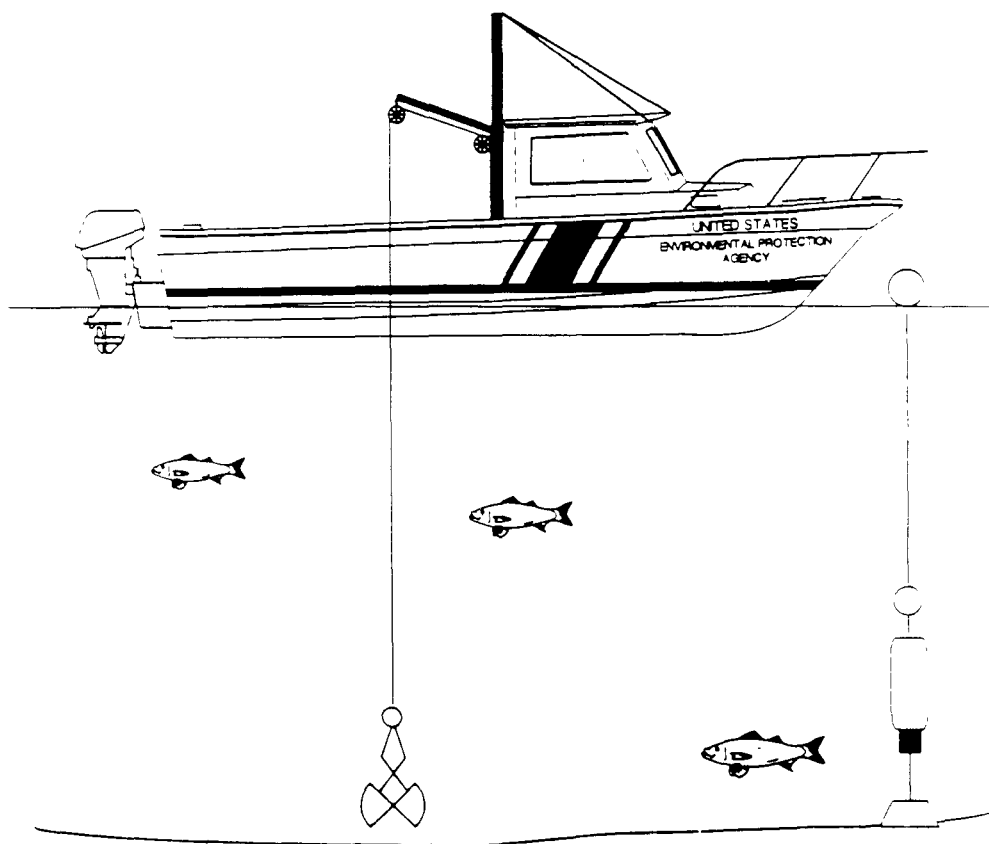


EPA

Near Coastal Program Plan for 1990: Estuaries



EPA

Environmental Monitoring and
Assessment Program

NEAR COASTAL PROGRAM PLAN FOR 1990: ESTUARIES

Edited by

A. F. Holland
Versar, Inc.
ESM Operations
Columbia, Maryland 21045

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Project Officer

John Paul
Environmental Research Laboratory
U.S. Environmental Protection Agency
Narragansett, Rhode Island 02882

ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
NARRAGANSETT, RHODE ISLAND 02882



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EXECUTIVE SUMMARY

Environmental regulatory programs in the United States have been estimated to cost more than \$70 billion annually. Most of these programs address specific local pollution problems. For the specific purposes for which they were designed, these programs appear to be effective; however, the means to assess the effectiveness of these programs for protecting the environment at national and regional scales and over the long-term do not exist. The U.S. Environmental Protection Agency (EPA) considers it critical to establish monitoring and assessment programs to confirm the effectiveness of pollution control strategies and to corroborate the science upon which they are based at regional and national scales.

The Environmental Monitoring and Assessment Program (EMAP) is a nationwide initiative being implemented by EPA's Office of Research and Development (ORD). It was developed in response to the demand for information on the condition of the nation's ecological resources. Although EMAP is funded by ORD, it is designed to be an integrated federal program. Throughout the planning of EMAP, ORD is working with other federal agencies including the National Oceanic and Atmospheric Administration (NOAA), the U.S. Fish and Wildlife Service (FWS), the U.S. Forest Service, U.S. Fisheries Service (USFS), and the U.S. Geological Survey (USGS), as well as other offices within EPA (e.g., the Office of Marine and Estuarine Protection (OMEP)). These other agencies and offices also will participate in the collection and use of EMAP data.

The goal of EMAP is to assess and document the status and trends in the condition of the nation's forests, wetlands, estuaries, coastal waters, lakes, rivers, and streams, Great Lakes, agricultural lands, and arid lands on an integrated and continuing basis. It is designed to answer the following questions on regional and national scales over the time period of decades:

- What is the status, extent, and geographical distribution of our ecological resources?
- What proportion of these resources is declining or improving? Where? At what rate?
- What are the factors likely to be contributing to declining condition?

- Are pollution control, reduction, mitigation, and prevention programs achieving overall improvement in ecological conditions?

Assessment of status and trends in the condition of the nation's ecological resources requires data collected in a standardized manner, over large geographic scales, and for long periods of time. Such assessments cannot be accomplished by aggregating data from the many individual, short-term monitoring programs that have been conducted in the past or are being conducted currently. Differences in the parameters measured, the collection methods used, timing of sample collection, and program objectives severely limit the value of historical and existing monitoring data for conducting regional and national assessments. An integrated, federal, multi-ecosystem monitoring and assessment program offers the advantages of earlier detection of problems and improved identification of their extent, magnitude, and likely causes. Such a program also enables more cost effective regulatory and remedial actions to ensure protection and restoration of the nation's ecological resources.

This document describes the plans for implementing EMAP in near coastal ecosystems, including estuaries, estuarine and coastal wetlands, coastal waters, and the Great Lakes. EMAP does not have the financial resources to implement regional monitoring programs in all near coastal ecosystems simultaneously. Therefore, a phased implementation is proposed, beginning with a demonstration project in the estuaries of the mid-Atlantic region (i.e., the Virginian Province) in 1990.

Information obtained from the 1990 EMAP Near Coastal (EMAP-NC) Demonstration Project will be used to:

- Demonstrate the value of integrated, multiagency monitoring programs for planning, setting priorities, and evaluating the effectiveness of pollution control actions,
- Define a sampling approach and network design for quantifying the extent and magnitude of pollution problems in estuaries and addressing objectives of multiple offices within EPA and NOAA,
- Develop standardized monitoring methods for estuaries that can be transferred to other programs and agencies for sampling near coastal environments,
- Identify and resolve logistical issues associated with implementing a multiagency national status and trends ecological monitoring program.

EMAP-NC does not have the resources to monitor all parameters of concern. Rather, EMAP-NC will identify, evaluate, and sample indicators of environmental quality that collectively characterize the overall condition of estuarine ecosystems and are applicable on regional and national scales.

The sampling design used by EMAP-NC for the 1990 Demonstration Project combines the strengths of systematic sampling designs with an understanding of estuarine systems to collect data that provide unbiased estimates of the status of estuarine resources with a known level of confidence. Information from individual sample sites will be pooled both within and between years to produce regional estimates for three classes of estuaries: (1) large estuaries (e.g., Chesapeake Bay, Long Island Sound); (2) large tidal rivers (e.g., Potomac, Delaware, Hudson Rivers); and (3) small, discretely, distributed estuaries, bays, inlets, tidal creeks, and rivers (e.g., Barnegat Bay, Indian River Bay, Lynnhaven Bay, Elizabeth River). Modifications of this design that are adequate for representing the status and trends in the extent and magnitude of ecological will be used when the program is implemented nationally.

EMAP-NC is, therefore, a regional monitoring program and is not specifically designed to collect monitoring data representing a particular estuary. Rather, it is designed to collect data that can be used to make statements about the population of estuaries in a region and the classes of estuaries sampled. The sample design allows assessments of status and trends for selected large estuaries and large tidal rivers (e.g., Chesapeake Bay, Long Island Sound, Delaware Bay) or other subpopulations of interest (e.g., EPA Regions). Subpopulation assessments will have a higher level of uncertainty than regional or class level assessments.

EMAP-NC, in close coordination with NOAA's National Status and Trends Program, will provide annual data summaries and periodic interpretive reports on the ecological condition of the Nation's estuaries. This information will be used to evaluate the effectiveness of existing pollution control programs and policies, to identify those types of estuarine ecosystems most in need of research, assessment, and remediation, and to identify emerging pollution problems.

TABLE OF CONTENTS

<u>Chapter</u>	<u>Page</u>
ACKNOWLEDGEMENTS	iii
EXECUTIVE SUMMARY	v
1.0 INTRODUCTION	1-1
1.1 Objectives	1-2
1.2 Perceived Estuarine and Coastal Ecological Condition	1-3
1.3 Identification of the Problem	1-6
1.4 Proposed Solution to the Problem	1-8
1.5 Coordination	1-10
1.6 Organization of the Remainder of This Plan . . .	1-11
2.0 APPROACH AND RATIONALE	2-1
2.1 Scope of the EMAP Near Coastal Component .	2-2
2.2 Sampling Design	2-4
2.3 Indicators of Environmental Quality	2-8
2.4 Analysis and Integration	2-10
2.5 Data Management	2-13
2.6 Quality Assurance	2-15

TABLE OF CONTENTS (Continued)

<u>Chapter</u>	<u>Page</u>
2.7 EMAP Reporting	2-17
2.8 1990 Demonstration Project	2-17
3.0 SAMPLING DESIGN	3-1
3.1 Elements of the Sampling Design	3-1
3.2 General Sampling Approach	3-2
3.3 Definition of Boundaries	3-4
3.4 Regionalization	3-4
3.5 Classification	3-7
3.6 Sampling Design for the Demonstration Project	3-15
3.7 Overview of Sampling Activities	3-41
4.0 INDICATOR DEVELOPMENT AND EVALUATION . . .	4-1
4.1 The EMAP Indicator Strategy	4-1
4.2 Framework for Indicator Selection	4-2
4.3 Application of Indicator Selection Strategy to Estuarine Ecosystems	4-10
4.4 Estuarine Candidate Indicators	4-14
4.5 Future Indicators	4-43

TABLE OF CONTENTS (Continued)

<u>Chapter</u>		<u>Page</u>
5.0	ANALYSIS AND INTEGRATION	5-1
5.1	Need for Analysis and Integration	5-1
5.2	Types of Analyses	5-3
5.3	Measurement of Trends	5-23
5.4	EMAP-NC As a Client	5-28
5.5	Dissemination of Results	5-32
6.0	INFORMATION MANAGEMENT	6-1
6.1	Data Management	6-2
6.2	Project Management	6-10
6.3	Staffing of NCIMS	6-12
7.0	LOGISTICS PLAN	7-1
7.1	Sampling Activities	7-2
7.2	Field Crews	7-5
7.3	Equipment	7-6
7.4	Sampling Logistics	7-8
7.5	Sample Shipment and Processing	7-10
7.6	Project Management	7-14
7.7	Contingencies	7-16

TABLE OF CONTENTS (Continued)

<u>Chapter</u>		<u>Page</u>
8.0	QUALITY ASSURANCE.	8-1
8.1	Data Quality Objectives	8-2
8.2	Quality Control	8-7
8.3	Quality Assessment	8-10
8.4	Quality Assurance of Data Management Activities	8-14
8.5	Quality Assurance Reports to Management . . .	8-17
9.0	REFERENCES	9-1
 <u>Appendices</u>		
A	Environmental Monitoring and Assessment Program Overview	A-1
B	Memorandum of Understanding Between Environmental Protection Agency and National Oceanic and Atmospheric Administration	B-1
C	List of Participants at the EMAP-NC Indicator Workshop	C-1

LIST OF TABLES

<u>Table</u>	<u>Page</u>
2-1 List of EMAP-NC indicators by major category	2-12
3-1 Summary of the characteristics of estuarine classes	3-9
3-2 List of estuarine resources within the Virginian Province with surface areas greater than 2.6 km ²	3-11
3-3 Estuaries in the Virginian Province included in the large estuarine system class	3-16
3-4 Tidal rivers in the Virginian Province included in the large tidal rivers class	3-17
3-5 Estuaries and tidal rivers in the Virginian Province included in the small estuarine system class	3-18
3-6 1990 base sampling locations for the large estuarine systems class	3-24
3-7 1990 base sampling locations [Random (R) and Index (I)] for large tidal river class	3-28
3-8 1990 sample locations [Random (R) and Index (I)] for the small estuarine systems class	3-30
3-9 1990 Demonstration Project sampling sites for continuous dissolved oxygen monitoring	3-34
3-10 Locations of indicator testing and evaluation sites for 1990 Demonstration Project	3-37
3-11 Locations of supplemental sampling sites in the 1990 Demonstration Project to assess spatial variability due to scale in large estuarine systems and small sample size in small estuarine systems	3-42

LIST OF TABLES

<u>Table</u>	<u>Page</u>
3-12 Number of samples that will be taken in the 1990 Demonstration Project in the Virginian Province and the 1990-1993 cycle that could be used for subpopulation estimation	3-44
4-1 General indicator selection critiera	4-4
4-2 Major categories of candidate indicators developed from EMAP-NC conceptual model	4-15
4-3 Indicators selected for measurement in the 1990 Demonstration Project	4-16
4-4 Chemicals to be measured in sediments during the 1990 Virginian Province Demonstration Project	4-22
4-5 Target fish taxa and the expected percentage of sampling sites at which they will be collected in each salinity zone, as determined from a Monte Carlo simulation analysis of available fish trawl data for the Virginian Province	4-29
4-6 Chemicals to be measured by EMAP-NC in fish and bivalve tissue during the 1990 Virginian Province Demonstration Project	4-31
4-7 Synopsis of potential data sources for stressor indicators . . .	4-40
4-8 Major data sources for the National Coastal Pollution Discharge Inventory	4-42
5-1 Translation of broad policy questions into policy relevant and scientific components	5-4
5-2 Comparison of Annual Statistical Summaries and Inter- pretative Assessment Report	5-33

LIST OF TABLES

<u>Table</u>		<u>Page</u>
7-1	Sampling activities that will be accomplished at each station type during each of the three sampling periods	7-3
7-2	Example of the proposed sampling schedule for Team 1 for the first 10 days of Sampling Interval 2	7-11
8-1	Measurement Quality Objectives for EMAP-NC indicators and associated data	8-5
8-2	Quality assurance sample types, type of data generated, and measurement quality expressed for all measurement variables	8-11
8-3	Warning and control limits for quality control samples	8-15
8-4	Recommended detection limits for EMAP-NC chemical analyses	8-16

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1-1 Framework for Marine Environmental Monitoring Systems . .	1-9
2-1 EMAP-NC biogeographical provinces	2-5
2-2 Overview of the indicator strategy for EMAP-NC. The manner in which indicators are related to the major environmental problems and impacts is also shown	2-11
2-3 Example cumulative frequency distribution	2-14
2-4 Role of data quality objectives in obtaining a balance between available resources and the level of uncertainty . . .	2-16
3-1 Base sampling sites for all classes of estuaries in the 1990 EMAP-NC Demonstration Project in the Virginia Province . . .	3-26
3-2 Sites for which dissolved oxygen concentrations will be monitored continuously from June 19 through August 30 for the 1990 EMAP-NC Demonstration Project in the Virginian Province	3-33
3-3 Indicator testing and evaluation sites to be sampled during the 1990 EMAP-NC Demonstration Project in the Virginian Province	3-38
3-4 Schematic summarizing the indicator testing and evaluation strategy for the 1990 EMAP-NC Demonstration Project in the Virginian Province	3-39

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
3-5 Supplemental sampling sites for the 1990 EMAP-NC Demonstration Project in the Virginian Province	3-40
3-6 All sites to be sampled during the 1990 EMAP-NC Demonstration Project in the Virginian Province	3-45
4-1 Framework for indicator development	4-3
4-2 Primary evaluation criteria used by EMAP-NC in the tiered indicator selection strategy	4-8
4-3 Conceptual model for defining indicators of estuarine quality	4-12
4-4 Schematic of how the Hydrolab DataSonde 3 will be deployed for continuous dissolved oxygen monitoring	4-26
5-1 Example cumulative frequency distribution	5-6
5-2 Components of the Estuarine Condition Index	5-9
5-3 Hypothetical cumulative frequency distribution for the Estuarine Condition Index	5-13
5-4 Example matrix for assessing the relative contribution of the Ecological Condition Index and the Human Use Index to subnominal environmental conditions	5-14
5-5 Example matrix for assessing the relative contribution of the Benthic Index and Fish Index to subnominal ecological conditions	5-16

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
5-6 Example matrix for evaluating the contribution of two exposure indicators, dissolved oxygen concentration and sediment toxicity, to subnominal values of the Benthic Index . . .	5-18
5-7 Example matrix for assessing the relative contribution of sediment contaminants to subnominal sediment toxicity values	5-20
5-8 Example matrix for identifying the attributes of benthic communities that are most influenced by exposure to subnominal dissolved oxygen concentrations	5-21
5-9 Example graph that will be used to display trends data for indices and indicators	5-24
5-10 Example graph that will be used to summarize trends data for the multiyear status estimates produced by EMAP-NC; 90% confidence limits are shown	5-25
5-11 Example matrix that is the starting point for detailed evaluation of trends	5-27
6-1 Matrix summarizing data access for various user groups as a function of the degree of data processing and the level of quality assurance that has been completed	6-8
7-1 Areas to be sampled by each team during the 1990 Demonstration Project in the Virginian Province	7-9
7-2 Management structure for the 1990 Virginian Province	7-15
8-1 The three stages of developing data quality objectives	8-3
8-2 Example of a control chart	8-18

1.0 INTRODUCTION

This document presents the rationale, approach, objectives, and plan for establishing a monitoring program to periodically assess the status and trends in ecological condition of the nation's estuarine and coastal ecosystems. The proposed program is designed to assess changes in the ecological condition of estuarine and coastal waters over broad biogeographical regions (e.g., the Mid-Atlantic region, the Gulf of Mexico) and over long time periods (e.g., decades). It is one element of the Environmental Monitoring and Assessment Program (EMAP), a nationwide program being conducted by the U.S. Environmental Protection Agency's (EPA) Office of Research and Development (ORD) to conduct similar assessments for all the nation's ecological resources. Appendix A provides a conceptual overview of EMAP.

The goal of EMAP is to document the condition of the nation's forests, wetlands, estuarine and coastal waters, inland surface waters, Great Lakes, agricultural lands, and arid lands in an integrated manner, on a continuing basis. Although EMAP is designed and funded by ORD, other offices and regions within EPA (e.g., Office of Marine and Estuarine Protection, Region III) and other federal agencies (e.g., Office of Oceanography and Marine Assessments of the National Oceanic and Atmospheric Administration (NOAA), the U.S. Forest Service, and the U.S. Fish and Wildlife Service (FWS)) have contributed to its development and will participate in the collection and use of EMAP data. When fully implemented, EMAP will form a complex national monitoring network, with a large proportion of the data collection and analysis being accomplished by other federal, state, and local agencies. EMAP must develop interagency agreements with these other agencies and establish a constituency within EPA regional offices and states.

EMAP is designed to provide the information required to formulate environmental protection policies of the 1990s and beyond by providing answers to the following questions:

- What is the status, extent, and geographical distribution of the nation's important ecological resources?
- What proportion of these resources is declining or improving? Where, and at what rate?
- What are the factors that are likely to be contributing to declining condition?

- Are control and mitigation programs achieving overall improvement in ecological conditions?
- Which resources are at greatest risk to pollution impacts?

EMAP is not a compliance or enforcement monitoring program; nor is it a diagnostic monitoring program. Site-specific field studies, bioassays, and fate and effects modeling programs generally are used to support compliance determinations, enforcement actions, and diagnostic programs. EMAP also is not an ecological research program; rather, it is a program designed to assist in identifying, defining, and prioritizing the ecological questions that must be resolved to ensure protection and restoration of the nation's ecosystems. EMAP will work with academic, governmental, and private research organizations, and particularly with EPA research laboratories and grant programs, to address those questions.

The information generated by EMAP will be used by the following groups:

- Decision makers at all levels of government who set environmental policy,
- Resource managers and regulators who require an objective basis for allocation of resources and prioritization of actions, especially those directed toward protecting and enhancing ecological resources, and
- Those interested in evaluating the effectiveness of the nation's environmental policies for protecting and enhancing ecological resources (e.g., the EPA Administrator and Senior Management staff, Congress, and the public).

1.1 Objectives

The specific objectives of EMAP-Near Coastal (EMAP-NC) are as follows:

- Provide a quantitative assessment of the regional extent of coastal environmental problems by measuring pollution exposure and ecological condition,
- Measure changes in the regional extent of environmental problems for the nation's estuarine and coastal ecosystems,

- Identify and evaluate associations between the ecological condition of the nation's estuarine and coastal ecosystems and pollutant exposure, as well as other factors known to affect ecological condition (e.g., climatic conditions, land use patterns), and
- Assess the effectiveness of pollution control actions and environmental policies on a regional scale (i.e., large estuaries like Chesapeake Bay, major coastal regions like the mid-Atlantic and Gulf Coasts) and nationally.

As a first step in accomplishing the above objectives, a Demonstration Project will be implemented in the mid-Atlantic region in 1990. The major goal of this demonstration project is to illustrate the benefits of regional monitoring data collected in a standard way for assessing status and trends of ecological resources and, at the same time, to collect the information necessary to develop a technically sound and cost-effective program that can be implemented over the long term.

1.2 Perceived Estuarine and Coastal Ecological Condition

Estuarine and coastal ecosystems are among the most productive of ecological systems. Historically, more than 70 percent of commercial and recreational landings of fish and shellfish are taken from estuaries (U.S. Department of Commerce 1929-1988). Estuaries also provide critical feeding, spawning, and nursery habitats, as well as migratory routes, for many commercially and recreationally important fish, shellfish, birds, waterfowl, and mammals (Lippson et al. 1979; Olsen et al. 1980). Marshes and submersed aquatic vegetation (SAV) that occur along the shores of estuaries are particularly valuable components of coastal ecosystems (Daiber and Roman 1988; Daiber 1986; Kemp et al. 1984; Pomeroy and Wiegert 1981). These vegetated communities stabilize shorelines from erosion, reduce nonpoint source pollution loadings, improve water clarity, and provide habitat for migrating waterfowl, fish, and shellfish (Daiber and Roman 1988; Odum 1988; The Conservation Foundation 1988; Daiber 1982; Redfield 1972).

The public values estuarine and coastal ecosystems for recreational and aesthetic pleasure (e.g., boating, swimming, hunting, and fishing). Approximately \$7 billion in public funds are spent annually on outdoor marine and estuarine recreation in the 22 coastal states (NOAA 1988). Millions of tourists visit coastal beaches annually, and coastal property is among the nation's most valuable real estate. The estuarine and coastal environment also provides cooling waters for energy production, transportation routes for ships, and space for economic

development. Most of the nation's major ports are located in coastal environments, mainly estuaries.

Billions of dollars have been spent to reduce the pollutant loadings entering estuarine and coastal ecosystems, with mixed results. In general, coastal pollution abatement programs have been effective at reducing the impacts of conventional pollutants (i.e., excess nutrients and organic materials) on water quality and controlling unacceptable production and disposal practices for most toxic chemicals. Some systems that once exhibited severely low dissolved oxygen concentrations because of the discharge of excessive amounts of conventional pollutants, such as the lower salinity regions of Delaware Bay and the Potomac River, have partially recovered (Lippson et al. 1979; Albert 1982). In addition, massive releases of toxic chemicals that were associated with faulty manufacturing practices (e.g., release of Kepone into the James River and PCB and DDT into the Southern California Bight) no longer occur (Huggett and Bender 1980; Huggett 1989; Logan et al. 1989; Mearns et al. 1988). The release of a few persistent toxic pesticides, such as chlorinated hydrocarbons, also has been controlled effectively by limiting their sale and production (Logan et al. 1989; Mearns et al. 1988). Many other pollution problems, particularly the accumulation of persistent toxicants in sediments and biota and the loss of critical habitat (e.g., SAV and wetlands), have proved to be difficult to control and correct (NRC 1989).

The environmental movement of the 1960s and 1970s resulted in the passage of major environmental legislation to protect the quality of estuarine and coastal waters, including the Federal Water Pollution Control Act and the Marine Protection, Research, and Sanctuaries Act. The environmental quality goals established by these legislative acts and associated amendments, such as the Clean Water Act of 1987, provide the regulatory basis for protecting and enhancing estuarine and coastal ecological resources. These laws clearly reflect society's desire to preserve the ecological integrity and human uses of natural resources. EPA protects the environmental quality, including ecological integrity and societal uses of coastal ecosystems, by promulgation and enforcement of uniform federal regulations in support of environmental legislation. These regulations are designed to limit the type and quantity of pollutants entering estuarine and coastal waters.

In principle, environmental regulations and associated testing programs should control the release of all pollutants. In practice, however, incomplete scientific information about the ecological and human health consequences of many pollutants, limitations of pollution control technologies, and the cost of implementing some control strategies have resulted in control of only a fraction of the pollutants presently released into the environment (Levin and Kimball 1984). In addition, existing regulations focus on control of point source discharges, which constitute only one major source of pollutants. EPA and the coastal states have

only recently begun to develop and initiate programs to address diffuse and nonpoint source pollutants and to require protection of critical habitats (e.g., wetlands, SAV). A major shortcoming of current pollution control policies is that the cumulative or incremental effects of multiple pollutants from multiple sources (e.g., point and nonpoint source) are not considered when discharge limits are established.

In many coastal regions, water and sediment quality and the abundance of living resources are perceived to have declined over the past 10 to 15 years, despite the implementation of more strict control programs. Increasingly, reports appear in the popular press (Morganthau 1988; Toufexis 1988; Smart et al. 1987) and scientific journals describing the decline of estuarine and coastal environmental quality, as exemplified by the following:

- Increases in the frequency, duration, and size of water masses that do not contain sufficient oxygen to sustain living resources (USEPA 1984; Officer et al. 1984; Parker et al. 1986; Rabalais et al. 1985; Whitledge 1985);
- Accumulation of contaminants in sediment and in the tissues of fish and shellfish to levels that threaten humans and the vitality of fish and shellfish populations (OTA 1987; NRC 1989);
- Declines in the amount and quality of ecologically important habitats (e.g., wetlands and SAV) that are associated with high population levels of waterfowl, shorebirds, fish, and shellfish (Frayer et al. 1983; The Conservation Foundation 1988; Orth and Moore 1983);
- Increased evidence that many restoration and mitigation efforts have not replaced losses of critical habitats (Sanders 1989; The Conservation Foundation 1988);
- Increased incidence of pathological problems in fish and shellfish in systems that have high levels of chemical contamination (Sinderman 1979; O'Connor et al. 1987; Buhler and Williams 1988; Capuzzo et al. 1988);
- More favorable conditions for and increased frequency and persistence of algal blooms and associated decreases in water clarity (USEPA 1984; Pearl 1988);

- Increased incidence of closures of beaches, shellfishing grounds, and fisheries because of pathogenic and chemical contamination (Smart et al. 1987; Food and Drug Administration 1971, 1985; Hargis and Haven 1988; Broutman and Leonard 1988; Leonard et al. 1989); and
- Increased incidence of human health problems from consumption of contaminated fish and shellfish or swimming in contaminated waters (Fein et al. 1984; Jacobson et al. 1983, 1984; Malins 1989).

The above symptoms of the declining environmental quality of estuarine and coastal systems are specific to particular areas; nonetheless, they are characteristic of the kinds of problems facing all coasts from New England to Alaska.

1.3 Identification of the Problem

Most of the symptoms of declining ecological condition in estuarine and coastal ecosystems have a common denominator--humans. Our species has directly affected these ecosystems by adding excessive amounts of pollutants to the air and water and by modifying or destroying ecologically important and rare habitats such as wetlands, SAV, and forested areas along the shoreline. Most important, however, human activities adversely affect estuarine and coastal ecosystems by changing the character of the land in ways that increase the amount and types of pollutants that reach them. Often, changes to the land that adversely affect estuarine coastal ecological condition occur in parts of the watershed that are far removed from coastal areas. For example, agricultural practices in Pennsylvania can adversely influence sediment and pollutant loadings in Chesapeake Bay (USEPA 1984).

Changes in relative abundance of ecological resources, particularly declines in the abundance and catch of harvested fish and shellfish, are perceived, often incorrectly, to be entirely the result of pollution impacts. Pollution is not the only factor affecting the productivity and condition of estuarine and coastal ecosystems. Declines in fish and shellfish populations also are due to over-harvesting. As a result, many fisheries management agencies have imposed catch restrictions. Natural climatic variation has major effects on recruitment success and abundance of marine organisms, especially fish and shellfish, as well as on overall ecological condition and the water quality of many estuaries and coastal regions (Rose et al. 1986; Holland et al. 1987; Cushing 1982; Helz 1988; Jeffries and Terceiro 1985; Summers and Rose 1987; Crecco et al. 1986). For example, a large fraction of the variation in recruitment success of striped bass is associated with the timing and amount of freshwater inflow and annual temperature cycles (Polgar 1982; Polgar et al. 1985).

Congressional hearings on the National Environmental Monitoring Improvement Act in 1984 concluded that despite considerable annual expenditures on monitoring, federal agencies could assess neither the current status of the nation's ecological resources nor the overall progress toward legally mandated environmental goals. A major factor contributing to this problem is that regulatory and resource management agencies have recognized only recently the complexity of many estuarine and coastal pollution and resource management problems, particularly the high degree of connectivity between the extent, type, and condition of ecosystems in the watershed and the amount and type of pollutants released into coastal habitats.

In a recent review of marine and estuarine monitoring programs, the Marine Board of the National Research Council (NRC) concluded that the integrated monitoring and assessment information needed for protecting and restoring estuarine and coastal ecosystems was not available (NRC 1990a). As a result, it presently is not possible to accomplish the following:

- Define which pollution insults (or natural problems) represent the greatest threat to marine and estuarine resources,
- Evaluate whether insults (or natural problems) and their consequences vary regionally or are similar from region to region,
- Objectively evaluate the effectiveness of past management actions in protecting and maintaining environmental quality and natural resources, and
- Separate natural changes in ecological condition from anthropogenically induced impacts.

The need to establish ecological baselines will become acute as the complexity, scale, and societal importance of estuarine and coastal environmental issues increase (NRC 1989, 1990a). The long- and short-term success of coastal environmental protection and restoration programs is dependent upon the ability to define baseline conditions and to establish attainable environmental quality goals (NRC 1990a). Progress toward achievement of environmental quality goals must also be measured routinely, as a means of assessing the effectiveness of previous management actions. If particular control strategies are ineffective, alternative strategies may be required or the initial approach may need to be modified. In short, monitoring and assessment information covering a range of spatial (national, regional, system-specific) and temporal (long- and short-term) scales, including information on the status of ecosystems in the watershed, is vital to the protection and restoration of estuarine and coastal ecosystems (Wolfe et al. 1987; NRC 1990a).

An additional problem hindering effective environmental decision making is the timely synthesis and dissemination of monitoring data and the associated interpretive assessments. Historically, many of the important decisions for which monitoring data were collected were made before the actual data were obtained and analyzed and a final assessment report was prepared (NRC 1990a).

1.4 Proposed Solution to the Problem

Recognizing the need for better environmental surveillance, the EPA Science Advisory Board (SAB) recommended in 1988 that EPA develop and implement a program to assess the status and trends of the nation's ecological resources, and that it should have the capability to identify emerging environmental problems before they reach crisis proportions (SAB 1988). The SAB made this recommendation because EPA's regulatory mandates and multimedia responsibilities require complex quantitative assessments of pollutant impacts on ecosystems and their human uses. Data collected by the program the SAB envisioned would be used to evaluate the overall effectiveness of environmental control policies and regulations. The recommendation by the SAB is one of the major factors contributing to ORD's decision to initiate development of EMAP.

The National Research Council (NRC) Marine Board review of marine and estuarine monitoring systems (NRC 1990a) also recommended the creation of a national network of regional monitoring programs for estuarine and coastal environments. This review recommended that the program be multiagency in nature, including both NOAA and EPA, and that it be designed in a manner that would incorporate and contribute to monitoring and assessment efforts being developed for systems in EPA's National Estuary Program. The NRC review emphasized the importance of ensuring that the data produced by monitoring programs were synthesized and integrated in a timely manner, into information that could be used by the public and decision makers. The Marine Board review also recognized the need for "new" monitoring efforts to build upon the vast amount of existing monitoring information and to extend monitoring programs landward as a means of identifying factors contributing to coastal pollution problems.

The NRC review developed a conceptual framework that identified the major components of successful monitoring and assessment systems (Fig. 1-1). This framework applies to all spatial and temporal scales and types of monitoring. It is particularly applicable to status and trends monitoring programs and was used in the development of EMAP-NC to ensure concerns identified by the NRC review were addressed. Deficiencies in monitoring strategies usually result from failure

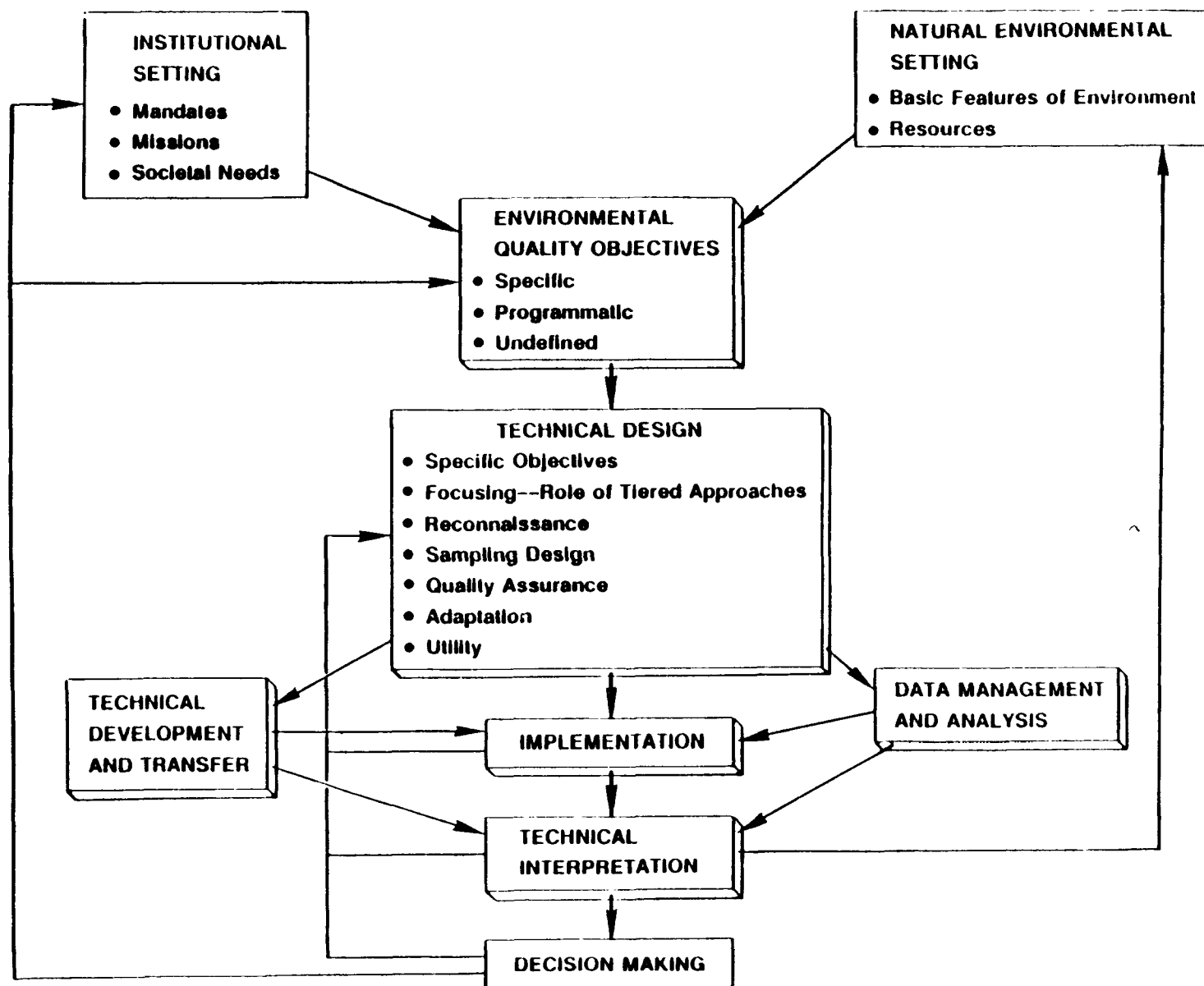


Figure 1-1. Framework for Marine Environmental Monitoring Systems (NRC 1990a)

to consider one or more elements of this framework or from considering them out of logical sequence or context (NRC 1990a).

1.5 Coordination

Meeting the objectives of EMAP requires close cooperation among many offices within EPA and with other federal, state, and local agencies involved in monitoring activities. Although EMAP is funded by the Office of Research and Development (ORD), other offices within EPA (e.g., the Office of Marine and Estuarine Protection) have participated actively in its development. EMAP-NC has coordinated with each of the National Estuary Programs in the mid-Atlantic region about activities planned in that region in 1990 and beyond. Coordination will occur with other National Estuary Programs and ongoing EPA programs (e.g., Gulf of Mexico Program) before monitoring activities are implemented in these regions.

Both NOAA and EPA have mandates to conduct a broad range of research and monitoring activities to assess the effects of pollution on coastal and estuarine environments. There are similarities and differences between existing NOAA and EPA programs; however, the combined results of both agencies' programs serve the national interest more than the results of individual programs. It is the intention of NOAA and the EPA to cooperate and coordinate, to the greatest extent possible, to integrate estuarine and coastal monitoring, research, and assessment activities and to ensure that data collected by EMAP and the NOAA National Status and Trends Program augment and complement each other to the maximum extent possible.

The framework for cooperating and coordinating monitoring and research activities between NOAA and EPA is a joint NOAA/EPA Committee for Coastal and Estuarine Environmental Quality Monitoring. This committee was created to ensure coordination and exchange of information between the two agencies on coastal monitoring, research, and assessment. The joint committee has held monthly meetings since October 1989. The purpose of these meetings has been to exchange planning information and to identify opportunities for joint complementary monitoring, research, and assessment activities. As a result of the activities of this committee, a joint NOAA/EPA quality assurance program has been implemented for sampling near coastal environments. Through the joint committee, NOAA has assisted EPA in the development and evaluation of coastal and estuarine environmental quality indicators by participating in workshops, providing data for retrospective analyses, and reviewing EPA plans and analysis results. The joint NOAA/EPA committee recently developed and executed a Memorandum of Understanding (MOU) that defines continued interagency cooperation and interaction and provides a framework for integrating the activities of the NOAA National

Status and Trends Program and EMAP into a unified national monitoring and assessment program for estuarine and coastal waters (Appendix B).

The extent, type, and ecological condition of terrestrial and aquatic ecosystems has a major influence on the amount and type of pollutants that are released into coastal waters. Therefore, it is critical that interagency cooperation and coordination on monitoring, research, and assessment does not stop with the activities of the joint NOAA/EPA Committee for Coastal and Estuarine Environmental Quality Monitoring. To ensure the protection and effective management of all the nation's ecological resources, the joint NOAA/EPA activities must be extended landward to incorporate other agencies and ecosystems. Then, the integrated ecological monitoring, research, and assessment programs required to address the complex, multimedia environmental issues of the 1990's and beyond will become a reality.

Coordination with NOAA and other federal agencies, as well as with other offices within EPA, avoids duplicative monitoring efforts and allows existing data to be used to maximum benefit. This coordination should lead to the incorporation of historical baselines established by other agencies, such as NOAA's baselines on contaminant concentrations in sediments and bivalves, into EMAP-NC analyses. It will also lead to the incorporation of EMAP-NC data into the analyses and assessments accomplished by other agencies. The regional-scale assessments resulting from EMAP-NC, in combination with the ongoing characterization work of NOAA, will provide a substantial portion of the technical information needed to: (1) characterize existing conditions and define coastal environmental problems; (2) coordinate the design and implementation of regional monitoring and assessment activities; and (3) identify, assess, and recommend management strategies and solutions that will enhance and protect regional coastal environmental quality.

1.6 Organization of the Remainder of This Plan

The remaining sections of this document are organized in the following manner:

- Approach and Rationale (Chapter 2.0) provides an overview of all aspects of EMAP-NC.
- Sampling Design (Chapter 3.0) provides a detailed description of the proposed sampling approach.
- Indicator Development and Evaluation (Chapter 4.0) details the strategy used to select the parameters to be measured (i.e.,

indicators of environmental quality), discusses the basis for selections, and describes activities that will be conducted to evaluate the indicators that have been selected and to identify additional indicators.

- Analysis and Integration (Chapter 5.0) provides an overview of what analyses will be conducted and how their results will be used.
- Information Management (Chapter 6.0) provides a general description of data management procedures that will be used to ensure that the collected data are provided to users quickly and efficiently. This chapter also describes the information management system that will be used to monitor the status of project activities.
- Logistics Plan (Chapter 7.0) describes how sampling activities will be conducted and how unanticipated logistical problems will be addressed.
- Quality Assurance (Chapter 8.0) details the procedures that will be used to ensure that the quality of the data collected is sufficient to meet program objectives and the needs of prospective users.
- References (Chapter 9.0) is the list of references cited in the text.
- Appendix A is a conceptual overview of EMAP.
- Appendix B is a copy of the MOU between NOAA and EPA relevant to status and trends monitoring of estuarine environments.
- Appendix C is a list of participants at the EMAP-NC indicator workshop.

2.0 APPROACH AND RATIONALE

Assessing the status and trends for the nation's estuarine and coastal ecological resources requires data collected in a standardized manner, over large geographic scales, for long periods of time. Such assessments cannot be accomplished by aggregating data from the many individual, short-term monitoring programs that have been conducted in the past and are being conducted currently. Differences in the parameters measured, the collection methods used, timing of sample collection, and program objectives severely limit the usefulness of historical monitoring data for conducting regional and national status and trends assessments (Beanlands and Duinker 1983, 1984; Wolfe et al. 1987; Chesapeake Bay Panel 1988; Panel on Particulate Wastes in the Ocean 1989; NRC 1989, 1990a, 1990b).

The EMAP Near Coastal program (EMAP-NC) proposes to monitor a defined set of parameters (i.e., indicators of estuarine and coastal environmental quality) on a regional scale, over a period of decades, using standardized sampling methods with a probability-based sampling design. These characteristics distinguish EMAP-NC from other monitoring programs and will provide the data for preparing the regional and national scale assessments that are needed to address the environmental issues of the 1990s and beyond (Reilly 1989; Thomas 1988a, 1988b).

Local programs that measure the same parameters and sample in a manner compatible with EMAP will be able to use EMAP products to obtain a regional and national perspective with which to evaluate the seriousness of local problems. This will assist them in two ways: (1) by determining whether their problems are unique, and (2) by facilitating detection of problems that are more easily measured on regional or national scales (e.g., determination of whether apparent declines in valued resources are associated with regional changes in climate or is more likely attributable to regional or local changes in pollutant loadings).

