experiments undertaken when Tier 2 or 3 samples indicate that a better understanding of cause-effect relationships among indicators and/or stressors is necessary to evaluate ecological condition.

top-down approach: A risk assessment methodology that uses ecoepidemiological analyses to assess environmental condition. This is an effects-driven form of risk assessment; that is, ecological effects or responses are first observed and then associated temporally or spatially with pollutant exposures, habitat condition, and pollutant sources. (See bottom-up approach.)

total quality management (TQM): The quality assurance process adopted by EPA in which management philosophy, planning, and operational methodology are completely committed to quality improvement in all aspects of the organization or the program.

V

variable: An attribute or characteristic. In statistics, variable refers to attributes of sampling units, and parameter refers to attributes of models or populations. Sometimes it is appropriate to refer to a particular attribute as a parameter in one context and variable in another; a parameter of a lake is a variable of the population of lakes.

variance: A measure of the variability or precision of a set of observations. It is calculated as the mean of the sum of squared deviations from the mean value. Normally, a sampling program is designed to achieve measurements that meet specified standards of precision.

W

watershed: The terrestrial area of the landscape contributing to flow at a given stream location.

Appendix B.

Indicator Fact Sheets

for

EMAP - Great Lakes

EMAP - Great Lakes Indicator Fact Sheet

Indicator: Benthic invertebrate community structure

Category: Response indicator

Resource class: Offshore, nearshore, and harbor/embayment zones

Application: The abundance of benthic invertebrate species complements measures of pelagic biota by representing the response of aquatic communities living in or on the sediments of the Great Lakes. Benthic organisms can be impacted by changes in physical sediment characteristics, chemical contamination in sediments, and by changes in the physical environment such as the frequency and duration of anoxia. These organisms often serve as important food sources for fish and can contribute to the transfer of contaminants through the food web. Benthic organisms often serve as the interface between sediment conditions and the pelagic community. Benthic organisms are relatively stationary and their abundance is therefore reflective of localized conditions. The life history characteristics of many benthic organisms is documented and suggests that their population fluctuations are less dramatic than is found with pelagic invertebrates such as zooplankton. A variety of metrics of benthic community structure have been proposed for use in aquatic ecosystems. There is, however, no widely accepted index of benthic community structure that provides quantification of healthy conditions. Perhaps the most widely used comparative tool is simply the number of species present and abundance of those species.

Index Period: Benthic community structure can be affected by the emergence of aquatic insects during the spring, summer, and fall. However, winter and early spring sampling can be difficult due to poor weather conditions and the presence of ice. Because rapidly changing environmental conditions are often coupled with changes in community structure, late summer would be a preferred sampling period. This would allow the development of newly hatched insects and more generally stable environmental conditions. In any case, sampling an area, within which comparisons are to be made, should occur over a relatively short time period.

Measurements: The measurements for benthic community structure consist of the number of individuals of each species collected in a sediment sample. These samples can be obtained by a variety of sampling devices. The most common are Eckman® and Ponar® dredges and box cores. The selection of devices depends in part on the substrate present. Eckman® dredges are usually lighter in weight and may have difficulty when large solid material (e.g., sticks, rocks) are present. After collection, samples are usually sieved to remove sediment and retain the animals. Sieve mesh size can also selectively affect the retention of organisms.

Variability: Variability of measures of community structure can be the result of variations in spatial distribution and temporal conditions. Spatial distribution is affected by natural differences in habitat and sediment characteristics (e.g., particle size distribution) that result from natural variations in water depth, current speed and current direction. Temporal variation is the result of variations in environmental conditions (season to season; year to year) and life history characteristics such as emergence and reproductive patterns. These types of variability can be accounted for by careful characterization of physical and environmental features and by selection and standardization of index periods for sampling. Additional variation can result from the use of sampling gear and the degree of consistency among scientists making identifications and counts. These also should be standardized to the extent possible.

Primary Problems: The primary difficulties associated with this indicator include the lack of an integrative/interpretive metric and the spatial/temporal variability. Knowledge of the natural variability will be necessary to make interpretive reports on the health of benthic communities in the Great Lakes.

EMAP - Great Lakes Indicator Fact Sheet

Indicator: *Hexagenia* abundance

Category: Response indicator

Resource class: Nearshore and harbor/embayment zones

Application: The abundance of *Hexagenia* mayflies is used as an indicator of water and sediment quality in the Great Lakes. *Hexagenia* were abundant in mesotrophic waters of the Great Lakes prior to the 1950's (Schneider et al. 1969, Reynoldson 1989). Their populations are sensitive to eutrophication (Rasmussen 1988), oil, metals, and other contaminants (Hiltunen and Schloesser 1983, Malueg et al. 1984, Specht et al. 1984). When water quality improves, *Hexagenia* populations often increase in abundance (Fleming 1989, Reynoldson et al. 1989) and the existence of historical data makes comparisons with previous population densities and ecosystem carrying capabilities possible.

Index Period: *Hexagenia* should be sampled monthly May through October to sample the seasonal variability that is characteristic of mayflies (Schneider et al. 1969, Rasmussen 1988).

Measurements: Sampling stations are already established in some areas (Reynoldson et al. 1989); others need to be chosen. Samples should be taken from sediments composed of mud or soft clay in mesotrophic waters in which *Hexagenia* have been recorded, or in which it seems likely they would be present if water and soil characteristics were suitable. *Hexagenia* are measured in number/m^2 of sediment. Sampling equipment varies; recent workers have used box core, Ponar®, and drag/dredge devices (Reynoldson 1989). Standardization of methods and equipment is necessary. Identification to species is desirable. Unfortunately, this sampling is time consuming and requires the use of specialized equipment.

Variability: *Hexagenia* abundance is spatially and temporally variable because seasonal fluctuations in weather and other abiotic factors affect the survival and developmental rate of the nymphs. One of the most important abiotic factors to consider is sediment type. Sediment consistency should be adequate enough to allow for burrow stability. Thus, long-term monitoring of a variety of sites is essential for the use of *Hexagenia* as an indicator of water and sediment quality.

Primary Problems: *Hexagenia* is an appropriate indicator of water and sediment quality only in sediments of appropriate substrata at depths up to 26 m (Mozley and LaDronka 1988). The high variability of *Hexagenia* abundance makes this an indicator that is useful for long-term monitoring and does not provide short-term information about changes in environmental quality (Reynoldson 1989). The great sensitivity of this genus to contamination and low oxygen concentrations means that recolonization occurs only after large changes in environmental quality are attained, so small improvements in water and sediment quality may not be indicated (Reynoldson 1989).

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EMAP - Great Lakes Indicator Fact Sheet

Indicator: *Diporeia* abundance

Category: Response indicator

Resource class: Offshore and nearshore zones

Application: The abundance of the benthic amphipod *Diporeia hoyi*, formerly *Pontoporeia hoyi*, (Bousfield 1989) has been suggested as an indicator of ecosystem health for oligotrophic waters in the Great Lakes (Ryder and Edwards 1985). This species is found in all the Great Lakes (Balcer et al. 1984) and is a food item for a variety of fish species. The benthic habit of *D. hoyi* makes it a good indicator of the environment at the water-substrate interface. Since many contaminants are found associated with sediment particles, it is important to have an indicator that is sensitive to the contaminants in this strata of the ecosystem. *D. hoyi* have been shown to bioconcentrate a variety of pollutants found in the Great Lakes, including PCBs, toxaphene, DDE (Evans et al. 1991), PAHs (Eadie et al. 1982). The abundance of the population is inversely correlated with contaminant concentrations in some areas (Nalepa and Thomas 1976, Kraft 1979). The existence of historical data for abundance in all of the Great Lakes makes comparisons with previous population densities and ecosystem carrying capacities possible.

Index Period: Sampling should take place in mid-summer when abundance is generally greatest.

Measurements: The number of *D. hoyi* per meter is measured. A variety of methods for collecting sediment and the associated organisms are used. *D. hoyi* is relatively easily distinguished from other amphipods in the Great Lakes. Densities of up to 11,00 individuals/m^2 have been recorded (Nalepa and Thomas 1976, Evans et al. 1990). Minimum *D. hoyi* population density standards must be set up for each of the Great Lakes.