Because of its unique approach to monitoring EMAP-NC will be able to accomplish the following:

- Assess the status, extent, and geographical distribution of the nation's estuarine and coastal ecological resources,

- Estimate the proportion of those resources that are declining or improving, where, and at what rate,
- Quantify pollution exposure on regional and national scales,
- Identify the factors that are contributing to declining conditions and assess which factors represent the greatest threat to valued resources and ecosystem attributes,
- Determine whether environmental regulations and enforcement actions are protecting near coastal ecological resources adequately, and
- Identify emerging problems before they reach crisis proportion.

2.1 Scope of the EMAP Near Coastal Component

EMAP-NC has established its inland boundary as the limit of tidal influence. The outer boundary is the continental shelf break. Ecosystems occurring between these boundaries that ultimately will be sampled by EMAP-NC are the following:

- Estuarine and Coastal Wetlands -- submerged lands characterized by periodic or constant saturation and the presence of vegetation adapted to or tolerant of saturated soils,
- Estuaries -- semi-enclosed bodies of water that have a free connection with the open sea and an inflow of freshwater that mixes with the seawater; estuaries include fjords, bays, inlets, lagoons, and tidal rivers,
- Coastal Waters -- the waters lying over the continental shelf that are more saline than estuaries, and
- The Great Lakes -- freshwaters not affected by marine currents; each lake has a unique, complex current pattern.

At the present time, EMAP does not have the financial resources to implement regional monitoring programs in all estuarine and coastal ecosystems simultaneously. Therefore, a phased implementation is proposed that focuses

much of the initial efforts on estuaries. The reasons for selecting estuaries as the starting point are:

- Natural hydrodynamic and chemical processes concentrate and retain pollutants in estuaries. As a result, estuaries are repositories for many of the pollutants released into the nation's waterbodies and atmosphere and are integrators of man's insults on the near coastal environment (Conomos and Peterson 1976; Schubel and Carter 1976, 1984; Goldberg et al. 1978; NRC 1983, 1989; Biggs and Howell 1984; Schubel and Kennedy 1984; OTA 1987; Nixon et al. 1986).
- Demographers project that the high urbanization rate of estuarine watersheds will continue through the 1990s; by the year 2000, over 75 percent of the nation will live within 50 miles of the coast (OTA 1987). Most of these individuals will live in a watershed that drains into an estuary.
- Estuaries provide critical spawning and nursery habitat for many commercially and recreationally important fish and shellfish (Gunter 1967; Tagatz 1968; Lippson et al. 1979). Protection of estuarine habitats and biota is critical to the sustainability of commercial and recreational fisheries (May 1974, Polgar 1982). Early life stages of these resources are very sensitive to pollution insults (Hall et al. 1982; Woltering 1984).
- The environmental quality and status of living resources in estuaries is strongly influenced by the ecological condition in estuarine and coastal wetlands, as well as by environmental conditions throughout the watershed (EPA 1983; Donovan and Tolson 1987; Costanza et al. 1990). As a result, information on the status and trends of estuarine ecosystems should provide information about the condition of other coastal ecosystem types, and perhaps, the entire watershed.
- The ecological condition of estuaries appears to be more degraded than that of coastal waters (OTA 1987).
- The U.S. Fish and Wildlife Service (FWS) and NOAA are assessing the status and trends of estuarine and coastal wetlands on a national scale. EMAP-NC will coordinate with the FWS and NOAA to define the scope of assessment activities required to initiate regional monitoring programs for estuarine and coastal wetlands. EMAP-NC considers it critical to include wetlands in its estuarine program

before a regional monitoring program is implemented in the southeastern United States and the Gulf of Mexico.

2.2 Sampling Design

The sampling design for EMAP-NC has three elements:

- A regionalization scheme for partitioning estuarine and coastal resources into regions with similar ecological properties that constitute reasonable reporting units,
- A classification scheme to define subpopulations of interest (e.g., classes of estuaries, types of wetlands) that can be sampled using a common approach, and
- A statistical design that will obtain unbiased estimates of the status and trends of near coastal ecological resources cost effectively.

EMAP-NC will use the regionalization scheme shown in Fig. 2-1 to divide the nation's estuarine and coastal resources into a series of biogeographical provinces. Initially, field activities will be implemented in the Virginian Province, with other provinces added in subsequent years. By 1995, all provinces in the continental U.S. should be included in the sampling program. At this time, EMAP-NC plans to sample only those portions of the Acadian and West Indian provinces that are under the control of the United States government.

The classification scheme is used to subdivide estuaries into classes that have similar physical features and are likely to respond to stressors in a similar manner. The classes defined include: (1) large, continuously distributed estuaries (e.g., Chesapeake Bay, Long Island Sound); (2) large tidal rivers (e.g., Potomac, Delaware, Hudson Rivers); and (3) small, discretely distributed estuaries, bays, inlets, tidal creeks, and rivers (e.g., Barnegat Bay, Indian River Bay, Lynnhaven Bay, Elizabeth River). The purposes of classifying estuaries into categories having similar attributes (e.g., size, shape, resource distributions) are: (1) a common sampling design can be applied to each class, (2) the variability in conditions within a class should be less than that which occurs among classes, reducing the number of samples necessary to characterize a class accurately, and (3) the degree of confidence with which inferences can be made about systems within a class that are not sampled is increased.

EMAP Biogeographical Provinces

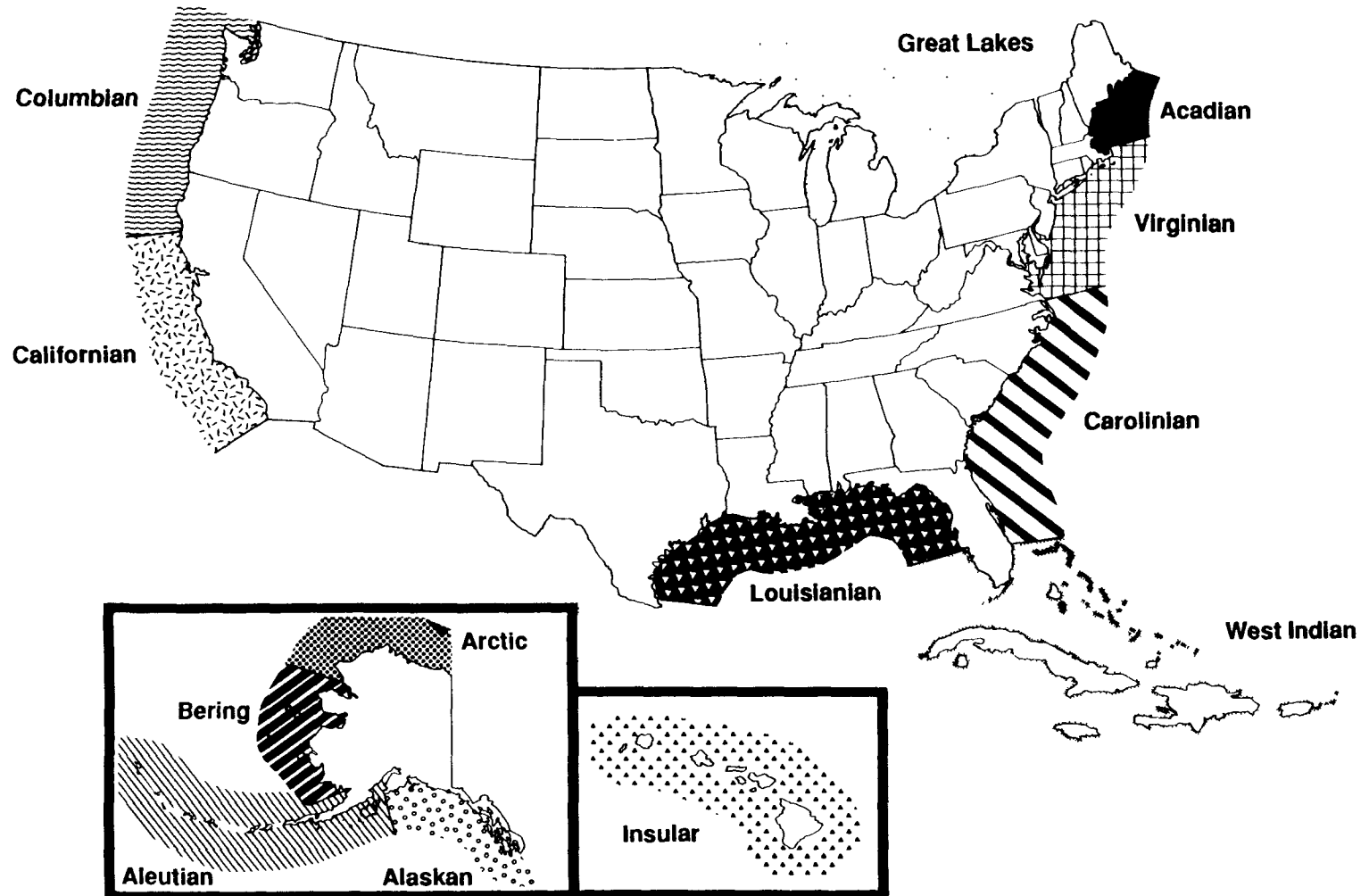


Figure 2-1. EMAP-NC biogeographical provinces

A critical issue that must be addressed by EMAP-NC is how best to represent the ecological condition of estuarine and coastal environments with limited financial resources and relatively few samples. It is obvious that one or two samples, from one or two locations, at one time of the day, in a specific season of a particular year cannot characterize the ecological condition of even a small estuary. Such a sampling program is justified only if it can be demonstrated that parameters that are indicative of the overall ecological condition of estuaries can be identified and a population approach to sampling can be used to characterize estuarine resources. That is, resources and locations that are sampled can be used to make inferences about unsampled resources and locations. One of the major goals of EMAP-NC 1990 field effort is to make this demonstration.

EMAP-NC does not have the resources to characterize natural variability or to assess status in all seasons. Therefore, sampling will be limited to a confined portion of the year (i.e., an index period), when measured parameters are expected to show the greatest response to pollution stress and within-season variability is expected to be reduced. EMAP-NC has selected summer as the appropriate index period. For most estuarine and coastal ecosystems in the northern hemisphere, mid-summer (July-August) is a period when dissolved oxygen concentrations are most likely to approach stressful low values (Holland et al. 1977; EPA 1984; Officer et al. 1984), and the cycling and adverse effects of contaminant exposure are greatest because of low dilution flows and high temperatures (Connell and Miller 1984; Sprague 1985; Mayer et al. 1989). In addition, fauna and flora are usually abundant during summer, increasing the probability of collecting the organisms required to complete assessments.

Within each estuarine class, elements of systematic, random, and fixed location sampling based on scientific judgement will be used. Large, continuously distributed estuaries will be sampled using a randomly placed systematic grid. Grid points will be about 18 km apart, and the entire estuary will be sampled. Large tidal rivers will be sampled along systematically spaced lateral transects. Transects are located about 25 km apart. The starting point for the first transect at the mouth of the river (between river mile 0-25) will be randomly selected. Two sampling points are located on each transect; one is randomly selected and one is an index sample. The goal of the index sample is to use scientific judgement to identify sampling locations that can be used to determine if degraded conditions occur in a system without having to conduct intensive surveys. The index sample site will be located in a depositional, muddy environment where sediments are accumulating, and the potential for exposure to low dissolved oxygen concentration and/or to contaminants is high. Small, relatively discrete estuaries will be sampled using a population approach. First, a list of all small estuaries is defined and placed in order according to latitude. Then the estuaries are classified into groups of four and one estuary from each group is randomly selected for sampling

without replacement. Two samples are located in each small estuary that is sampled; one is randomly selected and one is an index sample. Regional scale information from index sites will be combined with similar information from randomly selected locations.

Index samples will be used to estimate the proportion of sampling sites in small estuaries and tidal river segments that have unacceptable (or acceptable) indicator values in places that are particularly vulnerable to pollution impacts. However, the index samples are biased and cannot be used alone to estimate the extent of degradation. When regional scale information from index sites is combined with similar information from randomly selected locations, robust statements can be made about the proportion of systems that have pollution problems in highly vulnerable sites as well as about the extent and magnitude (i.e., areal extent) of degradation for the population of small estuaries and tidal river segments.

When it is implemented, EMAP-NC will operate on a four-year sampling cycle, with approximately one fourth of the total number of samples needed to make an overall assessment collected in each year. Regional interpretative assessments will be prepared every four years by combining the data collected over the four year cycle. Such a multiyear baseline reduces the confounding effect of year-related phenomena (e.g., weather) to the assessment process. Multiyear baselines are particularly important for evaluating the effectiveness of management actions (EPA 1983a, 1983b). Annual assessments can be made with the data collected during any year; however, these annual assessments will have a higher degree of uncertainty than assessments based on the full four year sampling program.

Many studies have defined the major problems facing the nation's estuaries and coastal waters (OTA 1987; EPA 1987; NRC 1989; NOAA 1988). In general, these studies conclude that the major environmental issues for estuarine and coastal ecosystems are those that adversely affect the maintenance of balanced indigenous populations of fish, shellfish, and other biota including the following:

- Increases in the amount of water that has low dissolved oxygen concentration levels,
- Eutrophication,
- Chemical and microbial contamination of water, sediments, and biological tissue,

- Habitat modification, and
- Cumulative impacts of more than one of the above.

The EMAP-NC indicator strategy was developed to address these problems and their associated impacts on valued ecosystem attributes.

2.3 Indicators of Environmental Quality

EMAP-NC does not have the resources to monitor all ecological parameters of concern to the public, Congress, scientists, and decision makers. Therefore, a defined set of parameters that serve as indicators of environmental quality will be measured. EMAP-NC indicators will be selected to be:

- Related to ecological condition in a way that can be quantified and interpreted,
- Applicable across a range of habitats and biogeographical provinces,
- Valued by and of concern to society, and
- Quantifiable in a standardized manner with a high degree of repeatability.

The selection of indicators that will be used by EMAP-NC is an ongoing process. It is anticipated that a number of years will be required to develop a complete list of indicators. The selection process consists of the following steps:

- Identification of valued ecosystem attributes and stressors that affect them,
- Development of a conceptual source-receptor model that links valued ecosystem attributes to stressors,
- Using the conceptual model to identify candidate indicators,
- Evaluation and classification of candidate indicators into categories (core, developmental, research) using evaluation criteria that are generic to all EMAP resource groups (e.g., forests, arid lands, agroecosystems),

- Testing and evaluation of indicators to assess their ability to discriminate between polluted and unpolluted sites,
- Conducting regional scale demonstration projects to show the feasibility of indicators and the value of indicator data to characterizing overall ecosystem status, and
- Periodic revaluation of indicators.

Categories of indicators that were identified and will be sampled by EMAP-NC include the following:

- Response Indicators -- Measurements that quantify the integrated response of ecological resources to individual or multiple stressors. Examples include measures of the condition of individuals (e.g., frequency of tumors or other pathological disorders in fish), populations (e.g., abundance, biomass), and communities (e.g., species composition, diversity).
- Exposure Indicators -- Physical, chemical, and biological measurements that quantify pollutant exposure, habitat degradation, or other causes of degraded ecological condition. Examples include contaminant concentrations in the water, sediments, and biological tissues; the acute toxicity of sediments to endemic or sensitive biota; and dissolved oxygen concentration.
- Habitat Indicators -- Physical, chemical, and biological measurements that provide basic information about the natural environmental setting. Examples include water depth, salinity, sediment characteristics, and temperature. Habitat indicators will be used to normalize values for exposure and response indicators across environmental gradients. Habitat indicators may also be used as a basis for defining subpopulations of interest for assessments.
- Stressor Indicators -- Economic, social, or engineering measures that can be used to identify the sources of pollution and causes of environmental problems and poor ecological condition. Examples include human demographics, land use patterns, discharge records from manufacturing and sewage treatment facilities, freshwater inflows, and pesticide usage on the watershed. Stressor data will be gathered primarily from existing federal and state programs (e.g., NOAA's National Coastal Pollution Discharge Inventory-NCPDI, wetland acreage and extent from FWS's National Wetland Inventory,

NOAA, and State wetland inventories and maps), from other EMAP task groups (e.g., the extent and distribution of forests, atmospheric deposition of pollutants), and from local permitting/planning agencies. EMAP-NC recognizes that it also will have to spend some of its resources on measuring stressors.

The relationships among indicator categories are summarized in Fig. 2-2. Information on exposure, habitat, and stressor indicators will be used to identify potential factors contributing to the status and trends of response indicators. A list of indicators that will be used in the first year of the program is provided in Table 2-1. In this first year, EMAP-NC will over-sample indicators and use the data collected to develop a reduced list of indicators that can be applied to characterize overall estuarine condition accurately when the program is fully implemented. The over sampling is necessary because indicators of estuarine condition that are acceptable to the public and scientists and have been demonstrated to be appropriate to apply at regional scales are not well developed.

2.4 Analysis and Integration

Integration and synthesis of EMAP-NC data into assessments of the condition of estuaries is a formidable challenge. Assessment results must be scientifically defensible and presented in a manner that can be understood by non-technical audiences. Unfortunately, estuarine science has not developed measures of the environmental condition of estuaries that are accepted by scientists and understood by the public and other non-technical audiences.

To accomplish its objectives, EMAP-NC will conduct the following types of analyses:

- Status assessments,
- Trends evaluations, and
- Diagnostic evaluations including identification of factors that may be affecting status and trends.

The analysis approach for status assessments will be hierarchical. First the overall condition of estuarine resources will be quantified using response indicators to define the extent and magnitude of pollution problems. Then, this integrated assessment will be decomposed to define associations between exposure, habitat,

EMAP-NC INDICATOR STRATEGY

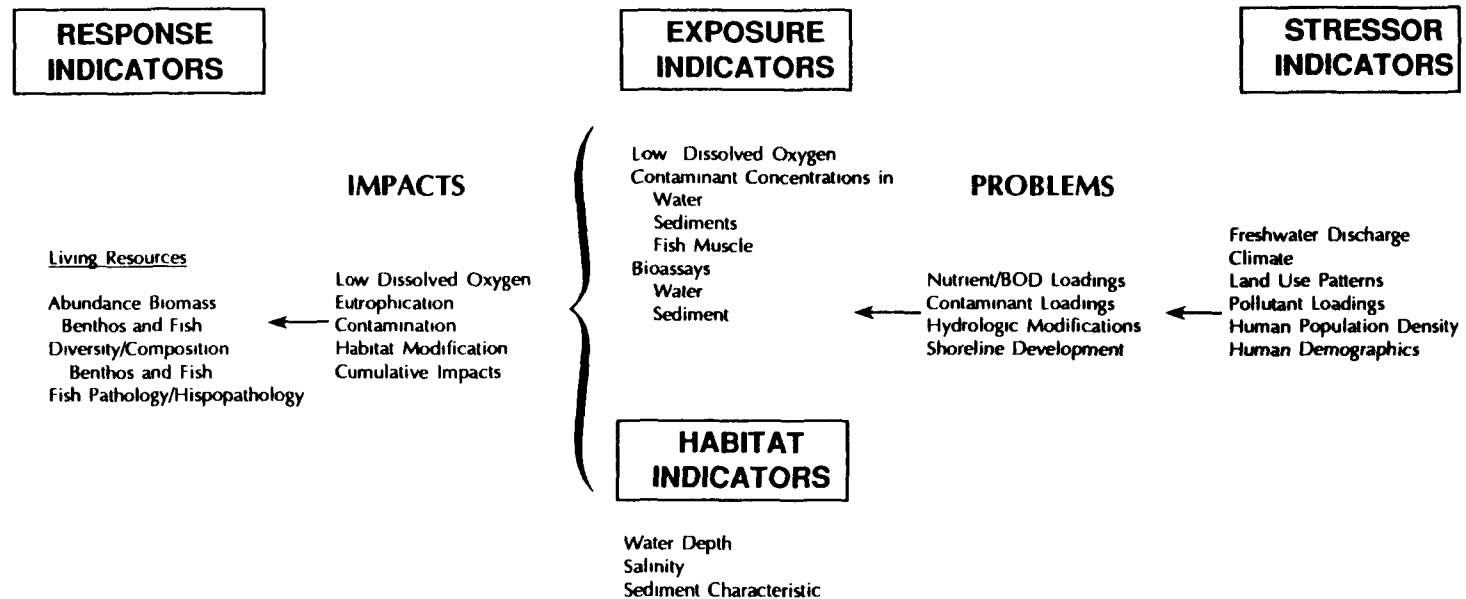


Figure 2-2. Overview of the indicator strategy for EMAP-NC. The manner in which indicators are related to the major environmental problems and impacts is also shown.

Table 2-1. List of EMAP-NC indicators by major category

Category	Proposed Indicator
Response	Benthic species composition and biomass Gross pathology of fish Fish community composition Relative abundance of large burrowing shellfish Histopathology of fish Apparent RPD
Exposure	Sediment contaminant concentration Sediment toxicity Contaminants in fish flesh Contaminants in large bivalves Water column toxicity Continuous and point measurements of dissolved oxygen concentration
Habitat	Salinity Sediment characteristics Water depth
Stressor	Fresh water discharge Climatic fluctuations Pollutant loadings by major category Land use patterns of watershed by major categories Human population density/demographics Fishery landings statistics

and stressor indicators and to identify likely causes and relative contributions of various stresses to problems.

A principal graphical representation of EMAP status information will be cumulative distribution functions (CDFs). CDFs were chosen because essential information on both central tendency (e.g., mean, median) and extreme values can be summarized in an easily interpreted graphical format (Fig. 2-3). CDFs will be prepared for response indicators for each estuary class, for all estuaries within the region, and eventually for all estuaries nationally. CDFs also will be prepared for selected exposure indicators and to characterize habitat conditions using habitat indicators.

The approach to trend assessment will consist of sampling a portion (e.g., one fourth) of the sampling sites each year in a manner that ensures geographic dispersion and repeating the cycle on a regular basis (e.g., every 4 years). Annual estimates of status can be evaluated individually or aggregated with other years to establish multi-year baselines that are more stable than annual estimates. Multi-year baselines are particularly useful for measuring trends and for evaluating the effectiveness of pollution control programs.

Although individual response indicators are important measures of specific aspects of environmental condition, the goal of EMAP-NC is to provide answers to questions with an holistic perspective of estuarine systems. Multiple statements (i.e., multiple CDFs) about the status and trends of the nation's estuaries, each based on a different response indicator, present information that may confuse many EMAP clients. Single, integrated statements about the overall status of estuarine resources are more easily communicated and understood. Therefore, EMAP-NC must develop an Estuarine Condition Index (ECI) that integrates the data collected for multiple response indicators into a single CDF describing the status of estuarine resources.

2.5 Data Management

EMAP-NC will use a distributed data management system. In this system, data are produced at a number of remote locations, where samples are processed. Results, are then transferred to a central site where they are verified to be reasonable and are integrated into the Near Coastal Information Management System (NCIMS). The NCIMS will include data in both raw and summary form to minimize costly redundant analysis (NCR 1990a). Information on study characteristics, institutional and organizational structures, sampling methods, sample status, data format, quality assurance, key scientists involved in the

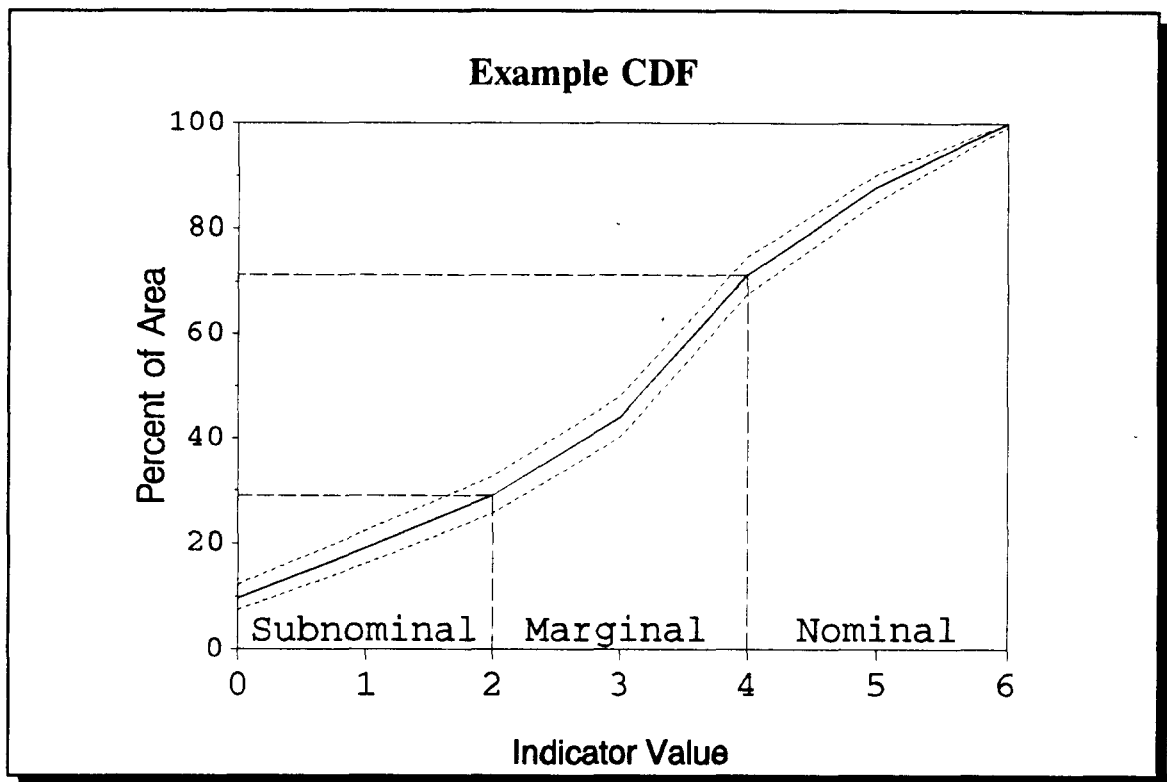


Figure 2-3. Example cumulative frequency distribution. Dotted lines represent confidence limits.

generation of each data set, and data access support will be available for all data sets. Data management reports that summarize the types, volume, and quality of data, as well as a list of the specific data sets that are available, will be prepared and distributed to potential users frequently (i.e., approximately every two years).

2.6 Quality Assurance

EMAP-NC will employ EPA's data quality objectives (DQO) approach to ensure that the type, amount, and quality of data collected are adequate to meet program goals and that analysis results have quantifiable and acceptable levels of uncertainty. The DQO process is an iterative approach, balancing costs against uncertainty, to achieve a desired or acceptable level of data quality (Fig. 2-4). The first step in the DQO process consists of determining the level of uncertainty that the decision makers who will use the data are willing to accept. Then, the uncertainty associated with the measurement program is estimated. The two estimates are compared and the sampling program modified (e.g., the intensity of sampling increased or decreased, sampling methods altered) until the proper balance between costs and uncertainty is achieved. Once an acceptable level of uncertainty has been established, quality control and quality assessment procedures are applied to each program element (e.g., field sampling, laboratory analysis, transfer of information to a data base, and data analysis) to ensure that the specified level of quality is attained and maintained.

Because regional data with which to estimate spatial and temporal variability within the summer index period are either unavailable or inaccessible for most, if not all, of the proposed indicators, it will not be possible for EMAP-NC to implement DQOs during the first year or two of the program. Accordingly, the first year's program will be implemented using Measurement Quality Objectives (MQOs). MQOs establish the acceptable level of uncertainty for field and laboratory methods. MQOs differ from DQOs in that they do not consider spatial and temporal variability in estimating uncertainty levels. The MQO uncertainty level for each indicator will be based on the available scientific literature for sampling, processing, and measurement methods or a manufacturer's specifications for a given instrument (Plumb 1981; Holme and McIntyre 1984; SeaBird Electronics, Inc. 1987; Pollard et al. 1990).

The data collected using MQOs during the first several years of EMAP-NC will be used to measure the uncertainty associated with the regional measurement program for each indicator. This information will then be evaluated, acceptable DQO's defined, and the sampling program modified as necessary to address program objectives. For additional information on the EMAP quality assurance

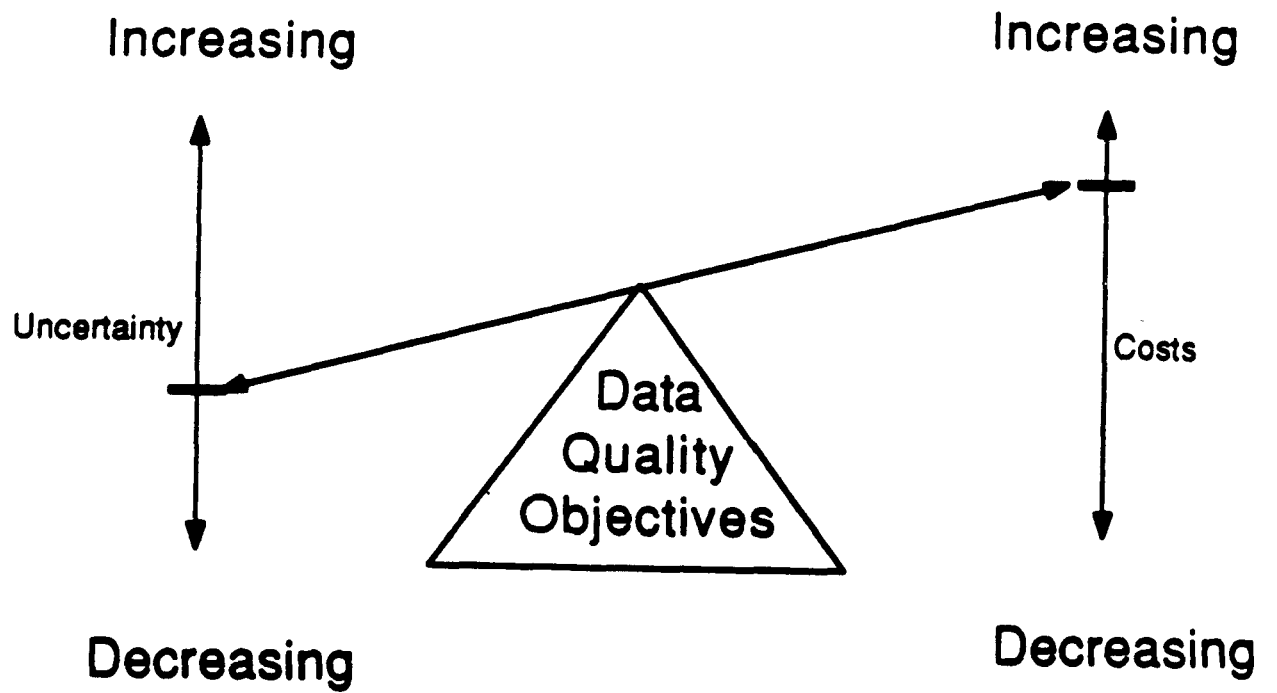


Figure 2-4. Role of data quality objectives in obtaining a balance between available resources and the level of uncertainty

program, readers should refer to the Quality Assurance Project Plan developed for the 1990 Demonstration Project in estuaries of the Virginian Province (Pollard et al. 1990). EMAP-NC also has developed field collection and laboratory processing methods manuals that standardize sampling and processing operations for this study (Stroebe1 1990; Graves 1990).

2.7 EMAP Reporting

EMAP-NC will produce three types of reports to meet the objectives of the program: (1) Annual Statistical Summaries, (2) Interpretive Assessment Reports, and (3) Special Scientific Reports. Annual Statistical Summaries will be prepared approximately 9 months after data are collected and will provide tabular and graphical summaries of each year's collections. They will be analogous to the annual reports prepared by the Department of Commerce for leading economic indicators. Interpretive Assessment Reports will be prepared for the public, Congress, interested scientists, and decision makers (e.g., the EPA Administrator) every 4 years and will:

- Assess status of ecological resources on regional scales,
- Measure trends in ecological resources,
- Identify likely causes of poor, deteriorating, or improving conditions,
- Assess the extent and magnitude of pollution exposure and impacts,
- Identify emerging problems and their likely causes before they reach crisis proportions, and
- Assess the effectiveness of regulatory/control programs.

Special Scientific Reports will be produced periodically to address specific concerns raised about the program (e.g., appropriateness of design) and topical areas of general interest (e.g., results of the indicator testing and evaluation program).

2.8 1990 Demonstration Project

As a first step in accomplishing the objectives of EMAP-NC, a Demonstration Project will be implemented in the Virginian Province in 1990. The

major goals of this Demonstration Project are to evaluate the utility of the EMAP sampling design and approach and, at the same time, collect the information necessary to develop a technically sound and cost-effective sampling program that can be implemented over the long term. The goals of the 1990 Virginian Province Demonstration Project include the following:

- Demonstrate the value of regional monitoring data collected in a standard way, measuring a defined set of parameters, using a robust sampling design as a basis for status assessments,
- Identify, test, and evaluate indicators of environmental quality for estuaries that can be applied over broad regions,
- Develop standardized sampling and processing methods for evaluating estuarine environmental quality,
- Evaluate alternative sampling designs and approaches for establishing a regional and national monitoring network in estuaries,
- Develop analysis procedures for converting monitoring data into information useful to the public, Congress, environmental decision makers, policy analysts, and the scientific community, and
- Identify and resolve logistical problems associated with conducting a regional/national scale monitoring program in estuaries.

EMAP-NC is being implemented in the Virginian Province (i.e., the Mid-Atlantic region) for the following reasons:

- There is a high level of public concern that estuarine resources in this region are degrading at a faster rate than those in other regions (Smart et al. 1987; Toufexis 1988; Morganthau 1988; OTA 1987).
- The information obtained will be invaluable to many forthcoming management decisions, including development of a restoration plan for the New York Harbor Complex; development of monitoring and management plans for the Delaware Bay, Narragansett Bay, Buzzards Bay, and Long Island Sound National Estuary Programs; and evaluation of the effectiveness of the Chesapeake Bay management plan.
- Many of the proposed indicators and sampling approaches have been tested and validated for broad regions of the Virginian Province (e.g.,

EPA 1984b; Holland et al. 1987; NOAA 1987; Dauer et al. 1988; Turgeon et al. 1989).

- Proximity to the EPA Environmental Research Laboratory at Narragansett, Rhode Island, will facilitate resolution of many logistical problems.

The 1990 Virginian Province Demonstration Project includes a number of program enhancements. These special studies include:

- An indicator testing and evaluation program that will evaluate the ability of indicators to discriminate between polluted and unpolluted environments,
- Temporal sampling for some indicators (e.g., dissolved oxygen concentration) extending beyond the boundaries of the anticipated index period to better define starting and ending times for the index period,
- Repeated measurements of selected indicators (e.g., dissolved oxygen concentration, fish community characteristics, and contaminants in fish flesh) during the index period to assess their stability and suitability for application in the sampling design, and
- Intensive spatial sampling conducted at a subset of stations (i.e., the Delaware River, Delaware Bay, Indian River Estuary), to evaluate the advantages and disadvantages of sampling at alternative spatial scales.

Because the objectives of the 1990 Virginian Province Demonstration Project are somewhat different from those envisioned for the full implementation of EMAP-NC, the reporting associated with the 1990 study will include several additional reports including the following:

- An Example Assessment Report, due in fall 1990, that will present examples of the kinds of assessment information that EMAP-NC will produce.
- A Demonstration Project Activities Summary, due in winter 1990-1991, that summarizes the data collected, describes the status of data records, identifies and discusses problems and issues encountered during the field program, and develops recommendations for improving logistical activities during the implementation phase.

- A Demonstration Project Interpretative Assessment Report, prepared in spring 1991, that makes a status assessment for the Virginian Province based on one year of data and presents the findings of the indicator testing and evaluation program, intensive spatial sampling efforts, and the evaluation of alternative sampling designs. The report will provide the technical basis for the design of future EMAP-NC monitoring efforts in the Virginian Province and elsewhere.

3.0 SAMPLING DESIGN

Program objectives are the major factor that influence the sampling design for monitoring and assessment programs, including when and where samples are collected and what parameters are measured. A sampling design that is closely linked to objectives not only ensures that the data collected will address those objectives, but also facilitates synthesis and integration of the data into useful information (NRC 1990a). In this chapter, the strategy and procedures that EMAP-NC will use to determine when and where samples will be collected is discussed. In the following chapter (4.0 Indicators of Environmental Quality), the process that will be used to identify and select the parameters (i.e., indicators) to be measured will be described.

Most of the resources for monitoring and assessment programs are expended on the collection and processing of samples (Downing 1979). For example, 70-80% of the cost for the benthic element of the Chesapeake Bay monitoring program is for sample collection and processing (Holland et al. 1986). In many monitoring and assessment programs the largest fraction of available resources is associated with data collection, leaving inadequate resources for synthesis and integration activities crucial for converting the data into information needed to address program objectives (NRC 1990a). It is critical that the EMAP-NC sampling design is constructed in a manner that ensures that sample collection and processing are not excessive and that adequate resources are available for synthesis and integration.

3.1 Elements of the Sampling Design

EMAP-NC seeks to assess the ecological condition of U.S. estuarine and coastal resources and to measure changes in that condition in a manner that facilitates determination of the effectiveness of environmental policies and regulations for protecting valued system attributes. To accomplish its objectives, EMAP-NC must develop a sampling program that:

- Determines the quantity, extent (e.g., kilometers, hectares), and geographic distribution of each estuarine and coastal ecosystems of interest,
- Estimates the proportion of each ecosystem class that is in acceptable and unacceptable condition,

- Measures the proportions that are degrading or improving, where, and at what rate,
- Determine the level of pollution exposure by ecosystem class and region, and
- Identifies the likely reasons for degradation or improvement in a manner that can be used to evaluate the effectiveness of environmental policies and regulatory programs.

EMAP-NC includes all estuarine and coastal ecosystems of the United States including estuaries, tidal wetlands, coastal waters, and the Great Lakes. The ecological characteristics (e.g., resource types, processes controlling distributional patterns) and environmental problems (e.g., low dissolved oxygen concentration, toxics contamination) affecting these ecosystems vary regionally, as well as across ecosystem types. A regionalization scheme is required to allocate estuarine and coastal resources into manageable sampling units for collection and reporting of data. The regions should be applicable to all near coastal ecosystem types. A classification scheme is required to organize the near coastal ecosystems within a region into classes that facilitate sampling and interpretation of data. Finally, a statistical sampling design must be developed for collection of samples across regions and ecosystem classes.

3.2 General Sampling Approach

EMAP-NC could use either of two general sampling approaches to collect the data required to accomplish its objectives. These are:

- Census the nation's estuarine and coastal ecosystems and important habitats on a periodic basis (e.g., every 4 years), and
- Sample a subset of estuarine and coastal resources periodically, and use the data to make inferences about unsampled areas.

The census technique is the appropriate sampling method for characterizing and assessing status and trends for some rare resources, because minimal population densities require that most of the resource must be sampled to characterize status and to measure trends (e.g., changes in abundance of rare and endangered species or habitats). The census technique is not a cost-effective or appropriate sampling approach for assessing the status and trends of broadly distributed, relatively abundant resources. EMAP-NC does not have the resources to conduct regular censuses of the nation's estuarine and coastal resources.

Sampling a subset of the resources and using the information obtained about the subset to make inferences about unsampled resources is the only approach that is appropriate for EMAP-NC.

The subset of resources sampled by EMAP-NC could be: (1) a sample which is determined, based on available scientific knowledge, to be "representative" of the range of environmental settings that exist in estuarine and coastal environments, or (2) a probability sample of estuarine and coastal resources. Collection of "representative" samples is an extreme case of stratified sampling and assumes that the data collected at the "representative" sampling locations can be extrapolated to broader spatial and temporal scales. Available scientific information is used to identify "representative" sampling locations, as well as to define the spatial scale and temporal periods that the samples represent. Periodic collection of "representative" samples is a powerful technique for measuring trends, because this approach minimizes interactions between spatial and temporal variation. Because "representative" samples can be located at any of a number of sites, they are generally easier to collect than probability samples and frequently can be located at a site for which there is existing historical data.

Unfortunately, the current scientific understanding of the environmental processes that control condition and distributions of estuarine and coastal resources is inadequate to define the bias and uncertainty associated with extrapolating environmental quality information for "representative" locations to other sites. This is especially true for data collected over broad geographic scales and long time periods. Therefore, EMAP-NC will use a probability sampling approach that samples resources in proportion to their abundance and distribution and obtains unbiased estimates of resource characteristics and variability. The probability sampling approaches selected will apply systematic (e.g., grid) sampling to facilitate characterizations of spatial patterns and to encourage broad geographic coverage.

Many of the proposed parameters that EMAP-NC will measure exhibit large intra-annual variability (Oviatt and Nixon 1973; Jeffries and Terceiro 1985; Grassle et al. 1985; Holland et al. 1987). EMAP-NC does not have the resources to characterize this variability or to assess status for all seasons. Therefore, sampling will be confined to a limited portion of the year (i.e., an index period), when indicators are expected to show the greatest response to pollution stress and within-season (i.e., week-to-week) variability is expected to be small.

For most estuarine and coastal ecosystems in the Northern Hemisphere, mid-summer (July-August) is the period when ecological responses to pollution exposure are likely to be most severe. During this period, dissolved oxygen concentrations are most likely to approach stressful low values (Holland et al. 1977; USEPA 1984; Oviatt 1981; Officer et al. 1984). Moreover, the cycling and

adverse effects of contaminant exposure are generally greatest at the low dilution flows and high temperatures that occur in mid-summer (Connell and Miller 1984; Sprague 1985, Mayer et al. 1989). Therefore, summer was selected as the appropriate index period for EMAP-NC.

Once unbiased quantitative information on the kinds, extent, condition, and distribution of estuarine and coastal resources and associated estimates of uncertainty are known, a baseline of the status of existing conditions will be established. This baseline information will be used to develop criteria for identifying "representative" sampling sites for future sampling (e.g., trends sites, detailed studies of processes associated with deterioration and recovery, the magnitude of natural variation). This baseline will also be used to determine the "representativeness" of historical data and sampling sites (e.g., NOAA status and trends sites). Over the long-term, EMAP-NC seeks to develop a sampling design that includes both "representative" and probability sampling, incorporating the advantages of both approaches.

3.3 Definition of Boundaries

Landward and seaward boundaries for estuaries, coastal and estuarine wetlands, and coastal waters are delineated as follows:

- Landward boundary -- The landward boundary of all estuarine and coastal ecosystems is the maximum inland extent of the tide (e.g., the Troy Dam for the Hudson River).
- Seaward boundary -- The seaward boundary of estuaries (as well as bays and sounds) is the point of confluence with the ocean. Wetland seaward boundaries are the continuously inundated (subtidal) margins, including nonvegetated mud flats. The seaward boundary for coastal waters is the continental shelf break (approximately the 200 m depth contour).

Landward and seaward boundaries of the Great Lakes will be defined in summer 1991, during the development of a conceptual plan to sample this province.

3.4 Regionalization

The EMAP-NC regionalization scheme consists of seven regions or provinces within the continental United States; five provinces in Alaska, Hawaii, and the

Pacific territories; and a region that comprises the Great Lakes (Fig. 2-1). These provinces are analogous to those used by NOAA and the U.S. Fish and Wildlife Service for their assessment programs and are applicable to all estuarine and coastal ecosystem types (Beasley and Biggs 1987; Terrell 1979).

The EMAP-NC regionalization scheme is based on two primary factors: major climatic zones and prevailing oceanic currents. The climatic zones are those described by Bailey (1970), and the ocean current delineation is based on Terrell (1979). Physical characteristics were used to define regional boundaries rather than ecological characteristics because of the ease and precision with which geographical boundaries can be defined using physical characteristics. Regional boundaries defined using ecological characteristics are less distinct than those delineated using physical characteristics. Boundaries defined by physical characteristics, however, are generally similar to those defined by ecological characteristics (Hedgpeth 1957; Knox 1986, Odum and Copeland 1974).