Variability: There is little seasonal variability in the abundance of *D. hoyi* in deep water; some variability may occur in shallow areas. Water depth and sediment type appear to influence *D. hoyi* abundance. Depths of 40-65 m generally have the greatest densities (from 470 individuals/m^2), and in deeper water, the species is most common in sediments with a mean grain size of less than 0.5 mm (Nalepa and Thomas 1976, Kraft 1979, Balcer et al. 1984). Sampling should be done at previously established stations when possible, and methods of sediment and organism collection should be standardized.

Primary Problems: The relationship between *D. hoyi* abundance and the condition of the whole benthic community needs to be defined. Additional research is required to set standards for the "healthy" abundance of *D. hoyi* at different sites in the Great Lakes.

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EMAP - Great Lakes Indicator Fact Sheet

Indicator: Fish pathology

Category: Response indicator

Resource class: Offshore, nearshore, and harbor/embayment zones

Application: When fish are exposed to contaminants, the effects observed often include morphological change. Assessments of the morphology of fish collected from different habitats within the lake could be used to indicate the proportion of the lake which is adversely affected by contaminants. Many of the observable effects occur only after a dose threshold is achieved, however, beyond the threshold, all or nearly all exposed organisms demonstrate the effect. Monitoring for structural pathology of this type can be very cost effective because small sample sizes can be used as indicators of adverse contaminant effects on lake ecosystems. Other types of structural pathology seem to be stochastic processes with an associated low probability of occurrence within the population, e.g., cancer. Detection of these processes requires large sample sizes.

Index Period: The sampling period can be variable, depending on the species selected. If reproductive status is important, the sample should be collected both before and after spawning to allow evaluation of the gonad during this critical event. Other considerations should include the temporal migration patterns of the fish in the context of the overall assessment strategy, i.e., the relative sizes of the fish home range, the sample site, and the area being assessed.

Measurements: Depending on the specific morphological indicators chosen, different measurement techniques should be applied. For the threshold-type morphological responses, fish of the appropriate segment of the year-class structure of the population should be collected. Relatively few specimens are required (between 10 and 20 fish per site). These specimens should be thoroughly examined, externally and internally, for gross lesions and anomalies. Following this examination, samples of the various tissues should be sampled and examined in the lab for histopathology.

Non-threshold, stochastic lesion responses require large sample sizes from each collection site. Because of this, detailed morphological analyses are very costly. Less costly but less robust measurements of these types of lesions can be accomplished with gross examinations. If both threshold and non-threshold lesions are selected for indicators, then a tiered measurement/sampling strategy is recommended. The first tier would be performed during routine sampling of fish for other purposes such as population estimates. This tier would consist of gross internal and external examination of the appropriate year-class specimens for lesions and anomalies. Tier two would consist of systematic subsampling of fish from the gross examination (for example, every 20th specimen) to be examined for microscopic lesions within selected tissues such as the liver.

Variability: There is little field data to analyze for variance. Given that exposures in the field are consistent, the variance in the response would be expected to be quite low as evidenced by lab investigations. The simple threshold toxicant induced pathology measurements allow repeated measures at several sites for determination of variance.

Primary problems: Little lab or field data exist to describe the variance of the low frequency non-threshold pathological lesions. Even with large sample sizes, the ability to reliably detect the presence of cancer within the population is difficult. Variance determinations would be even more difficult to estimate.

References:

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EMAP - Great Lakes Indicator Fact Sheet

Indicator: Diatom assemblages in lake sediment cores and sediment traps

Category: Response indicator

Resource class: Offshore and nearshore zones

Application: The Bacillariophyceae (diatoms) are an important component of the plankton community and of littoral substrata. Diatom taxa and assemblages have been used as indicators of environmental conditions, and have been used to reconstruct past lake conditions (Lowe 1974, Kilham and Hecky 1984). They have also been used as indicators of anthropogenic influence in the Great Lakes (Stoermer et al. 1985a, 1985b). Diatom taxa are known to be resistant or susceptible to toxicity from heavy metals (Elner and Happy-Wood 1980, Stoermer et al. 1985c, Kingston and Birks 1990), and to eutrophication (David 1964, Harris and Vollenweider 1982, Agbeti and Dickman 1989), temperature (Stoemer and Ladewski 1976), and land use (Tuchman et al. 1984). Historical diatom communities have been investigated in the Great Lakes (Duthie and Sreenivasa 1971, Frederick 1981, Kingston et al. 1978, Stoermer et al. 1985c), and provide evidence for the usefulness of sub-fossil diatom remains for providing historical information. Use of diatom assemblages in contemporary water column and sediment trap samples will also provide information on the current status of the lakes (Stoermer and Kreis 1980).

Index Period: The timing of collection of sediment cores for historical analysis is not crucial. Sediment trap sampling also provides some flexibility in the time of collection. Since sediment traps collect samples over relatively long periods, they integrate the diatom community over time. Deployment and retrieval of sediment traps could be accomplished in one (summer) or two (spring and fall) trips/year, depending on the trap's susceptibility to damage by ice.

Measurements: Sediment cores for historical data would be taken in depositional areas in both offshore and nearshore waters. Cores would be sectioned and the sections dated using radioisotope and/or paleotonlogical methods. Diatom remains in the sections would be analyzed by a taxonomist. The resulting taxa counts would be analyzed using multivariate techniques which might include, but are not limited to: similarity indices, canonical correspondence analysis, and clustering.

Sediment traps would be deployed in offshore and nearshore locations at hypolimnetic or near-bottom depths. These traps would remain in place for a minimum of six months to collect an integrated sample of the diatom community at each location. Sediment traps would be retrieved and the samples preserved for taxonomic analysis. Data resulting from taxonomic analysis would be treated similarly to that from derived from cores.

Variability: Because both sediment cores and sediment traps collect diatom remains over relatively long periods of time, as compared with a grab sample, the temporal component of variability is eliminated. Spatial variability of diatom remains in sediment cores and trap samples is expected to be small in the offshore areas of the Great Lakes. The spatial variability in nearshore core and trap samples is largely unknown. However, these samples will reflect local influences (e.g., tributary loadings) and will be inherently more variable.

Primary Problems: Potentially, problems exist for this indicator in several areas. It has not been determined whether enough highly trained taxonomists are available to analyze the large number of samples which will be initially generated. Secondly, a quantitative index and/or a baseline "pristine" diatom community must be established to make reporting of data straightforward. The question of reporting of levels of individual indicator species must also be resolved.

References:

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EMAP - Great Lakes Indicator Fact Sheet

Indicator: Chlorophyll-a composition in water

Category: Response indicator

Resource class: Offshore, nearshore, and harbor/embayment zones

Application: This indicator assesses the trophic status endpoint. Chlorophyll-a has been used as a measure of phytoplankton biomass and as an indicator of the productivity of aquatic systems. The amount of chlorophyll in a water body corresponds most closely to the nutrient input to the lake (Vollenweider 1968, Smith 1982). Chlorophyll-a is the primary photosynthetic pigment of algae and provides an estimate of the total phytoplankton community. Pigment concentration does not respond rapidly to stressors (Schindler 1987) other than nutrient input. It has been assumed to be an indicator of food web changes (Carpenter and Kitchell 1984), but this may not be the case for the Great Lakes (Lehman 1988). Chlorophyll-a as an indicator would best be interpreted by including measurement of other water chemistry variables in the monitoring design.

Index Period: The index period will be late July through August. This is a period of (generally) low chlorophyll in the Great Lakes. The main requisite is that chlorophyll be sampled during the same time period each year.

Measurements: Measurements would be made using an *in situ* fluorometer. The instrument of choice is a Sea-Tech, Inc. fluorometer, which is interfaced to a Sea Bird Electronics, Inc. CTD probe. For consistency, surface water chlorophyll-a would be measured. Although this sampling scheme would potentially miss any sub-thermocline chlorophyll-a peak (Brooks and Torke 1977), it would greatly reduce variability among samples. The *in situ* fluorometer would be checked against filtered and acetone extracted chlorophyll-a measurements.

Variability: Spatial variability in the offshore areas of the Great Lakes will be relatively low, with a coefficient of variation in the 10% - 30% range. The variability in the nearshore area will be higher, perhaps up to 100% in any lake, and several times that among lakes.

Primary Problems: The primary problem with the use of chlorophyll-a as a response indicator is that it is unresponsive to many stressors. While it is a good indicator of eutrophication, there is some uncertainty as to its response to food web changes. As there are constant food web manipulations occurring in the Great Lakes, through stocking of salmonids and through the introductions of exotic species (e.g., *Dreissena polymorpha* and *Bythotrephes cederstroemi*) this indicator requires information on water chemistry and biology for interpretation.