In its initial phases, EMAP-NC will monitor estuarine and coastal status and trends in only the seven provinces comprising the continental United States:

- Acadian Province -- This region spans the Gulf of Maine and includes estuarine and coastal systems from the eastern United States-Canada border to Cape Cod, Massachusetts. The Acadian Province is characterized by a continental climate and is directly affected by the Labrador Current. It is typified by a deeply incised, "drowned" coastline, with high tidal energy in the northern portion of the Gulf of Maine, and rocky, cobble, and sandy beaches along the southern portion of the Gulf of Maine.
- Virginian Province -- This region includes the wide expanse of irregular coastline from Cape Cod, Massachusetts, to the mouth of Chesapeake Bay (Cape Henry, Virginia). It includes many large estuarine systems (e.g., Long Island Sound, Delaware Bay, Chesapeake Bay) as well as a substantial number of small estuaries and tidal rivers. The Virginian Province is affected by both the Labrador Current and the Gulf Stream and is characterized by a continental/ subtropical climate.
- Carolinian Province -- This region includes the South Atlantic coast from Cape Henry, Virginia, to Cape Canaveral, Florida. The Carolinian Province is characterized by wide, shallow estuarine systems (e.g., Albemarle-Pamlico Sounds), extensive barrier island systems (e.g., Georgia and Carolina sea islands), complex lagoon systems (e.g., Indian River), and broad expanses of coastal marsh.

This region is dominated by the Gulf Stream and has a subtropical climate.

- West Indian Province -- This region includes South Florida (both the southern Atlantic and Gulf coasts) and the Caribbean territories. The portion of the West Indian Province that will be sampled by EMAP-NC extends from Cape Canaveral, Florida, on the Atlantic Coast, to Anclote Key, Florida, on the Gulf Coast and includes the Florida Keys and Florida Bay. EMAP-NC is not planning to sample the Caribbean territories at this time. The West Indian Province is dominated by a tropical climate, resulting from the Florida current. It is composed of diverse ecological resources, including regions of low, swampy coastline (e.g., Biscayne Bay), large coastal wetlands (e.g., Everglades), extensive sea grass beds (e.g., shallow tidal flats around the Florida Keys), coral reefs/heads (e.g., Florida Keys), and mangrove islands (e.g., Ten Thousand Islands).
- Louisianian Province -- This region includes the majority of the coastline of the continental United States along the Gulf of Mexico. The Louisianian Province extends from Anclote Key, Florida, to the eastern United States-Mexico border. The region has a sub-tropical climate and is characterized by extensive sandy beaches (e.g., Pensacola region), extensive marsh and swamp areas (e.g., Atchafalaya/Vermilion Bays), barrier island systems (e.g., Texas barrier islands), hypersaline lagoons (e.g., Laguna Madre), and an expansive deltaic system (e.g., Mississippi Delta.)
- Californian Province -- This region includes the Pacific Coast of the Southwestern United States and is dominated by the California Current. The Californian Province extends from the western United States-Mexico border to Point Reyes, California. The region is characterized by a dry, Mediterranean climate, beaches bordered by high cliffs (e.g., Big Sur area), deep canyon estuaries (e.g., Monterey Bay), extensive kelp beds, sporadic freshwater inflow, and two relatively large estuarine systems (i.e., San Francisco Bay and San Diego Bay).
- Columbian Province -- This region includes the Pacific Coast of the Northwestern United States and is dominated by the Alaska and California Currents. The Columbian Province extends from Point Reyes, California, to the United States-Canada border. This region has a continental/subtropical climate and is characterized by beaches bordered by high cliffs, high freshwater inflow (e.g., Columbia River),

numerous rocky islands, extensive eelgrass beds, and two large estuarine systems (i.e., Puget Sound and Columbia River Estuary).

A pilot project for the Great Lakes is planned for 1992. Additional provinces that comprise the remainder of the estuarine and coastal ecosystems of the United States are not included in the initial planning for EMAP-NC (e.g., Alaskan, Aleutian, Bering, Arctic, and Insular) and are not discussed further.

EMAP-NC will be implemented in phases, beginning with a demonstration project in the estuaries of the Virginian Province in 1990. In 1991, a demonstration project is planned for the Louisianian Province, followed by programs in the Carolinian Province in 1992, the Acadian and West Indian Provinces in 1993, and the Californian and Columbian Provinces in 1994. The schedule for initiating programs for coastal waters, wetlands, and estuaries in Alaska, Hawaii, and the Pacific and Caribbean territories will be developed after successful programs have been implemented in the estuaries of the Virginian and Louisianian Provinces and the value of the EMAP approach has been demonstrated. Major reasons for initiating EMAP-NC in the estuaries of the Virginian Province have already been discussed.

3.5 Classification

Estuarine resources vary widely in size, shape, and ecological characteristics. Many estuaries, like the Chesapeake Bay, are large, continuously distributed resources that consist of expansive regions of a broad variety of habitat types (e.g., multiple salinity zones and sediment types); whereas others (e.g., small bays, inlets, and salt ponds) are relatively discrete resources composed predominantly of one (or a few) habitat type(s). It would not be cost-effective or logical to sample such vastly different resource types using the same spatial scale with a single sampling design. Excessive number of samples would be collected for extensive and abundant resources and rare resources would not be adequately represented. A classification scheme that organizes estuaries into groups with similar physical and ecological characteristics is required to facilitate sampling and interpretation of data.

The specific goals of the classification process are to categorize estuaries into groups or classes:

- For which a common sampling design can be used,

- That facilitate synthesis and integration of the data collected into assessments that can be used for evaluating the effectiveness of management actions,
- Where the variability of indicators within a group (i.e., class) is less than that which occurs among groups, reducing the number of samples necessary to represent ecological condition of a class accurately and facilitating measurement of similarities and differences among groups, and
- That allow inferences about systems that are not sampled to be made with a quantifiable and high degree of confidence.

The classification scheme presented in this section is specific to estuaries; however, the approach used and the principles developed are applicable to all coastal ecosystem types.

Potential classification variables evaluated for classifying estuarine resources included salinity, sediment type, and physical dimensions. Physical dimensions (surface area, aspect ratio) were chosen as the basis for the EMAP-NC classification scheme for estuaries, and the estuarine waters of the Virginian Province were classified into three categories: large estuarine systems, large tidal rivers, and small estuarine systems. Large estuarine systems were defined as systems having surface areas greater than 260 km² (~ 100 mi²) and aspect ratios (length/ average width) less than 20. Large tidal rivers were defined as systems having surface areas greater than 260 km² (~ 100 mi²) and aspect ratios greater than 20. Small estuarine systems were defined as systems having surface areas less than 260 km² (~ 100 mi²) but greater than or equal to 2.6 km² (~ 1 mi²).

The boundaries of the classes defined above can be delineated accurately from available NOAA maps and are not likely to change within the time frame of EMAP. In addition, these classes are meaningful to a broad range of audiences, including environmental managers, Congress, scientists, policy analysts, and the public, because they form groups of ecosystems for which regional and national management actions could be implemented. Table 3-1 summarizes the important characteristics of the estuarine classes defined.

A classification scheme based on salinity distribution or sediment characteristics was not selected because such schemes did not:

- Define groups of systems that could be sampled with a common design. Classes based on salinity distributions, sediment characteristics, and pollution loadings included rare and abundant as

Table 3-1. Summary of the characteristics of estuarine classes

Characteristics	Large Estuaries	Large Tidal Rivers	Small Estuaries
Surface Area	> 260 km ²	> 260 km ²	2.6 - 260 km ²
Shape	Aspect ratio < 20	Aspect ratio > 20	Any
Salinity	Strong salinity gradients	Partial salinity gradients	Generally does not have salinity gradients
Sediments	Heterogeneous	Heterogeneous	Relatively homogeneous
Watersheds	Large, complex	Large, complex	Small
Management Regions	Multi-state	Multi-state	Usually, a single state
Contaminant Sources	Multiple	Multiple	Relatively few

well as large and small system types. Such widely different system types can not be sampled with a common design.

- Facilitate the synthesis and integration of data into information that could be used for evaluating the effectiveness of management actions. If samples are grouped into different classes from year to year as a result of natural variation (e.g., annual changes in the sizes of salinity zones that occur as a result of year-to-year variation in rainfall), then trend assessments are not reliable because it is unclear whether the trends observed are real or are due to variation in the classification process.
- Identify groups of systems that could be delineated using available data and maps. This delineation is necessary to ensure that the number of samples allocated to each class is adequate to meet program objectives.
- Allow aggregation or segregation of the data into geographic units that were meaningful from a regulatory and general interest perspective (e.g., EPA regions). Most environmental management actions are taken for whole systems or groups of systems.

Although salinity, sediment characteristics, and pollutant loadings were not appropriate a priori classification variables, they will be used as post-classification variables during the analysis process to create subpopulations (strata) that facilitate interpretation and synthesis of the data. The major constraint associated with using salinity, sediment characteristics, and pollution loading variables in a post-classification mode is that the number of samples comprising subpopulations will vary from year-to-year. The consequence of variable sample sizes will be that the uncertainty levels associated with findings will vary in an uncontrolled manner.

A total of 22,873 km² (~ 8,935 mi²) of estuarine waters occurs in the Virginian Province. Table 3-2 provides a list of the estuarine resources of the Virginian Province with surface areas greater than or equal to 2.6 km² (~ 1 mi²). Resources with surface areas less than 2.6 km² were not included in the sampling frame.

Application of the classification scheme to the Virginian Province results in the identification of:

- Twelve (12) large estuarine systems with a total surface area of 15,754 km² (~ 6,153 mi² or 70 percent of the total area to be sampled)

Table 3-2. List of estuarine resources within the Virginian Province with surface areas greater than 2.6 km²

System	Estuary	Surface Area (km²)
Cape Cod	Nantucket Ponds	2.6
	Vineyard Ponds	2.6
	New Bedford Harbor	2.8
	Massachusetts Bays/Ponds	3.4
	Cape Cod Canal	4.1
	Westport River	6.2
	Nantucket Harbor	14.2
	Chatham Harbor	34.2
	Edgartown Harbor	37.0
	Vineyard Sound	265.2
	Buzzards Bay	604.8
	Nantucket Sound	1883.4
Block Island Sound/ Narragansett Bay	Rhode Island Ponds	2.6
	Connecticut Ponds	4.1
	Taunton River	8.8
	Providence River	17.4
	Mt. Hope Bay	34.4
	Sakonnet River	51.3
	Narragansett Bay	268.1
	Block Island Sound	1342.4
East Long Island	Island Ponds	2.6
	Shelter Sound	27.7
	Little Peconic Bay	56.7
	Napeague Bay	86.8
	Great Peconic Bay	93.5
Long Island Coast	Moriches Bay	31.9
	Hempstead Bay	37.3
	Shinnecock Bay	55.2
	Gardiners Bay	173.8
	Great South Bay	343.7
Long Island Sound	Quinnipac River	2.6
	Harlem River	2.6
	Mystic River	8.5
	Housatonic River	9.1
	Niantic River	9.1
	Thames River	11.9
	East River	14.0

Table 3-2. Continued

System	Estuary	Surface Area (km ²)
Long Island Sound (Continued)	West Long Island Bays	22.3
	New Haven Harbor	23.8
	Connecticut River	39.1
	Fishers Sound	71.5
	Long Island Sound	2884.2
Hudson River/ Raritan Bay	Passaic River	2.6
	Kill Van Kull	4.1
	Hackensack River	4.7
	Raritan River	8.8
	Arthur Kill	9.8
	Newark Bay	14.0
	Upper NY/NJ Bay	33.9
	Jamaica Bay	35.0
	Sandy Hook Bay	61.6
	Raritan Bay	71.7
	Lower NY/NJ Bay	217.3
	Hudson River	335.1
New Jersey Coastline	Shark River	2.8
	New Jersey Coastal Bays	3.9
	Manasquan River	6.2
	Metedeconk River	6.7
	Mullica River	7.5
	Toms River	8.0
	Navesink River	9.8
	Shrewsbury River	11.1
	Great Egg Harbor	22.3
	Great Bay	40.9
	Little Egg Harbor	86.2
	Barnegat Bay	201.0
Delaware Bay	Smyrna River	2.6
	Stow Creek	2.6
	St. Jones River	2.6
	Blackbird Creek	2.6
	Leipsic River	2.6
	Mispillion River	2.6
	Alloway Creek	2.6
	Christina River	4.7
	C&D Canal	4.7
	Cohansey River	6.5

Table 3-2. Continued

System	Estuary	Surface Area (km ²)
Delaware Bay (Continued)	Schuylkill River	7.0
	Maurice River	7.8
	Appoquinimink River	13.0
	Salem River	44.0
	Delaware River	239.3
	Delaware Bay	1533.8
Delaware Bays	Pepper Creek	7.3
	Indian River Bay	25.6
	Rehobeth Bay	28.7
Maryland Coastline	Little Assawoman Bay	7.0
	Sinepuxent Bay	11.4
	Assawoman & Isle of Wight Bays	61.6
	Chincoteague Bay	354.3
Virginia Coastline	Virginian Coastal Bays	2.6
	Fishermans Inlet	7.5
	Magothy Bay	43.3
	Back Bay	83.7
Chesapeake Bay	Anacostia River	2.6
	Appamatox River	2.8
	Aquia Creek	4.7
	Herring Bay	6.2
	Wicomico River	6.5
	Lynnhaven Bay	7.0
	Pocomoke River	7.3
	Port Tobacco River	7.5
	Bohemia River	9.1
	Nanjemoy Creek	9.1
	Wye River	9.1
	Breton Bay	11.1
	West River	11.1
	South River	14.5
	Northeast River	14.5
	Back River	14.8
	Middle River	15.0
	Tred Avon River	15.0
	Magothy River	17.9

Table 3-2. Continued

System	Estuary	Surface Area (km ²)
Chesapeake Bay Continued)	Corrotoman River	18.1
	Mattaponi River	19.7
	St. Clements Bay	20.2
	Elizabeth River	21.8
	Gunpowder River	21.8
	Broad Creek	22.0
	Big Annemessex River	23.3
	Pamunkey River	23.3
	Chickahominy River	23.3
	Nansemond River	24.1
	Bush River	25.4
	Sassafras River	26.2
	Monie Bay	28.0
	Miles River	29.0
	Severn River	29.3
	Susquehanna River	31.1
	Harris Creek	35.0
	Piankatank River	37.3
	St. Marys River	39.6
	Nanticoke River	51.5
	Elk River	53.1
	Wicomico River (Potomac)	55.4
	Patapsco River	61.4
	Manokin River	69.9
	Little Choptank River	74.3
	Chester River	78.5
	Fishing Bay	80.8
	Susquehanna Flats	89.9
	Honga River	115.5
	Patuxent River	126.7
	Mobjack Bay	138.3
	York River	144.0
	Eastern Bay	173.0
	Choptank River	219.9
	Pocomoke Sound	324.8
	Rappahannock River	435.6
	Tangier Sound	559.2
	James River	651.1
	Potomac River	1179.5
	Chesapeake Bay Mainstem	5658.1

- Five (5) large tidal rivers (i.e., Hudson, Potomac, James, Delaware, and Rappahannock Rivers) with a total surface area of 2,840 km² (~ 1,109 mi² or 13 percent of the total area to be sampled)
- One hundred thirty-seven (137) small estuarine systems with a total surface area of 4,279 km² (~ 1,671 mi² or 17 percent of the total area to be sampled).

Tables 3-3 through 3-5 provide lists of estuaries in each class.

3.6 Sampling Design for the Demonstration Project

EMAP-NC is being initiated as a regional-scale demonstration project in the estuaries of the Virginian Province because available scientific information is not adequate to develop a cost-effective and scientifically defensible sampling program for full-scale implementation. Important questions have been raised about the timing and locations of sampling, as well as about justification for the measurement of particular parameters. Concerns also have been raised about the value of regional scale status and trends information for evaluating the effectiveness of environmental protection actions and defining environmental priorities for estuarine resources. The objectives of the 1990 Demonstration Project are to address the above questions and concerns by obtaining the data needed to accomplish the following:

- Evaluate alternative sampling designs and trade-offs between cost and uncertainty, allowing specified data quality objectives to be developed for the full-scale implementation of EMAP in estuaries
- Identify reliable indicators for inclusion in an implementation program including development of a strategy for adding and deleting indicators in the future
- Develop a logistically feasible, cost-effective sampling design that will define the status and trends of estuaries in the Virginian Province
- Demonstrate the usefulness and ease of presentation of the data resulting from applying an EMAP sampling approach.

Table 3-3. Estuaries in the Virginian Province included in the large estuarine system class (> 259 km²)

Estuary	State(s)	Surface Area (km²)	Aspect Ratio
Buzzards Bay	Massachusetts	604.8	2.6
Nantucket Sound	Massachusetts	1883.4	1.9
Vineyard Sound	Massachusetts	265.2	2.3
Narragansett Bay	Rhode Island	268.1	2.7
Block Island Sound	Rhode Island, New York, Connecticut	1342.4	1.8
Long Island Sound	New York, Connecticut	2884.2	6.2
Great South Bay	New York	343.7	9.3
Delaware Bay	Delaware	1533.8	3.0
Chincoteague Bay	Maryland	354.3	4.7
Pocomoke Sound	Maryland, Virginia	324.8	7.3
Tangier Sound	Maryland, Virginia	559.2	8.1
Chesapeake Bay	Virginia, Maryland	5658.1	17.5

Table 3-4. Tidal rivers in the Virginian Province included in the large tidal rivers class

Estuary	State(s)	Surface Area (km²)	Aspect Ratio
Hudson River	New York, New Jersey	335.1	150.5
Delaware River	Delaware, New Jersey Jersey, Pennsylvania	239.3	62.4
Potomac River	Maryland, Virginia	1179.5	41.8
Rappahannock River	Virginia	435.6	68.2
James River	Virginia	651.1	37.2

Table 3-5. Estuaries and tidal rivers in the Virginian Province included in the small estuarine systems class

Estuary/ Tidal River	State	System	Surface Area (km ²)
Chatham Harbor	MA	Cape Cod	34.2
Cape Cod Canal	MA	Buzzards Bay	4.1
New Bedford Harbor	MA	Buzzards Bay	2.8
Nantucket Harbor	MA	Cape Cod	14.2
Nantucket Ponds*	MA	Cape Cod	1.3
Vineyard Ponds*	MA	Cape Cod	1.8
Edgartown Harbor	MA	Cape Cod	37.0
Massachusetts Bays/ Ponds*	MA	Cape Cod	3.4
Westport River	MA	Cape Cod	6.2
Rhode Island Ponds*	RI	Narragansett Bay	1.8
Sakonnet River	RI	Narragansett Bay	51.3
Mt. Hope Bay	RI	Narragansett Bay	34.4
Taunton River	RI, MA	Narragansett Bay	8.8
Providence River	RI	Narragansett Bay	17.4
Shinnecock Bay	NY	Long Island Coast	55.2
Moriches Bay	NY	Long Island Coast	31.9
Gardiners Bay	NY	Long Island Coast	173.8
Hempstead Bay	NY	Long Island Coast	37.3
Great Peconic Bay	NY	East Long Island	93.5
Little Peconic Bay	NY	East Long Island	56.7
Shelter Sound	NY	East Long Island	27.7
Napeague Bay	NY	East Long Island	86.8
Long Island Ponds*	NY	East Long Island	2.3
West Long Island Bays*	NY	Long Island Sound	3.9
East River	NY	Long Island Sound	13.7
Housatonic River	CN	Long Island Sound	9.1
New Haven Harbor	CN	Long Island Sound	23.8
Quinnipac River	CN	Long Island Sound	2.6
Connecticut River	CN	Long Island Sound	39.1
Niantic River	CN	Long Island Sound	9.1
Thames River	CN	Long Island Sound	11.9
Mystic River	CN	Long Island Sound	8.5
Fishers Sound	CN	Long Island Sound	71.5

* Multiple small ponds and bays, many of which are < 2.6 km², are combined as a potential sampling entity; one random pond or bay is selected representing the set of ponds or bays; surface area represents an average pond or bay.

Table 3-5. Continued

Estuary/ Tidal River	State	System	Surface Area (km ²)
Connecticut Ponds *	CN	Block Island Sound	3.9
Harlem River	NY	Hudson/Raritan	2.6
Jamaica Bay	NY	Hudson/Raritan	35.0
Lower NY/NJ Bay	NY, NJ	Hudson/Raritan	217.3
Upper NY/NJ Bay	NY, NJ	Hudson/Raritan	33.9
Sandy Hook Bay	NJ	Hudson/Raritan	61.6
Kill Van Kull	NJ	Hudson/Raritan	4.1
Arthur Kill	NJ	Hudson/Raritan	9.8
Raritan Bay	NJ	Hudson/Raritan	71.7
Newark Bay	NJ	Hudson/Raritan	14.0
Hackensack River	NJ	Hudson/Raritan	4.7
Passaic River	NJ	Hudson/Raritan	2.6
Raritan River	NJ	Hudson/Raritan	8.8
Navesink River	NJ	New Jersey Coast	9.8
Shrewsbury River	NJ	New Jersey Coast	11.1
Shark River	NJ	New Jersey Coast	2.8
Manasquan River	NJ	New Jersey Coast	6.2
Metedeconk River	NJ	New Jersey Coast	6.7
Toms River	NJ	New Jersey Coast	8.0
Barnegat Bay	NJ	New Jersey Coast	201.0
Little Egg Harbor	NJ	New Jersey Coast	86.2
Great Bay	NJ	New Jersey Coast	40.9
Mullica River	NJ	New Jersey Coast	7.5
New Jersey Coastal Bays*	NJ	New Jersey Coast	3.9
Great Egg Harbor	NJ	New Jersey Coast	22.3
Mispillion River	DE	Delaware Bay	2.6
St. Jones River	DE	Delaware Bay	2.6
Maurice River	NJ	Delaware Bay	7.8
Leipsic River	NJ	Delaware Bay	2.6
Cohansey River	NJ	Delaware Bay	6.5
Smyrna River	DE	Delaware Bay	2.6
Stow Creek	NJ	Delaware Bay	2.6
Alloway Creek	NJ	Delaware Bay	2.6
Blackbird Creek	DE	Delaware Bay	2.6
Appoquinimink River	DE	Delaware Bay	13.0

Table 3-5. Continued

Estuary/ Tidal River	State	System	Surface Area (km ²)
C&D Canal	DE, MD	Delaware Bay	4.7
Salem River	NJ	Delaware Bay	44.0
Christina River	DE	Delaware Bay	4.7
Schykill River PA	PA	Delaware Bay	7.0
Rehobeth Bay	DE	Delaware Coast	28.7
Indian River Bay	DE	Delaware Coast	25.6
Pepper Creek	DE	Delaware Coast	7.3
Little Assawoman Bay	MD	Maryland Coast	7.0
Assawoman Bay	MD	Maryland Coast	61.6
Sinepuxent Bay	MD	Maryland Coast	11.4
Virginia Coastal Bays*	VA	Virginia Coast	2.6
Magothy Bay	VA	Virginia Coast	43.3
Fishermans Inlet	VA	Virginia Coast	7.5
Back Bay	VA	Virginia Coast	83.7
Elizabeth River	VA	Chesapeake Bay	21.8
Lynnhaven Bay	VA	Chesapeake Bay	7.0
Mobjack Bay	VA	Chesapeake Bay	138.3
Nansemond River	VA	Chesapeake Bay	24.1
Chickahominy River	VA	Chesapeake Bay	23.3
Appamattox River	VA	Chesapeake Bay	2.8
York River	VA	Chesapeake Bay	54.1
Mattaponi River	VA	Chesapeake Bay	19.7
Pamunkey River	VA	Chesapeake Bay	23.3
Piankatank River	VA	Chesapeake Bay	37.3
Corrotoman River	VA	Chesapeake Bay	18.1
Great Wicomico River	VA	Chesapeake Bay	29.0
Pocomoke River	MD	Chesapeake Bay	7.3
Manokin River	MD	Chesapeake Bay	69.9
Big Annemessex River	MD	Chesapeake Bay	23.3
Monie Bay	MD	Chesapeake Bay	28.0
Wicomico River	MD	Chesapeake Bay	6.5
Fishing Bay	MD	Chesapeake Bay	80.8
Honga River	MD	Chesapeake Bay	115.5
St. Marys River	MD	Chesapeake Bay	39.6
Breton Bay	MD	Chesapeake Bay	11.1
St. Clements Bay	MD	Chesapeake Bay	20.2
Wicomico River (Potomac)	MD	Chesapeake Bay	55.4

Table 3-5. Continued

Estuary/ Tidal River	State	System	Surface Area (km ²)
Chester River	MD	Chesapeake Bay	78.5
Choptank River	MD	Chesapeake Bay	62.9
Patuxent River	MD	Chesapeake Bay	76.1
Nanticoke River	MD	Chesapeake Bay	129.8
Port Tobacco River	MD	Chesapeake Bay	7.5
Aquia Creek	MD	Chesapeake Bay	4.7
Nanjemoy Creek	MD	Chesapeake Bay	9.1
Anacostia River	MD, DC	Chesapeake Bay	2.6
Little Choptank River	MD	Chesapeake Bay	74.3
Tred Avon River	MD	Chesapeake Bay	15.0
Harris Creek	MD	Chesapeake Bay	35.0
Broad Creek	MD	Chesapeake Bay	22.0
Eastern Bay	MD	Chesapeake Bay	173.0
Herring Bay	MD	Chesapeake Bay	6.2
Miles River	MD	Chesapeake Bay	29.3
Wye River	MD	Chesapeake Bay	9.1
West River	MD	Chesapeake Bay	11.1
South River	MD	Chesapeake Bay	14.5
Severn River	MD	Chesapeake Bay	29.3
Magothy River	MD	Chesapeake Bay	17.9
Patapsco River	MD	Chesapeake Bay	61.4
Back River	MD	Chesapeake Bay	14.8
Middle River	MD	Chesapeake Bay	15.0
Gunpowder River	MD	Chesapeake Bay	30.0
Bush River	MD	Chesapeake Bay	25.4
Romney Creek	MD	Chesapeake Bay	5.7
Sassafras River	MD	Chesapeake Bay	26.2
Bohemia River	MD	Chesapeake Bay	9.1
Elk River	MD	Chesapeake Bay	53.1
Northeast River	MD	Chesapeake Bay	14.5
Susquehanna River	MD	Chesapeake Bay	31.1
Susquehanna Flats	MD	Chesapeake Bay	89.9

The 1990 Demonstration Project includes the following elements:

- A base sampling effort that will collect the data to make an initial assessment of the status of the estuaries of the Virginian Province
- Intensive spatial sampling to evaluate the influence of spatial scale on the assessment of status, to define a spatial scale that is adequate for full-scale implementation, and to assess the value of information collected from "representative" sampling sites relative to information collected at probability sample sites
- Intensive temporal sampling including continuous monitoring of water quality, primarily dissolved oxygen concentration, to evaluate the reliability of an index period approach for assessing ecological status
- Testing and evaluation of indicators of environmental quality to determine the reliability, sensitivity, specificity, and repeatability of indicator responses for discriminating between polluted and unpolluted conditions and to identify parameters that should be measured during the implementation phase.

EMAP-NC plans to conduct demonstration or pilot projects prior to implementing operational programs in all new regions, as well as when initiating programs in new resource types (i.e., coastal waters). The amount of intensive sampling conducted during these demonstration projects is expected to decline substantially as additional regions are incorporated into the program and more information on the scale of regional and temporal variation is made available.

3.6.1 Base Sample Selection for Large Estuarine Systems

Sampling sites in large estuarine systems were selected using a randomly placed systematic grid. The distance between the systematically-spaced sampling points on the grid is approximately 18 km. This grid is an extension of the systematic grid proposed for use throughout EMAP (Overton 1989).

The random placement of the grid was established assuming a planar projection and using the following steps described by Overton (1989):

1. Establish the appropriate planar distance for the grid,

2. Establish a cardinal orientation for the grid, relative to the plane, to determine one of the three alignment axes, and fix the remaining two axes,
3. Establish a 0-position of the grid, providing the x-location and the y-location of each of the points in the grid, spanning the United States and its adjacent coastal waters,
4. Select, at random, a perturbation from this 0-location, as follows:
 - a. Select u , a uniform random variable, between 0 and 1
 - b. Select v , a uniform random variable, between 0 and $\sqrt{3}/2$
 - c. If $u < 1/2$ and $v < 1/2 \sqrt{3} - u/2 \sqrt{3}$, then reset
 $u = u + 1/2$ and $v = v + \sqrt{3}/2$
 - d. If $u > 1/2$ and $v < u/2 \sqrt{3} - 1/2 \sqrt{3}$, then reset
 $u = u - 1/2$ and $v = v + \sqrt{3}/2$
5. Translate the origin to the center of the hexagon, and rescale by the appropriate planar grid distance:
 - a. $u = (u - 1/2)d$.
 - b. $v = (v - 1/\sqrt{3})d$.
6. Translate the grid from its 0-position to its randomized position by adding u to all of the x-locations and v to all of the y-locations.

For the 1990 Demonstration Project, 54 sample sites were identified within the boundaries of large estuarine systems, in areas that could be sampled using the available boats (i.e., sites in water greater than 1 m in depth). Sites are listed in Table 3-6 and are shown in Fig. 3-1. All of these sites will be sampled in the 1990 Demonstration Project.

3.6.2 Base Sample Selection for Large Tidal River Systems

The selection of sampling sites for the large tidal rivers class was based on a linear analog of the design for the large estuarine systems. A systematic linear grid was used to define the spine of the five large tidal rivers in the Virginian

Table 3-6. 1990 base sampling locations for the large estuarine systems class

Estuary	Location			
	Latitude (°N)		Longitude (°W)	
Buzzards Bay	41°	30.54'	70°	57.55'
Block Island Sound	41°	21.31'	71°	30.24'
	41°	12.72'	71°	36.31'
	41°	12.33'	71°	49.53'
	41°	11.91'	72°	2.75'
Chesapeake Bay				
Pocomoke Sound	37°	53.72'	75°	46.65'
	37°	44.83'	75°	51.70'
Tangier Sound	37°	52.78'	75°	59.14'
	38°	1.68'	75°	54.10'
	38°	9.63'	76°	1.56'
Bay Mainstem	37°	35.94'	75°	56.72'
	37°	10.18'	75°	59.26'
	37°	27.03'	76°	1.71'
	37°	43.88'	76°	4.16'
	37°	1.27'	76°	4.19'
	37°	18.13'	76°	6.67'
	37°	34.98'	76°	9.15'
	37°	9.21'	76°	11.61'
	37°	51.83'	76°	11.62'
	37°	26.07'	76°	14.11'
	37°	0.30'	76°	16.52'
	37°	42.92'	76°	16.61'
	38°	0.73'	76°	6.60'
	38°	8.67'	76°	14.09'
	38°	59.20'	76°	21.48'
	38°	16.61'	76°	21.59'
	38°	33.45'	76°	24.08'
	38°	50.29'	76°	26.57'
	38°	41.25'	76°	31.42'
	39°	7.75'	76°	16.88'
Chincoteague Bay	38°	4.37'	75°	16.53'

Table 3-6. Continued

Estuary	Location			
	Latitude (°N)		Longitude (°W)	
Buzzards Bay	41°	30.54'	70°	57.55'
Delaware Bay	38°	55.76'	75°	10.55'
	39°	4.60'	75°	5.27'
	39°	12.60'	75°	12.72'
	39°	3.76'	75°	18.00'
	39°	20.60'	75°	20.20'
Great South Bay	40°	44.45'	72°	59.87'
Long Island Sound	40°	50.77'	73°	46.53'
	41°	1.82'	72°	48.23'
	41°	9.97'	72°	55.55'
	41°	11.46'	72°	15.96'
	41°	10.99'	72°	29.16'
	41°	2.33'	72°	35.06'
	41°	10.49'	72°	42.36'
	41°	1.28'	73°	1.39'
	41°	0.72'	73°	14.54'
	41°	0.13'	73°	27.68'
Narragansett Bay	41°	38.48'	71°	18.01'
	41°	29.90'	71°	24.14'
Nantucket Sound	41°	31.50'	70°	4.31'
	41°	23.00'	70°	10.60'
	41°	31.30'	70°	17.63'
	41°	22.79'	70°	23.89'
	41°	31.08'	70°	30.94'
Vineyard Sound	41°	22.28'	70°	50.45'

Base Sampling Sites

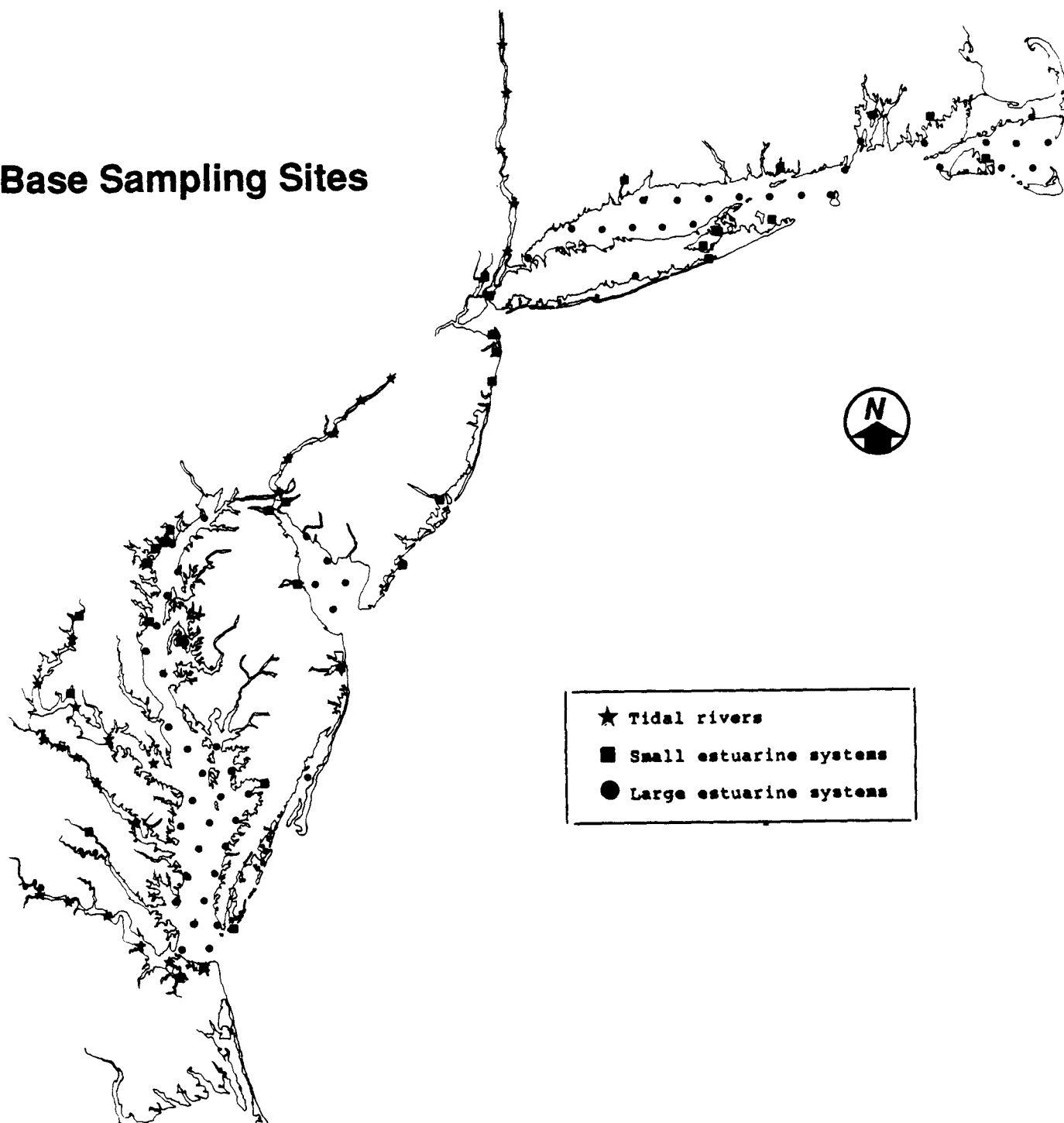


Figure 3-1. Base sampling sites for all classes of estuaries in the 1990 EMAP-NC Demonstration Project in the Virginian Province

Province. The start-point of the spine was at the mouth of the tidal river. The first transect ("rib") was located at a randomly selected river-kilometer between 0 and 25. Additional transects were placed every 25 km from the first, in an upstream direction. On each transect, both an index site and a randomly located sampling point were identified. The randomly selected site was located along the rib. The index site was located in a deep, muddy portion of the transect, usually near the channel, that was expected to have depositional characteristics. Areas of known dredging activity were avoided. The design for large tidal rivers resulted in 25 transects and 50 sampling locations (25 index samples and 25 random samples). The 50 sample locations (index and random) for the large tidal rivers are listed in Table 3-7 and are shown in Fig. 3-1.

3.6.3 Base Sample Selection for Small Estuarine Systems

The small estuarine systems class was composed of 137 systems. For the 1990 Demonstration Project, 32 (i.e., ~ 23%) of the available small estuarine systems were selected for sampling. To ensure the systems selected for sampling were geographically dispersed, they were ordered from north to south by combining adjacent small estuaries into groups of four and selecting a sample at random from each group. Both an index sampling site and a randomly selected sampling site having a depth ≥ 1 m were identified within the boundaries of these 32 small estuaries. The index site was selected using available information on sediment type, depth, and geometry to identify a depositional environment. In small tidal rivers, the index site was located at the mouth of the river in a soft, muddy sediment (e.g., Thames River). In small lagoonal estuaries, the index site was located at the deep central portion in soft mud sediments. The 64 sampling sites (index and random) for small estuarine systems are listed in Table 3-8 and shown in Fig. 3-1.

3.6.4 Definition of the Index Period

Accurate definition of the boundaries of the summer index period is critical to the development of a sampling design that can be used by EMAP-NC over the long term. This is particularly true for indicators that have large seasonal variation (e.g., dissolved oxygen concentration) and for indicators for which little is known about their seasonal variation on regional scales (e.g., contaminants in fish flesh, gross pathology of fish). Because of the importance of accurately defining the boundaries of the index period, sampling for the 1990 Demonstration Project will encompass the entire summer (June 19-September 30). During the summer index period, each of the previously defined sampling locations will be sampled up to

Table 3-7. 1990 base sampling locations [Random (R) and Index (I)] for the large tidal river class

Tidal River	Transect Number	Sample Type	Location			
			Latitude (°N)		Longitude (°W)	
Potomac River	1	R	38°	4.21'	76°	27.88'
		I	38°	3.06'	76°	29.86'
	2	R	38°	13.10'	76°	47.14'
		I	38°	12.22'	76°	47.14'
	3	R	38°	23.89'	77°	5.21'
		I	38°	24.00'	77°	5.00'
	4	R	38°	30.00'	77°	16.49'
		I	38°	30.00'	77°	17.08'
	5	R	38°	44.20'	77°	2.00'
		I	38°	45.00'	77°	2.16'
James River	1	R	36°	55.30'	76°	25.04'
		I	36°	56.10'	76°	25.04'
	2	R	37°	1.92'	76°	34.33'
		I	37°	2.00'	76°	35.00'
	3	R	37°	12.55'	76°	47.89'
		I	37°	12.55'	76°	47.51'
	4	R	37°	16.20'	77°	4.25'
		I	37°	16.10'	77°	4.25'
	5	R	37°	20.00'	77°	16.37'
		I	37°	20.00'	77°	16.50'
Rappahannock River	1	R	37°	44.20'	76°	35.07'
		I	37°	44.00'	76°	35.11'
	2	R	37°	57.90'	76°	52.03'
		I	37°	58.00'	76°	51.71'
	3	R	38°	6.63'	77°	0.00'
		I	38°	6.61'	77°	0.00'
	4	R	38°	9.90'	77°	8.53'
		I	38°	10.00'	77°	8.26'
	5	R	38°	12.02'	77°	15.10'
		I	38°	12.00'	77°	15.13'
Delaware River	1	R	39°	35.00'	75°	34.90'
		I	39°	35.00'	75°	33.50'
	2	R	39°	45.00'	75°	29.00'
		I	39°	45.00'	75°	29.30'
	3	R	39°	52.88'	75°	11.00'
		I	39°	52.91'	75°	11.00'
	4	R	40°	3.03'	74°	58.00'
		I	40°	3.17'	74°	58.00'
	5	R	40°	10.00'	74°	43.68'
		I	40°	10.00'	74°	43.75'

Table 3-7. Continued

Tidal River	Transect Number	Sample Type	Location			
			Latitude (°N)		Longitude (°W)	
Hudson River	1	R	40°	53.00'	73°	56.57'
		I	40°	53.00'	73°	56.00'
	2	R	41°	9.00'	73°	52.97'
		I	41°	9.00'	73°	53.75'
	3	R	41°	23.00'	73°	57.38'
		I	41°	23.00'	73°	57.20'
	4	R	41°	44.00'	73°	56.71'
		I	41°	44.00'	73°	56.60'
	5	R	42°	0.00'	73°	56.33'
		I	42°	0.00'	73°	56.50'

Table 3-8. 1990 sample locations [Random (R) and Index (I)] for the small estuarine systems class

Tidal River or Estuary	Sample Type	Location			
		Latitude (°N)		Longitude (°W)	
<u>Buzzards Bay</u>					
New Bedford Harbor	R	41°	38.55'	70°	54.70'
	I	41°	38.50'	70°	55.25'
<u>Chesapeake Bay</u>					
Pocomoke River	R	37°	59.90'	75°	37.30'
	I	37°	57.80'	75°	38.75'
West River	R	38°	52.70'	76°	31.10'
	I	38°	51.22'	76°	31.10'
Broad Creek	R	38°	44.60'	76°	14.50'
	I	38°	44.99'	76°	14.80'
Anacostia River	R	38°	52.18'	76°	59.85'
	I	38°	51.52'	77°	1.00'
Port Tobacco River	R	38°	22.42'	77°	2.33'
	I	38°	25.01'	77°	1.55'
Patapsco River	R	39°	14.78'	76°	33.42'
	I	39°	13.16'	76°	32.58'
Middle River	R	39°	18.30'	76°	24.60'
	I	39°	18.57'	76°	24.51'
Back River	R	39°	16.20'	76°	26.60'
	I	39°	15.29'	76°	26.62'
Elk River	R	39°	28.78'	75°	56.50'
	I	39°	25.69'	76°	0.82'
Elizabeth River	R	36°	49.91'	76°	17.63'
	I	36°	55.50'	76°	20.70'
Mattaponi River	R	37°	40.50'	76°	54.67'
	I	37°	31.60'	76°	52.63'
<u>Delaware Bay</u>					
Salem River	R	39°	34.83'	75°	29.72'
	I	39°	34.19'	75°	30.84'
Alloway Creek	R	39°	30.10'	75°	32.00'
	I	39°	30.20'	75°	32.06'
Maurice River	R	39°	16.62'	74°	58.70'
	I	39°	12.71'	75°	2.32'
<u>Delaware Coast</u>					
Indian River Bay	R	38°	35.60'	75°	6.70'
	I	38°	36.10'	75°	7.74'

Table 3-8. Continued

Tidal River or Estuary	Sample Type	Location			
		Latitude (°N)		Longitude (°W)	
<u>East Long Island</u>					
Great Peconic Bay	R	40°	57.40'	72°	30.20'
	I	40°	55.88'	72°	31.09'
Little Peconic Bay	R	41°	0.00'	72°	24.70'
	I	41°	0.00'	72°	25.03'
Napeague Bay	R	41°	3.70'	72°	0.10'
	I	41°	4.20'	72°	28.40'
Shinnecock Bay	R	40°	52.30'	72°	28.40'
	I	40°	51.58'	72°	28.85'
<u>Hudson/Raritan</u>					
Hackensack River	R	40°	45.00'	74°	5.20'
	I	40°	45.00'	74°	5.00'
Sandy Hook Bay	R	40°	27.60'	74°	4.50'
	I	40°	26.50'	74°	1.60'
Upper New York Bay	R	40°	38.80'	74°	3.50'
	I	40°	40.00'	74°	2.70'
<u>Long Island Sound</u>					
Mystic River	R	41°	21.88'	71°	57.87'
	I	41°	19.50'	71°	58.50'
Housatonic River	R	41°	17.20'	73°	4.32'
	I	41°	10.00'	73°	5.50'
<u>New Jersey Coast</u>					
Mullica River	R	39°	32.50'	74°	24.50'
	I	39°	31.10'	74°	24.50'
Shrewsbury River	R	40°	20.60'	73°	59.20'
	I	40°	20.55'	74°	0.00'
Shark River	R	40°	11.38'	74°	1.90'
	I	40°	11.60'	74°	2.40'
Barnegat Bay	R	39°	56.60'	74°	6.11'
	I	29°	46.71'	74°	7.50'
<u>Nantucket/Vineyard</u>					
Edgartown Harbor	R	41°	25.60'	70°	31.00'
	I	41°	24.50'	70°	28.90'
<u>Virginia Coast</u>					
Magothy Bay	R	37°	7.80'	75°	54.90'
	I	37°	10.00'	75°	55.27'
Sand Channel	R	37°	17.98'	75°	50.00'
	I	37°	18.16'	75°	48.10'

three times for parameters anticipated to have high within-summer variability (e.g., dissolved oxygen concentration, fish abundance and species composition). The three sampling intervals will be: (1) June 19 through July 18, (2) July 19 through August 31, and (3) September 1 through approximately September 30.