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EMAP - Great Lakes Indicator Fact Sheet

Indicator: Trophic status index

Category: Response indicator

Resource class: Offshore, nearshore, and harbor/embayment zones

Application: These indicators come under the general class of TSIs (trophic state indices) as described in the EMAP-Surface Waters Fact Sheets. One in particular, called the CTI (Composite Trophic Index, Gregor and Rast 1979), has been developed for Great Lakes nearshore zones. For the upper lakes, the index is calculated as:

$$CTI = \frac{\left(\frac{14.04}{SD} = 0.556\right) + 1.67\ CHLa + 0.31\ TP}{3}$$

except for highly turbid regions (harbors) where the index is calculated as:

$$CTI = \frac{\left(\frac{7.91}{SD} - 0.409\right) + 1.67\ CHLa + 0.31\ TP}{3}$$

where SD is the secchi depth in meters
CHLa is the chlorophyll-a concentration in µg/l
and TP is the total phosphorus concentration in µg/l

The attached table indicates the trophic state corresponding to the value of the CTI.

Trophic State (Water Quality)	CTI
Eutrophic (poor)	>11.0
Eutrophic/Mesotrophic	9.0 - 11.0
Mesotrophic (fair)	4.6 - 8.9
Oligotrophic/mesotrophic	3.1 - 4.5
Oligotrophic (good)	>3.1

Index Period: Summer (July)

Measurements: The CTI can be calculated from basic water chemistry measurements that would normally be part of any core sampling effort. These data are available on all Great Lakes historically going back to the early 70's.

Variability: The expected variability of the CTI is <10% from the mean value, but more variability is expected for high values of CHLa and TP. The variability also depends on the coefficient of variations of the individual measurements.

Primary Problems: The CTI was developed for average or steady-state nearshore conditions and therefore, the index period may not always occur at the same time each year. Also, although data from all five Great Lakes were used to develop the CTI, Lake Michigan had the least data available, and therefore, would require further testing to ensure the reasonableness of the index values.

References:

Gregor, D.J. and W. Rast. 1979. Trophic characterization of the U.S. and Canadian nearshore zones of the Great Lakes. Report to Pollution from Land Use Activities Reference Group, International Joint Commission, Windsor, Ontario:38 pp.

EMAP - Great Lakes Indicator Fact Sheet

Indicator: Sediment toxicity to *Hyallela azteca*

Category: Exposure indicator

Resource class: Nearshore and harbor/embayment zones

Application: The acute toxicity of Great Lakes sediments to the talitrid amphipod, *Hyalella azteca*, has been proposed as an indicator of the toxicity of sediments to the broader array of Great Lakes benthic macroinvertebrates. This species is an important food organism for many Great Lakes fish species and is a representative of one of the dominant groups (Amphipoda) of Great Lakes benthic macro-invertebrate fauna. *Hyalella azteca* is a clean water, benthic/epibenthic invertebrate which is found primarily in the nearshore areas of the Great Lakes.

Index Period: not applicable

Measurements: Sediment samples for toxicity testing can be collected with a variety of techniques depending on the exact purposes of the study. Core samples may be required to determine the vertical extent of sediment contamination or to quantify the volume of toxic sediments at a given location. Grab sampling may be sufficient if the sole purpose of the study is to determine the spatial distribution of toxic surficial sediments or to compare the toxicity of surficial sediments between sites. If there is no statistically significant difference in mortality between the field-collected and control or reference sediments, the field-collected sediments are classified as not acutely toxic. If there is statistically greater toxicity in the field-collected sediments, relative to controls or reference sediments, the field-collected sediments are classified as acutely toxic.

Variability: The sources of variability for this indicator can be separated into sampling variability and measurement variability. The representativeness of the sediment samples for testing and the health of the test species are the primary concerns. Test methods, conditions, and the source of test organisms should be standardized to eliminate these factors as sources of variability.

Primary Problems: (1) How well do laboratory assays predict the toxicity of in-place sediments? (2) How representative of the total benthic macroinvertebrate fauna of the Great Lakes are the sensitivities of *H. azteca* to contaminants in sediments? (3) How many samples are necessary to adequately characterize the toxicity of sediments in a given area of the Great Lakes and how frequently must samples be collected and tested to adequately address the potential seasonal changes in sediment toxicity.[2]

EMAP - Great Lakes Indicator Fact Sheet

Indicator: Contaminant concentrations in sediments from cores and traps

Category: Exposure indicator

Resource class: Offshore, nearshore, and harbor/embayment zones

Application: Many contaminants in the Great Lakes associate with particulate matter and eventually are delivered to the sediments where they are subsequently buried. Sediment concentrations and accumulation rates provide a sensitive measure of the presence of these chemicals, provide a spatial distribution of the contamination, and provide an historical record back in time of previous contaminant inputs to sediments.

Index Period: Anytime during the stratified period, when resuspension is limited.

Measurements: This approach is most effective for hydrophobic contaminants and metals, which preferentially associate with sedimenting material. A subset of possible chemicals should be considered, to possibly include the IJC Critical Pollutant list. It is strongly recommended that initially three cores per lake are sampled to obtain a detailed historical record of occurrence and input, as well as obtain numerous surface samples for spatial coverage. The detailed cores should be dated by Pb-210 and Cs-137, and normalized for focusing. This would not need to be repeated. Due to the slow sedimentation rates in the Great Lakes, yearly surficial samples would not be used or cost-effective, as little or no change may be detected. For yearly trends in accumulation and concentrations, sediment traps should be deployed at master sites and time-integrated samples collected and analyzed. This will provide a measure of shorter-term changes. The NOAA lab in Ann Arbor has an active sediment trap program in several of the Great Lakes. Supporting measurements such as dry weight, porosity, organic carbon, and particle size distribution also need to be made.

Variability: There will be a certain analytical error associated with each chemical determination. In addition, there is considerable spatial heterogeneity in bottom sediments. Some variability can be reduced, such as normalizing the organic contaminant concentrations to sediment organic carbon, and adjusting for sedimentation rate.

Primary Problems: Depending on the number of analytes, the analyses are expensive. Regarding sediment traps, material needs to be collected or isolated frequently to limit degradation by natural processes or grazing losses. Preserved material would likely need to be composited to have enough material to analyze.

Indicator: Contaminant residue in fish

Category: Exposure indicator

Resource class: Offshore, nearshore, and harbor/embayment zones

Application: Fish can be used as bioindicators of the presence of persistent chemicals that accumulate in organism lipids. Many of the chemicals of concern in the Great Lakes persist in the environment because they are resistant to biological and chemical degradation processes. Often these chemicals have low water solubilities and high octanol-water partition coefficients, resulting in a high bioaccumulation potential. These same properties tend to give these chemicals toxic properties which make consumption of contaminated fish a public health concern. Chemicals of concern in the Great Lakes with such properties include PCBs, PCDDs, PCDFs, and chlorinated pesticides (DDT and products, mirex, toxaphene, chlordane, dieldrin, nonachlor, heptachlor, heptachlor epoxide). Methyl mercury is also of concern in fish; it accumulates in muscle tissue rather than lipids. Concentrations of these chemicals in fish can be used to indicate the presence of contaminants in water at levels that may be harmful to the environment, but at levels that cannot be easily measured directly in water. They also can be used to directly indicate whether fish are safe for consumption, as indicated by health advisories and FDA action levels. Fish contaminant concentrations are used to provide an early warning indication of exposure for animals higher in the food chain, such as fish-eating birds and mammals.

Index Period: The best collection period is late summer to early fall (August-September) prior to spawning, when lipid stores and contaminants are at their peak in top predators.

Measurements: Whole-body contaminant burdens should be measured for PCBs, PCDDs, PCDFs, and chlorinated pesticides. Top predators should be used as indicators, such as lake trout and walleye. Young-of-the-year fish with narrow geographical range can be used to monitor local trends in contaminants; choice of species would be site-specific. Lipid measurements should also be made, as yearly variations in contaminant concentrations due to lipid differences need to be taken into account.

Variability: Precision and accuracy in data would depend on collection variability (spatial and temporal) and on the variability associated with the analytical methodology used for a given chemical. Contaminant concentrations are also a function of age and sex, and this variability should be limited as much as possible in sample collection design. Some of the inherent variability in sampling can be reduced by normalizing concentrations to lipid content.