Seasonal variation in dissolved oxygen concentration and temperature are two of the most important factors controlling index period boundaries. To assist with defining index period boundaries, continuous dissolved oxygen, temperature, tidal stage, salinity, and pH measurements will be made from the middle of June to the end of August at 30 of the 116 sampling sites (Fig. 3-2; Table 3-9). At each of these stations the benthic species composition and biomass indicators will also be measured at approximately the beginning, middle, and end of the deployment period to define relationships between environmental conditions (e.g., dissolved oxygen exposure) and benthic parameters and to assess the stability of benthic indicators over the index period. Continuous monitoring can not be initiated at a larger number of stations because it is not logistically feasible.

The 30 locations selected for continuous water quality monitoring include 13 locations in large estuarine systems, five locations in large tidal rivers, and 12 locations in small estuarine systems. They are dispersed throughout the region. Available information and expert opinion suggested that during summer, these stations should experience a broad range of dissolved oxygen conditions. Many have a high probability of consistently exhibiting dissolved oxygen concentrations greater than 3.0 mg/l. At the other extreme, many also have a high probability of consistently exhibiting dissolved oxygen concentrations of less than 2.0 mg/l.

Some (up to 25%) of the Hydrolab DataSonde 3 monitors will be removed from service because they become damaged, lost, stolen, or fail to operate properly. As a result, by the end of the second sampling interval continuous monitoring will probably be conducted at only a subset of the original stations. To ensure that measurements are continued at those stations which are likely to provide the data of highest value to EMAP-NC, the relative order in which stations will be removed from service if necessary to ensure coverage of higher value data is shown in Table 3-9.

Dissolved Oxygen Monitoring Sites

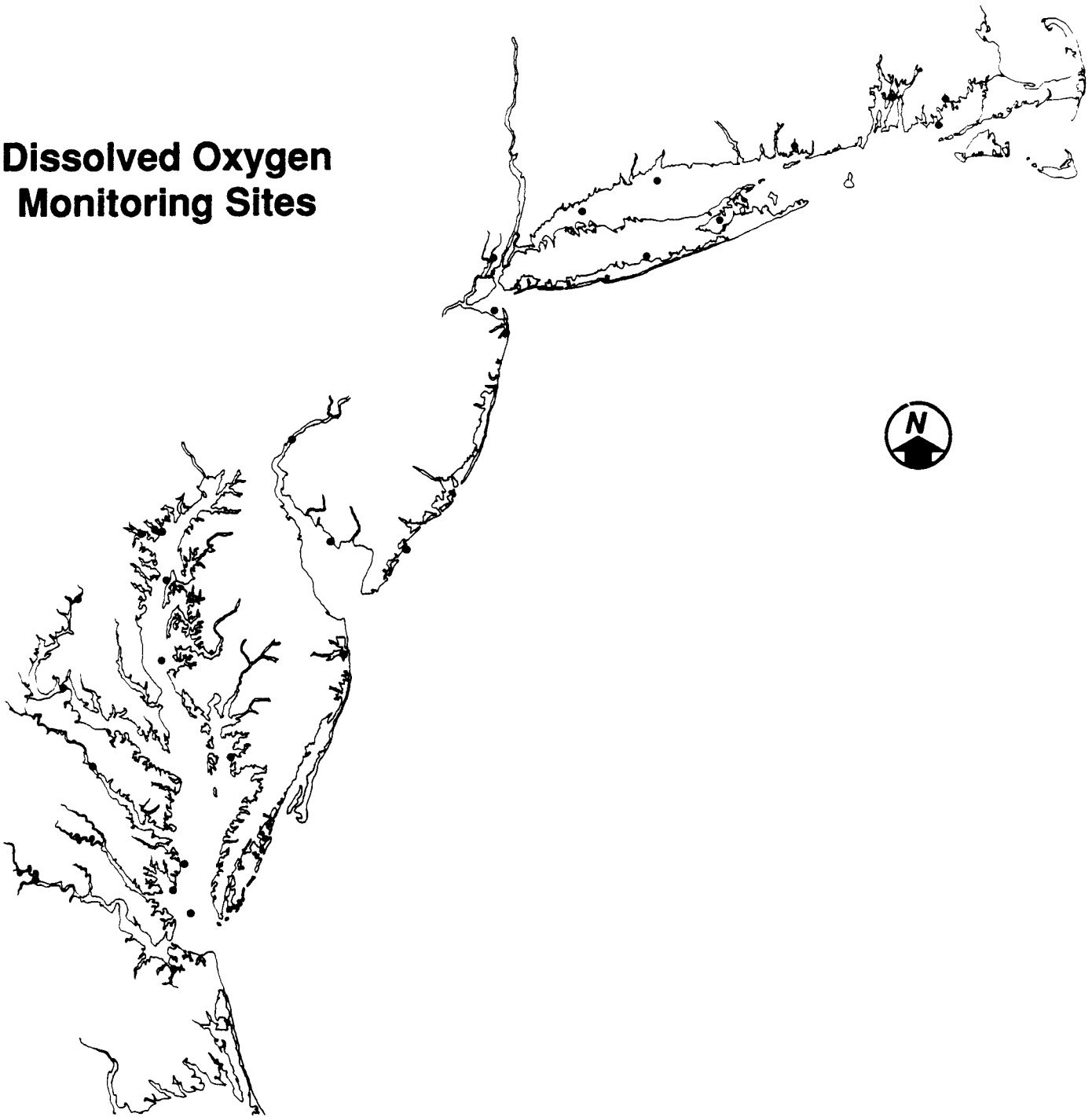


Figure 3-2. Sites for which dissolved oxygen concentrations will be monitored continuously from June 19 through August 30 for the 1990 EMAP-NC Demonstration Project in the Virginian Province

Table 3-9. 1990 Demonstration Project sampling sites for continuous dissolved oxygen monitoring

Tidal River or Estuary	Order of Removal of Service	Latitude (°N)		Location Longitude (°W)	
<u>Buzzards Bay</u>					
Buzzards Bay	4	41°	30.54'	70°	57.55'
New Bedford Harbor	24	41°	38.55'	70°	54.70'
<u>Narragansett Bay</u>					
Narragansett Bay	19	41°	38.48'	71°	18.01'
<u>East Long Island</u>					
Great Peconic Bay	18	40°	57.40'	72°	30.20'
Napeague Bay	1	41°	3.70'	72°	0.10'
<u>Long Island Sound</u>					
Long Island Sound	30	41°	9.97'	72°	55.55'
Long Island Sound	29	41°	0.13'	73°	27.68'
Mystic River	8	41°	21.88'	71°	57.87'
<u>Hudson/Raritan</u>					
Sandy Hook Bay	2	40°	27.60'	74°	4.50'
Hackensack River	28	40°	45.00'	74°	5.20'
<u>New Jersey Coast</u>					
Barnegat Bay	23	39°	56.60'	74°	6.11'
Shrewsbury River	26	40°	20.60'	73°	59.20'
<u>Delaware Coastal Bays</u>					
Indian River Bay	25	38°	35.60'	75°	6.70'
<u>Delaware Bay/River</u>					
Delaware Bay	17	39°	20.60'	75°	20.20'
Delaware River	13	39°	45.00'	75°	29.00'
Delaware River	5	40°	3.03'	74°	58.00'

Table 3-9. Continued

Tidal River or Estuary	Order of Removal of Service	Location			
		Latitude (°N)		Longitude (°W)	
<u>Chesapeake Bay</u>					
Tangier Sound	12	38°	1.68'	75°	54.10'
Chesapeake Bay	16	38°	59.20'	76°	21.48'
Chesapeake Bay	11	38°	33.45'	76°	24.08'
Anacostia River	27	38°	52.18'	76°	59.85'
Potomac River	9	38°	23.89'	76°	5.04'
Elk River	6	39°	28.78'	75°	56.50'
Patapsco River	15	39°	14.78'	76°	33.42'
Back River	21	39°	16.20'	76°	26.60'
Elizabeth River	20	36°	19.91'	76°	17.63'
Chesapeake Bay	14	37°	9.21'	76°	11.61'
Chesapeake Bay	3	37°	26.07'	76°	14.11'
Chesapeake Bay	10	37°	17.15'	76°	19.05'
Rappahannock River	22	37°	57.90'	76°	52.03'
James River	7	37°	20.00'	77°	16.37'

3.6.5 Indicator Testing and Evaluation

Sufficient information is not available to verify the reliability of indicator responses for the estuaries in the Virginian Province. Therefore, a study to determine the reliability of indicators to discriminate between polluted and unpolluted environments will be conducted. Samples for this study will be collected at 23 locations (11 polluted and 12 unpolluted) (Table 3-10; Fig. 3-3). These 23 locations include three major salinity zones (i.e., marine/polyhaline, mesohaline, oligohaline/tidal freshwater) and two geographic regions (Chesapeake Bay and coastal regions north of the New York Harbor). Four sample sites, which are expected to exhibit varying combinations of pollution stress, are located in each salinity zone of each geographic region (Fig. 3-4). For example, the polyhaline zone within Chesapeake Bay will be represented by samples from Hampton Roads, Virginia (high contaminant levels, high dissolved oxygen); Elizabeth River, Virginia (high contaminant levels, low dissolved oxygen); Rappahannock Shoals, Virginia (low contaminant levels, low dissolved oxygen), and the lower mainstem of Chesapeake Bay (low contaminant levels, high dissolved oxygen). Indicator testing and evaluation sites will be sampled to the degree possible during the July 20-August 30 interval. The entire suite of core, developmental, and research indicators will be measured at each site.

3.6.6 Supplemental Sampling

Sufficient data are not available to ascertain the spatial sampling scale necessary to represent the ecological condition of estuarine systems in the Virginian Province adequately. To address this problem for large estuaries and large tidal rivers, Delaware Bay (both the estuary and tidal river portion) will be sampled at a density four times greater (i.e., sample points approximately 9 km apart; 33 additional sampling sites) than other large estuaries and tidal rivers (Table 3-10 and Fig. 3-5). This spatially intensive data set will be used to evaluate the benefits of an enhanced grid for the assessment of ecological condition for large estuarine systems and large tidal rivers. The data resulting from the supplemental sampling program in Delaware Bay also will provide information to assist the Delaware Bay National Estuary Program in identifying environmental concerns, designing future monitoring activities, and preparing the Comprehensive Conservation Management Plan (CCMP). This information will provide a data set EMAP-NC can use to evaluate the effect of spatial scale on DQOs.

Table 3-10. Locations of indicator testing and evaluation sites for 1990 Demonstration Project. [G (Geographic Location): N = North, S = South; S (Salinity): P = Polyhaline, M = Mesohaline, O = Tidal Fresh/Oligohaline; C (Sediment Contaminant Concentrations): H = High, L = Low; DO (Dissolved Oxygen Concentration): H = High, L = Low; * = base program stations]

Indicator Test Site	G	S	C	DO	Location	
					Latitude (°N)	Longitude (°W)
Chesapeake Bay	S	M	L	L	38° 53.38'	76° 24.06'
Bear Creek	S	M	H	L	38° 14.60'	76° 29.79'
Colgate Cove	S	M	H	H	38° 15.20'	76° 33.10'
South River	S	M	L	H	38° 52.70'	76° 30.90'
Rappahannock River	S	P	L	L	37° 37.40'	76° 27.90'
Chesapeake Bay	S	P	L	H	37° 4.00'	76° 10.00'
Elizabeth River *	S	P	H	L	36° 49.91'	76° 17.63'
James River	S	P	H	H	37° 0.00'	76° 20.00'
Anacostia River *	S	O	L	L	38° 52.18'	76° 59.85'
Bohemia River	S	O	L	H	39° 22.70'	76° 0.00'
Back River *	S	O	H	L	39° 16.20'	76° 26.60'
Bush River	S	O	H	H	39° 26.60'	76° 14.75'
Connecticut River	N	M	L	H	41° 20.80'	72° 22.70'
Arthur Kill	N	M	H	L	40° 37.30'	74° 12.20'
Quinnipiac River	N	M	H	H	41° 18.80'	72° 53.15'
Hempstead Bay	N	P	L	L	40° 55.22'	73° 38.70'
Long Island Sound *	N	P	L	H	41° 11.46'	72° 15.96'
Blackrock Harbor	N	P	H	L	41° 9.58'	73° 12.62'
New Bedford Harbor *	N	P	H	H	41° 38.55'	70° 55.00'
Shrewsbury River *	N	O	L	L	40° 20.60'	73° 59.20'
Hudson River *	N	O	L	H	41° 23.00'	73° 57.38'
Hackensack River *	N	O	H	L	40° 45.00'	74° 5.20'
Passaic River	N	O	H	H	40° 45.00'	74° 9.90'

Indicator Testing and Evaluation Sites

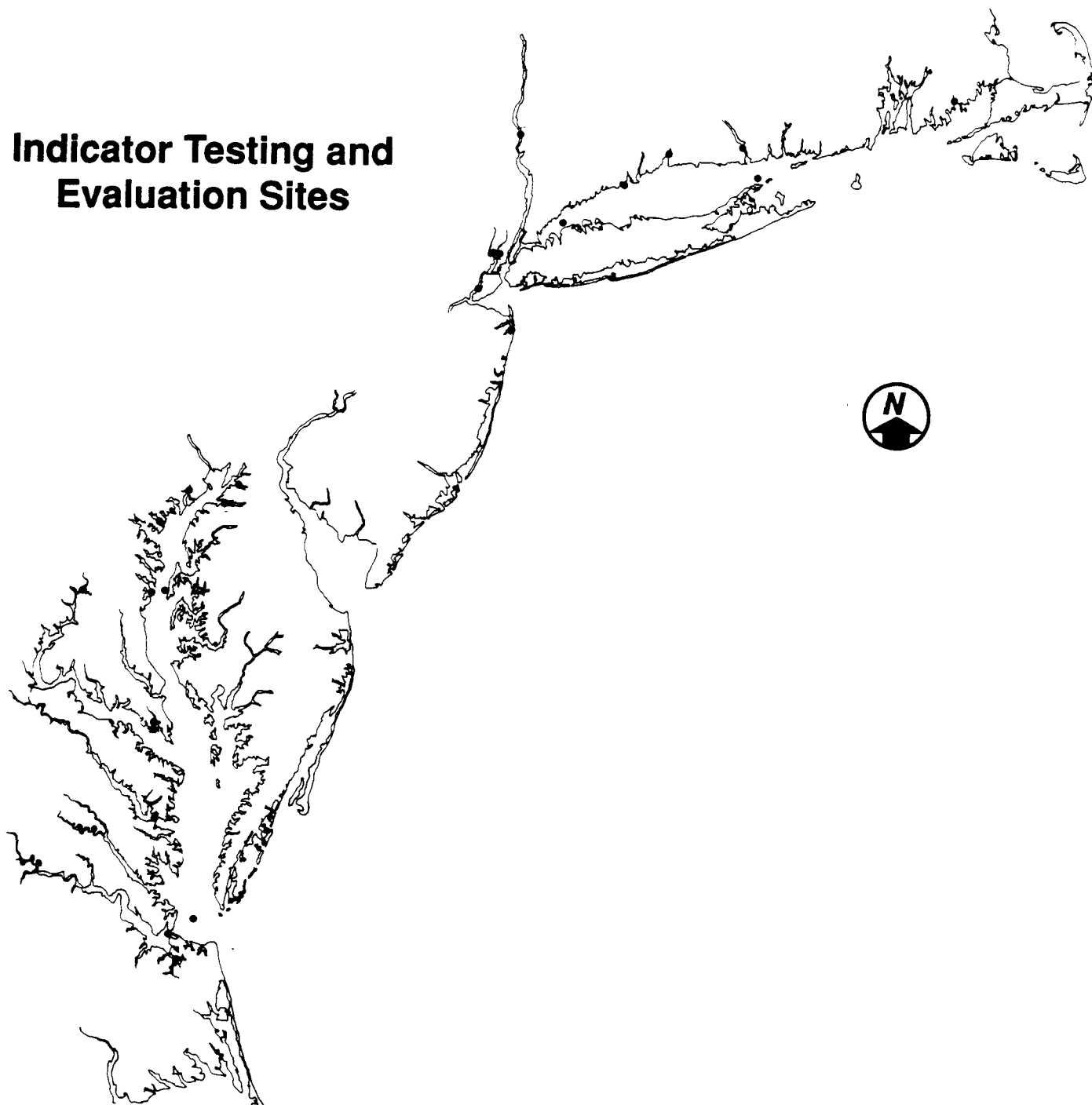
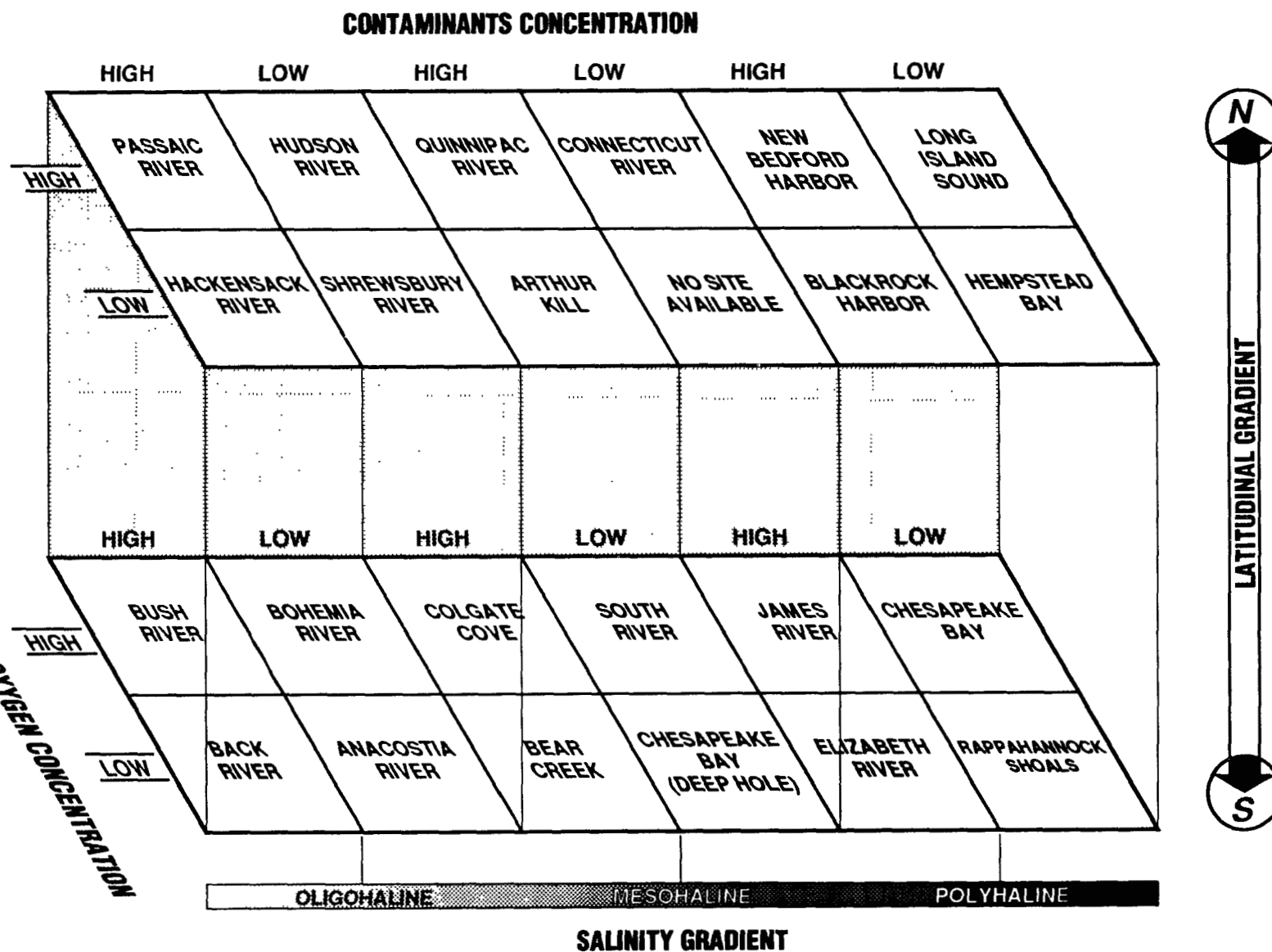


Figure 3-3. Indicator testing and evaluation sites to be sampled during the 1990 EMAP-NC Demonstration Project in the Virginian Province



Supplemental Sampling Sites

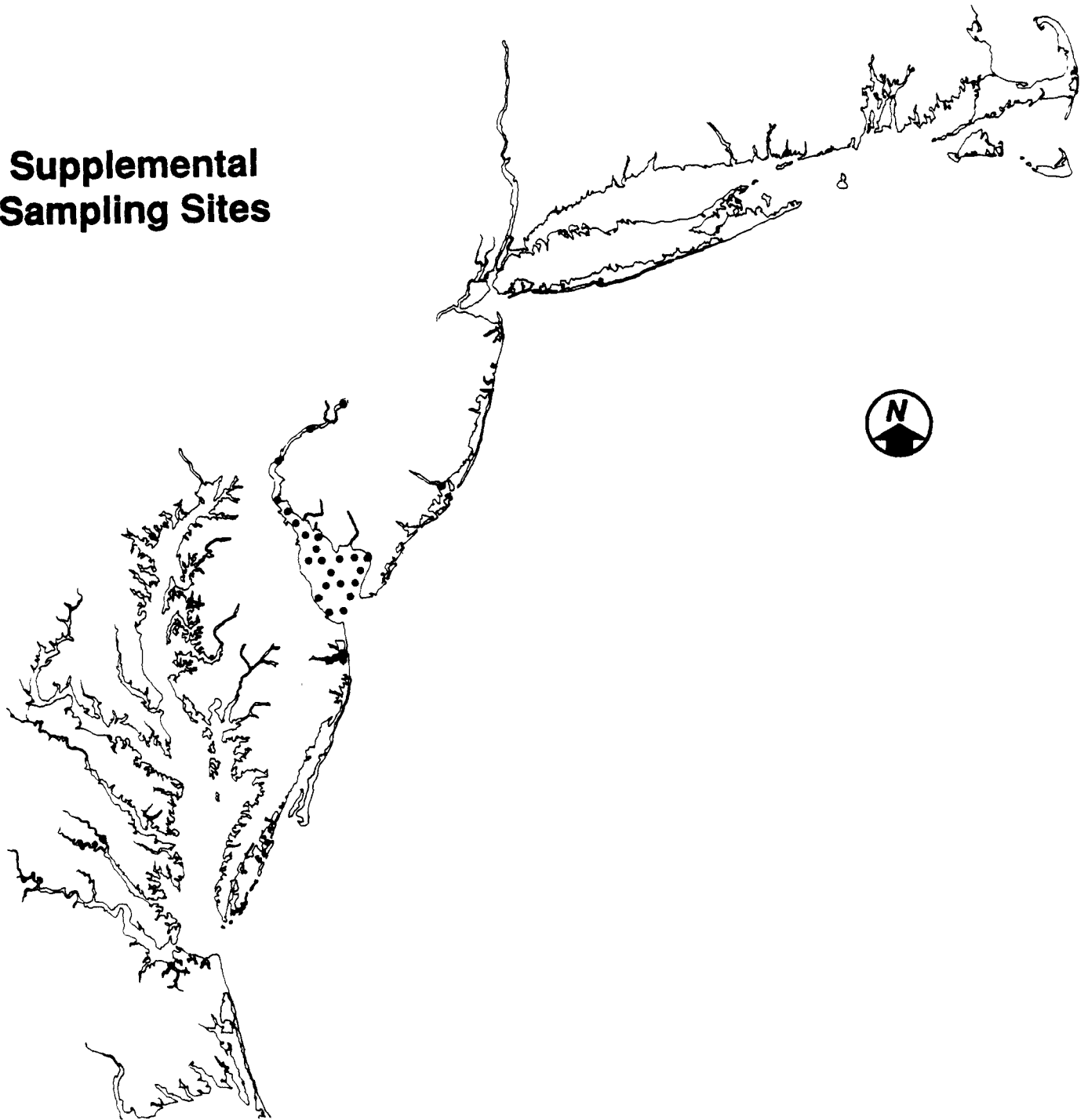


Figure 3-5. Supplemental sampling sites for the 1990 EMAP-NC Demonstration Project in the Virginian Province

Two types of supplemental samples will be collected to determine the appropriate scale for representing resource condition for small estuarine systems: (1) five randomly located replicate samples from five separate systems, and (2) four randomly located supplemental samples in one small estuarine system (i.e., Indian River). Supplemental samples from small estuarine systems will be used to determine the effect of replicate samples on estimates of variance and population estimates. The supplemental sample sites in small estuarine systems for the 1990 Demonstration Project are listed in Table 3-11 and shown in Fig. 3-5.

3.6.7 Potential for Subpopulation Estimation

Table 3-12 delineates the anticipated number of samples within some of the subpopulations of interest for the Virginian Province. Variables used to form these classes include geographic sub-region, salinity, and vulnerability to pollution loadings. The distribution of sampling sites based on vulnerability to pollution stress was based on physical characteristics that determine the capacity of an estuary to retain pollutants (Biggs and Howell 1984). The number of samples included in some subpopulations (e.g., salinity zones) in Table 3-12 is subject to change due to the transient nature of variables that define those classes. The information in Table 3-12 suggests that the proposed design allows definition of a broad range of subpopulations.

Due to the incomplete knowledge of sediment distributional patterns for the Virginian Province, the potential numbers of samples available for assessing the status for major sediment types was not estimated. Historical data for sediment distributions of the estuaries of the Virginian Province will be compiled, and maps of sediment distributions will be prepared by NOAA Strategic Assessment Branch as a part of EMAP-NC activities during 1990-1991.

3.7 Overview of Sampling Activities

The Virginian Province Demonstration Project sampling activities will be conducted during a summer index period, extending from mid-June through the end of September. This period is divided into three sampling intervals: June 19 through July 18, July 19 through August 30, and September 1 through approximately September 30. A total of 215 sites will be sampled in 1990 (Fig. 3-6) as follows:

- 111 base sampling sites

Table 3-11. Locations of supplemental sampling sites in the 1990 Demonstration Project to assess spatial variability due to scale in large estuarine systems and small sample size in small estuarine systems

Tidal River or Estuary		Location			
		Latitude (°N)		Longitude (°W)	
<u>Large Systems</u>					
Delaware Bay		38°	51.72'	75°	6.52'
		38°	51.37'	75°	12.93'
		38°	56.33'	75°	4.03'
		38°	55.48'	75°	16.78'
		38°	59.93'	75°	13.93'
		39°	9.27'	75°	55.51'
		39°	4.98'	75°	59.14'
		39°	8.91'	75°	1.86'
		39°	8.72'	75°	8.12'
		39°	8.25'	75°	15.23'
		39°	7.97'	75°	20.40'
		39°	12.24'	75°	17.70'
		39°	16.62'	75°	14.97'
		39°	16.21'	75°	22.31'
		39°	20.23'	75°	26.27'
		39°	27.86'	75°	33.72'
		39°	24.21'	75°	29.45'
		39°	0.71'	75°	1.52'
		39°	0.32'	75°	8.00'
		39°	4.11'	75°	11.76'
<u>Delaware River</u>					
Transect 1B	R	39°	40.00'	75°	32.09'
Transect 2B	R	39°	50.81'	75°	20.00'
Transect 3B	R	39°	58.41'	75°	6.00'
Transect 4B	R	40°	6.00'	74°	50.36'

Table 3-11. Continued

Tidal River or Estuary	Location			
	Latitude (°N)		Longitude (°W)	
<u>Indian River Bay</u>				
	38°	35.01'	75°	10.59'
	38°	36.14'	75°	8.22'
	38°	35.71'	75°	4.99'
	38°	36.67'	75°	6.58'
	38°	36.62'	75°	5.65'
<u>Small Systems</u>				
Back River, MD	39°	16.50'	76°	27.00'
Elizabeth River, VA	36°	50.10'	76°	21.40'
Mattaponi River, VA	37°	36.90'	76°	50.80'
Mystic River, CN	41°	20.30'	71°	58.50'
Mullica River, NJ	39°	33.10'	74°	24.90'

Table 3-12. Number of samples that will be taken in the 1990 Demonstration Project in the Virginian Province and the 1990-1993 cycle that could be used for subpopulation estimation. Number of samples in salinity categories could change based on actual salinities.

Subpopulation Estimation Classes	Number of Samples Including Replicates
Geographic Sub-regions:	
Buzzards Bay	4
Nantucket Sound	5
Cape Code Region	8
Narragansett Bay	2
Block Island Sound	4
Long Island Sound	20
East Long Island Bays	6
Coastal Long Island Bays	3
Hudson/Raritan	20
New Jersey Coastal Bays	10
Delaware Bay/River	49
Delaware Inland Bays	6
Maryland/Virginia Coastal Bays	5
Chesapeake Bay	93
Salinity Zones:	
Polyhaline	90
Mesohaline	98
Tidal Fresh/Oligohaline	27
Pollution Vulnerability Zones:	
Low	35
Moderate	120
High	60

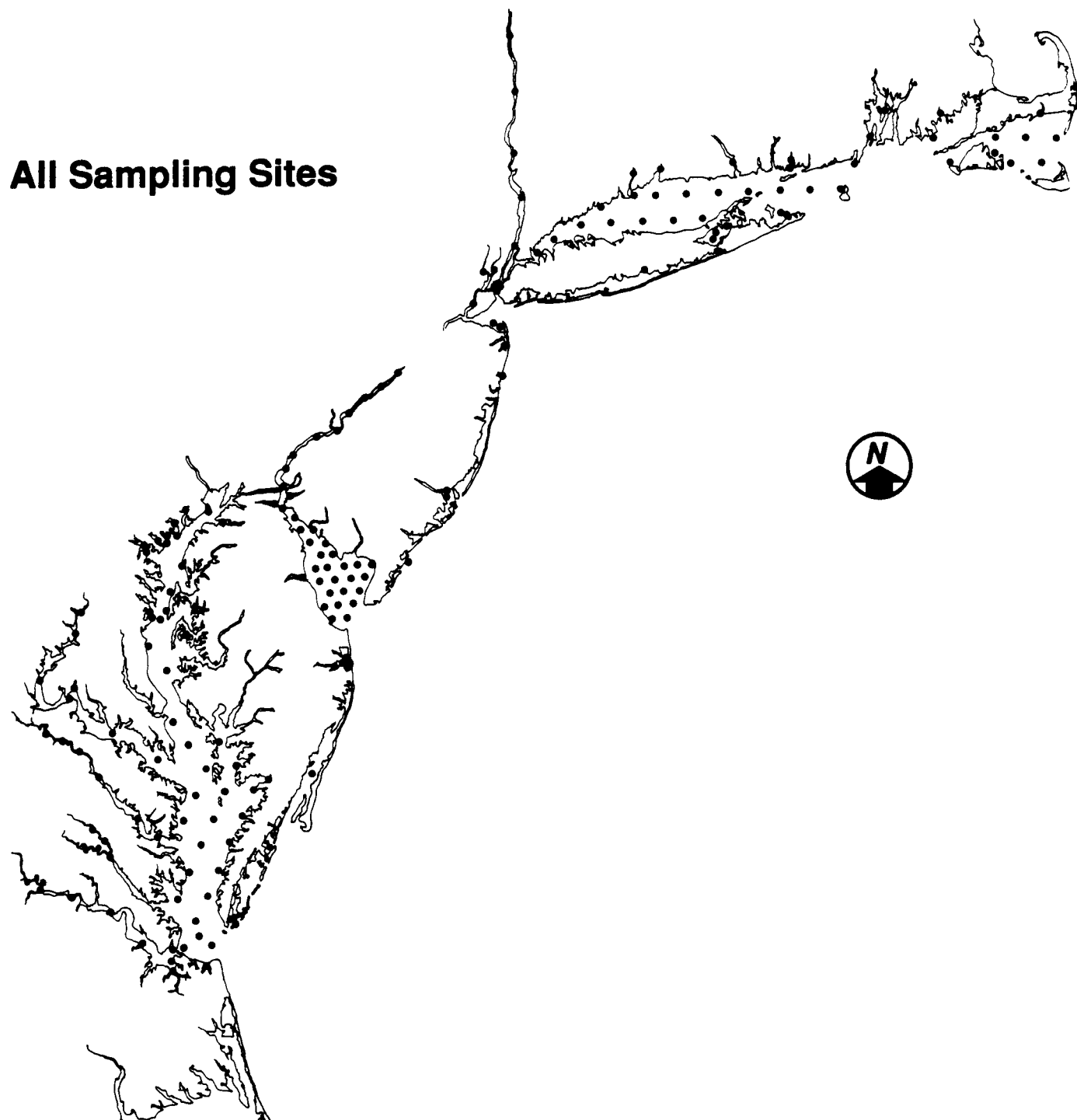


Figure 3-6. All sites to be sampled during the 1990 EMAP-NC Demonstration Project in the Virginian Province

- 30 continuous dissolved oxygen monitoring sites (a subset of the 111 base sampling sites)
- 23 indicator testing and evaluation sites (9 of which are a subset of the 111 base sampling sites)
- 57 index sampling sites in small estuaries and large tidal rivers
- 33 supplemental sampling sites.

EMAP-NC will be focused on collecting data for indicators of environmental quality during an index period, when responses to stress are anticipated to be most severe. The sampling design will combine the strengths of systematic and random sampling with an understanding of estuarine systems to collect data that will provide unbiased estimates of the status of the nation's estuarine resources. This design also will provide reasonable approximations of the variability associated with status estimates.

The following characteristics distinguish the EMAP-NC sampling design from that used by most other monitoring program designs:

- The scale of sampling is regional. The spatial scale of most other monitoring programs is smaller (i.e., individual estuarine systems or portions of systems) (Wolfe et al. 1987; NRC 1990a, 1990b).
- Standardized sampling methods are used across broad geographical regions. Sampling methods used by most monitoring programs are not generally standardized across regions; therefore, data rarely can be combined to perform regional or national assessments (NRC 1990a, 1990b).
- Measurements are focused on categories of indicators that are linked to major environmental concerns (i.e., endpoints) and to each other, allowing identification of the extent and magnitude of impacts associated with potential stressor categories or causes. Most other monitoring programs are specific to one pollution problem and sample only a few parameters directly related to it. Frequently, different programs monitoring the effects of the same pollution problem, in the same system, sample different parameters (NRC 1990b). As a result, data from ongoing programs rarely can be combined to estimate the regional extent of impacts of even one pollution problem (NRC 1990a).

- A combination of random and systematic sampling is used to obtain complete geographic coverage of rare and abundant resources and unbiased estimates of status and trends for all estuarine types. Most other monitoring programs sample at fixed stations, do not have complete coverage of resource types or distributions, and do not include both random and systematic elements (NRC 1990a; Wolfe et al. 1987).
- Index samples will be collected to facilitate and enhance the interpretation of the data from randomly selected sites. Most other monitoring programs sample only at representative sample sites. Unfortunately, these programs do not know the degree to which the data they collect are representative of actual conditions in a probabilistic sense (NRC 1990a).
- The time frame of sampling is long-term (decades), and trend evaluations will be based on multiyear baselines. Most other monitoring programs are limited in duration (several years), and establish baselines based on one or two years of data; therefore, evaluation of trends relies on differences among years (Wolfe et al. 1987; NRC 1990a). This approach is clearly flawed because of the high year-to-year variation characteristic of estuarine and coastal resources (Holland et al. 1987).

4.0 INDICATOR DEVELOPMENT AND EVALUATION

EMAP-NC does not have the resources to monitor all of the ecological parameters of concern to the public, Congress, scientists and environmental managers. Therefore, the limited resources available must be focused on the system attributes that are of greatest concern and best address program objectives. The purpose of this chapter is to describe and explain the strategy used by EMAP-NC to identify and select indicators. In the first two sections of the chapter, we describe the generic approach to indicator selection that is being used by all resource groups within EMAP. In the remaining sections of the chapter, we describe the application of that approach to identify indicators to be measured during the 1990 Virginian Province Demonstration Project and those that are still being considered for incorporation into the program in future years.

4.1 The EMAP Indicator Strategy

Selection of indicators is based on a "top-down", risk assessment approach. Within a risk assessment framework, anthropogenic influences that have the potential to affect indigenous populations deleteriously (e.g., inputs of toxic materials) are referred to as stressors. The magnitude of the stress to which living resources are exposed depends on the concentration and duration of the exposure, as well as the habitat characteristics and physical conditions prevailing at the exposure site. Most animals have a variety of behavioral responses that minimize or reduce exposure to pollutants, including avoidance and/or modification of certain biochemical and physiological processes. If behavioral responses fail to reduce exposure, a "dose" occurs that may cause impaired function, alterations in physiological condition, death, or a change in species composition (e.g., Pearson and Rosenberg 1978; Gray 1982). These impairments may, in turn, adversely alter ecosystem attributes, such as production of fisheries and wildlife, as well as beneficial functions, such as fishing and swimming, that are valued by society.

The traditional "bottom-up" approach to risk assessment emphasizes measurement of stressors and uses mathematical models of transport, transformation, and fate processes to estimate exposure levels. Estimates of exposures are coupled to the results of laboratory toxicological information using dose-response models, and ecological effects are predicted. The "bottom-up" approach to risk assessment is a reasonable way to approach the assessment of

single pollutant hazards where transport, transformation, and effects are understood and can be modeled reliably (Fava et al. 1987).

Ecological resources, however, are more often affected by multiple pollutants arriving in multiple media. These interactions, mediated by highly variable natural processes and pollution abatement actions, exert both direct and higher order (e.g., indirect) effects. The "bottom-up" approach to risk assessment may not detect unanticipated interactions and is often incapable of modeling poorly understood natural processes (Wolfe et al. 1987, Levin et al. 1984, Fava et al. 1987). To resolve these problems, EMAP has adopted the "top-down," effects-driven approach to risk assessment. Here, emphasis is placed on identification of higher order effects which then are decomposed to identify the associated hazard or stressors, by using exposure information. This approach is more likely to measure and explain cumulative impacts of natural and anthropogenic influences on ecological resources than is a "bottom-up" approach.

4.2 Framework for Indicator Selection

EMAP is an evolving program; therefore, the selection of indicators to be used in the program is an ongoing process. The selection process consists of six phases in which all potential indicators are identified as candidates, and each is classified on an ascending scale from candidate to research to developmental to core (Fig. 4-1), according to the degree to which evaluation criteria generic to all resource groups of EMAP are met (Table 4-1). At each successive stage in the scale (candidate through core), the number of evaluation criteria that must be met, the degree to which the criteria must be exhibited, and the extent of external review, become more stringent. This section describes the tiered approach to indicator selection and development being used by all resource groups in EMAP, and the following section describes the application of this approach to EMAP-NC.

The six phases of the EMAP indicator selection process are:

- 1) Identification of issues (environmental values and apparent stressors) and valued ecosystem attributes (assessment endpoints)
- 2) Development of a conceptual model that links expected stressors to the identified endpoints and, in so doing, assists in identifying candidate indicators of environmental stress
- 3) Screening the candidate indicators based on a set of evaluation criteria, selecting as research indicators those that appear to fulfill key requirements, rejecting those indicators that clearly do not, and

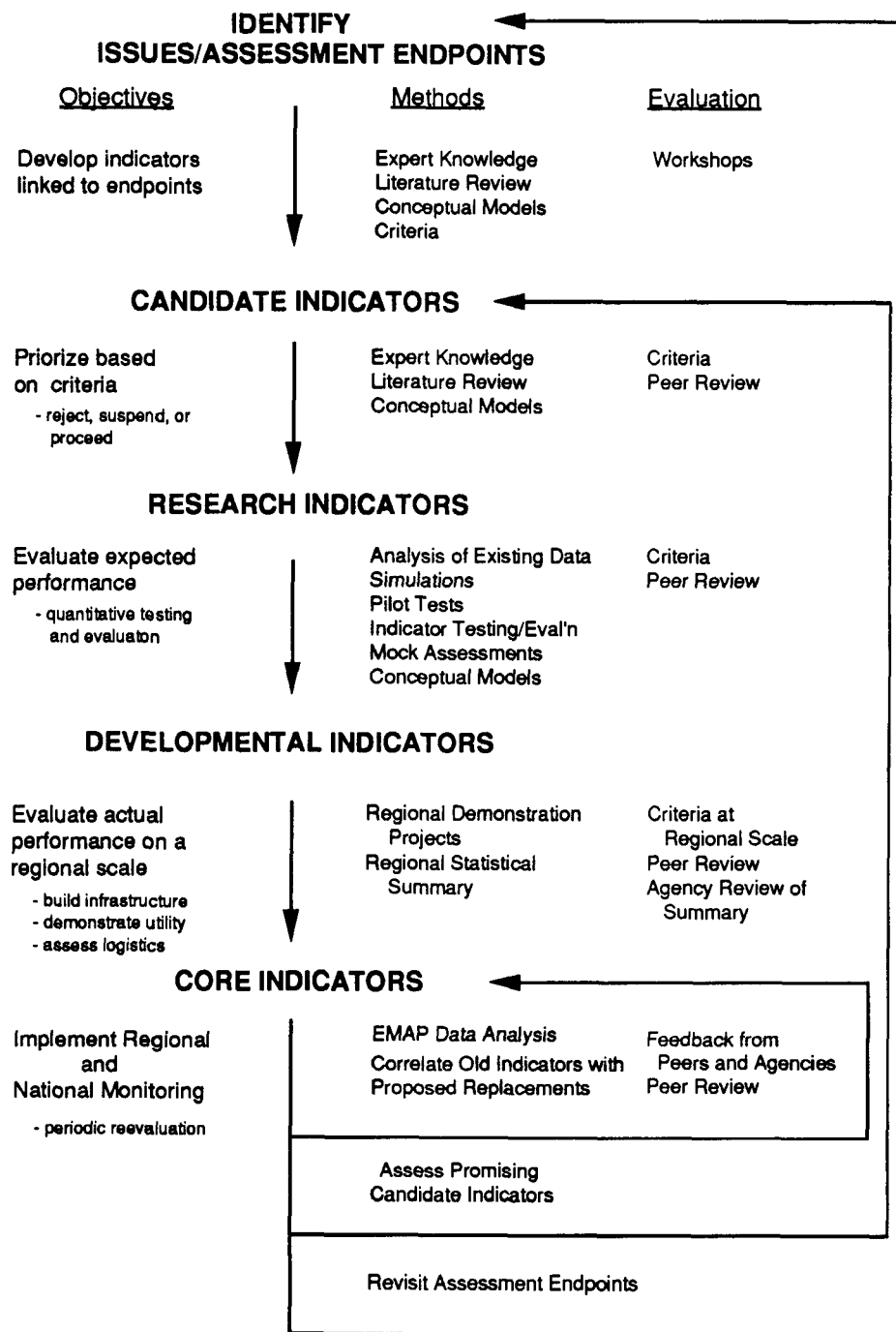


Figure 4-1. Framework for indicator development

Table 4-1. General indicator selection criteria

Critical Criteria

Regionally Responsive	Must reflect changes in ecosystem condition and respond to stressors of concern across most resource classes and habitats within a region
Unambiguously Interpretable	Must be related unambiguously to an assessment endpoint or relevant exposure or habitat variable that forms part of the ecosystem group's overall conceptual model of ecological structure and function
Low Measurement Error	Exhibits low measurement error and stability of regional cumulative frequency distribution during index period (low temporal variation in regional statistics)
Simple Quantification	Can be quantified by synoptic monitoring or by cost effective automated monitoring
Environmental Impact	Sampling must have minimal environmental impact
Low Year-to-Year Variation	Must have sufficiently low natural year-to-year variation to detect ecologically significant changes within a reasonable time frame

Desirable Criteria

Sampling Unit Stable	Measurements of response indicator taken at a sampling unit (site) should be stable over the course of the index period (to conduct associations)
Available Method	Should have a generally accepted, standardized measurement method that can be applied on a regional scale
Historical Record	Has a historical data base, or a historical data base can be generated from accessible data sources
Retrospective	Can be related to past conditions via retrospective analyses
Anticipatory	Provides an early warning of widespread changes in ecosystem conditions or processes
Cost Effective	Has low incremental cost relative to its information
New Information	Provides new information; does not merely duplicate data already collected by cooperating agencies

holding in a state of "suspended evaluation" those candidate indicators for which there is insufficient information to advance to research status but for which no "fatal flaw" has been identified

- 4) Evaluation and testing of the ability of research indicators to discriminate between polluted and unpolluted sites over the range of environmental settings that occur on regional scales to identify the subset of developmental indicators suitable for application in a regional demonstration project
- 5) Regional scale demonstration of the sensitivity, reliability, and specificity of response for developmental indicators, using the sampling frame, sampling methods, and data analyses that will be used in the fully-implemented EMAP
- 6) Periodic re-evaluation of core indicators after they have been incorporated into EMAP.

In the first two phases of the indicator development process, a comprehensive list of potential indicators is developed by identifying all state and process variables that link stresses to impacts. The next three phases are a stepwise reduction of this list by critical evaluation to a defensible, practical set of core indicators that will be used in the implementation phase of the program.

The first phase focuses on defining the two ends of a conceptual model that links sources and receptors. At one end are the environmental perturbations that are causes of concern (e.g., human population density, deforestation, improper waste treatment, sea level rise). At the other end are the valued ecosystem attributes that are likely to be affected by the environmental stressors. Consistent with the "top-down" approach, more emphasis is placed on identifying all of the valued ecosystem attributes than on identifying all of the possible stressors.

Valued ecosystem attributes are often referred to as endpoints of concern, or assessment endpoints, and are formal expressions of the actual environmental value that is to be protected. The goal of EMAP is to identify endpoints that: (1) have unambiguous operational definitions, (2) have social and/or biological relevance, and (3) can be predicted or measured. Identification of environmental values and assessment endpoints requires a broad perspective of resource values (as expressed by resource managers, scientists, private industry, legislators, and the general public) and resource stresses (which may occur on local to global spatial scales, and over short to long term temporal scales). Many of the potential clients of EMAP, including EPA Regional Offices, EPA Program Offices, and other state and federal agencies, as well as scientists, environmental activity groups, and industry are consulted during this phase to ensure that the valued ecosystem

attributes and problems identified have broad-based support and will yield useful information.

The second phase of the process is to develop an explicit conceptual model of the ecosystem that links the valued ecosystem attributes with the environmental stresses identified in phase 1. The model identifies the causal pathways by which stresses and valued ecosystem attributes are connected, and serves as a tool for identifying candidate indicators. The ecological components and processes within the model include all possible measures of system function between the two ends of the spectrum of interest. The model also provides a framework for defining how the core indicators ultimately selected will be linked together in the analysis and interpretation phase.

One of the ecosystem attributes that will be employed as an endpoint by all of the EMAP resource groups is biotic integrity. It is important to recognize that not all indicators leading to that endpoint will serve the same function in analysis of the data. For a model related to the biotic integrity endpoint, EMAP will be measuring four types of indicators including the following:

- 1) Response Indicators -- Characteristics of the environment measured to provide evidence of the ecological condition of a resource for supporting valued ecosystem attributes (e.g., species composition, abundance, and biomass of important biota)
- 2) Exposure Indicators -- Characteristics of the environment measured to provide evidence of the occurrence or magnitude of physical, chemical, or biological stress (e.g., contaminant concentrations in sediments, the toxicity of sediments to endemic biota, dissolved oxygen concentration)
- 3) Habitat Indicators -- Physical, chemical and biological attributes measured to characterize conditions necessary to support an ecological or human use in the absence of pollutants (e.g., sediment characteristics, salinity vegetation type and extent)
- 4) Stressor Information -- Natural processes, environmental hazards, or management actions that effect changes in exposure and habitat indicators (e.g., pollutant loadings, hydrologic modifications, land use).

Response indicators are the measures that will be used to assess status and trends. Exposure and habitat indicators will be used to explain patterns observed for response variables. Exposure or habitat indicators also identify possible threats

to ecosystems. Stressor information will be used to identify the likely sources of the problem. Figure 2-2 shows the relationships among indicator types schematically.

While the first and second phases of the indicator selection process are targeted towards inclusion of all relevant possible indicators, the next three phases of the EMAP indicator development strategy focus on exclusion of indicators that currently cannot be measured within EMAP constraints, as well as identifying a subset of the indicators to be elevated to higher levels (e.g., research, developmental). The process is guided both by a set of criteria (Table 4-1) and by peer reviews of research plans. As indicators advance through the indicator development process, different criteria are emphasized (Fig. 4-2). At each step the criteria become more focused on the value of the data for addressing EMAP objectives.

In the third phase (selection of research indicators), a candidate indicator meeting a set of positive criteria may be advanced to the research stage, one meeting a set of negative criteria may be rejected, or available information may be deemed insufficient either to reject or advance a candidate. Existing literature information and expert knowledge (including workshops) are the major sources used to identify which candidate indicators should become research indicators. Key considerations in this evaluation are: (1) demonstrating responsiveness along an environmental quality gradient, (2) being an important link in the conceptual model, and (3) requiring low incremental cost. It is not critical to meet all of the criteria in this phase, provided that at least some of the criteria are met decisively. For instance, a gross external pathologic examination of biota is extremely inexpensive if the biota are already being collected for other reasons (e.g., collection of fish for determination of tissue contaminant concentrations). Therefore, it makes sense to include this indicator at the research level, even if information about its ability to meet some of the other criteria is not conclusive. The principal reasons that an indicator would be rejected at this stage are redundancy with superior measures, temporal instability within the index period, or demonstrated non-responsiveness to environmental quality gradients.

In the fourth phase (selection of developmental indicators), the selection criteria are expanded to a more detailed set of questions that center around demonstrating that indicator responsiveness to pollution gradients is strong enough to be distinguished from natural environmental gradients (e.g., salinity, temperature, depth) by statistical means. It also involves a more detailed examination of the costs and feasibility of sampling the indicator on a regional scale (e.g., holding time requirements, processing times). As many potential indicators have been tested only in the laboratory or across limited local environmental gradients, the answer to these questions quantitatively will require more than a literature review. In most cases it will involve field measurements at

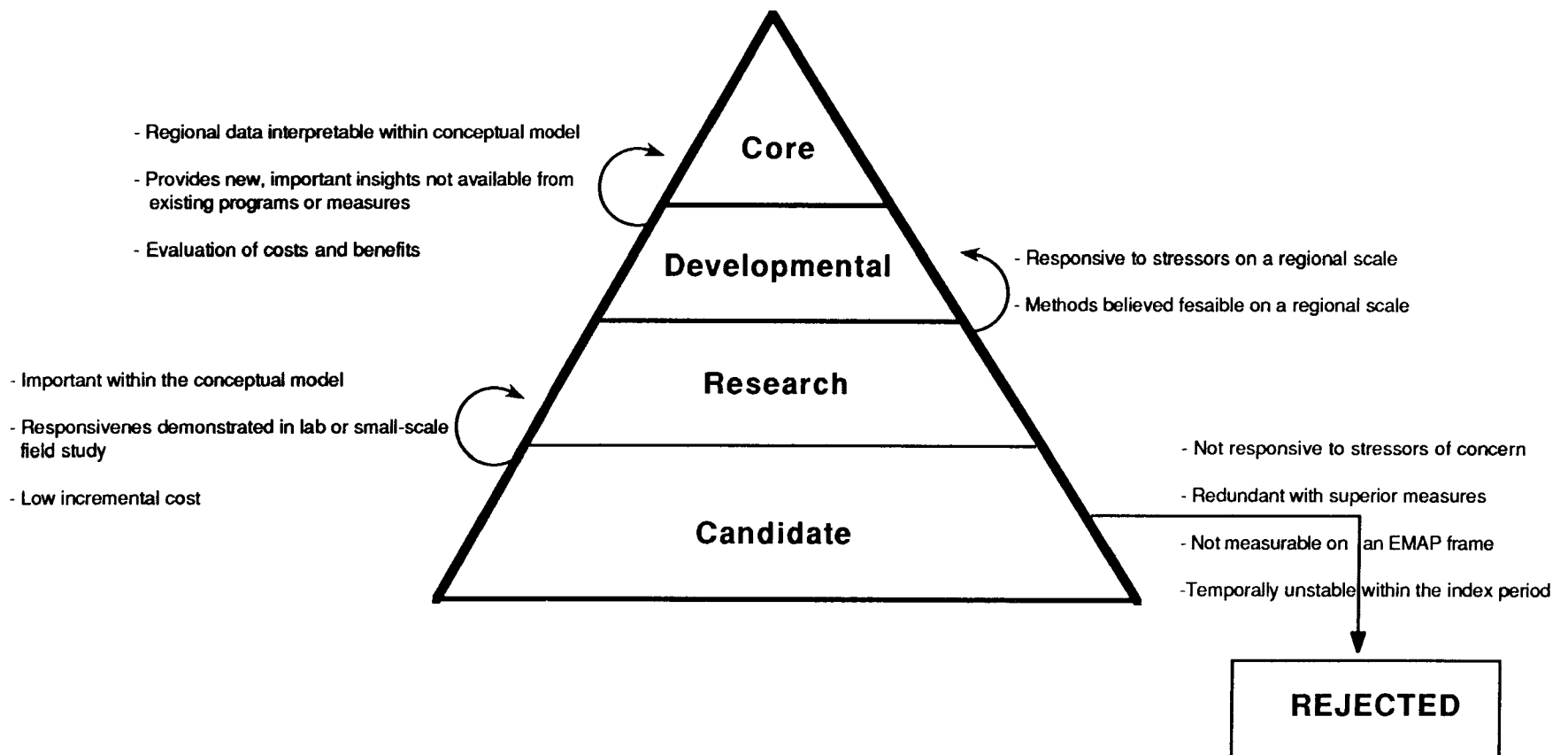


Figure 4-2. Primary evaluation criteria used by EMAP-NC in the tiered indicator selection strategy

a subset of sample stations such as the indicator testing and evaluation stations, discussed in Chapter 3.

The fifth phase (identification of core indicators through a regional demonstration project) addresses questions that can be answered only by applying EMAP sampling and data analysis protocols at a regional scale including:

- Can the required data be collected at the regional scale?
- Do the regional data provide new information not available from existing data?
- Are regional cumulative frequency distributions stable over the index period?

The sixth phase is the implementation of core indicators at regional and national spatial scales. In this phase, it is important for EMAP to balance continuity of measurement procedures with a set of procedures for continually improving indicators to maximize trend detection capability. Major activities that occur in this phase include:

- Evaluation of the costs and benefits of using newly developed superior indicators or sampling methods, and
- Examination of the degree to which core indicators represent valued ecosystem attributes.

An important component of the EMAP indicator development strategy is the continual re-evaluation of assessment endpoints and response indicators. An important part of this review process is the rejection of indicators at all levels once they are shown to be non-responsive or redundant with other indicators. Candidate indicators for which evaluation was suspended previously may be reviewed as new assessment endpoints or environmental problems emerge. Also, candidate indicators that are suspended because of technological limitations may advance to higher categories rapidly when those limitations are removed by new technological developments. The application of remote sensing for measuring properties of estuarine waters is a good example of this case.

4.3 Application of Indicator Selection Strategy to Estuarine Ecosystems

4.3.1 Valued Ecosystem Attributes

As noted above, it is important to translate public and scientific values and concerns into ecosystem attributes and assessment endpoints that can be assessed directly through the measurement of indicators. The ecosystem attributes important to estuarine systems are: biotic integrity and human uses. Biotic integrity includes maintenance of populations and ecosystems capable of recovering from stress. The health, and consequently, the abundance of fish and shellfish populations are related to the biotic integrity endpoint. The most evident public concern over the condition of the estuarine ecosystems relates to human uses (i.e., the fishable, swimmable goals of the Clean Water Act). When beaches are closed to swimming or shellfish beds are closed to harvesting, the public's attention becomes focused on the causes of the problem. The public also values estuarine waters highly for commercial or recreational fishing. Fish and shellfish populations must be abundant enough to make harvesting feasible. They also must be free of disease and other manifestations of stress, as well as being safe for human consumption. Aesthetics is another component of the human use endpoint. Over half of the U.S. population resides within 50 miles of the coastal zone. A significant segment is drawn to coastal areas for recreational purposes, such as boating, swimming, and sightseeing. Floating debris, odor, excessive plant growth, and discoloration of the water have a pronounced effect on public attitudes about water quality and environmental health.

There appear to be seven major types of environmental perturbations that are likely to affect biotic integrity and human uses of estuaries:

- Inputs of conventional pollutants,
- Inputs of toxic contaminants,
- Inputs of solids,
- Inputs of pathogens,
- Overharvesting of resources, and
- Cumulative impacts from all of the above.

Each of these inputs may take many forms (e.g., point-source, non-point, or atmospheric), and may come from many types of activities (e.g., shoreline development, industrial activity, urban runoff).

In addition, there are several emerging problems that can affect the way estuaries function (e.g., global climate change). As a long-term monitoring and assessment program, EMAP must consider perturbations likely to occur 20 years in the future and beyond. The mechanisms by which such impacts will become apparent undoubtedly will be numerous, and they will be nearly impossible to predict. The "top down" approach allows for identification of the effects of emerging problems without advance knowledge of causal relationships.

4.3.2. Development of a Conceptual Model for the Selection of EMAP-NC Indicators

The second phase of the indicator selection process is the development of a conceptual source-receptor model that links the valued ecosystem attributes and the stressors identified above. The model developed by EMAP-NC is shown in Fig. 4-3. It is based on the following premises:

- The higher trophic levels of interest are benthos and fish, and the health of these populations is directly related to the assessment endpoint of biotic integrity.
- There are two routes by which stress is transmitted to higher trophic levels: (1) the stress exerts a direct effect on suborganismal or organismal responses; and (2) stress alters energy and materials flow, indirectly affecting high trophic levels, including species composition and abundance.
- Suborganismal responses are usually more indicative of exposure than response, and during initial indicator selection, emphasis is focused on organism, population, and community level effects.
- Point, nonpoint, and atmospheric source inputs are measurable parameters that are related to stressor indicators, including management actions, natural processes, or environmental hazards. These inputs include pathogens, contaminants, nutrients, and solids.

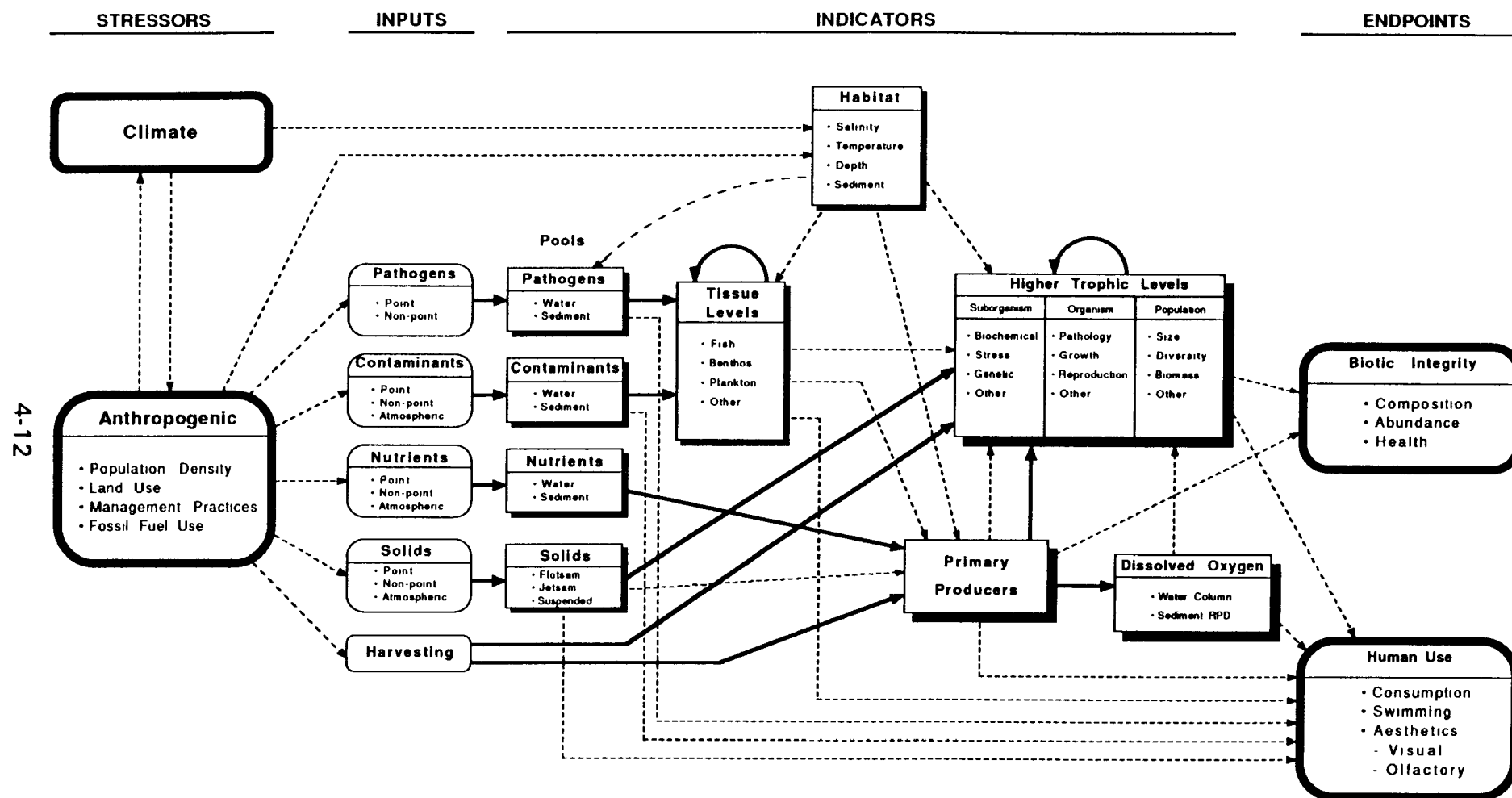


Figure 4-3. Conceptual model for defining indicators of estuarine quality. Solid arrows indicate material flows. Dashed arrows indicate influence.

- Source inputs form pools in water and sediments, and these pools are the basis for organism exposure. This exposure results in tissue uptake or direct biological effects in plankton, rooted macrophytes, benthos, and fish.
- Certain basic characteristics of the habitat, such as salinity, temperature and sediment characteristics, can modify exposure and response.
- There is no attempt to quantify linkages; the purpose of the model is only to define linkages.

The conceptual model was used to identify as many candidate indicators as possible. It is based on an understanding of the causal mechanisms of natural and anthropogenic stress effects for estuarine systems. In the assessment phases, the conceptual source-receptor model will be used to generate hypotheses related to causal mechanisms that can be tested using EMAP-generated data and specific research approaches.

4.3.3 Special Constraints on the Selection of Estuarine Indicators

In addition to the indicator selection criteria discussed in Section 4.2, there are several specific constraints that the sampling design described in Chapter 3 imposes on the indicator selection process, including the following:

- Samples must be amenable to collection from trailerable vessels. The maximum length of these boats is 25 feet; therefore, sampling gear must be of moderate size and relatively lightweight.
- Samples are collected during a summer index period, and indicators must be measurable and stable over that period.
- The indicator must have a standardized method of collection or analysis that generally can be conducted during a single visit to the sample site. A second visit to the site to retrieve deployed gear is acceptable, but continued visits to the site are beyond the resources available to EMAP-NC, given its regional nature.
- Indicators must be measurable at random sites. A probability sampling design does not allow for selection of sampling sites based on where the indicator is most easily measured or is most likely to be responsive.

4.4 Estuarine Candidate Indicators

Approximately 150 candidate indicators were identified from the conceptual model of estuarine systems (Table 4-2). Following preliminary selection and categorization of candidate indicators, a series of workshops was held in December 1989 to identify, evaluate, and discuss potential indicators of ecological condition and environmental quality. Workshop participants (see Appendix C for a list of participants) were selected based upon recommendations from the Estuarine Research Federation (ERF), NOAA, and EPA Program Offices and Regions. They included a combination of researchers from universities, private consulting firms, governmental agencies (e.g., U.S. Geological Survey, National Marine Fisheries Service, NOAA, EPA, and state regulatory and resource management agencies), and non-profit organizations. Participants had a broad range of monitoring experience on all coasts (i.e., Atlantic, Pacific, the Gulf of Mexico) and in a wide variety of marine/estuarine environments (e.g., tidal flats, large and small estuaries, tidal rivers, and coastal waters).

Prior to the indicator workshop, participants were provided documents that: (1) outlined the EMAP conceptual approach and rationale, (2) described the EMAP-NC indicator strategy, and (3) contained a list of potential indicators. Each participant was requested to review the material and to come to the workshop prepared to identify, evaluate, and establish priorities for indicators for the 1990 Demonstration Project. Participants also were requested to be prepared to recommend measurement and analysis methods for potential indicators. Conclusions and findings of the workshops were used to refine the list of indicators and to identify those that will be measured in the 1990 Demonstration Project.

The indicator selection process yielded five research indicators, nine developmental indicators, and two core indicators (Table 4-3). This section of the chapter identifies which candidate indicators were placed into each category and the rationale for these placements and gives an overview of the methodology that will be used for measurement of those indicators selected for use in the 1990 Demonstration Project. Detailed descriptions of collection and processing methods are provided in Strobel (1990) and Graves (1990). Although the tiered selection process for indicators was conducted from candidate upwards to core, they are presented in the following section from core downward to place emphasis on those measurements most important to the program.

Table 4-2. Major categories of candidate indicators developed from EMAP-NC conceptual model

POOLS		
Water	Sediment	
Nutrients	Nutrients	
Nutrient Ratios	Nutrient Ratios	
Algal Growth Potential	Pathogens	
Pathogens	Contaminants	
Contaminants (water column or microlayer)	Total Organic Carbon	
Suspended Solids	Acid Volatile Sulfides	
Light Transmission	RPD	
Light Quality	Jetsam	
Particle Size Distribution		
Total Organic Carbon		
Dissolved Oxygen		
Flotsam		
PRIMARY PRODUCERS		
Algal	Macrophytes	
Species Composition (diversity, indicator species)	Species Composition (diversity, indicator species)	
Biomass/Abundance	Biomass/Abundance	
Production	Production	
Condition Indices	Size Structure	
Biomarkers	Shape Characteristics of Beds	
Tissue Contaminants	Condition Indices	
Tissue Pathogens	Biomarkers	
	Tissue Contaminants	
	Tissue Pathogens	
SECONDARY PRODUCERS		
Population/Community	Individual	Subnominal
Species Composition	Condition Indices (length-weight, Lipids, HSI)	Biochemical
Abundance	Pathology	- MFD's
Community Function Measures (trophic status, IBI, BRAT etc.)	Behavior	- Metalotheincins
Secondary Production	Growth	- AAH
	Reproduction	Genetic
	Tissue Contaminant Levels	- DNA Adducts
	Respiration	- Chromosome Damage
	Immune Response	- Microsomes
		- T-cells
LINKAGES		
Toxicity (water column, sediment)		
Contaminant Uptake Rates (primary, secondary)		
Biochemical Oxygen Demand (water column, sediment)		
Food Consumption		
ENVIRONMENTAL SETTING		
Salinity	Sediment Grain Size	
Temperature	Flushing Rate	
Depth	Energy Regime	
pH		
4-15		

Table 4-3. Indicators selected for measurement in the 1990 Demonstration Project

CATEGORY	PROPOSED INDICATOR
Core	Benthic species composition and biomass Habitat indicators (salinity, tempertaure, pH, sediment characteristics, water depth)
Developmental	Sediment contaminant concentration Sediment toxicity Dissolved oxygen concentration Contaminants in fish flesh and shellfish Gross pathology of fish Relative abundance of large burrowing shellfish Aesthetic indicators (flotsam, jetsam, odor, water clarity)
Research	Fish community composition Histopathology of fish Apparent redox potential discontinuity Water column toxicity

4.4.1 Core Indicators

4.4.1.1 Benthic Species Composition and Biomass

Macrobenthic organisms play an important role in the estuarine conceptual model. As major secondary consumers in estuarine ecosystems, they represent an important linkage between primary producers and higher trophic levels for both planktonic and detritus-based food webs (Frithsen 1989, Holland et al. 1989). They are a particularly important food source for juvenile fish and crustaceans (Chao and Musick 1977, Bell and Coull 1978, Homer et al. 1980, Holland et al. 1989). Macro- benthic feeding activities can remove large amounts of particulate material from the water, especially in shallow (< 10 m) estuaries, improving water quality by increasing water clarity and limiting phytoplankton production (Cloern 1982, Officer et al. 1982; Holland et al. 1989).

The benthic macroinvertebrate species composition and abundance indicator has been placed in the core group not only because of its importance, but also because of its responsiveness to the kinds of environmental stress gradients of interest to EMAP-NC. Benthic assemblages are composed of diverse taxa with a variety of reproductive modes, feeding guilds, life history characteristics, and physiological tolerances to environmental conditions (Warwick 1980; Frithsen 1989; Bilyard 1987). As a result, benthic populations respond to changes in conditions, both natural and anthropogenic, in a variety of ways (Pearson and Rosenberg 1978, Rhoads et al. 1978; Boesch and Rosenberg 1981). Responses of some species (e.g., filter feeders, species with pelagic life stages) are indicative of water quality changes, while responses of others (e.g., organisms that burrow in or feed on sediments) are indicative of changes in sediment quality.

Furthermore, most benthic species have limited mobility and cannot avoid stressful environmental conditions. Benthic assemblages thus cannot avoid and must respond to many of the problems that will be emphasized by EMAP-NC, including toxic pollution, eutrophication, sediment quality, habitat modification, multiple pollution stresses, and climate change (Sanders et al. 1980, Elmgren and Frithsen 1982, Rhoads et al. 1978, Frithsen et al. 1985, Holland et al. 1987). Benthic community studies have a history of use in regional estuarine monitoring programs and have been proven to serve as an effective indicator for describing the extent and magnitude of pollution impacts in estuarine ecosystems, as well as for assessing the effectiveness of management actions.

Benthic species composition, abundance, and biomass also are influenced by habitat conditions including salinity and sediment type (Sanders et al. 1965, Carriker 1967, Boesch 1977, Dauer et al. 1984, Holland et al. 1987, 1989).

Distributions of benthic organisms, however, are remarkably predictable along estuarine gradients and are characterized by similar groups of species over broad latitudinal ranges (Thorson 1957; Holland et al. 1987). Information on changes in benthic population and community parameters due to habitat characteristics can be useful for separating natural variation from changes associated with human activities (Holland et al. 1987).

Data for the benthic species composition and biomass indicator will be obtained by collecting three replicate 413 cm² samples with a Young-modified Van Veen grab. The Young grab was selected as the appropriate sampling gear because it is deployed easily from small boats and adequately samples both mud and sand habitats. Other gear possibilities did not sample such a broad range of sediment types adequately (e.g., Wildco Box Corer, Ponar grab, Van Veen grab) or could not be deployed as easily from the small boats proposed for use by EMAP-NC (e.g., spade box corer, Smith-McIntyre grab). Hard sediments (e.g., rock or shell) that cannot be sampled adequately by the Young-modified Van Veen grab will not be sampled by EMAP-NC; however, the proportion of these habitat types will be estimated.

Benthic samples will be sieved in the field through a 0.5 mm screen and preserved in a 10% buffered formalin solution to which rose bengal has been added. In the laboratory, organisms will be identified to the lowest taxonomic level practical and counted. The dry weight biomass of major taxa will be measured.

4.4.1.2 Habitat Indicators -- Salinity, Temperature, pH, Sediment Characteristics, and Water Depth

Habitat indicators provide important information about the environmental setting of a sample site. Salinity and temperature are among the most important factors controlling the distribution of biota and ecological processes in estuaries (Remane and Schlieper 1971). Organic content, grain size distribution, and depth of the redox potential discontinuity (RPD) layer are the major sediment characteristics that influence sediment quality and processes, as well as benthic invertebrate distributions. Water depth itself has little direct effect on estuarine biota because most estuaries are relatively shallow, and the pressure changes that occur are minor. However, in almost all estuaries, changes in water depth are associated with changes in sediment characteristics, dissolved oxygen concentration, and temperature regime. Therefore, information about depth is useful for explaining many of the observations that will be taken by EMAP-NC.

Cumulatively, the above parameters define the major habitats sampled by EMAP-NC, and information on these habitat indicators will be essential for normalizing responses of exposure and response indicators to natural environmental gradients. They will also be used to define subpopulations for analysis and integration activities.

These indicators have been advanced to core status because they are essential to interpretation of response and exposure indicators, because regional sampling is feasible, and because it can be accomplished at a small incremental cost. Some of the measures, notably salinity and temperature, are variable within the index period, but they vary in a predictable manner with respect to known factors such as tide, month, and freshwater flow. Furthermore, the instruments that are being used to continuously monitor dissolved oxygen (see Section 4.4.2.3) at a subset of the sites also measure salinity, temperature and pH. This continuous water quality monitoring will enhance EMAP-NC's ability to predict the importance of fluctuations in these habitat variables at a site.

Point-in-time salinity, temperature, pH, and water depth measurements will be taken each time a sampling site is visited, using the SeaBird CTD.

Sediment characteristics (e.g., water content, grain size distribution, organic carbon content) will be determined for all sampling sites during the July 20-August 20 sampling period, using the procedures of Plumb (1981). In addition, the silt-clay content of a subsample of each grab collected for benthic community analyses will be determined.

4.4.2 Developmental Indicators

Table 4-3 includes a list of the developmental indicators proposed for the 1990 Demonstration Project. A brief justification for the selection of each of these indicators, and a summary of the measurement methods that will be used for each indicator, is provided below. Detailed methods that will be used to collect and process data for developmental indicators are provided in Strobel (1990) and Graves (1990). Developmental indicators will be measured at base sampling sites up to three times during the summer index period. The major objective of measuring these indicators multiple times is to examine the stability of the CDFs for these indicators within the summer index period. Repeated visits to sample sites also will increase the probability of capturing the targeted fish species at least once during the summer index period.

4.4.2.1 Sediment Contaminant Concentrations

Metals, organic chemicals, and fine-grained sediments entering estuaries from freshwater inflows, point sources of pollution, and various nonpoint sources, including atmospheric deposition, generally are retained within estuaries and accumulate within the sediments (Turekian 1977; Forstner and Wittman 1981; Nixon et al. 1986; Hinga 1988; Schubel and Carter 1984). This is because most contaminants have an affinity for adsorption onto particles (Hinga 1988; Honeyman and Santschi 1988). Chemical and microbial contaminants generally adsorb to fine-grained materials in the water and are deposited on the bottom, accumulating at deposition sites, including regions of low current velocity, deep basins, and the zone of maximum turbidity. The concentration of contaminants in sediments is dependent upon interactions between natural (e.g., physical sediment characteristics) and anthropogenic factors (e.g., type and volume of contaminant loadings) (Sharpe et al. 1984).

Bottom sediments in some estuaries (e.g., harbors near urban areas and industrial centers) are so contaminated that they represent a threat to both human and ecological health (OTA 1987; NRC 1989; Weaver 1984). Contaminated sediments are not limited to harbors near industrial centers and urban areas. Pollutant runoff from agricultural areas also is an important source of contaminant input to estuaries (Boynton et al. 1988; Pait et al. 1989), and many relatively rural estuarine settings have levels of toxic chemicals in sediments that adversely affect biota.

Sediment contamination meets three criteria for elevation to developmental status. It is feasible to sample on a regional scale; it is clearly important to assessment endpoints; and the expected variability within the index period is small. This indicator was not elevated to core status at this time because it may not be required at every location or on every sampling date and may be redundant with data on sediment toxicity.

The geographic extent of contaminated sediments and the ecological effects of exposure to them are poorly defined (NRC 1989, NOAA 1988). Even in highly contaminated bays and harbors (e.g., New York Harbor, Commencement Bay, Baltimore Harbor, Elizabeth River), the extent and magnitude of contamination often is not known (NRC 1989). Because regional information on the extent and magnitude of sediment contamination does not exist, environmental managers do not know whether the pollution abatement measures that have been taken to reduce contaminant loadings are having the desired effect, nor do they have the information to establish priorities for future cleanup efforts. The sediment contamination indicator addresses these needs.

Sediment samples for determination of contaminant levels will be collected using a stainless steel Young-modified Van Veen grab. The surface sediment (top 2 cm) will be removed from three grab samples and composited. During collection, care will be taken to avoid collection of material from the edge of grabs and to use only samples that have undisturbed sediment surfaces. The composite sample will be homogenized, and a subsample will be taken for measurement of contaminant concentrations.

Initially, the NOAA National Status and Trends suite of contaminants will be measured in the homogenized subsample (Table 4-4). The NOAA suite includes chlorinated pesticides, polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), major elements, and toxic metals. Clostridium spores in sediments will also be measured as an indicator of sewage loading (Cabelli 1977). The NOAA Status and Trends and EMAP quality assurance programs have developed measurement methods jointly that will provide data of sufficient quality to meet the objectives of both the Agencies. EMAP-NC plans to work with NOAA, the Office of Pesticide Programs (OPP), Office of Marine and Estuarine Protection (OMEP), the Office of Policy, Planning, and Evaluation (OPPE), regional offices and academic researchers to refine the list of contaminants to include "new" generations of pesticides and herbicides, as well as toxic chemicals that are projected to represent a threat to estuarine and coastal ecosystems in the 1990's and beyond. Many of these refinements will be made before 1991 field programs are implemented.

4.4.2.2 Sediment Toxicity

Sediment toxicity tests are the most direct measure available for determining the toxicity of contaminants in sediments. These tests provide information that is independent of chemical characterizations and ecological surveys (Chapman 1988). They improve upon the direct measure of contaminants in sediments because many contaminants are tightly bound to sediment particles or are chemically complexed and are not biologically available (USEPA 1989). However, sediment toxicity can not be used entirely in replacement of direct measurement of sediment contaminant concentrations, since the latter is an important part of interpreting observed mortality in toxicity tests.

Sediment toxicity testing has had many applications in both marine and freshwater environments (Swartz 1987; Chapman 1988) and has become an integral part of many benthic assessment programs (Swartz 1989). A particularly important application of sediment toxicity testing is in programs seeking to establish contaminant-specific effects. Sediment toxicity passes to developmental indicator status on the same criteria as sediment contaminants: 1) regional scale

Table 4-4. Chemicals to be measured in sediments during the 1990 Virginian Province Demonstration Project

<u>Polyaromatic Hydrocarbons (PAHs)</u>	<u>DDT and its metabolites</u>
Acenaphthene	o,p'-DDD
Anthracene	p,p'-DDD
Benz(a)anthracene	o,p'-DDE
Benzo(a)pyrene	p,p'-DDE
Benzo(e)pyrene	o,p'-DDT
Biphenyl	p,p'-DDT
Chrysene	
Dibenz(a,h)anthracene	
2,6-dimethylnaphthalene	<u>Chlorinated pesticides</u>
Fluoranthene	<u>other than DDT</u>
Fluorene	
2-methylnaphthalene	Aldrin
1-methylnaphthalene	Alpha-Chlordane
1-methylphenanthrene	Trans-Nonachlor
Naphthalene	Dieldrin
Perylene	Heptachlor
Phenanthrene	Heptachlor epoxide
Pyrene	Hexachlorobenzene
Benzo(b)fluoranthene	Lindane (gamma-BHC)
Acenaphthylene	Mirex
Benzo(k)fluoranthene	
Benzo(g,h,i)perylene	
	<u>18 PCB Congener:</u>
<u>Major Elements</u>	Congener Location
	Number of Cl's
Aluminum	8 2 4'
Iron	18 2 2' 5
Manganese	28 2 4 4'
Silicon	52 2 2' 5 5'
	44 2 2' 3 5'
	66 2 3' 4 4'
	74 2 4 4' 5
	99 2 2' 4 4' 5
	101 2 2' 4 5 5'
	118 2 3' 4 4' 5
	153 2 2' 4 4' 5 5'
	105 2 3 3' 4 4'
	138 2 2' 3 4 4' 5'
	187 2 2' 3 4' 5 5' 6
	128 2 2' 3 3' 4 4'
	180 2 2' 3 4 4' 5 5'
	170 2 2' 3 3' 4 4' 5
	195 2 2' 3 3' 4 4' 5 6
	206 2 2' 3 3' 4 4' 5 5' 6
	209 2 2' 3 3' 4 4' 5 5' 6 6'
<u>Trace Elements</u>	<u>Other measurements</u>
Antimony	Tributyltin
Arsenic	Acid Volatile Sulfides
Cadmium	Total organic carbon
Chromium	
Copper	
Lead	
Mercury	
Nickel	
Selenium	
Silver	
Tin	
Zinc	

sampling appears to be feasible, 2) results are important to assessment endpoints, and 3) variability within the index period is anticipated to be small. This indicator was not elevated to core status because it may only be required for a subset of stations and may be redundant with data for sediment contaminant concentrations.

EMAP-NC proposes to measure acute (10 day) toxicity of surface sediments. The sediments used for the toxicity tests will be a subsample of the same composite from which sediment contaminant concentrations and sediment physical/chemical properties are determined. Data on the physical and chemical characteristics of sediments (e.g., grain size, acid volatile sulfides, and organic carbon content) will be used to determine whether these sediment properties are associated with the degree of toxicity.

The sediment toxicity tests proposed for EMAP-NC will employ standard methods (Swartz et al. 1985) but will use the east coast amphipod Ampelisca abdita. This species has been shown to be both acutely and chronically sensitive to contaminated sediments (Breteler et al. 1989; Scott and Redmond 1989; DiToro et al. in press). Because Ampelisca is a tube dweller, it is tolerant of a wider range of sediment types than Rhepoxynius, the genus of amphipod that is most commonly used in sediment toxicity evaluations (Long and Buchman 1989).

For a typical bioassay, 200 ml of sediment from the homogenized grab samples collected at each sampling site will be placed in 1 liter beakers and covered with 775 ml of water. The bioassays will be conducted for 10 days, under static conditions, at constant temperature (20 °C) and 30 ppt salinity. Five replicate tests will be conducted for each station. Sediment toxicity tests will include a broad range of controls, including uncontaminated reference sediments and exposure to toxic levels of specific chemicals in water.

A potential problem with the proposed toxicity test is that contaminants in sediments from low salinity waters may become less available (i.e., less toxic) in the higher salinity water (30 ppt) used for conducting tests. To address this problem, a series of low salinity toxicity tests (5 ppt) using low salinity species (e.g., Hyaella azteca or Leptocheirus plumulosus) will be conducted jointly with the 30 ppt Ampelisca tests for all sampling sites where the ambient salinity is less than 10 ppt. The data obtained from this comparison will be used to develop a correction factor for the Ampelisca test over all salinities if it is demonstrated to be necessary.

4.4.2.3 Dissolved Oxygen Concentration

Dissolved oxygen concentration met three criteria for advancement to developmental status: (1) it is a parameter of overwhelming importance to assessment endpoints and is one of the most important factors contributing to fish and shellfish mortality in estuarine and coastal waters; (2) as a link in the eutrophication process, it is a critical component of the EMAP-NC conceptual model; and (3) it has been shown to be responsive to environmental stress in the form of nutrient input, regardless of habitat gradients. The concern with using dissolved oxygen as an indicator, and the reason it was not advanced to core status is that it is extremely variable temporally (i.e., a point measurement of acceptable oxygen levels at a site does not mean that site was not exposed to low dissolved oxygen as little as several hours previously). Technology exists to integrate measurements of dissolved oxygen over time, but that technology has not been tested over a regional scale, which is the objective of advancing dissolved oxygen concentration to the developmental indicator category for the 1990 Demonstration Project.

Dissolved oxygen (DO) is a fundamental requirement for the maintenance of balanced indigenous populations of fish, shellfish, and other aquatic biota. Most estuarine populations can tolerate short exposures to dissolved oxygen concentrations below 100% saturation without apparent adverse effects. Prolonged exposures to less than 60% oxygen saturation may result in altered behavior, reduced growth, adverse reproductive effects, and mortality (Vernberg 1972; Reish and Barnard 1960). Exposure to less than 30% saturation (~ 2 mg/l) for 1 to 4 days causes mortality to most biota, especially during summer months, when metabolic rates are high. Stresses that occur in conjunction with low dissolved oxygen (e.g., exposure to hydrogen sulfide) may cause as much, if not more, harm to aquatic biota than exposure to low dissolved oxygen concentration alone (Brongersma-Sanders 1957; Brown 1964; Theede 1973). In addition, aquatic populations exposed to low dissolved oxygen concentration may be more susceptible to the adverse effects of other stressors (e.g., disease, toxic chemicals).