Primary Problems: These analyses are expensive. Care should be taken to include emerging problem chemicals in future monitoring.

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Indicator: N/P/Si ratios

Category: Exposure indicator

Resource class: Offshore and nearshore zones

Application: The ratios of total nitrogen (TN) to total phosphorus (TP), and total reactive silicon (Si) to total phosphorus (TP) have been proposed as indicators of conditions that favor blue-green algal abundance (at the expense of more desirable algal groups such as diatoms). The ratio TN:TP is indicative of favorable conditions for blue-green dominance when it is less than 29:1 (weight basis). The ratio Si:P is indicative of unfavorable conditions for diatoms when it is less than 93:1 (molar basis). Blue-green algae are the least desirable algal group not only because of their tendency to form mats and scum on water surfaces and to cause taste and odor problems in potable water supplies, but also because they are not preyed upon by zooplankton. If either of these ratios is below the threshold value, eutrophic conditions are extremely likely to be present.

Index Period: After the spring diatom bloom (May) or the fall diatom bloom (October).

Measurements: These ratios may be calculated from basic water chemistry measurements that would normally be part of any core sampling effort. There is sufficient data, especially for TN:TP, to establish an historical baseline and to test this indicator.

Variability: The variability of this indicator depends on the variability of the measurements that are used in the calculation. Usually the coefficient of variation (C.V.) for individual water chemistry measurements in open waters will be less than 10%. In nearshore waters, this C.V. will be higher, and in harbors and small embayments, it may be prohibitive.

Primary Problems: (1) Some lakes or areas of lakes may have other limiting factors besides phosphorus and nitrogen that inhibit blue-greens; (2) If neither phosphorus nor nitrogen is limiting in a lake, blue-greens may dominate at TN:TP ratios > 29.

References:

Smith, V.H. 1983. Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton. Science 221:669-671.

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Indicator: Water column toxicity to *Ceriodaphnia dubia/affinis*

Category: Exposure indicator

Resource class: Offshore, nearshore, and harbor/embayment zones

Application: Water column toxicity tests are designed to indicate the integrated exposure of organisms residing in ambient waters to toxic substances and suitability of the water column habitat for aquatic life in tributaries, nearshore zones, and offshore waters. Acute and chronic toxicity tests are conducted to reflect potential short-term and long-term impacts, respectively.

Water column toxicity is one indicator of water quality and is emphasized in the Water Quality Act and Great Lakes Water Quality Agreement. Legislation provides the basis for a nontoxic environment, striving toward zero discharge, protection of aquatic life, and risk reduction. Results of the water column toxicity tests indicate the potential success or impairment of resident populations regarding habitat condition. Similarly, these results can be used to assess the success of nonpoint and point source control strategies on a regional basis. Selection of one or more water column toxicity tests will be necessary to assess toxicity trends in ambient waters, exposure potential, habitat condition, and control mechanisms.

The *Ceriodaphnia dubia/affinis* toxicity tests provide a surrogate for cladoceran populations and the zooplankton community in the Great Lakes. Even though *Ceriodaphnia* does not occur in substantial numbers in the Great Lakes basin, it appears to be indicative of zooplankton community exposure. The zooplankton community is the link between primary producers and higher trophic levels, i.e., zooplanktivorous forage and immature predatory fishes. Zooplankton survival and reproduction is critical to fish stock maintenance and production. The endpoints for the *Ceriodaphnia* toxicity tests are lethality in the acute test and reproductive impairment in the chronic test.

Index Period: Acute and chronic effects can be measured during the late summer or early autumn, when contaminant concentrations are likely to be at maxima during the low-flow period. This period also approximates the period of young-of-the-year recruitment for many fish species when zooplankton abundance is critical for survival.

Measurements: Standard methods for the *Ceriodaphnia* toxicity tests are available (ASTM 1988; Weber et al. 1989). The *Ceriodaphnia* tests have been applied to various environmental samples in the Great Lakes (Lien et al. 1986, McNaught and Mount 1986, White et al. 1989, Ankley et al. 1990) and applied and evaluated nationally (Cowgill et al. 1984; 1985, Mount and Norberg 1984, Hamilton 1986, DeGraeve and Cooney 1987, Takahashi et al. 1987, Winner 1988).