Dissolved oxygen concentration is a particularly important exposure indicator. However, dissolved oxygen concentration, even in bottom waters, can fluctuate greatly with tide, wind patterns, and biological activity. In deeper areas of the Chesapeake Bay, bottom dissolved oxygen has a strong tidal signal; high tide corresponds to lower oxygen concentrations near the bottom. Significant autocorrelation of oxygen concentration persists for 6 to 8 days, indicating that consecutive measurements less than 8 days apart may not be independent. In the

Gulf of Mexico and other shallow estuaries, dissolved oxygen has a strong diurnal signal. Before dissolved oxygen can be used as a core indicator, the following questions on its stability and variability must be answered:

- What is the best parameter for representing dissolved oxygen exposure (e.g., percent of time below a critical value, frequency of occurrence of exceedance value, mean over some defined period)?
- Is the frequency distribution of dissolved oxygen concentration stable over the summer index period at regional scales?
- Is there sufficient predictability in dissolved oxygen patterns so that the degree of low dissolved oxygen stress (magnitude and duration of extreme events) which biota might be exposed to during the summer period can be predicted using a short-term (e.g., less than one week) continuous measurement record?

Two types of dissolved oxygen measurements will be made in the Virginian Province Demonstration Project to examine the reliability of dissolved oxygen as an indicator: (1) point-in-time measurements along water column profiles, and (2) continuous bottom water measurements (approximately every 20 minutes). Point-in-time water column profiles of dissolved oxygen concentration will be made each time a sampling site is visited, using a SeaBird CTD (Model JBE 25) equipped with a Beckman type polarographic dissolved oxygen electrode. The point-in-time measurements will be used as a response indicator to estimate the extent of low dissolved oxygen conditions. The continuous bottom water measurements of dissolved oxygen concentration will be made at up to 30 sampling sites over a 60 to 70 day period between the middle of June and early September. The selected sample sites are representative of the various habitat types (e.g., estuarine classes, salinity zones, sediment types, and water depths) that occur within the Virginian Province and were chosen using information provided by EPA regional offices, state and federal researchers working in the region, and local experts. They are anticipated to represent the range of dissolved oxygen exposures likely to occur in the region.

A Hydrolab DataSonde 3, equipped with a polarographic dissolved oxygen electrode and a digital datalogger, will be used to make continuous dissolved oxygen and related measurements (Fig. 4-4). The DataSonde 3 will take measurements of conductivity, temperature, salinity, depth, pH, and oxygen concentration about 1 m off the bottom every 20 minutes. The unit will be serviced, and the stored data will be retrieved approximately every 10 days (refer to Chapter 7.0 for servicing schedule). Before deployment and upon retrieval, the performance of the various sensors on the DataSonde 3 will be tested and validated. In addition, point-in-time measures of dissolved oxygen concentration

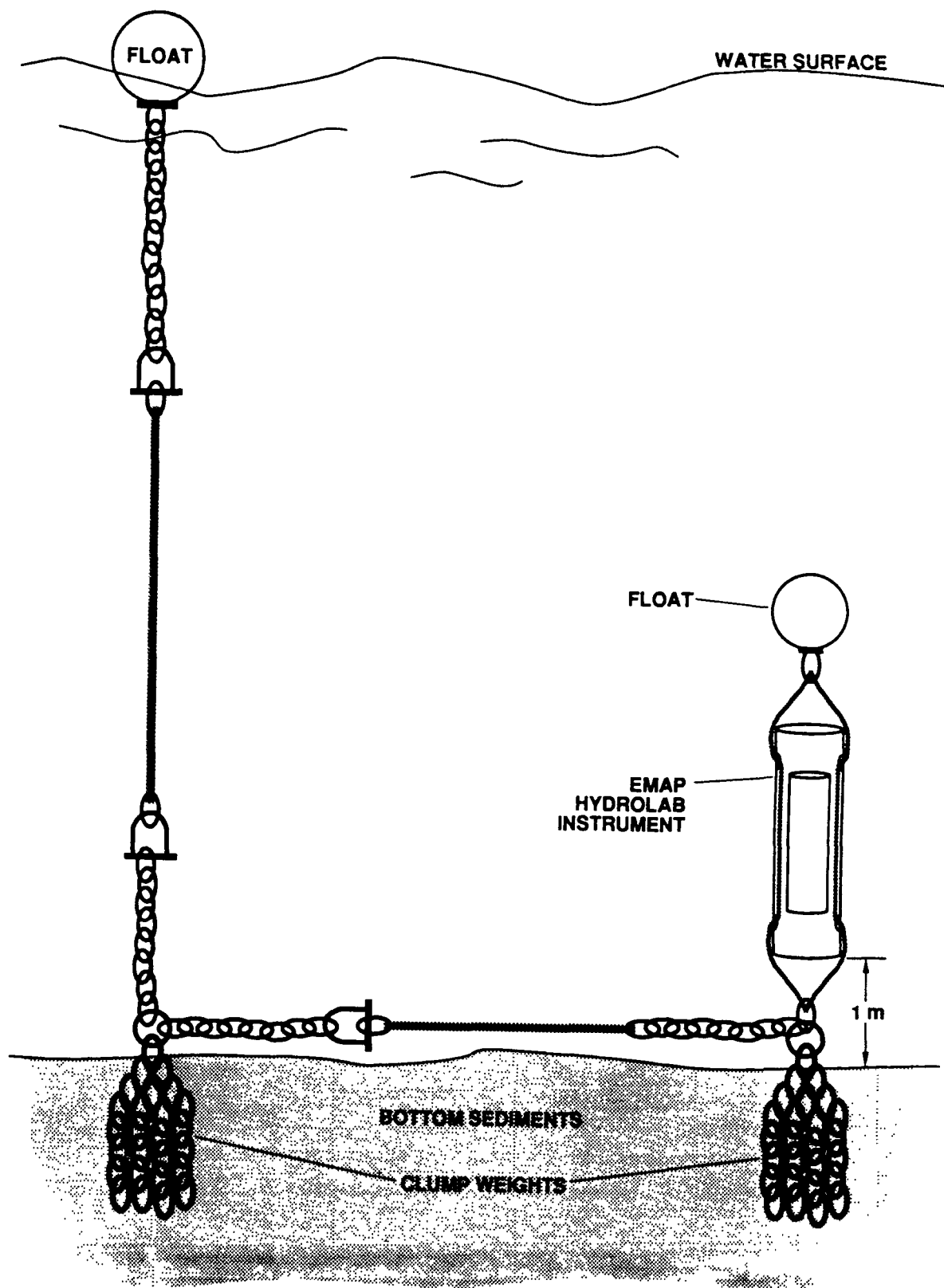


Figure 4-4. Schematic of how the Hydrolab DataSonde 3 will be deployed for continuous dissolved oxygen monitoring

and other parameters will be taken with the SeaBird CTD during the deployment period as a check on the data collected by the DataSonde 3.

4.4.2.4 Contaminants in Fish Flesh

One of the questions that the concerned public most frequently asks environmental managers is "Are the fish safe to eat?" The contaminants in fish flesh indicator is of overwhelming importance to this assessment endpoint and is intended to provide the data to answer this question on a regional scale. It is a critical component of the estuarine conceptual model, and analytical methods for analyzing contaminants are well-established. For these reasons, this indicator was advanced to developmental status. The largest concern with the contaminant in fish flesh indicator is that we may be unable to catch the desired kinds of fish at a sufficient number of the sites to include this measure in the program. This concern applies to all indicators that require collection of specific kinds of fish at a large number of sites (e.g., organismal and suborganismal measures of environmental quality). Fish samples will be archived initially, and the decision to proceed with chemical analysis will be contingent upon catching sufficient numbers of the kinds of fish needed.

In addition to serving as a response indicator for human usage of estuaries, contaminants in fish tissue also will provide a measure of ecological exposure of valued biota to contaminants in the environment. As previously noted, the presence of contaminants in sediments does not mean that they are available for uptake into the food web. Contaminants present in fish tissue obviously have made their way into the food web and are available to higher trophic levels. In addition, long-term, region-wide changes in the average concentration of a particular contaminant in fish flesh over a number of years provides useful information about contaminant input, bioavailability, or both (NOAA 1989). This information, however, must be normalized for the influence of size, species-specific physiological differences, and other factors that are known to influence contaminant levels in fish flesh (Sloan et al. 1988).

While the presence of contaminants in tissue indicates exposure to bioavailable contaminants, the absence of contaminants in fish flesh does not necessarily indicate the absence of bioavailable contaminants. The reasons for this are:

- Many contaminants are taken up and metabolized by fish; consequently, even when fish are exposed to a contaminant, they may not accumulate that contaminant in their flesh.

- Contaminants may cause mortality before they accumulate in the flesh.

Many of the factors that influence contaminant concentration in fish flesh are species and compound specific. The indicator testing and evaluation program is designed to define the relative importance of these factors to EMAP-NC.

Major questions that the Virginian Province Demonstration Project will address for the contaminants in fish flesh indicator include the following:

- Can sufficient numbers and kinds of target species be collected, given the sampling design and logistical constraints?
- Are CDFs for the contaminants in fish flesh indicator stable over the summer index period?
- Does this indicator provide important information about the status of estuarine ecosystems?

Answers to these questions should provide the information needed to determine if the contaminants in fish flesh indicator should be added to the core indicator suite during full implementation of EMAP-NC. Answers to the first question also will provide information regarding the feasibility of including other organismal or suborganismal indicators (e.g., biomarkers) in the program in the future.

Fish for tissue analysis will be collected up to three times at each sampling location, using a 16-m high-rise otter trawl. Trawls will be towed for 10 minutes against the tide, at a boat speed of approximately 1 m/s. Up to five individuals from each of 10 target species will be retained from each trawl and frozen for tissue analysis (Table 4-5). The list of target species is based on: (1) the expectation of capture at a high percentage of sampling stations, (2) commercial/recreational value, (3) use by one or more coastal states in toxics monitoring programs, and (4) use by the NOAA National Status and Trends Program in contaminant or bioeffects assessments. Catch expectations were estimated by conducting a Monte Carlo simulation analysis of available fish trawl data for the Virginian Province.

Not all of the target species that are collected and frozen will be processed for chemical analysis. Selection of taxa for processing will depend largely on the number and distribution of sampling sites at which each species is captured; more broadly distributed species will be favored. In addition, bottom-dwelling fish will be processed preferentially because: (1) they tend to be more stationary than pelagic fish, and (2) they generally accumulate contaminants at a faster rate and

Table 4-5. Target fish taxa and the expected percentage of sampling sites at which they will be collected in each salinity zone, as determined from a Monte Carlo simulation analysis of available fish trawl data for the Virginian Province

	Polyhaline	Mesohaline	Oligohaline
Channel Catfish	0.0	1.8	39.7
Atlantic Croaker	20.5	68.0	19.0
Hogchoker	35.2	87.0	37.3
Summer Flounder	63.1	29.3	0.0
Spot	35.3	88.3	32.0
White Catfish	0.0	26.3	24.4
Weakfish	48.3	53.5	19.8
Winter Flounder	63.1	66.8	0.0
Windowpane Flounder	55.1	0.0	0.0
White Perch	0.7	78.4	52.1

have a higher incidence of pathologic abnormalities than pelagic fish. The selection of fish for chemical analyses will not be made until after all collections have been completed and an evaluation has been made to determine the target species collected at the greatest number of stations by estuarine class, salinity zone, sediment type, and geographic subregions.

Generally, five individuals from each of the target species will be composited for analysis; however, the final decision on the number of fish to composite will be delayed until the number of each target species collected at sampling sites and the size of the individuals is known. Muscle tissue will be dissected from the dorsal region of the fish using titanium blades, with care being taken not to incorporate skin, scales, or bone into the sample. The chemicals measured and analytical procedures used are similar to those used in the NOAA National Status and Trends Program (Table 4-6). As was the case for contaminants in sediments, EMAP-NC plans to work with NOAA, OPP, OPPE, OMEP, regional offices, and academic researchers to refine the list of contaminants in biota to one that is agreeable to all parties concerned but does not over burden the program with excessive chemical measurements.

4.4.2.5 Gross Pathology of Fish

The incidence of gross pathological disorders in fish such as fin erosion, somatic ulcers, cataracts, and axial skeletal "aesthetic" abnormalities is a major means used by the public to judge the environmental quality of a water body. The gross pathology of fish indicator was advanced to developmental quality status because it is clearly important to assessment endpoints, it is responsive, and there is a small incremental cost for measuring the indicator, given that trawling activity is already taking place at each site to capture fish for tissue analysis.

Gross pathological disorders have a scientific base; severely polluted habitats have a higher frequency of gross pathological disorders than similar, less polluted habitats (Sinderman 1979; O'Connor et al. 1987; Buhler and Williams 1988; Malins et al. 1984, 1988). Laboratory exposures to contaminants such as PCBs, petroleum products, and pesticides, also suggest that many gross pathological disorders are associated with contaminant exposure (Sinderman 1979; Capuzzo et al. 1988). However, fish pathology is not ready for core status because the following questions remain to be answered:

- Can sufficient numbers and kinds of target species be collected within the EMAP-NC sampling design and logistical constraints to provide meaningful data on the incidence of gross pathological disorders?

Table 4-6. Chemicals to be measured by EMAP-NC in fish and bivalve tissue during the 1990 Virginian Province Demonstration Project

DDT and its Metabolites

o,p'-DDD
p,p'-DDD
o,p'-DDE
p,p'-DDE
o,p'-DDT
p,p'-DDT

**Chlorinated Pesticides
other than DDT**

Aldrin
Alpha-Chlordane
Trans-Nonachlor
Dieldrin
Heptachlor
Heptachlor epoxide
Hexachlorobenzene
Lindane (gamma-BHC)
Mirex

Trace Elements

Aluminum
Arsenic
Cadmium
Chromium
Copper
Iron
Lead
Mercury
Nickel
Selenium
Silver
Tin
Zinc

18 PCB Congeners:

Congener Number	Location of Cl's
8	2 4'
18	2 2' 5
28	2 4 4'
52	2 2' 5 5'
44	2 2' 3 5'
66	2 3' 4 4'
101	2 2' 4 5 5'
118	2 3' 4 4' 5
153	2 2' 4 4' 5 5'
105	2 3 3' 4 4'
138	2 2' 3 4 4' 5'
187	2 2' 3 4' 5 5' 6
128	2 2' 3 3' 4 4'
180	2 2' 3 4 4' 5 5'
170	2 2' 3 3' 4 4' 5
195	2 2' 3 3' 4 4' 5 6
206	2 2' 3 3' 4 4' 5 5' 6
209	2 2' 3 3' 4 4' 5 5' 6 6'

- Are CDFs for gross pathological disorders in fish stable over the summer index period, and do they provide important information about the status of near coastal ecosystems?
- Is the incidence of pathological defects sufficiently high at polluted sites to be distinguished from "clean" sites, given the level of sampling effort (i.e., previous studies at severely polluted sites have found incidences of 10% or less, and it is likely that EMAP-NC will collect less than 100 fish at most sites in the Virginian Province).

Answers to these questions should provide the information needed to determine whether the fish gross pathology indicator should be added to the core indicator suite during full implementation of EMAP-NC.

Up to 30 individuals of each target species from each trawl will be examined externally for gross pathological disorders including skin ulcers, fin erosion, gill abnormalities, visible tumors, cataracts, or spinal abnormalities. Fish found to have pathological defects will be preserved for detailed histopathological examination. Results of the detailed examination will be used to identify possible causes of aberrations and to ensure that the defects were not ones that could have resulted from abrasion and physical damage occurring during collection.

4.4.2.6 Relative Abundance and Tissue Contaminant Concentrations of Large Burrowing Shellfish

Estuarine waters produce large quantities of economically important shellfish despite the closure of substantial portions of shellfish producing areas in virtually every coastal state due to pollution impacts (Broutman and Leonard 1986; Leonard et al. 1989). The large shellfish indicators (i.e., abundance of large shellfish and tissue contaminant concentrations) were given developmental status because of their importance to the assessment endpoint of human use, a small incremental cost, and the availability of proven methods to analyze contaminants.

Pollution problems that threaten shellfish populations include increases in low dissolved oxygen concentration, toxic contamination of sediments and tissues, and microbial contamination of tissues. These insults reduce growth and survival, adversely affecting production. They also reduce the value and quality of shellfish meats for human consumption. The relative immobility of shellfish makes them good integrators of long-term environmental conditions for the site from which they were collected. The burrowing life style of many shellfish places them at a location where exposure to pollution insults, such as low dissolved oxygen stress and contaminants, is likely to be high. The occurrence of large-sized (i.e., older)

shellfish at a site generally is considered to be an indicator that environmental conditions at that site have been relatively stable over time.

Filter feeding bivalves pump large quantities of water across the surface of their gills and remove large amounts of particulate material from the water (Dame et al. 1980; Cloern 1982; Jorgensen et al. 1986; Doering et al. 1986). A substantial portion of the captured material is ingested, and the associated contaminants are concentrated in tissues to concentrations many times higher than those in the water. Tissue contamination increases or decreases whenever the surroundings become more or less contaminated (Roesijadi et al. 1987; Pruell et al. 1987). Bivalve tissue contaminant concentrations are influenced by many factors including species, size, physiological condition, season, and environmental setting. If variation due to these factors can be accounted for, and sufficient numbers of individuals can be collected, contaminant concentrations in the tissues of bivalves is a potentially useful indicator of contaminant exposure.

The NOAA National Status and Trends program has been measuring contaminant concentrations in tissues of bivalves (oysters and mussels) of higher salinity estuarine waters (> 10 ppt) since 1986. NOAA, however, does not collect data on burrowing shellfish or shellfish from low salinity areas. As a part of the 1990 Demonstration Project, EMAP-NC will determine whether sufficient numbers of large, easily collected filter feeding bivalves occur in lower salinity waters to justify their inclusion in the NOAA National Status and Trends Program. Such a program would provide useful information on the extent and magnitude of contaminant exposure in habitats that are particularly vulnerable to contaminant impacts (Schubel and Carter 1984; Sharpe et al. 1984). The data from the bivalve survey also will be used to determine whether high-salinity, burrowing bivalves should be considered for inclusion in the NOAA National Status and Trends Program.

Large infaunal shellfish will be collected from each site, using a rocking chair dredge equipped with a 2.5 cm mesh liner. The duration of the dredge tows will be five minutes. All large shellfish collected in each sample will be counted and identified to species level. Shell length of target species (i.e., Anadonta spp., Ensis directus, Macoma balthica, Corbicula manilensis, Mercenaria mercenaria, Mya arenaria, Musculinium spp., Rangia cuneata, Tagelus plebius) will be measured to provide an indication of the age structure of the population.

Up to 10 individuals of each target species will be scrubbed of sediment and other material using a nylon or natural fiber brush, frozen, and shipped to the analytical laboratory on dry ice. These 10 individuals will represent the largest size class available in the collection. In the laboratory, composited whole body tissue samples will be made by homogenizing soft parts, and the NOAA National Status and Trends suite of bivalve tissue contaminants will be measured on homogenized

tissue subsamples (Table 4-6). As with fish, the decision regarding whether to proceed with chemical analysis, and the species which will actually be analyzed, will be determined based upon the species that are collected and the number of sites at which they are found.

4.4.2.7 Aesthetic Indicators (Flotsam, Jetsam, Odor, Water Clarity)

One of the human use endpoints is visual aesthetics of the environment. A habitat is degraded for the aesthetics indicator if floating and deposited garbage and trash are abundant, if there are noxious odors, or if the water is not clean in appearance. Because of their importance to the human use endpoint and the low incremental cost for making these observations, the aesthetics indicators were advanced to developmental status.

Although they are relatively easy to observe and measure, flotsam, jetsam and odor generally are not measured by monitoring programs, and almost nothing is known of their variability and stability as indicators of environmental quality. Flotsam is likely to be highly variable, because it is subject to movement by wind and tides, and its input rates are likely to be dominated by events (e.g., storms). The presence of flotsam and odors will be noted at each sampling site during the Demonstration Project before other samples are collected. Jetsam will be measured as trash collected in fish trawls. The types, and relative amount of jetsam will be recorded.

Water clarity will be measured in three ways: transmissometry, fluorometry, and photosynthetically active radiation (PAR). Transmissometry provides information on the turbidity of water; fluorometry provides information concerning the degree to which reduction in light penetration may be due to the presence of photosynthetic algae, and PAR provides information on the degree to which turbidity can inhibit photosynthetic activity. The incremental cost for measuring all three is small since each can be obtained with a probe added to the SeaBird CTD package. Transmissometry will be measured with a Seatech transmissometer, PAR will be measured with a Biospherical QAP 200, and fluorometry will be measured with a Seatech fluorometer.

4.4.3 Research Indicators

Table 4-3 includes the list of the research indicators that will be used for the 1990 Demonstration Project. A brief justification for the selection of each of these indicators, and a summary of the measurement methods that will be used is

provided below. The general purpose of sampling these indicators during the Demonstration Project is to obtain the information required to determine whether they should be evaluated further, should be removed from the list of potential indicators because of some deficiency, or should be incorporated into the developmental indicator suite. Detailed methods that will be used to collect and process data for research indicators are provided in Strobel (1990) and Graves (1990).

4.4.3.1 Fish Community Composition

Estuarine fish have economic, recreational, and ecological value. Some are harvested; others serve as forage for predatory organisms that have great aesthetic value (e.g., birds, sport fish, mammals). Most fish species hold a position near the top of the estuarine food chain. The impact of anthropogenic activities on fish concerns the public. Therefore, fish community indicators were advanced to research status because of their importance to assessment endpoints and their role in the conceptual model of Near Coastal resources.

Factors controlling species composition and abundance of estuarine fish communities are complex and not well understood. However, most fish ecologists agree that the assemblage of fish that occurs at a sampling site is controlled by water and sediments quality parameters, including contaminant concentrations and inputs, and habitat conditions (Weinstein et al. 1980). For example, polluted sites are thought to contain less diverse and less stable fish assemblages than unpolluted sites and are dominated by pollution-tolerant species, such as mummichogs and carp, (Haedrich and Haedrich 1974; Jeffries and Terceiro 1985; Weinstein et al. 1980; Livingston 1987). The degree to which information on fish community composition can be used to assess the status of estuarine environments on regional scales is unknown. A major purpose of evaluating fish community composition as part of the Demonstration Project is to determine whether regional scale information on fish community characteristics can be used as an indicator of environmental quality. If fish community data could be used in this manner, it would be particularly meaningful to a broad range of audiences, especially the public.

Analysis methods for integrating and synthesizing data on fish community properties into assessments of status and trends are poorly developed. For example, the average biomass of fish caught for a standard amount of effort and the capture frequency of tolerant species are parameters that can be measured in a straightforward manner. Unfortunately, these parameters are not sensitive to many pollution stresses, and fisheries science has not developed methods for predicting the fish assemblage that would be expected at a site under a given set

of environmental conditions, polluted or unpolluted. EMAP-NC will use the indicator testing and evaluation data to determine whether a method for defining the expected species composition at a site, based on physical characteristics, including salinity, temperature, bottom type, and latitude can be developed. If an expected assemblage can be determined, it will be compared with those actually observed. Failure of expected taxa to occur in an area would be attributed to undesirable environmental conditions, and subnominal conditions would be defined on the basis of the percentage of the expected taxa that are not caught at a site.

4.4.3.2 Histopathology of Fish Populations

While gross fish pathology is a potential response indicator of environmental status that is easy and economical to measure, it may not provide insight into the potential cause of the pathology (O'Connor et al. 1987) . To address this concern, EMAP-NC will perform detailed histopathological examinations of randomly selected individuals of target and non-target fish species at the indicator testing and evaluation sites. All individuals of each target species that "fail" the field gross pathology examination and up to 25 randomly selected individuals of each target species that "pass" the field examination at the indicator testing and evaluation sites will undergo a detailed histopathological examination. In addition, up to 10 randomly selected individuals from non-target species collected at these sites will be examined similarly. Histopathology advanced to research indicator status on the same criteria as gross pathology; however, it is not being implemented on a regional basis until it can be shown to discriminate between polluted and unpolluted sites. Detailed histopathology exams will also be conducted on collected fish that have gross pathological disorders.

Representative tissue samples will be taken from specimens and processed for histological analysis. Tissue samples will be dehydrated in an ethanol gradient, cleared in a xylene substitute, infiltrated, and embedded in paraffin. Sections will be cut at 6 μ m on a rotary microtome, stained with Harris' hematoxylin and eosin, and examined microscopically. The results of this microscopic examination will be used to assess the relationship between the incidence of external abnormalities and internal histopathological abnormalities, to characterize the types of external/internal pathologies, and to create a baseline of histopathological information for the Virginian Province. Based on these findings, a determination will be made regarding whether histopathological examination warrants further consideration by EMAP-NC.

4.4.3.3 Apparent Depth of the Redox Discontinuity Profile

The redox potential discontinuity (RPD) is the transition zone at which sediment processes become anaerobic. RPD depth varies with sediment organic content and biological activity in the sediment. Depth to the RPD advanced to research indicator status because of its small incremental cost. Benthic animals are important regulators of the deposition and resuspension of bottom sediments and of the exchange of constituents between bottom sediments and the overlying water (Rhoads 1974; Rhoads et al. 1978; Rhoads and Boyer 1982; Aller 1982). By ventilating and displacing sediments during burrowing and feeding, they affect geochemical profiles in sediments and interstitial water. This is particularly true for higher salinity, fine grained sediments where wave disturbance and tidal scour do not occur. In these habitats, the depth to the redox potential discontinuity (RPD) is negatively associated with physical and anthropogenically induced disturbance and positively associated with acceptable and desirable ecological conditions. Chemically contaminated and organically enriched sediments generally have shallow RPD depths and are dominated by shallow burrowing short-lived species that are resistant to pollution (Scott et al. 1987; Rhoads and Germano 1987; O'Connor et al. 1987).

Although these patterns for RPD depth are well established for high salinity (< 15 ppt) waters, they may not apply to moderate and low salinity regions of estuaries (Holland et al. 1988, 1989). One of the objectives of evaluating RPD depth as a research indicator is to determine the degree to which this measure is applicable to the array of low salinity environments that will be sampled by EMAP-NC. The applicability of RPD depth to low salinity waters and the reliability it demonstrates at indicator testing and evaluation sites will be used to determine whether it should be included as a core indicator during full implementation.

RPD depth will be estimated in two ways: (1) by visually measuring the depth of the color change in sediments in clear plastic cores inserted into each grab sample collected for benthic species composition and biomass, and (2) by deploying a sediment-profile camera at selected indicator testing and evaluation sites (Rhoads and Germano 1982). The sediment-profile camera photographs the sediment-water interface in the vertical plane. The photograph is processed by computer image analysis to quantify apparent RPD depth, grain size, and relative abundance of surface tube structures, surface boundary roughness, penetration depth, and presence of feeding voids and methane gas bubbles. The rapidity with which these pictures can be processed makes this method particularly useful for large-scale characterization and mapping studies. Estimates of the apparent RPD depth obtained by measuring the cores and from the sediment-profile camera photographs will be compared at the selected indicator testing and evaluation sites. This comparison will determine the reliability of the visual measurement of the

apparent RPD depth in cores. If this simple indicator can be demonstrated to be reliable, it would greatly enhance the amount of information that could be obtained from a single benthic grab sample.

4.4.3.4 Water Column Toxicity

An important environmental quality concern of environmental managers and the public is the toxicity of estuarine waters to biota. Because of these concerns, EPA has developed standardized laboratory methods for measuring water column toxicity in marine environments. The measurement of toxicity has many advantages over direct measurement of contaminant concentrations in the water column. Direct measurement of contaminants in the water is expensive, costing up to \$1,000 per sample. Moreover, data on chemical concentrations in the water are difficult to interpret. Chemicals may be bound in ways that make them biologically unavailable. In addition, chemical concentrations that produce adverse biological effects frequently are near or below detection limits of analytical methods. Measurement of water column toxicity is economical, usually costing only a few hundred dollars per sample, and interpretation of the experimental endpoints is straightforward.

EMAP-NC proposes to evaluate three water column toxicity tests, using a 2 liter water surface sample collected approximately 1 m below the surface at each indicator testing and evaluation site. The three water column bioassays are: (1) sea urchin (Arbacia punctulata) fertilization test (Nacci et al. 1987); (2) red algal (Champia parvula) sexual reproduction test (Thursby and Steele 1987); and (3) bivalve (Mulinia lateralis) fertilization and larval growth test (APHA 1985). Results of the three tests will be compared to determine their relative sensitivity. All tests will be conducted within 48 hours after the sample is collected at 30 ppt and 20 °C. Natural seawater (100 ppt) will be used to bring low salinity water up to the standard salinity. This will dilute some whole water samples by as much as 20% but is necessary because of the salinity tolerances of the test organisms.

The observed responses will be correlated with those for other indicators (e.g., sediment toxicity, sediment contaminant concentration, benthic species composition and biomass, contaminants in fish tissue, and fish gross pathology). Based on these findings, a determination will be made regarding whether water column toxicity should be included in EMAP-NC during full implementation or removed from further evaluation.

4.4.4 Stressor Indicators

The stressor indicators, including an overview of the specific parameters to be estimated and their sources, are defined in Table 4-7. Most of the information on stressor indicators will be obtained from an update to NOAA's National Coastal Pollution Discharge Inventory (NCPDI). The data sources NOAA includes in the NCPDI are extensive; a partial list of these sources is presented in Table 4-8. Stressor indicators will not be sampled in the field concurrently with other indicators.

4.4.5 Rejected and Suspended Indicators

Over 100 of the candidate indicators were not advanced to higher categories and were either rejected or suspended. Evaluations for most of these were suspended because insufficient information was available with which to evaluate them. Of the rejected indicators, most were eliminated because of inherent variability during the index period, ambiguity in their interpretation, or because data on them are not easily sampled within the constraints of EMAP-NC.

Emphasis in the Demonstration Project is on population or community measures of response; most individual and suborganismal measures were suspended for future consideration. A principal concern with the use of suborganismal measures is that it may not be possible to gather target specimens at a sufficient number of sampling sites to justify their inclusion in the sampling program. Alternatively, it may be necessary to perform analyses on a relatively large number of species and develop interspecies calibrations of responses. Such methods have not yet been developed.

Indicators for birds and mammals, including population measures, community measures, and measures of contaminant uptake were rejected primarily because it was not possible to obtain population estimates of large, wide-ranging animals given the constraints of the sampling equipment (i.e., 25 foot boats) and resources. Information on basin-wide trends for birds will be obtained using historical data (e.g., FWS breeding bird surveys, Audubon Christmas bird count) and existing programs. In addition, EMAP-NC has initiated discussions with FWS to determine if response and exposure indicators can be identified for colonial nesting birds. Secondary production was rejected for all animals because it would require sampling outside the EMAP-NC index period of mid-summer.

Table 4-7. Synopsis of potential data sources for stressor indicators

Stressor Indicator	Specific Parameters	Source(s)
Freshwater Discharge	Volume of inflow	• U.S. Geological Survey (USGS) - National Stream Quality Accounting Network (NASQAN) - Water Data Reports - National Water Data Exchange (NAWDEX) • National Oceanic and Atmospheric Administration (NOAA) - National Coastal Pollution Discharge Inventory (NCPDI)
Atmospheric Temperature	Daily mean, median, and range at the earth's surface for key locations within each region	• National Climate Center Archives (NCCA)
Wind Speed and Direction	Wind speed and direction at the earth's surface for key locations within each region	• National Climate Center Archives (NCCA) • National Oceanic and Atmospheric Administration (NOAA) - Local Climatological Data
Atmospheric Deposition Precipitation	Rainfall in cms, loading of atmospheric pollutants	• National Climate Center Archives (NCCA) • National Atmospheric Deposition Program (NADP) • Multi-state Atmospheric Power Production Pollution Study (MAP3S) • Utility Acid Precipitation Program (UAPSP)
Pollutant Loadings by Categories including: • Point Sources -- Industrial Discharge by Category -- Municipal Sewage • Non-Point Sources -- Urban Runoff -- Non-Urban Runoff (i.e., agriculture, forests, etc.) -- Irrigation Return Flows	Flow, biological oxygen demand, organic pollutants, inorganic pollutants, number of wastewater treatment plants, number of industrial dischargers, number of power plants	• National Oceanic and Atmospheric Administration (NOAA) - National Coastal Pollution Discharge Inventory (NCPDI)

Table 4-7. (Continued)

Stressor Indicator	Specific Parameters	Source(s)
Land Use Patterns	Area, % urban, % agriculture, % forest, % wetland, % water, % barrier, number of major and minor urban areas	• National Oceanic and Atmospheric Administration (NOAA) - National Coastal Pollution Discharge Inventory (NCPDI)
Human Population Density	Density, density by occupation and industrial category	• U.S. Census of Population • United Nations Demographic Yearbook • U.S. Census of Manufacturing • U.S. Agriculture Census
Fishery Landings	Commercial and recreational catch statistics	• National Oceanic and Atmospheric Administration (NOAA) • National Marine Fisheries Service (NMFS)
Shellfish Bed Classification	Area, % approved for harvesting	• National Shellfish Register of Classified Estuarine Waters

Table 4-8. Major data sources for the National Coastal Pollution Discharge Inventory (modified from Basta et al. 1985)

Source Category	Institutions	Major Data Sources
Pollutants in Streamflow Entering the Coastal Zone	• U S Geological Survey • State Water Quality Agencies	• USGS National Stream Quality Accounting Network (NASQAN) • USGS Water Data Reports • State Water Quality Reports
Point Sources	• EPA Regional Offices • State Water Quality Agencies • Section 208 and Regional Planning Offices • Industry Organizations	• EPA Data Bases, Reports, and Regulations -- NPDES Discharge Monitoring Reports (DMR) -- Permit Compliance System (PCS) -- 1982 Needs Survey -- Industrial Facilities Discharge (IFD) File -- Section 201, 208, and 303e Basin Plans -- Effluent Limitations Guidelines and Standards • State Water Quality Reports • Regional Basin Planning Reports
Urban Nonpoint Runoff	• U.S. Geological Survey • National Weather Service • Bureau of the Census • State Water Quality Agencies • Section 208 and Regional Planning Offices	• EPA National Urban Runoff Program (NURP) • EPA Nationwide Evaluation of Combined Sewer Overflows and Urban Stormwater Runoff • USGS Land Use Data and Analysis Program (LUDA) • 1982 Census of Population • 1982 and 1983 County and City Data Book • 1982 EPA Needs Survey • NOAA Local Climatological Data
Non-urban Nonpoint Runoff	• U S Geological Survey • National Weather Service • U.S. Department of Agriculture • Soil Conservation Service • State Water Quality Agencies • Agricultural Extension Offices • Section 208 and Regional Planning Offices	• USGS LUDA Program • SCS 1982 National Resource Inventory (NRI) • SCS SOILS-5 Data Base • Cornell Nutrient Simulation Model • USGS Study, "Elemental Concentration in Soils" • Agricultural Extension Office Records for Fertilizer and Pesticide Use • NOAA Local Climatological Data • County Soil Surveys and Maps • Section 208 and Regional Planning Studies
Irrigation Return Flows	• U S. Department of Agriculture • Soil Conservation Service • EPA Regional Offices • USGS Regional Offices • Local Water Management Districts	• USGS, State, and Regional Water Quality Management Studies
Oil and Gas Operations	• U.S. Geological Survey • EPA Regional Offices • U.S. Coast Guard • State Oil and Gas Programs • American Petroleum Institute • Environmental Subcommittee of the Offshore Operators Committee	• USCG Pollutant Incident Reporting System (PIRS) • USGS Conservation Division Accident File and Production and Drilling File • EPA Drilling Platform Permits and Platform Discharge Characterization Studies • API Inventory of Wells and Drilling Statistics • State Oil and Gas Program Files • OOC Pollutant Discharge Characterization Studies
Marine Transportation	• U.S. Department of Commerce Maritime Administration • U S. Army Corps of Engineers • U.S. Coast Guard • UN International Maritime Organization • Port Authorities in the U.S. and Mexico • Industry Organizations	• MARAD Vessel Movement Monthly Master Data File • USGS Documented Vessel File • COE, "Waterborne Commerce Statistics"
Dredging Operations	• U.S. Army Corps of Engineers • EPA Regional Offices • UN International Maritime Organization	• EPA Ocean Dumping Permit Files • COE Report to Congress, "Administration of Ocean Dumping Activities" • IMO Dredge Material Disposal Reports

Abbreviations. SCS, U S Department of Agriculture Soil Conservation Service; API, American Petroleum Institute; OOC, Offshore Operators Committee; USCG, U.S. Coast Guard; MARAD, U.S. Department of Commerce Maritime Administration; COE, U.S. Army Corps of Engineers; IMO, UN International Maritime Organization (formerly IMCO -- Intergovernmental Maritime Consultative Organization).

No measures of primary producers were advanced to research or developmental status. Measures of phytoplankton species composition and productivity were suspended because they are too variable within the index period. Productivity measures also more appropriately interpreted from data collected in the spring than in the summer index period. Contaminant concentrations in phytoplankton were considered insensitive and uninterpretable measures because of rapid turnover and were rejected. Measures of submersed aquatic vegetation (SAV) were suspended because their discontinuous distribution is not compatible with the present EMAP sampling design. EMAP-NC will develop methodologies for periodically measuring the status and trends in SAV jointly with NOAA and FWS during 1991-1992.

Measurements of water column pools were rejected because of high variability and methodological problems with sampling. For instance, pools of elevated concentrations of many contaminants are present in the water column only after runoff events. Water column nutrient concentrations and nutrient ratios are highly variable, and their interpretation generally requires integrated measures or sampling at a time other than the mid-summer index period. These measures were suspended until technology that integrates their concentration over time advances. Pools of toxic contaminants will be measured in the sediment, but nutrient concentrations in the sediments were rejected because their effects on eutrophication processes and biota are not easily interpreted or well understood.

4.5 Future Indicators

In a long-term status and trends monitoring program it is important to maintain continuity in the indicators that are measured. However, it is also important to continually re-evaluate whether the techniques used to measure those indicators remain the most cost-effective and precise, particularly as technology improves (NRC 1990a). In addition, developing indicators must be examined continually to determine whether their addition to the program would improve our ability to characterize environmental conditions and identify factors contributing to that condition.

EMAP-NC will maintain two types of indicator development activities as the program progresses. One will concentrate on development of new candidate indicators, or studies to advance candidate indicators to research indicator status. This program will emphasize basic research, will be conducted primarily through extramural research, and will be funded through ORD or the EPA grants program that is administered independently of, and integrates across, resource groups. In contrast, studies conducted within EMAP-NC will be more applied and will concentrate on tests to advance research indicators to developmental or core

status. EMAP-NC efforts will build upon basic research conducted in laboratory settings or at local scales by testing and evaluating indicators on a regional or national scale. While it is difficult to be precise about future plans, it appears likely that indicator development within EMAP-NC will focus on three areas during the next few years: 1) suborganismal measures such as biomarkers, 2) remote sensing of primary producers, and 3) measurement of status and trends for wetlands and SAV.

The 1990 Demonstration Program contains little in the way of measurements at the suborganismal level. Considerable basic research effort is being conducted on a wide range of suborganismal measures, that includes genetic, biochemical and tissue biomarkers, and many of these have been found to be promising indicators of environmental stress. The major advantage of biomarkers is that they may be an early warning indicator of exposure to environmental stress. At present, EMAP-NC is stressing measures that provide reliable indication that an impact has occurred. In the future, however, EMAP-NC undoubtedly will need to incorporate early warning indicators into its measurement program. EMAP-NC is interacting with the EPA Research Laboratories in Gulf Breeze, FL, Cincinnati, OH, and Narragansett, RI, to develop a basic research strategy that will be used to incorporate suborganismal indicators into the program in future years.

Primary production is an important component of the estuarine conceptual model but is not being measured in the Demonstration Project because of large temporal variability in conventional measures that could be used to estimate the status and trends for primary producers. However, there appear to be two feasible methods that might be used to overcome this problem: 1) remote sensing techniques for estimating status and trends in chlorophyll stocks (a measure of algal biomass), and 2) automated in situ fluorometers with digitizing capability. Remote sensing of chlorophyll by satellite has the advantage of allowing multiple estimates of a site over a season without having to visit the site. This would permit integration over time at a reasonable cost. The technique has been tested to a limited degree, with mixed success. The principle problem appears to be one of interference from turbidity. There appear to be ways to solve this problem, which EMAP-NC will investigate over the next year. Automated fluorometers would solve the temporal variability problem for primary production in the same way that the deployed dissolved oxygen meters solve this problem for dissolved oxygen. Analogous instrumentation for measuring fluorescence that includes data logging capability is just becoming available on the market, and EMAP-NC is working with several potential manufacturers to examine the feasibility of such a product.

The 1990 Demonstration Program currently does not include measurement of SAV and wetlands. This absence stems not from a lack of importance of these habitats, but from a realization that these land-margin ecosystems are complex, and factors controlling their distributions and quality are poorly understood. The

conceptual source-receptor model for aquatic habitats developed by EMAP-NC for the 1990 Virginian Province Demonstration Project is not adequate for identifying indicators that represent these complex interactions or the health of these complex ecosystems. In addition, most wetlands and SAV have discontinuous distributions in the Virginian Province and are relatively rare resources that cannot be sampled in the same manner as purely aquatic resources. The boats used by EMAP-NC are not appropriate for sampling these resources. Many agencies (e.g., FWS, NOAA, U.S. Army Corps of Engineers, state agencies) have or are currently developing programs that attempt to assess the status and trends of wetlands and SAV. The activities of these other agencies include tidal, non-tidal, and riparian habitats. Because of the complexity of technical issues involved with identification of indicators and sampling design and the complexity of coordination tasks involving other agencies, EMAP-NC decided to delay sampling wetlands and SAV until these issues could be resolved. A wetlands resource group has been established within EMAP to address these issues. The wetlands resource group plans to produce a draft program plan for wetlands in 1990 and will work with EMAP-NC to develop plans for conducting a pilot study to evaluate the ability of potential indicators to discriminate between disturbed and undisturbed wetlands as a part of a planned 1991 Demonstration Project for the Gulf of Mexico. EMAP-NC also plans to address issues relative to SAV as part of the 1991 Gulf of Mexico studies.

5.0 ANALYSIS AND INTEGRATION

The success of any monitoring program depends on the degree to which the data that are collected are used to answer the questions for which the program was designed (Wolfe et al. 1987; NRC 1990a). Conversion of data into information requires the appropriate analysis tools and the resources to apply those tools. Recognizing that analysis and integration represent the return on investment made during the design and data collection phases, EMAP-NC: (1) is committed to developing the analysis tools that will be required before collection of the data begins, and (2) has targeted about 15% to 20% of its resources to analysis and integration activities.

Synthesis of the data that will be collected by EMAP-NC into an integrated assessment of the ecological status of estuaries of the Virginian Province, and eventually of the nation, is a formidable challenge. Results of this assessment must be not only scientifically defensible, but also presented in a manner that can be understood by non-technical audiences. Unfortunately, estuarine science has not developed measures of the condition of estuaries that are accepted by scientists and understood by the public and other non-technical audiences. Standardized methods for assessing cumulative environmental impacts and partitioning those impacts into the contributions associated with major pollution stresses also are not available.

This chapter describes the approach that EMAP-NC will use to accomplish the following: (1) synthesis and integration of the data collected into an integrated assessment of the ecological condition of estuarine resources; (2) evaluation of changes in ecological condition resulting from human action or in action; (3) development of an implementation sampling design for the estuaries of the Virginian Province; and (4) dissemination of results to a broad range of audiences.

5.1 Need for Analysis and Integration

Because of its national and regional scope, EMAP-NC will serve a broad spectrum of clients. It is important that the analyses and reports that are produced

address the primary concerns of all types of clients. Potential clients of EMAP-NC data include:

- Congress,
- The Administrator of EPA and the Council on Environmental Quality (CEQ),
- EPA Regions and Program Offices,
- Other federal and state agencies with environmental management authority (e.g., NOAA, FWS, state water pollution control agencies, state natural resource agencies),
- Regional advisory boards (e.g., Delaware River Basin Commission, Interstate Commission on Potomac River Basin),
- Industry/utility environmental associations,
- Environmental activist organizations (e.g., Environmental Defense Fund),
- Scientists and researchers, and
- The concerned public.

Another function of EMAP-NC will be to adapt and improve itself. Many of the sampling activities conducted for the Demonstration Project are intended to obtain the information needed to refine the sampling design. In addition, results of the indicator testing and evaluation study will be used to refine the list of the indicators that will be sampled in the implementation phase.

The goal of EMAP-NC integration activities is to translate scientific results into answers to policy-relevant questions. Statistical analysis is the first step in this activity and will be used to characterize the data, to determine the uncertainty associated with indicator measurements, and to test for spatial and temporal trends. Integration activities follow statistical analyses and involve converting analysis results into evaluations of the effectiveness of regulatory programs; integrated assessments of the extent, magnitude, and consequences of pollution impacts; and identification of the pollution hazards and risks that pose the greatest threat to the ecological condition of estuaries.

EMAP-NC will work with clients to refocus their broad policy questions into specific scientific questions that can be addressed using EMAP-NC data. It is

important for EMAP-NC to use this opportunity to educate clients about the usefulness and limitations of the data that will be produced. Examples of how broad policy questions will be converted to specific questions that can be answered with EMAP-NC data are shown in Table 5-1. An important result of the above process is to ensure that users' expectations of monitoring data are realistic.

EMAP is designed to assess the condition of ecological resources, to measure trends in that condition, and to identify likely causes of changes in condition at regional scales. However, the sampling design also allows questions to be answered for major classes of estuaries (i.e., large estuaries, large tidal rivers, and small estuaries) and selected subpopulations of interest (e.g., salinity and sediment strata, specific large estuarine systems like the Chesapeake Bay). EMAP-NC will not address questions that are specific to any particular sampling site or identify cause and effect relationships. For example, EMAP-NC will not address questions such as:

- "What is the impact of industry x's discharge on downstream fisheries?"
- "Are excess contaminant inputs causing low abundance of benthic invertebrates?"

Rather, EMAP-NC is designed to identify factors that are associated with existing conditions and changes in conditions.

5.2 Types of Analyses

To accomplish its objectives, EMAP-NC must conduct the following types of analyses:

- Assessment of the status of estuarine resources in terms of their capacity to support valued ecological resources and human uses,
- Management of changes in status that occur over time (i.e., trends), and
- Identification of likely factors that are contributing to status and changes in status (i.e., associations).

More generally, the detailed analysis EMAP-NC data will focus on status, trends, and associations among indicators. These analyses will be synthesized into evaluations of the effectiveness of environmental policies and regulations.

Table 5-1. Translation of broad policy questions into policy relevant and scientific components

Policy Questions

Why do so many fish have tumors?

Is the problem related to contaminants?

How extensive is the problem? Is it getting worse?

Policy Relevant Questions

What percentage of fish have gross pathological abnormalities?

Is this percentage changing?

Is there an association between sites that have high levels of sediment contaminant and sites that have pathological abnormalities in fish?

Scientific Components

Estimate the proportion of fish with gross abnormalities within 25% of the true proportion with 90% confidence.

Estimate the rate of change in gross abnormalities and determine if the slope is significantly different from zero with 90% confidence.

Using categorical regression, determine with 90% confidence whether there is a relationship between percentage of gross abnormalities and sediment contaminant concentration of PCBs or other contaminants.

Before a description of the specific analyses to be conducted is accomplished, the format for presentation of the data and the strategy that will be used to reduce complex data into integrated assessments must be described. A brief description of the criteria that will be used to define acceptable and unacceptable ecological condition also will be presented.

5.2.1 Cumulative Distribution Functions

A principal means by which EMAP-NC will represent information graphically to technical audiences is through the use of cumulative distribution functions (CDFs). CDFs were chosen as a major presentation method because they present information on both central tendency (e.g., median) and extreme values (i.e., range) in one easily interpreted graphical format (Overton et al. 1990). Figure 5-1 is an example of the type of CDF that EMAP-NC will prepare and use.

Development of CDFs and estimation of their associated variance will be accomplished using the procedures defined in Horvitz and Thompson (1952) and Overton and Stehman (1987). These procedures reduce the estimation process to the specification of inclusion probabilities. Because the EMAP-NC sampling program is probability based, inclusion probabilities can be estimated for each of the estuarine resource classes sampled. The nature of these approximations and their adequacy for meeting EMAP-like objectives is described in Stehman and Overton (1987) and Overton and Stehman (1987).

Two types of inclusion probabilities must be determined: first and second order. First order inclusion probabilities are the probabilities with which individual sampling units are included in the sample. These inclusion probabilities must be determined for each sample, and the probability becomes an essential part of the data record. Data collected at a sampling site have little value to EMAP-NC without the associated first order inclusion probability. Inclusion probabilities can be viewed as an objective criteria for defining the representativeness of a specific sampling location. First order inclusion probabilities are generated at the time of sample collection and will be referred to as p_i . Second order, or pairwise, inclusion probabilities are the probabilities with which two specific sampling units are included in the sample and are designated as p_{ij} . The estimation of variance requires the determination of second order inclusion probabilities.

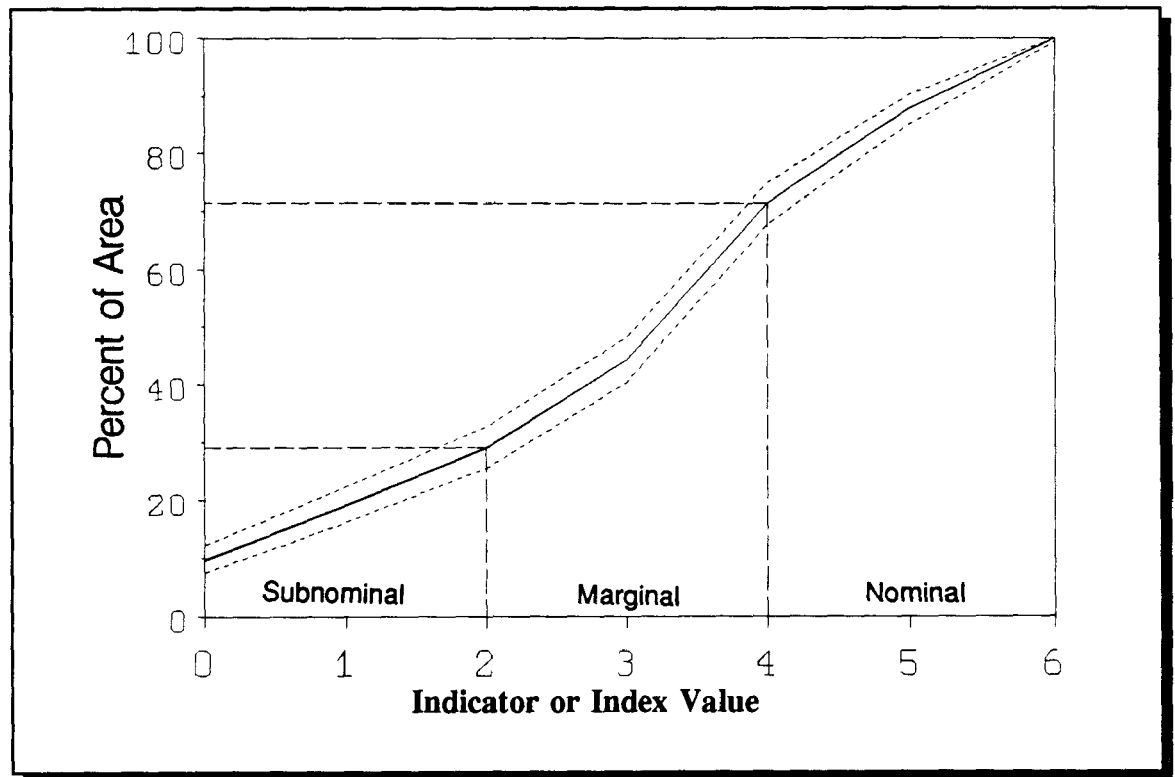


Figure 5-1. Example cumulative frequency distribution. Dotted lines are the 90% confidence bounds.

The specific calculations for producing CDFs use weighing factors (w_i or w_{ij}) rather than actual inclusion probabilities. These factors are the inverse of the inclusion probability so that:

$$w_i = 1/p_i \text{ and } w_{ij} = 1/p_{ij} .$$

CDFs will initially be constructed for response indicators for each estuary class (i.e., large estuaries, large tidal rivers, and small estuaries). Each of the class-level CDFs uses the specific inclusion probabilities associated with that class (i.e., proportional representation of the surface area of the class). The class-level CDFs will be combined into an integrated CDF by weighting the observations for response indicators by the ratio of the total surface area of the class to the total surface area of estuarine resources in the region.

EMAP-NC has chosen to combine the class-level CDFs into an integrated CDF on the basis of spatial area because this approach represents a straightforward integration that has a basis in the primary objectives of EMAP; that is, the status of estuarine resources in the region. This weighting system is not the only method that could be used. Other reasonable methods include weighting by volume or by system (i.e., each estuary is weighted equally regardless of size). In addition, subjective weighing schemes could be developed that weighted highly valued systems or sites more heavily than other habitat types (e.g., spawning and nursery areas would be weighted more heavily than other habitats types).

In the Virginian Province, the proposed integration scheme results in more "weight" being given to samples from the large estuarine class because this class represents about 70% of the estuarine surface area. Integrated CDFs, therefore, may not be representative of problems in less abundant resource types (e.g., smaller estuarine systems). As a result, EMAP-NC will present CDFs at the class and province levels for all response indicators. CDFs for other subpopulations of interest (e.g., EPA regions; selected large estuarine systems like Chesapeake Bay, San Francisco Bay, and Long Island Sound; and specific habitats such as sediment types, salinity zones, and depth strata) also will be prepared. The confidence limits for subpopulation CDFs will depend upon the number of observations taken for each subpopulation. One of the objectives of the 1990 Demonstration Project is to determine the uncertainty associated with CDFs for specific large systems and other subpopulations of interest. These data will be used as a basis for determining whether the sampling design should be modified.

5.2.2 Environmental Indices

Although individual response indicators are important measures of specific aspects of environmental condition, the goal of EMAP-NC is to provide answers to questions with an holistic perspective of estuarine systems. Multiple statements (i.e., assessments) about the status and trends of the nation's estuaries, each based on a different response indicator, present information that may confuse many EMAP clients. Single, integrated statements about the overall status of estuarine resources are more easily communicated and understood. Single statements about the condition of estuaries are also valuable for establishing and measuring progress toward goals. Therefore, EMAP-NC must integrate the data collected for multiple response indicators into an integrated assessment (i.e., single statement) of the status of estuarine resources. This integration must be accomplished in a manner that allows estimation of the contribution of each indicator to the overall assessment. In short, EMAP-NC must develop an Estuarine Condition Index (ECI) that can be decomposed into the relative contribution of each response indicator.

The conceptual framework that EMAP-NC will use to develop an Estuarine Condition Index (ECI) is presented in Fig. 5-2. Essential features of this framework are as follows:

- The ECI will be based on multiple independent indices that provide information on the two assessment endpoints: biological integrity and human use.
- All indices composing the ECI will be derived from aggregate information for the indicators measured by the field program.
- Because of the hierarchical construction of the ECI, the relative contribution of each indicator to the ECI can be determined.

The mathematical procedures (e.g., weighting schemes) that will be used to combine indicators and indices into the ECI have not been developed. Limited index development work will be accomplished during the next year using existing data (e.g., benthic data from the Chesapeake Bay monitoring program, fish data from selected state and private trawling programs). The major source of information that will be used to develop indices will be the Demonstration Project, particularly the indicator testing and evaluation study.

EMAP-NC recognizes that development of indices that reflect the overall quality of estuaries will be controversial. There undoubtedly will be conflicting views of the value of particular indicators and combinations of indicators for the

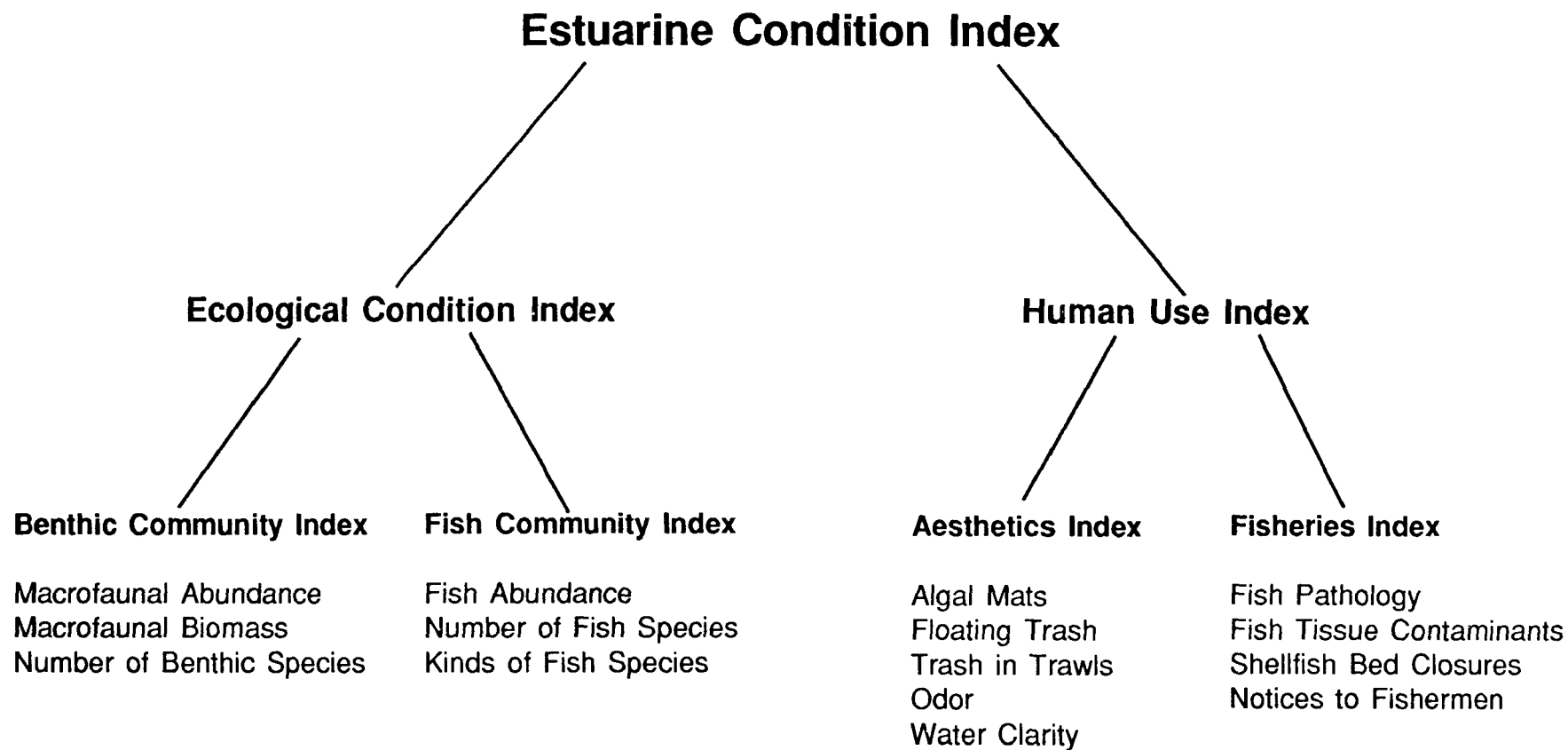


Figure 5-2. Components of the Estuarine Condition Index

assessment of status. To alleviate these concerns, EMAP-NC will conduct extensive testing of the indices to demonstrate their reliability and sensitivity. Most importantly, indices will be developed in a manner which allows determination of the contribution of each indicator to the overall index value.

In summary, EMAP-NC must develop an Estuarine Condition Index (ECI) that synthesizes the information for multiple indicators into a single integrated statement of status. This index will be composed of multiple indices, each summarizing information for a different valued attribute of estuaries. These indices are an objective way to summarize a large amount of complex and often conflicting information into a form that can be presented easily and understood by EMAP-NC clients. The indicators used by EMAP-NC will be analogous to the leading economic indicators used by the Department of Commerce to report the status of the economy.

5.2.3 Definition of Nominal and Subnominal Boundaries

EMAP-NC plans to estimate, for each type of estuarine and coastal ecosystem type of interest, the proportion that is in unacceptable condition. Meeting this objective requires determining the values that are considered unacceptable for each environmental quality index and for all response indicators. Acceptable and unacceptable values also may need to be determined for key exposure indicators (e.g., dissolved oxygen concentration, sediment contaminant concentrations). EMAP-NC will use the terms nominal to refer to acceptable or undesirable conditions and subnominal to refer to unacceptable or desirable conditions. For all response indicators and indices, there will be a value that cannot be categorized without ambiguity due to the inadequacy of current scientific knowledge. These values will be referred to as marginal. For those indices and indicators that are well understood, the ability to classify sites as being nominal or subnominal will be strong, and the range of marginal values will be small. With greater classification uncertainty, the range of marginal values will be proportionately larger.

There are currently few generally accepted limits that can be used to define subnominal and nominal boundaries for most of the indicators and indices that will be measured by EMAP-NC. EMAP-NC will establish boundaries for nominal and subnominal conditions by contrasting data from reference sites of known and acceptable environmental quality with data for sites of known and unacceptable quality (NRC 1990a). The specific source of these data will be the indicator testing and evaluation program described in Chapter 3. Subnominal and nominal condition will be relatively easy to define for qualitative measures of environmental condition. For example, the presence of floating trash, trash in trawls, or floating, smelly algal mats is clearly a subnominal (unacceptable) condition, whereas the

absence of these conditions is nominal (acceptable). Guidelines also exist that may be used to assist in defining subnominal and nominal conditions for contaminant levels in fish tissue, including Food and Drug Administration limits or EPA criteria (EPA 1989).

Nominal and subnominal boundaries will not be defined for habitat or stressor indicator categories. These boundaries have no ecological meaning for habitat indicators. Unacceptable salinity zones do not exist; the ecological function and human uses of each estuarine salinity zone are different (e.g., Carriker 1967; Lippson et al. 1979). Nominal and subnominal boundaries for stressor indicators (e.g., land use patterns) are dependent upon a wide variety of system specific factors, such as dilution capacity and flushing time. Over the long term, EMAP may provide information that contributes to the establishment of nominal and subnominal boundaries for stressor indicators, but this will not occur until relationships between stressor, exposure, and response indicators are better understood.

The initial nominal and subnominal boundaries established by EMAP-NC may be controversial; however, because CDFs 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.

Nominal and subnominal boundaries will vary with habitat type for many indicators. For example, the nominal/subnominal boundary for the number of benthic species per unit area clearly will be a function of salinity. Nominal high-salinity habitats will be composed of 2 to 10 more species per unit area than nominal low-salinity habitats (Holland et al. 1987, 1989). EMAP-NC will address this problem by: (1) identifying normalizing variables and applying them to make indicator values for all habitats comparable, and/or (2) developing different nominal/subnominal boundaries for each habitat type and integrating the information from the multiple curves into an overall statement. For example, in the benthic example presented above, bottom salinity could be used as a normalizing factor to develop a CDF for an estuarine class and all estuarine classes combined, or different CDFs could be developed for each salinity zone.

5.2.4 Status Assessments

The analytical approach for status assessments will be hierarchical. First the overall condition of estuarine resources will be quantified. Then, this integrated assessment will be decomposed to identify major pollution problems and to define

associations between those problems and exposure, habitat, and stressor indicators.

The hierarchical or decompositional approach for assessing status begins with an overall assessment of condition using the ECI. A hypothetical CDF for the ECI is shown in Fig. 5-3. This figure summarizes a large amount of information and gives "the big picture," a single number assessment that is easily communicated to and understood by regulators, environmental managers, Congress, and the public. For example, using the hypothetical CDF and applying the values for subnominal and nominal conditions for the ECI shown, the following types of statements can be made:

- 29% of the estuarine area within the region is subnominal or unacceptable,
- 42% of the estuarine area within this region is nominal or acceptable, and
- 29% of the estuarine area within this region has specific problems that may require action and should be considered indeterminate or marginal, but conditions are not yet critical.

In addition to knowing the overall areal extent of subnominal conditions within a region, the specific problems that contribute to that condition must be identified and their relative importance determined. For example, the degree to which degraded ecological conditions and reduced human usage contribute to subnominal ECI values in Fig. 5-3 needs to be estimated. CDFs for the Ecological Condition Index and the Human Use Index will be constructed to show the proportion of estuarine area that exhibits subnominal (and nominal) conditions for each. However, these independent CDFs do not show the percentage of sites that has both subnominal ecological condition and subnominal human uses. EMAP-NC will evaluate estuarine areas having specific problems by focusing analyses on the subset of samples that have subnominal ECI values using the procedure shown in Fig. 5-4. From the hypothetical data in Fig. 5-4, the following types of statements can be made for sites having subnominal ECI values:

- 77% are subnominal with respect to either ecological resources or human use,
- 51% have subnominal ecological resources,
- 47% are subnominal with respect to their ability to support human use activities,

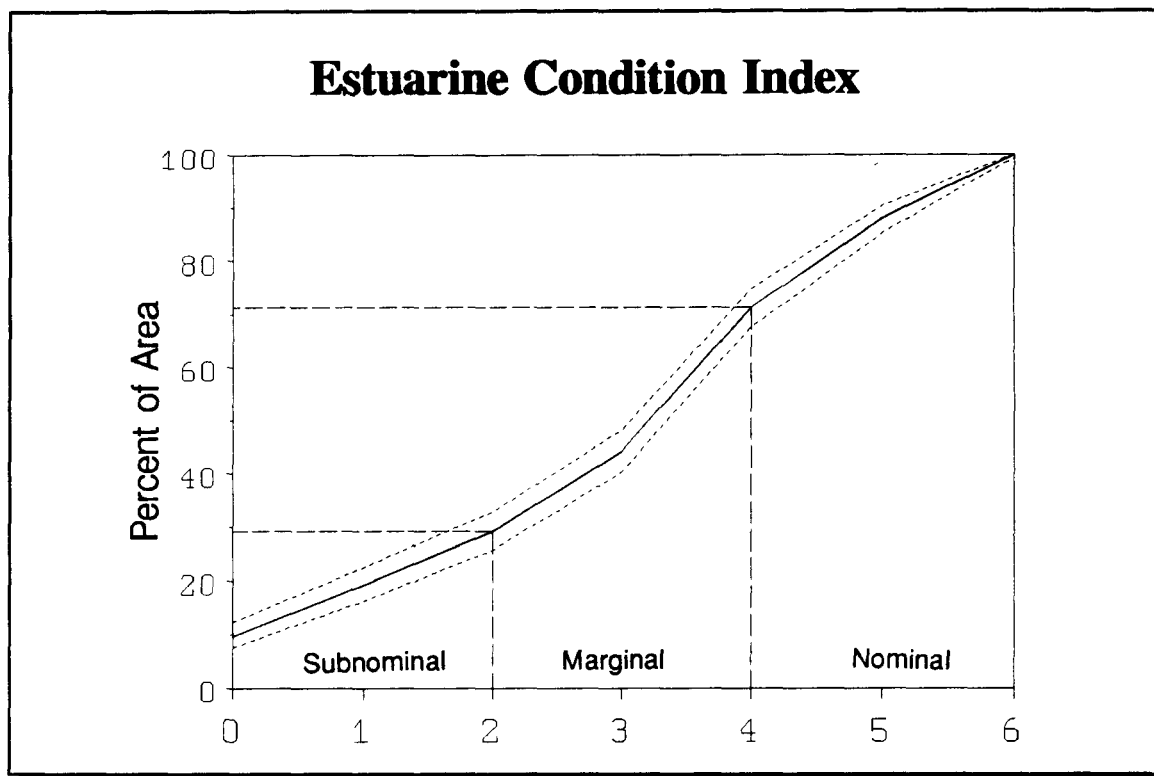


Figure 5-3. Hypothetical cumulative frequency distribution for the Estuarine Condition Index. Dotted lines are the 90% confidence limits.

		<u>Human Use Index</u>			
		Nominal	Marginal	Subnominal	
<u>Ecological</u> <u>Condition</u> <u>Index</u>	Nominal	0	1	9	
	Marginal	0	22	17	
	Subnominal	7	23	21	Σ 51
				Σ 47	

Figure 5-4. Example matrix for assessing the relative contribution of the Ecological Condition Index and the Human Use Index to subnominal environmental conditions. Values shown are the percent of area having subnominal ECI values.

- 21% have both subnominal ecological resources and human use activities, and
- 22% are characterized as having marginal conditions for human use and ecological condition.

Nominal values for the independent indices are unlikely to cause subnominal values for the dependent index. Therefore, the value for the top left hand corner of Fig. 5-4 has been set to zero.

The status assessment resulting from the Virginian Province Demonstration Project will be based on one year of data. When EMAP-NC is implemented fully, however, status assessments will be conducted using data collected over a four year period (Hunsacker and Carpenter 1990). Using four years of data to describe status reduces the variance associated with climatological or other unpredictable events (e.g., oil spills) that strongly influence estuarine condition during any specific year. Although such events are of interest, EMAP-NC is designed to measure multi-year baselines. These multi-year baselines ultimately may provide a means of quantifying the effects of such unpredictable events.

5.2.5 Identification of Associations Relevant to Status Assessments

To determine which indices and which response indicators are associated with the status defined by Fig. 5-3, a decompositional approach will be used. Figure 5-5 presents hypothetical data to illustrate how the factors contributing to subnominal ecological condition will be partitioned into the contributions due to the benthic and the fish indices. Based on the hypothetical data in Fig. 5-5, the following types of statements can be made:

- 85% of the area with subnominal ecological condition has either subnominal benthic or fish communities,
- 68% of the area with subnominal ecological condition has subnominal benthic communities,
- 29% of the area with subnominal ecological condition has subnominal fish communities,
- 12% of the area with subnominal ecological condition has both subnominal benthic and fish communities, and
- 13% has marginal benthic and fish communities.

		<u>Benthic Index</u>			<u>Fish Index</u>	
		Nominal	Marginal	Subnominal		
	Nominal	2	2	18		
	Marginal	3	8	38		
	Subnominal	2	15	12		
				Σ 68		
					Σ 29	

Figure 5-5. Example matrix for assessing the relative contribution of the Benthic Index and Fish Index to subnominal ecological conditions. Values shown are the percent of area having subnominal ecological condition index values.

A similar approach to that shown in Fig. 5-5 would be used to decompose the Human Use Index into contributions due to the Aesthetics Index and Fisheries Index.

Figure 5-6 presents hypothetical data to illustrate how associations between exposure indicators (e.g., sediment toxicity and dissolved oxygen concentration) and subnominal conditions for response indicators (e.g., benthic index) relevant to status assessments will be evaluated. The following types of statements can be made using the data in Fig. 5-6:

- 43% of the area with subnominal benthic communities is exposed to either subnominal dissolved oxygen concentrations or toxic sediments,
- 36% of the area with subnominal benthic communities is exposed to low dissolved oxygen concentrations,
- 12% of the area with subnominal benthic communities has toxic sediments,
- 5% of the area with subnominal benthic communities is exposed to both low dissolved oxygen concentrations and toxic sediments, and
- 13% of the area with subnominal benthic communities is exposed to marginal values for dissolved oxygen concentration and toxic sediments.

The proposed analysis approach presented in Fig. 5-6 can be used to prioritize future actions. For example, based on the hypothetical data shown, dissolved oxygen concentration is probably the major factor influencing the condition of benthic communities on the regional scale. A relatively small proportion (12%) of the area having subnominal benthic communities was exposed to sediments which were toxic to sensitive biota. In this hypothetical example actions (e.g., pollution abatement, remediation, research) that reduce exposure to low dissolved oxygen concentrations or provide greater understanding of the effects of low dissolved oxygen potentially would be of greater benefit than actions that reduced exposure to toxic sediments. The costs and benefits of reducing dissolved oxygen exposure, however, must be contrasted with the costs benefits of reducing exposure to toxic sediments before making a final determination of priorities. EMAP-NC will provide information that can be used for cost-benefit analyses but does not plan to conduct such analyses.

		<u>Dissolved Oxygen Concentration</u>			
		Nominal	Marginal	Subnominal	
<u>Sediment</u> <u>Toxicity</u>	Nominal	15	21	19	
	Marginal	8	13	12	
	Subnominal	3	4	5	
		Σ 36			Σ 12

Figure 5-6. Example matrix for evaluating the contribution of two exposure indicators, dissolved oxygen concentration and sediment toxicity, to subnominal values of the Benthic Index. Values shown are the percent area having subnominal Benthic Index values.

The analysis approach (in Fig. 5-6) can also be used to identify emerging problems. For example, 15% of the estuarine area with subnominal benthic communities was not exposed to subnominal dissolved oxygen concentrations or toxic sediments. Therefore, these two factors are unlikely to contribute to the subnominal benthic communities found at these sites. Some other factor potentially is having an adverse effect on benthic communities at these sites. This unknown factor may be another exposure indicator (e.g., physical disturbance of sediments) or a factor not being measured by the EMAP-NC program. If the number of sites that have subnominal values for an index or response indicator that cannot be associated with an exposure, habitat, or stressor is large and increasing, it may be an indication of an emerging problem requiring further study. If this number is small and is not changing, it is probably not important to conduct studies to identify contributing factors.

Figure 5-7 uses hypothetical data to illustrate how the information for sites with subnominal benthic communities that also exhibited sediment toxicity will be decomposed to identify specific sediment contaminants likely to be associated with the observed toxicity responses. Figure 5-8 shows how the attributes of benthic communities that are most responsive to exposure to low dissolved oxygen will be identified, using data from sites with subnominal benthic communities that were also exposed to low dissolved oxygen stress. Similar analyses will be used to decompose and explain associations for all indices and indicators.

5.2.6 More on Associations

The decompositional approach described above is only one method that EMAP-NC will use to identify associations between spatial and temporal patterns for response indicators and factors likely to be contributing to those patterns. Associations among indicators also 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 scientific analysis to be selected will depend upon the characteristics of the data for each indicator (e.g., censored or not censored, distribution) and the specific question to be answered by each analysis (Rose et al. 1986).

The decompositional analysis approach also will be applied to subsets of the data set to evaluate associations that may be masked by analyzing the complete data sets. For example, large estuaries, which receive drainage from large, complex watersheds, may have different pollution problems and ecological responses to pollution than small estuaries, which are surrounded by less complex and more homogeneous watersheds. In addition to analyzing subsets of the data by resource class (i.e., large estuaries, large tidal rivers, and small estuaries),

		<u>Organic Contaminant (e.g., PCBs)</u>			
		Nominal	Marginal	Subnominal	
<u>Inorganic Contaminants</u> (e.g., Cr)	Nominal	3	4	8	
	Marginal	4	11	12	
	Subnominal	9	12	37	Σ 58
				Σ 57	

Figure 5-7. Example matrix for assessing the relative contribution of sediment contaminants to subnominal sediment toxicity values. Values shown are percent of area having subnominal sediment toxicity.

		<u>Number of Species</u>			
		Nominal	Marginal	Subnominal	
<u>Benthic</u> <u>Biomass</u>	Nominal	2	2	4	
	Marginal	13	10	15	
	Subnominal	4	9	47	
				Σ 66	Σ 64

Figure 5-8. Example matrix for identifying the attributes of benthic communities that are most influenced by exposure to subnominal dissolved oxygen concentrations. Values shown are percent of area exposed to subnominal dissolved oxygen concentrations.

habitat type subsets will be analyzed. For example, low salinity regions of estuaries may have different pollution problems and may be controlled by different processes than high salinity regions. The practical limit to analyzing subsets of the data set is that as more and more data are excluded from an analysis the uncertainty of estimates increase. Subsets that are reasonably large ($n > 25$) must be chosen in order to ensure that the uncertainty associated with conclusions is not unacceptably large.

As an illustration of the value of the above analysis approach for making status assessments, the major findings resulting from the hypothetical data presented are highlighted as examples of the types of statements that would appear in an EMAP-NC Interpretive Assessment Report:

- 29% of the estuarine area within the hypothetical region is subnominal or unacceptable,
- 51% of the subnominal estuarine area has subnominal ecological resources; 47% is subnominal with respect to human uses,
- 68% of the area with subnominal ecological resources has subnominal benthic communities; 29% has subnominal fish communities, and
- Exposure to low dissolved oxygen concentration is the major factor associated with subnominal benthic communities, affecting both diversity and abundance of benthic biota.

5.2.7 Analysis of Spatial Distribution

The spatial distribution of resources within a province will be characterized and evaluated as a part of status assessments. The major spatial analysis to be conducted is an evaluation of broad scale patterns (e.g., north/south gradient) for resources and pollution problems within provinces. The question being addressed by this analysis is whether pollution problems are more severe in some locations than others. This analysis will be conducted by estuarine class and for subpopulations (e.g., salinity zones, sediment type, depth zone) across classes. The techniques that will be used include the following:

- Graphic display of data for indicators on maps using bar charts, and

- Multivariate statistical analyses (e.g., clustering, principal components analyses) to determine whether identifiable subpopulations occur within regions.

In addition, spatial patterns for selected indicators (e.g., dissolved oxygen concentration, benthic biomass, contaminants in fish flesh) in the large estuarine system and large tidal river classes will be delineated for any pattern that is apparent at the resolution of the sampling grid (i.e., 18 km for large estuaries and 25 km for large tidal rivers). In Delaware Bay, which will be sampled at four times the density of other systems (i.e., sample points in the Delaware estuary will be about 9 km apart), such mapping activities may provide new insight into the distribution of resources and general location of pollution problems within the system (e.g., indicate that toxic sediments were confined to specific regions of the estuary).

5.3 Measurement of Trends

The goal of EMAP-NC is to estimate trends in areal extent of subnominal values for response indicators and indices nationally, by province, by EPA region, and by selected large estuaries. This is different from the normal usage of the term trend, which is measurement of the change in a specific parameter value that occurs over time at a specific site or in a specific system. EMAP-NC data can be used to evaluate trends for specific sites or single systems. However, the uncertainty associated with such trend assessments would be large because of the small number of samples collected for any particular site or system at any one time (usually one per year).

The approach to trend assessment being used by EMAP-NC is called the interpenetrating design. This approach consists of sampling a portion (e.g., one fourth) of the sampling sites each year in a systematic or systematic random manner that ensures geographic dispersion and repeating the cycle based on the portion sampled (e.g., every 4 years). Annual data collected in this way can be evaluated individually (i.e., annual estimates of status) or aggregated with other years (i.e., moving averages) as shown in Figs. 5-9 and 5-10. The annual estimates provide the large number of data points needed for the evaluation of associations. The aggregated estimates establish multi-year baselines that are more stable than annual estimates and are useful for measuring trends and for evaluating the effectiveness of pollution control programs.

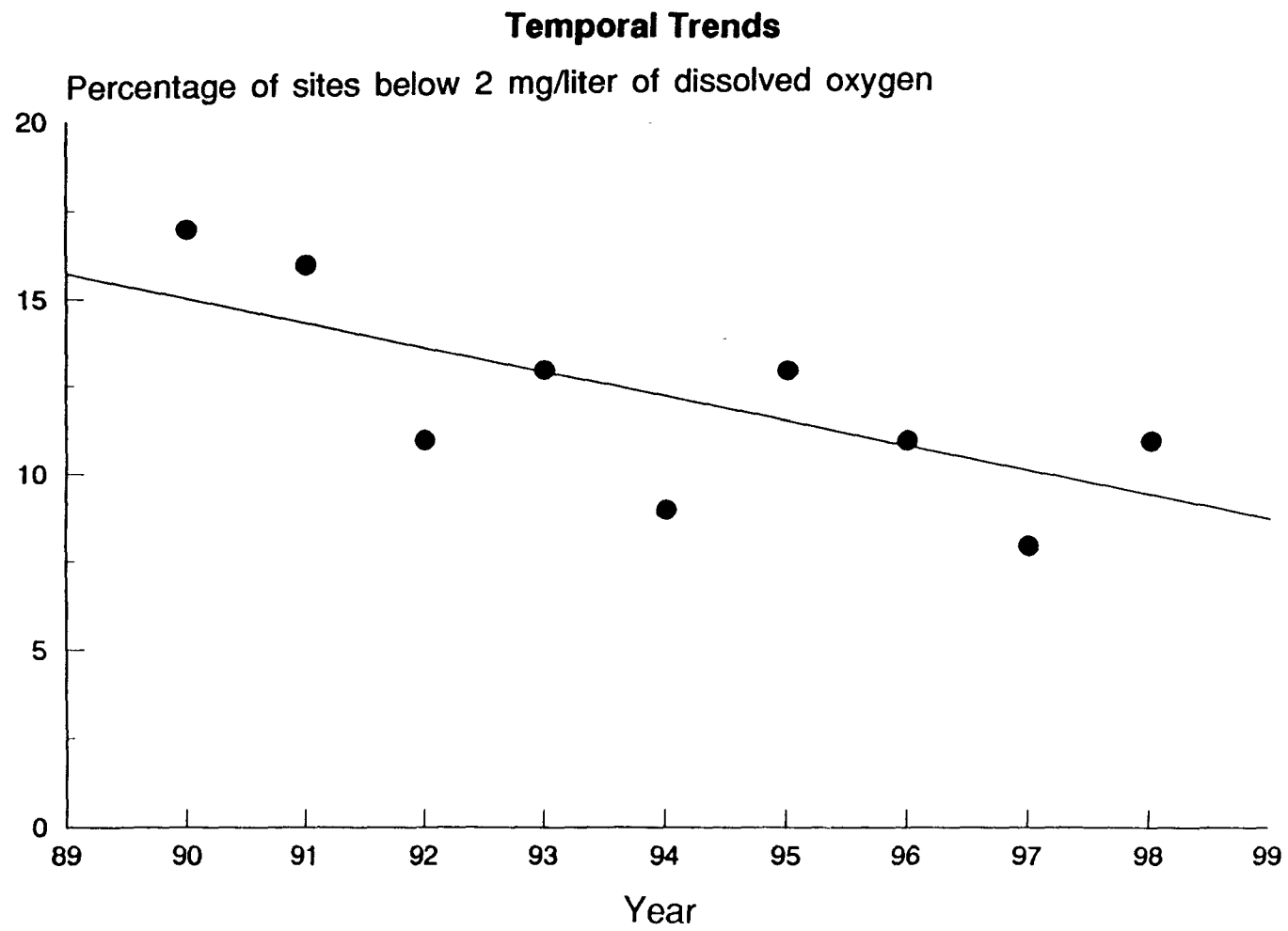


Figure 5-9. Example graph that will be used to display trends data for indices and indicators

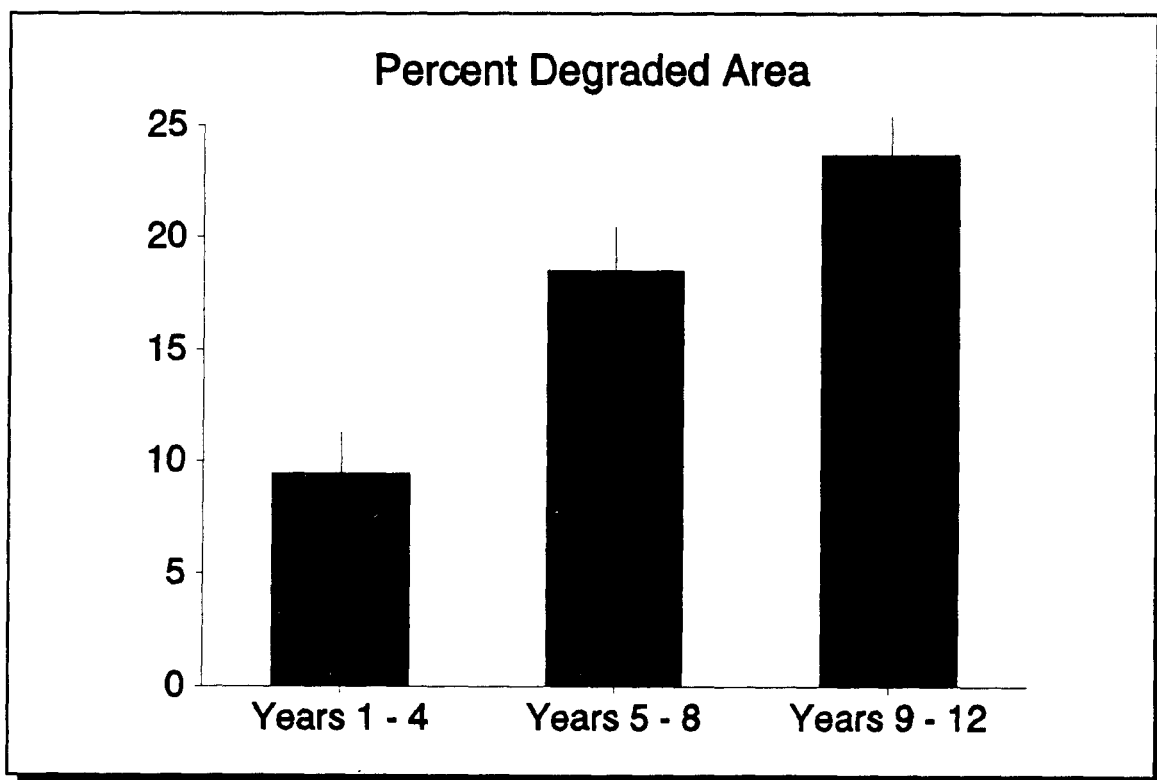


Figure 5-10. Example graph that will be used to summarize trends data for the multiyear status estimates produced by EMAP-NC; 90% confidence limits are shown.

The descriptive ability of a four year interpenetrating design is great. The basic population moving average estimates for years 1 through 4 are given as:

- Year 1
$$T_y = \frac{\sum y_w}{s=1}$$
- Year 2
$$T_y = \frac{1}{2} \frac{\sum \sum y_w}{yr\ s}$$
- Year 3
$$T_y = \frac{1}{3} \frac{\sum \sum y_w}{yr\ s}$$
- Year 4
$$T_y = \frac{1}{4} \frac{\sum \sum y_w}{yr\ s}$$

The last representation applies to all subsequent years. Variance estimates for the moving average estimates would follow the procedures of Horvitz and Thompson (1952) and Stehman and Overton (1989). Subpopulation estimates and their associated variances would follow standard subsetting protocols for subpopulation estimation, including the generation of distributions and confidence limits for distributions (Stehman and Overton 1989).

Factors contributing to trends (i.e., associations) will be identified and evaluated using a matrix approach similar to that described previously for status assessments (Fig. 5-11). The proportion of samples showing no change in status over time will not be used for these analyses. Evaluations of factors associated with trends will focus instead on the subset of sites that show declining and improving conditions (Fig. 5-11). These subsets will be analyzed using a decompositional approach identical to that described for status assessments to identify the following:

- Which valued ecosystem attributes, ecological or human use, are changing, at what rate, and on what spatial scale, and
- Which specific indices and indicators are associated with improving and degrading conditions.