Whole water samples are collected using a Niskin® bottle and transported to the testing laboratory within 24 to 48 h. *Ceriodaphnia* neonates (<24 h in age) are initially used in the acute and chronic toxicity tests. Ten replicate test vessels in triplicate can be used in the assays (30 test vessels total). Acute toxicity can be determined in 48- or 96-h tests. Chronic toxicity can be determined in the 7-day test. Controls (10 test vessels) are conducted with every test series; 80% or greater survival and an average of 15 or more young surviving per female in the controls and controls with at least 60% of surviving females, producing a third brood is acceptable. Positive controls will also be conducted. Aeration, daily static renewal, and feeding are required during the chronic test period. Daily monitoring of physical and chemical factors is required. Lethal concentrations (LC10:50) and effective concentrations (EC10:50) for acute and chronic tests are possible using a dilutional series, however, may not be necessary for the purposes of EMAP.

Lethality is expressed as a percentage with a standard deviation for acute test periods. Reproduction is expressed as the number of neonates, broods, and percentages with standard deviations. Results of both tests must be examined relative to controls. Proposed interpretation of data is that results with greater than 10% mortality or reduction in neonate production is considered an effect. Less than 10% is considered approximating a NOEL or within the potential variability of the control or mean of all controls for a year. Ten to 30% impact is considered an effect, 30-50% a moderate effect, 50-75% a great effect, and 75-100% a severe effect. Data treatment will result in indicating the percent of the resource and habitat region which fall into the above toxic effect categories. Although some historical data are available, the approach will primarily be comparisons to the controls.

Variability: It is expected that spatial variation in response within and among the Great Lakes (both the lakes and habitat types) and temporal variation will far exceed the test variability.

Primary Problems: Specific delineation of test design for the purposes of EMAP and index of period selection.

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Indicator: Water column and optical characteristics

Category: Habitat indicator

Resource class: Offshore, nearshore, and harbor/embayment zones

Application: This indicator provides exposure information for chemical and physical stressors of aquatic biota. By using different subsets of the variables, as well as examining values for individual variables, several potential stressors could be evaluated. For example, a subgroup of the variables measured would be used to determine the state of eutrophication. Particularly, N, P, chlorophyll-a, and dissolved oxygen measurements would provide an indicator of the state of eutrophication (Dillon and Rigler 1974, Smith 1982, Vollenweider 1968). Dissolved oxygen measurements would also measure a stressor of fish and other aquatic biota (Makarewicz and Bertram 1991). In nearshore areas, conductivity, conservative variables (Na, Cl, SO_4) and measures of particulates could be used to investigate water masses and tributary inputs potentially associated with nutrient and toxic loadings.

Index Period: The index period would coincide with biological sampling in late July and August. This period coincides with stable thermal stratification, and in the Great Lakes, as stable a biological period as any except winter.

Measurements: Variables that would be measured are: Total P, Total N, NO_2-NO_3, Si, Na, Mg, Ca, SO_4, Cl, Dissolved oxygen, pH, Secchi depth, conductivity, transmissivity, temperature, *in situ* chlorophyll, TSS, DOC, and POC. A subset of these variables (conductivity, temperature, pH, DO, transmissivity, and chlorophyll) would be measured with a Sea Bird Electronics, Inc. CTD cast. Other variables would be measured with discrete water samples taken in mid-epilimnion, metalimnion, and hypolimnion.

Variability: The magnitude of spatial variability is a function of each variable. In the open waters of the Great Lakes, variability will be considerably less than in nearshore or harbors and embayments. As a rough estimate, one could expect a coefficient of variation (cv) of between 10 and 30% for offshore areas and as much as 100% for nearshore areas. Between lake variability will be higher.

Primary Problems: The primary problem involved in measuring these variables is the problem of sampling once per year. There will be some additional variability incorporated in the data because of climatic conditions varying greatly from the average (e.g., a particularly cold or cloudy summer) which may have the effect of changing the rates of ecosystem processes and community changes. This is a problem for interannual comparisons as well as for interpretation of exposure in any year. A possible solution to this problem is implementation of low cost monitoring, on a daily basis, of easily measured physical and chemical parameters as is done at municipal water intake plants.

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