Emphasis will be placed on evaluation of associations between stressor indicators and trends in other indicators and indices.

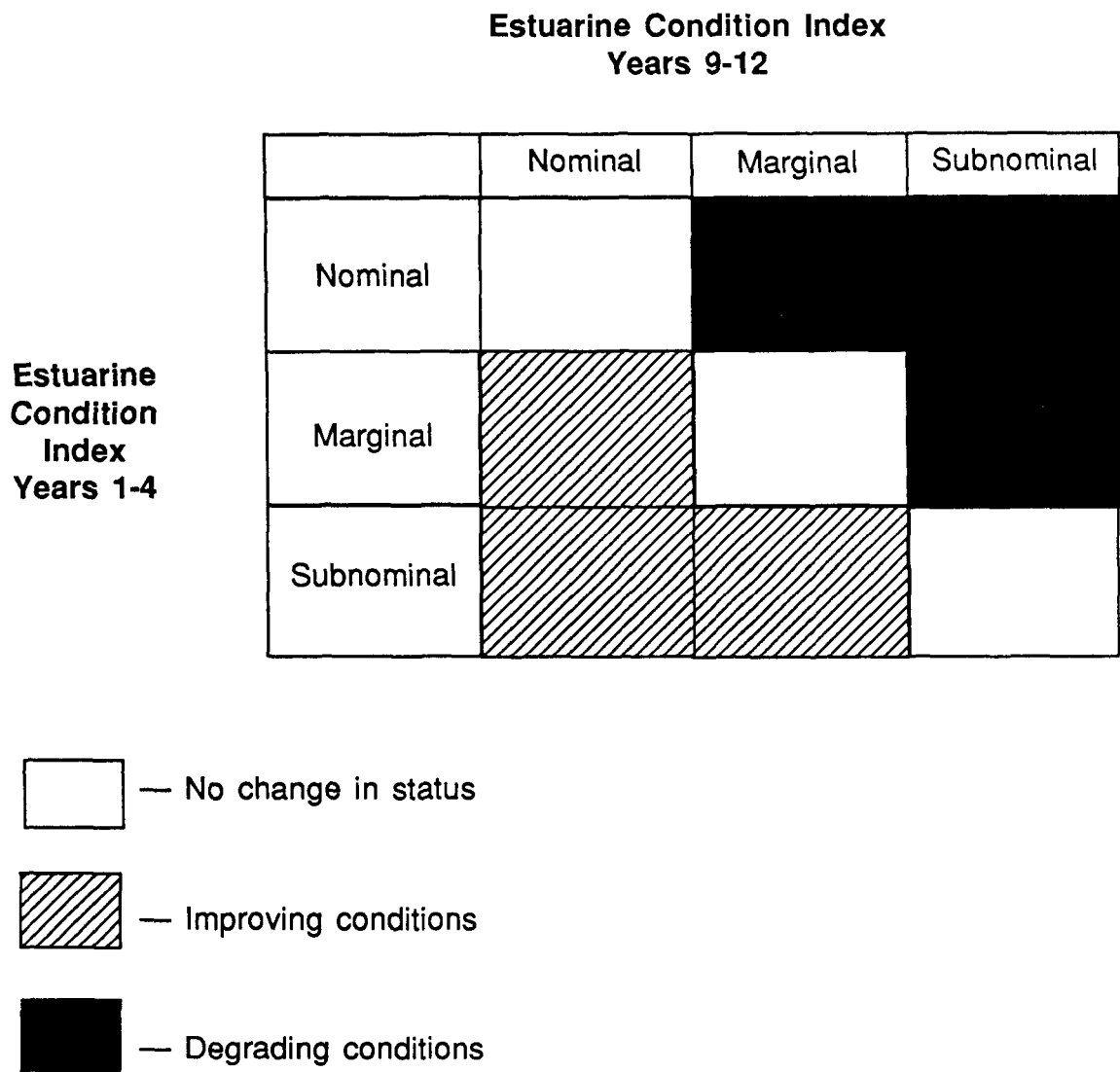


Figure 5-11. Example matrix that is the starting point for detailed evaluation of trends

The EMAP-NC team will answer the following questions relevant to trends assessment in 1990-1991:

- To what degree and with what limitations can historical data be incorporated into trend analyses conducted by EMAP-NC?
- What are the uncertainties associated with combined CDFs for indicators? How will these uncertainties be estimated and with what degree of confidence?
- What is the analytical power of the EMAP-NC design for trend estimation using the variance and distributions observed in the 1990 Demonstration Project?
- Can variability due to climatic forcing be partitioned from that due to anthropogenic effects for each indicator using an analysis of variance approach that treats climate as a covariate?

5.4 EMAP-NC As a Client

A major part of the 1990 Demonstration Project will be the collection of information that can be used to develop a sampling design appropriate for implementation over the long-term. Specific issues that must be addressed before a final implementation design can be developed include the following: (1) evaluation of the influence of spatial scale on status assessments, (2) evaluation of the reliability, specificity, and sensitivity of indicator responses, (3) definition of the appropriate sampling window (i.e., index period) for representing estuarine ecological condition, (4) evaluation of the stability of indicator responses over the index period, and (5) comparison of the value of probability and index (i.e., judgement or fixed station) samples for representing the status of small estuaries and large tidal river segments. An overview of the analyses that will be conducted to address each of these issues is presented below.

5.4.1 Spatial Scale of Sampling

A major assumption of the sampling design is that the spatial variability of indicators is sampled adequately. This represents an untried assumption and its evaluation is a major goal of the 1990 Demonstration Project. Information from the supplemental sampling program will be used as the basis for model-based simulations to determine the advantages and disadvantages of sampling at

alternative spatial scales. The goal of these analyses will be to define a spatial scale that is adequate for representing the ecological condition of estuaries. The major focus of these simulations will be the evaluation of the effects that changes in spatial scale have on: (1) CDFs and associated measures of uncertainty, (2) classification error for "key" response indicators, (3) measures of variance and central tendency, (4) the ability to describe general ($> 100 \text{ km}^2$) and localized ($< 500 \text{ km}^2$) changes in condition, and (5) the detection of small (1-2% per year) trends. Because sampling scales may vary regionally, EMAP-NC plans to conduct studies to define the appropriate sampling scales before implementing programs in other regions of the country (e.g., Gulf of Mexico).

5.4.2 Testing and Evaluation of Indicators

One of the primary goals of the 1990 Demonstration Project is the assessment of the reliability of the indicators for discriminating between polluted and unpolluted environments over broad geographical scales and a range of environmental settings. To accomplish this objective, samples of all indicators will be collected from a variety of polluted and unpolluted sites selected specifically because they display particular geographic and environmental characteristics (Fig. 3-9). Direct comparisons of indicator values within salinity types and across geographic sub-regions will be made to assess the reliability of the indicators and to distinguish between sites of known "good" environmental quality and sites of known "bad" environmental quality using ANOVA, MANOVA, and or T-tests. Within each geographic sub-region, the responses of indicators will be compared across salinity zones to determine the magnitude of salinity effects on indicator responses. Similarly, comparison of indicator responses will be made within salinity zones but across geographic sub-regions to assess the role of latitudinal gradients on indicator responses.

5.4.3 Definition of the Appropriate Index Period

The continuous water quality measurements, dissolved oxygen and temperature, will be analyzed to determine an appropriate sampling period for characterizing dissolved oxygen exposure. First, the data records will be compared to quality control checks taken at the beginning and end of deployment period to determine the degree to which fouling and drift affected measurements. Portions of the data records that are determined to be of unacceptable quality (e.g., those that drifted by more than 20% from actual) will be removed. Interpolation techniques will be used to fill in the missing portions of records, and spectral analysis will be conducted to identify periodic signals. The data will be filtered for

the major periods defined during spectral analysis, and residuals will be plotted to identify a 45 to 60 day period when dissolved oxygen and temperature were relatively stable. If the missing data or data that are of low quality are a substantial portion of the data record, it may not be reasonable to use interpolation to fill in data gaps (e.g., if there are more gaps than data). In this case, trigonometric functions that represent identifiable periodicities (e.g., 12.5 hrs, 24 hrs, 14 days, 28 days) will be fit to the data using ANCOVA. Residuals will be plotted and used to define the 45 to 60 day period when dissolved oxygen is relatively stable.

The continuous records will also be sub-sampled and evaluated using model-based sampling strategies to determine the degree to which various possible alternative sampling strategies (e.g., 1 day records, 2 day records) collect data that represent "true" dissolved oxygen exposure. The test of successful representation is the ability to classify sites correctly into nominal, subnominal, and marginal categories for dissolved oxygen exposure at least 80% of the time. A variety of measures of dissolved oxygen exposure (e.g., percent of time below critical values, frequency of exposure to low values, daily minimum) will be used for these simulations.

5.4.4 Stability of Indicator Responses

While present ecological knowledge of estuarine systems in the Virginian Province strongly suggests that the six-week sampling interval between mid-July and the end of August will produce temporally stable values for most response and exposure indicators, little information is available for several indicators (e.g., gross pathology of fish, fish community parameters, point-in-time measures of dissolved oxygen, salinity) to verify the assumption. During 1990, many of the base sampling locations will be revisited up to three times to sample indicators with a high potential for within-index period variation. In addition, at the 30 stations where continuous water quality measurements are made, benthic community parameters will be measured up to three times. CDFs will be created for each indicator in each of the three possible sampling intervals. Lack of significant difference in the resulting curves would suggest regional population stability. Furthermore, similar distributions of points within the CDFs would suggest stability at a sub-regional scale. Sampling sites will be classified into groups having similar environmental characteristics, and the values of the selected indicators within the groups will be compared for the three sampling periods. Both univariant and multivariant comparisons will be conducted.

5.4.5 Value of Index Sampling Sites

In each of the 32 small estuarine systems and on 25 transects in the five large tidal rivers, both an index site and a random site will be sampled for benthic community parameters. These values will be compared using paired T-tests to determine whether the values for indicators taken from index and random locations are significantly different. Separate analyses will be conducted for large tidal rivers and small estuaries. In addition, CDFs for each indicator across the region will be calculated for index sites and random sites, and a determination will be made regarding whether the curves are significantly different. Separate CDFs will be prepared for large tidal rivers and small estuaries.

5.4.6 Representativeness of NOAA Status and Trends Sampling Sites

The approach described above for comparing index sites and randomly selected sites also will be used to determine the representativeness of sediment contaminant data collected by the NOAA National Status and Trends Program. This comparison will be accomplished differently for each estuarine class. For example, the CDF developed using EMAP-NC data from the small estuarine systems class data will be compared to a similar CDF constructed from NOAA sites within small estuaries. The lack of significant differences between curves produced by NOAA sites and EMAP sites would indicate that NOAA sites sample small estuaries representatively. Similar comparisons will be made for large estuarine systems. In addition, in the estuaries where NOAA takes multiple samples, NOAA National Status and Trends Program sites will be paired with adjacent EMAP-NC sites, based on proximity and the data collected. For example, NOAA has nine (9) sites within the mainstem of Chesapeake Bay, while EMAP will sample 23 sites in the Chesapeake Bay in 1990. These 23 stations would be paired with the NOAA sites based on proximity, and comparisons of "representativeness" would be accomplished using an ANOVA approach. If this testing shows no significant differences between the NOAA sites and the EMAP-NC sites with regard to local setting and regional distribution, then the NOAA sites would be judged to be representative of the condition of the estuarine resources. NOAA and EPA have agreed to consider modification of their respective sampling designs, based on the results of the analysis described above.

5.5 Dissemination of Results

The findings of EMAP-NC must be disseminated to a broad range of audiences at a variety of technical levels. A major deficiency of many monitoring programs is that they produce only technical reports and do not provide the information in a form that can be used by decision makers (NRC 1990a; Beanlands and Duinker 1983, 1984). In addition, the information that is needed frequently is not available in a timely manner. EMAP-NC has developed a reporting strategy designed to address this problem by producing a range of reports, for a variety of audiences, in a timely manner. The three major types of reports EMAP-NC will produce are:

- Annual Statistical Summaries prepared approximately nine months after data are collected and providing tabular and graphical summaries of the data, including CDFs and trends plots for each indicator sampled,
- Interpretative Assessment Reports involving a high degree of synthesis and integration prepared approximately every four years, and
- Special Scientific Reports published periodically for technical audiences, to address specific concerns and to evaluate interim results.

Table 5-2 contrasts the contents of Annual Statistical Summaries and Interpretative Assessment Reports. Each type of report is discussed briefly below.

5.5.1 Annual Statistical Summaries

Annual Statistical Summaries will be analogous to the annual reports prepared by the Department of Commerce for Leading Economic Indicators. They will present the data in summary tables and will include annual CDFs. The summaries will include measures of uncertainty and an evaluation of the quality of the data (i.e., results of QA evaluations). They also will include a summary of sampling information (e.g., number of sampling sites sampled by subpopulation, parameters measured, maps showing sampling locations, an overview of the sampling design). Annual Statistical Summaries will not include evaluations of associations. They will include a discussion of the limitations and assumptions associated with the sampling design and analysis procedures and define how the data should be used. Inclusion of this information will reduce the

Table 5-2. Comparison of Annual Statistical Summaries and Interpretative Assessment Reports

Annual Statistical Summary	Interpretive Assessment Report
Includes all indicators measured within EMAP-NC	Discussions limited to selected indicators to tell a story or to address specific questions
Provides a summary of sampling statistics	Does not discuss sampling statistics
Detailed description of sampling and processing methods	Short overview of sampling and processing methods; includes a brief description of analysis methods
Will not include indicator data from other sources	Will include any data necessary
Will provide status summaries for all indicators	Status assessment focused on response indicators
Will provide trends summaries for all indicators	Trends evaluations focused on response and stressor indicators
Includes descriptive statistics only; extremely limited interpretation of results; no association analysis	Includes descriptive and interpretive statistics; association analysis leading to plausible explanations of status and trends are included
Directed toward technical audiences, with examples and major findings highlighted for a general audience	Short document, intended for general audiences and managers. Analysis and conclusions may need to be backed up by Special Scientific Reports. Detailed scientific explanations of major findings will be highlighted for technical audiences.

degree to which the data are used in an inappropriate manner. A major goal of Annual Statistical Summaries will be to facilitate identification of future analyses that should be conducted. Annual Statistical Summaries will be broadly distributed but will be addressed mainly to a technical audience.

5.5.2 Interpretive Assessment Reports

Interpretative Assessment Reports will be prepared for the public, Congress, program and regional offices, agency decision makers, and the interested scientific community. They will: (1) describe associations among indicator categories, (2) identify the likely causes of poor ecological condition, (3) assess the extent and magnitude of pollution impacts, (4) describe trends, (5) identify emerging hazards before they reach crisis proportions, and (6) evaluate the effectiveness of pollution control programs and policies on regional scales. Because Interpretative Assessment Reports are prepared for a broad range of audiences, the information they contain will be presented in summary as well as detailed form (i.e., they will contain a good executive summary).

5.5.3 Special Scientific Reports

Examples of Special Scientific Reports that will be prepared include:

- Methods Manuals providing a detailed description of and justification for sampling and processing methods,
- Data Management Reports providing a description of available data, how to access it, and who to contact for more information,
- Design and Analysis Evaluations presenting detailed evaluations of the sampling design and analysis procedures and identifying modifications to the design or analysis protocols that would better address objectives, and
- Research Reports presenting the approach, rationale, and findings of research projects such as the development and validation of "new" indicators, development of new statistical methods, and evaluations of the adequacy of proposed sampling methods or technologies.

Special Scientific Reports will be prepared mainly for technical audiences; however, a summary of their results will be presented in the Interpretative Assessment Reports.

The 1990 Virginian Province Demonstration Project will produce a number of Special Scientific Reports including:

- Field Operations Manual, due in Spring 1990, that provides detailed guidance to field crews on safety, communications, boat and vehicle operations, training sampling activities, and the shipping of samples to processing laboratories for the 1990 Demonstration Project. This manual will be a model for developing field operations when EMAP-NC implements programs in other provinces.
- An Implementation Plan, due in Spring 1990, that provides detailed plans for how the 1990 Demonstration Project will be implemented and managed. This plan will provide a model that can be followed for implementation programs in other provinces.
- An Example Interpretive Assessment Report, due in Fall 1990, that presents examples of the kinds of assessment information EMAP-NC will produce and provides a detailed analysis plan for future EMAP-NC data.
- A Laboratory Methods Manual, due in Summer 1990, that provides detailed descriptions of the laboratory methods that will be used to process samples for the Demonstration Project and will form a basis for laboratory processing activities for all future EMAP-NC activities.
- A Data Management Plan, due in Summer 1990, that provides detailed information on the data management system that will be used to manage the data generated by the 1990 Demonstration Project and forms a basis for data management for all future EMAP-NC activities. Examples of field and laboratory data sheets are included in the Data Management Plan.
- A Demonstration Project Activities Summary, due in Winter 1990-1991, that summarizes the data collected, describes the status of data records, identifies and discusses problems and issues that were encountered during the field program, and develops recommendations for improving logistical activities.
- A Demonstration Project Interpretive Assessment Report, due in Summer 1991, that details the findings of the indicator testing and

evaluation program and intensive spatial sampling efforts. The report will include evaluations of alternative sampling designs and develop recommendations about future sampling efforts. Most importantly, this report will make a preliminary (i.e., one year) assessment of the status of the estuaries of the Virginian Province that will be a model for future Interpretative Assessment Reports to be prepared by EMAP-NC.

5.5.4 Example Assessment Report

Because of the importance of defining precisely how the data collected by EMAP-NC will be used for integrated assessments, a brief discussion of the Example Interpretative Assessment Report is provided below. This report will include examples of the kinds of analyses and graphics that can be produced using EMAP-NC data. Most importantly, the Example Interpretative Assessment Report will identify and develop the analysis tools for synthesizing and integrating the data before data collection is completed. The Example Assessment Report also will identify the types of data and information required from other EMAP resource groups (e.g., forests, agroecosystems) and other agencies (e.g., NOAA, USGS) permitting arrangements to obtain these data to be made well before they are needed.

The data to be used for the Example Assessment Report will be a combination of simulated and actual data for key indicators. Characteristics of the simulated data (e.g., mean, range, variance, distribution) will be based on retrospective analysis of existing data. The example assessment data set will be compiled in a manner that allows associations (i.e., interdependence) among indicators to be varied for various subpopulations (e.g., estuarine classes, salinity strata, sediment strata). Initially, the example assessment will include a limited number of indicators and estuarine classes. Once the preliminary simulated data set is developed, it will be used to:

- Identify analysis approaches that adequately define associations among indicators
- Present examples of the kinds of summary results and conclusions EMAP-NC will produce.

Additional levels of complexity (e.g., more indicators, estuary classes) will be incorporated into the example data set as linkages among indicators are better understood. When evaluating the analyses for the example assessments, emphasis will be placed on determining the adequacy of the uncertainty estimates for

extreme values because these are the areas of the curves that are most likely to change as a result of management action (or inaction).

6.0 INFORMATION MANAGEMENT

During the course of the EMAP-NC Demonstration Project, more than 5,000 samples will be collected at over 200 sample sites. In addition, many of the parameters (i.e., indicators) that will be measured (e.g., contaminants in fish flesh) involve the collection of large amounts of data for each sampling site. As the sampling program is expanded to include other provinces, the quantity of data collected will increase exponentially. The ability of EMAP-NC to manage and disseminate the large amounts of information that will be collected will have a major influence on the success of the program. Development of an adequate information management system is therefore as important to the success of EMAP-NC as is collection of the data (NRC 1990a).

The analyses to be accomplished by EMAP-NC range from tabular summaries and statistical comparisons to evaluations of spatial distributions using Geographical Information Systems (GIS). During the implementation mode, EMAP-NC plans to publish statistical summaries of each year's collections within nine months after collection of the last sample. Analysts, therefore, require access to data of high quality shortly after they are collected. A computerized data management system is required to ensure that EMAP-NC data are made available for analysis in a timely manner.

EMAP-NC will be conducting a range of activities (e.g., sample collection, laboratory processing, statistical analyses) simultaneously over broad geographical areas. In order to identify problems, develop alternative plans, control costs, and modify schedules, project management within EMAP will require frequent (daily and weekly) reports on the status of each program activity. Therefore, a project management information system is needed to organize and track EMAP-NC project management data.

The remainder of this chapter is organized in two sections that parallel the two general types of information management activities identified above: (1) data management and (2) project management. The objectives of this chapter are to provide an overview of the way information collected by EMAP-NC will be managed and to inform potential users of when and how they will have access to EMAP-NC data. A detailed description of the EMAP-NC information management system is provided in Rosen et al. (1990). Rosen et al. (1990) also contains copies of data sheets and forms on which EMAP-NC will be recorded.

6.1 Data Management

Data management within EMAP will occur at three levels of organization. Each level will function independently, but their activities will be coordinated to form an integrated data management system that covers all ecosystems and related EMAP activities. The three levels of organization are as follows:

- Regional -- each region (e.g., Virginian Province) within a task group (e.g., Near Coastal),
- National -- each task group (i.e., ecosystem type), with data aggregated over all regions, and
- Program-wide -- entire EMAP program, integrated over all task groups (i.e., national evaluations across multiple ecosystem types).

EMAP information management activities are coordinated by the EMAP Information Management Committee (IMC). The EMAP-NC senior data analyst, Technical Director, and the ERLN ADP coordinator are members of the IMC. They are responsible for ensuring that information management activities within EMAP-NC are consistent with EMAP objectives, with activities occurring in other ecosystem types, and with Agency IRM policies and procedures. The EMAP-NC senior data analyst will use the IMC as an advisory group in the development, establishment, and maintenance of the Near Coastal Information Management System (NCIMS). The EMAP-NC team will participate in the development of standards for EMAP data processing through representation on the IMC. EMAP-NC data management will adhere to all standards developed by the IMC.

6.1.1 Data Storage

EMAP-NC will use a distributed data base system that consists of a central site and multiple remote nodes. The three major types of remote nodes are (1) regional coordination nodes, (2) field teams, responsible for collecting samples and making primary measurements, and (3) laboratories, responsible for processing samples. Field and laboratory nodes will transfer data and preliminary analyses to the appropriate regional coordination node for some processing prior to transfer to the NCIMS. Specific data management activities that will occur at the remote nodes are:

- Data collection,

- Initial calculation of parameter values,
- Initial entry of data into electronic format,
- Preliminary data analysis and summary,
- Quality assurance for sample tracking, sample preparation, and analytical techniques, and
- Transfer of appropriate data, in specified electronic formats, to the NCIMS, indicating progress on analyses, summarizing results, and identifying potential problems.

The core of the distributed EMAP-NC data management system is the Near Coastal Information Processing Center located at the Environmental Research Laboratory-Narragansett (ERL-Narragansett). Personnel at this facility are responsible for maintaining a comprehensive Data Inventory, a Data Set Index, Code Libraries, and a Data Dictionary for EMAP-NC. They will also maintain and disseminate EMAP-NC data and ensure that appropriate data are incorporated into the NCIMS. The Near Coastal Information Processing Center will also support the data processing requirements of the remote nodes and the exchange of data with other agencies and organizations.

The NCIMS must have the flexibility to handle the array of data types resulting from sample collection and processing. It must also support a variety of analysis, presentation, and reporting activities. For the 1990 Demonstration Project, the Statistical Analysis System (SAS) will be used as the data management system. SAS will also be used for most statistical analyses. SAS has been selected as the data management system because no relational data base system is available to EPA through current contacting mechanisms. When a relational data management system is available to EPA through the Office of Information Resource Management (OIRM), the EMAP-NC data management system will be converted to the selected relational data base system. This will allow users more flexible and efficient access to EMAP-NC data. After the conversion to a relational data base system, SAS will continue to be used as a principal data analysis tool.

At a minimum, the NCIMS will contain the following information:

- Complete records of each sampling event,

- Complete data for vertical CTD profiles for salinity, temperature, water depth, dissolved oxygen concentration, pH, transmissometry (an estimate of water clarity), fluorometry (an estimate of algal abundance), and photosynthetically active radiation (PAR),
- Data on concentrations of contaminants, organic content, physical sediment characteristics, and apparent redox potential discontinuity (RPD) depth of sediments for each sampling site,
- Data on silt/clay content for each grab sample processed for benthic community parameters,
- Benthic counts and biomass by taxonomic groupings,
- Counts and sizes for target bivalve species collected by the bivalve dredging program,
- Counts and size measurements for fish species, concentrations of contaminants in fish flesh for targeted fish species, gross pathological disorders for targeted fish species at the base sampling sites and for a subset of all species at the indicator testing and evaluation sites, detailed histopathology information for fish that were found to have gross pathological disorders, and detailed histopathology for a subset of all species at indicator testing and evaluation sites,
- Raw and summarized data of dissolved oxygen concentration, salinity, temperature, pH, and tidal stage (as indicated by change in water depth) for the continuous dissolved oxygen monitoring sites, and
- Data resulting from standard toxicity tests of (1) water samples collected at the indicator testing and evaluation sampling sites, and (2) sediment samples collected at all stations.

Data will be stored in SAS data libraries by indicator and topical area (e.g., benthic species composition and biomass, contaminant concentration in fish flesh, ancillary physical/ chemical data collected for each station sampling event).

A directory of data sets and libraries (Data Set Index) that are available at the NCIMS will be developed. This index will provide users with important information about the contents of each data set. It will also describe how to

access a particular data set. Information in the Data Set Index will include the following:

- A description of the data set and its purpose,
- Spatial and temporal sampling information about the collection site (e.g., length of record, geographical location),
- A list of the variables measured (e.g., salinity, sediment characteristics, numbers of benthic species, abundance of each species, biomass by major taxa, etc.),
- Name, address, and telephone number of the scientist working on EMAP-NC who is most informed about the data set,
- A description of the storage format of the data,
- An indication of whether the data is a subset/superset of other data sets (i.e., Does it belong to a particular data library?),
- The location of the data (i.e., where it physically resides),
- An assessment of the quality of the data including results of quality assurance evaluations conducted on it,
- Identification of and directions for access to other data sets that contain similar or related information, and
- Information on how to access the data set including names of contacts, approximate costs, and length of time required to access the data set.

The Data Set Index will be updated weekly. Potential users will have access to the most current version.

Historical data sets will be evaluated to determine whether they contain data of value to EMAP-NC. Those that contain useful information and are available will be incorporated into the NCIMS as data sets or data libraries. Historical data that are used frequently will be converted into SAS data sets. Information for historical data sets available from the NCIMS will be included in the Data Set Index.

A major requirement of the Near Coastal Information Processing Center capabilities will be to create maps and perform geographically based analyses. Therefore, the data generated for EMAP-NC will be referenced to a spatial entity,

such as a latitude and longitude. Spatial analyses will be accomplished using ARC-INFO, a Geographic Information System (GIS) that is used throughout EPA. ARC-INFO is also used by most of the other federal and state agencies participating in EMAP. ARC-INFO is a powerful tool that includes extensive analytical capabilities and interfaces with a number of other major software products, including SAS and ERDAS (a common software tool for processing data collected by satellites). ARC-INFO is not user friendly. Therefore, user friendly interfaces for routine data analysis and display will be developed by the Near Coastal Information Processing Center. EMAP-NC data analysts will work with other data management groups within EMAP (e.g., the Las Vegas GIS group) and other agencies (e.g., NOAA) to develop standards and coverages for GIS applications. Standards will be developed for assuring data accuracy, naming conventions, and documenting and archiving completed maps.

The initial base map for the Virginian Province will be at a scale of 1:100,000. Overlays for this base map delineating Virginian Province sampling locations and sampling plan (i.e., anticipated sampling dates, sampling crews, sample types), major road networks, and locations of facilities to which the field crew may require access will be a part of the NCIMS.

6.1.2 Incorporation of Data into the NCIMS

All data received by the Near Coastal Information Processing Center will be quality assured using procedures described in Chapter 8.0 and converted into SAS data sets. The data sets will be stored in data libraries by indicator type. Following initial data processing, the EMAP-NC Synthesis and Integration Team will perform the required data analyses and produce summary data bases. Examples of the types of information stored in summary data bases are dissolved oxygen summary data (e.g., percent of values below 2 mg/l for continuous dissolved oxygen monitoring stations), cumulative distribution functions for each indicator by estuarine class and for subpopulations of interest (e.g., salinity zones), and means and standard deviations for all indicators by estuarine class and subpopulations of interest. The NCIMS will maintain data and relevant analysis results in both raw and summarized form. This will eliminate costly redundant analyses.

6.1.3 Data Access and Transfer

The EPA VAX network will be the main means of access to data in the NCIMS. All data base design work and documentation, including the code libraries,

the data dictionary, standard operating procedures for data handling, and Geographical Information System (GIS) standards and base coverages, will be available over this network. Users who do not have access to the VAX network will be provided direct dial access to the NCIMS, as appropriate. Access authorization will be established under the direction of the Technical Director of EMAP-NC.

Data will be made available to different types of users, on different time scales, based on the quality assurance level of the data. The following groups of potential data users and their order of access have been defined:

- EMAP-NC entities that generate data -- Field crews, sample processing laboratories,
- Near Coastal Primary Users -- The Field Coordinator, data management personnel, QA/QC Officer, Synthesis and Integration Team, Technical Director, and NOAA personnel working on EMAP-NC,
- EMAP Data Users -- All other EMAP task groups, NOAA, and other federal agencies, and
- General Public -- Academic personnel, EPA program and regional offices, and other federal, state, and local governmental agencies.

Access for each of the user categories is defined in Fig. 6-1.

Ultimately, the data, reports, and findings of EMAP-NC will be important to many other groups within EMAP, the scientific community, and the general public. Data that are available to the entire EMAP community will be transferred to and maintained on the EPA National Computer Center (NCC) VAX Cluster. Public access to EMAP-NC data will be through the NCC.

Historical data sets or data collected by other organizations that may be important, though not likely to be used regularly, will be documented, processed, and quality assured; however, they will not be incorporated into the data sets that are available on the NCC VAX cluster. Data sets which are not likely to be used or which contain data that cannot be quality assured will be maintained on tape. These data will be documented but will not be made available through the NCIMS. The amount of confidential data or data for which the quality is suspect or cannot be determined that is available through the NCIMS will be limited.

All data in the NCIMS made available for general use will be in read-only format, allowing users to access the data without compromising the integrity of

Level of QA	Degree of Processing		
	Raw	Initial Summaries	Final Summaries
None	I*	I*	I*
Machine	I*, II*	I*, II*	I*, II*, III*
Complete	I*, II*, III*	I, II, III	I, II, III
Analysis Results	I, II, III, IV	I, II, III	I, II, III, IV

* These data users have explicitly agreed not to disseminate the data released to them and to use it only for specific purposes confirmed by the EMAP-NC Technical Director.

Figure 6-1. Matrix summarizing data access for various user groups as a function of the degree of data processing and the level of quality assurance that has been completed. Group 1 = Organizations that generated the data; Group II = EMAP-NC primary users, including the Technical Director, NOAA, data management support staff and synthesis and integration staff; Group III = Other EMAP users and task groups; Group IV = General public.

the data base. Requests to obtain copies of or access to data in the NCIMS will be submitted to the EMAP-NC Senior Data Analyst. The EMAP-NC Senior Data Analyst in conjunction with the EMAP-NC Technical Director will develop a schedule for providing access to these data. The release schedule will depend on the availability of personnel to process the data and the urgency of the request.

6.1.4 Documentation

The comprehensive documentation that will be available to all users of the NCIMS includes the following:

- Information system documentation,
- Data base dictionary,
- Data base directory,
- Code tables,
- Internal and external documentation for all processing programs,
- Directory structures, and
- Access control for directories, files, and data bases.

6.1.5 Redundancy

All data generated, processed, and incorporated into the NCIMS will be stored in redundant systems to ensure that if one system is destroyed or incapacitated, the Information Management team will be able to reconstruct the data base. The raw data for these data bases will reside on at least three different physical devices.

All data files will be backed up regularly. For field operations, backups will be accomplished on a daily basis. In the Information Center, incremental backups to removable media will be performed on all files daily. Backups of EMAP directories will be performed weekly. Intermediate files will be downloaded to tape weekly.

All original data files will be saved on-line for at least two years. After that, the files will be permanently archived on floppy disks or tapes. All original files will be protected so that they are read-only; write and delete privileges will be removed from these files, and the deletion of an original file will not be permitted.

6.2 Project Management

EMAP-NC program management will need frequent and accurate status reports about field collection and laboratory processing activities. The Project Management Information System will be used for this purpose. The Project Management Information System has two major elements: (1) a communications system for rapidly transferring information between field crews, processing laboratories, and the NCIMS, and (2) a sample tracking system for monitoring the status of sampling events on a periodic basis. These two elements of the Project Management Information System are discussed below.

The computer programs that will be used to communicate with field crews and sample processing laboratories will be developed by the Near Coastal Information Management Team. The programs will include: (1) navigational assistance; (2) a system for recording events and observations made by field crews and for transferring these data to the NCIMS; (3) bar code readers for rapidly and effectively entering sample identification information; (4) communications capabilities for data retrieval from a broad range of electronic data logging/recording devices; and (5) access to a data base of logistical information (e.g., boat repair facilities). In addition, this system will automatically conduct routine quality assurance checks (e.g., validation of station identification information), as well as provide documentation for sampling events (e.g., latitude and longitude of sampling sites). The system also will assist in monitoring the transfer of samples from the field teams to the processing laboratories.

6.2.1 Communications

Field crews and processing laboratories will submit data to the NCIMS in established time frames using standard formats. The communications software available for the NCIMS will facilitate this information exchange. For example, software in the NCIMS will automatically log remote computers into the central processing center, then perform file transfers into predetermined directories. Initial processing of the data will be begun automatically. When processing is complete, the EMAP-NC information management center will be notified and requested to acknowledge that it is aware the data are ready for additional processing.

Data in the NCIMS that will be available to the field crews via the communications link include the following:

- Logistical Information -- locations of boat ramps, overnight delivery offices, dry ice suppliers, airports, bus stations, hospitals, police stations, marinas with boat repair facilities, Coast Guard stations, motels, restaurants, gas stations, automotive repair centers, etc.
- Sampling Locations -- including latitude and longitude, LORAN coordinates, sample identification numbers, expected sediment and water quality characteristics, estuary class, and station type (e.g., base sampling site, indicator testing and evaluation sampling site, or supplemental sample site) for each sampling location.

6.2.2 Sample Tracking Information

The sample tracking system will track samples from their initial collection through completion of all analyses and/or processing. To accomplish this, each sampling event and sample type will be assigned a unique identification number. These numbers will be entered into the NCIMS prior to collection of data. Sample numbers will be bar coded to facilitate data entry by the field crews.

Information entered for each sample in the sample tracking system that will be available for retrieval and review will include:

- Sampling site name (cross referenced to a Station Data Base),
- The time the sample was collected, including date, hour, and duration of sampling effort,
- Type of sample (e.g., grab samples to be processed for benthic species composition and biomass, fish tissue sample to be processed for contaminant concentrations),
- Identification of the individual/team that collected the sample,
- A list of the analyses and processing activities which are planned for that sample and the status of those analyses and activities (e.g., collection completed, analyses completed),
- Directions to files containing "raw" data generated for each sample (e.g., CTD profiles), and

- Directions to textual files containing descriptive information about the sampling event (e.g., field team comments).

When samples are transferred from field crews to analytical laboratories, a record of the exchange will be entered into the sample tracking system, both upon release and upon receipt of the materials. The identity and disposition of any sample can therefore be established by checking the sample status in the NCIMS. The status of all analyses and results will also be available through the sample tracking system.

6.3 Staffing of NCIMS

The NCIMS will consist initially of five full-time data management professionals. The positions and their responsibilities are as follows:

- A Senior Data Analyst (member of IMC) responsible for system design, liaison with other ecosystems and agencies, development of data management standards for EMAP-NC, and ensuring that EMAP-NC adheres to standards developed by IMC,
- A Programmer responsible for development of the software needs to implement the EMAP-NC information management system,
- A GIS Programmer responsible for development of the software to display and analyze EMAP-NC data using GIS technology,
- A Fortran/System Programmer responsible for development of programs to incorporate data coming from field crews and other remote sources into the NCIMS efficiently, and
- A Data Clerk responsible for documenting EMAP-NC data sets, including historical data obtained from other agencies, transfer of data to other agencies, routine reports of the data quality of NCIMS, routine processing of "new" data, and data entry.

7.0 LOGISTICS PLAN

The sampling design for the 1990 Virginian Province Demonstration Project is complex and involves collection of ecological information from a broad geographical area (Cape Cod to Chesapeake Bay) over a relatively short time period (summer 1990). It includes routine data collection and processing, as well as the conduct of special studies to obtain the information needed to evaluate indicators of environmental quality and alternative sampling designs. Major logistical activities that must be undertaken for successful completion of the Demonstration Project include:

- Selection and procurement of sampling equipment (e.g., boats, motors, vehicles, sampling gears) and supplies (e.g., bottles, shipping containers, chemicals),
- Testing and evaluation of sampling equipment (e.g., water quality monitors, data recording devices, navigational aids),
- Identification and selection of technical staff and contractors for the conduct of sample collection and processing (e.g., approximately 40 individuals),
- Training of field crews including development of a Field Operations Manual,
- Establishment and management of an Operations Center and communications network,
- Conduct of the data collection program including collection and processing of samples,
- Tracking of performance and progress on sample collection and processing activities, and
- Maintenance of equipment and resupply of field crews.

Details of implementation activities for the 1990 Demonstration Project are provided in Schimmel (1990).

Sample collection and processing activities for the 1990 Virginian Province Demonstration Project require the activities of 50 to 60 technical staff to be coordinated and managed. When implemented nationally, EMAP-NC sample collection and processing activities will be the responsibility of Regional Offices and likely will be conducted by a combination of NOAA, ORD, EPA Regional, state, university, and private contractor laboratories. For this national program, the activities of hundreds of technical staff must be managed and coordinated. The findings of sample collection and processing activities for the 1990 Demonstration Project will be the major basis used to identify logistical issues (e.g., training requirements, procurement and contracting limitations, equipment maintenance and performance issues, methods development problems) that must be resolved before EMAP-NC can be implemented nationally.

This chapter provides an overview of the logistics plan for implementing the 1990 Demonstration Project. A discussion of the lessons learned and recommendations for implementation of sampling programs in other regions and nationally will be prepared as part of the Interpretative Assessment Report for the 1990 Virginian Province Demonstration Project. This report will be prepared in 1991.

7.1 Sampling Activities

Sampling activities for the Virginian Province Demonstration Project will be conducted from mid-June through the end of September. This index period is divided into three intervals: June 19 through July 18, July 19 through August 30, and September 1 through approximately September 30. Interval 1 will be used mainly to identify and resolve sampling problems and to provide an opportunity for the field crews to become proficient at sampling activities. Most of the data critical to the success of the Demonstration Project, including the special studies, will be collected in Interval 2 when the most stressful environmental conditions (e.g., lowest dissolved oxygen concentrations) are expected to occur. Interval 3 will be used to fill in data gaps, including collection of data for those indicators for which it was not critical to collect during the Interval 2 period (e.g., estimates of the abundance and distribution of large bivalves). An evaluation of indicators measured during all three sampling periods will provide data for an analysis of the variability of indicators over the index period.

During the Demonstration Project, samples will be collected from 215 sites (Fig. 3-6). These sites consist of the six station types. Sampling activities associated with each station type are detailed in Table 7-1 and described below.

Table 7-1. Sampling activities that will be accomplished at each station type during each of the three sampling periods

Station Type	Interval 1	Interval 2	Interval 3
Base Sampling Site	CTD Profile Fish Trawling ^(a)	CTD Profile Fish Trawling Benthic Grab ^(b)	CTD Profile Fish Trawling Shellfish Dredging
Spatial Supplement/ Scale Supplement Sites	Not sampled	Same as base sampling site	Not sampled
Continuous Dissolved Oxygen Monitoring Sites	CTD Profile Fish Trawling Benthic Grab ^(b)	Same as base sampling site	CTD Profile Fish Trawling Benthic Community Shellfish Dredging
Continuous Dissolved Oxygen Servicing Revisits	CTD Profile Replace DataSonde	CTD Profile Replace DataSonde	Not conducted
Index Sites	Not sampled	CTD Profile Benthic Community	Not sampled
Indicator Testing/ Evaluation Sites	Not sampled	CTD Profile Fish Trawling Benthic Grab ^(b) Shellfish Dredging Sediment Profile Camera Water Column Sampling	Not sampled

^(a) Fish trawling includes measurement of fish community, tissue contaminants, and gross pathology.

^(b) Benthic grab sampling includes samples for determining benthic community structure, sediment contaminants, and sediment toxicity.

- The 111 base sampling sites form the core of the sampling program and were selected using the sampling design described in Chapter 3. Data collected at these sites will be the basis used to assess the ecological status of the Virginian Province. Data for selected indicators (e.g., dissolved oxygen concentration, fish community parameters, fish gross pathology) will be collected at as many base sample sites as possible during all three sampling intervals and will be used to evaluate the consistency of their distributions over the index period.
- Continuous dissolved oxygen (DO) monitoring will be conducted throughout the first and second sampling intervals at 30 of the base sampling sites using Hydrolab DataSonde 3 dissolved oxygen monitors. Each monitor will be serviced approximately every 10 days. Servicing activities consist of retrieving the deployed unit, transferring the data to an on-board computer, installing a calibrated replacement unit, and performing the quality control (QC) checks to evaluate the performance of both the unit that is being deployed and the one that is being retrieved. Data for all core and developmental indicators, except sediment contaminant concentrations and sediment toxicity, will be collected from the continuous dissolved oxygen monitoring sites during each sampling interval.
- Indicator testing and evaluation sites were selected to represent a broad range of dissolved oxygen levels and levels of toxics contamination (see Chapter 3.0) and will be sampled only during the second sampling interval. Eight of these sites are coincident with base sampling sites. Indicator testing and evaluation sites will be sampled for the same parameters as the base sampling sites. In addition, research indicators, which require further evaluation to determine their suitability (e.g., reliability, specificity of response) for broad-scale application, will also be sampled at these sites. The data collected from the indicator testing and evaluation sites will be the basis used to determine the degree to which indicators discriminate between polluted and unpolluted sites.
- Each of the base sampling sites in the small estuaries and large tidal rivers will have an associated index sample site. Index sites were chosen to represent depositional environments. In systems that are exposed to pollutants, such depositional environments have a high probability of exposure to unacceptable dissolved oxygen concentrations and/or toxic levels of contaminants. There are 57 index sites; they will be sampled only during the second sampling interval.

- The 33 spatial supplemental sampling sites will provide the information necessary to evaluate alternative sampling strategies, including defining the appropriate sampling density for full-scale implementation. Supplemental samples will be collected only during the second sampling interval.

7.2 Field Crews

Sampling will be conducted by three teams. Each team will be composed of two, four-person field crews rotating every five days. Field crew activities will be directed from an Operations Center located at the EPA Environmental Research Laboratory at Narragansett, Rhode Island (ERL-Narragansett). The Operations Center will be responsible for maintaining daily contact with each crew and tracking and reporting on the progress of sample collection and processing activities. A commercial "800" number has been purchased to facilitate communications between the Operations Center and field crews (1-800-NET-EMAP). The "800" telephone line will be manned 24 hours per day to ensure that field crews can communicate with the Operations Center at any time. The Operations Center is also responsible for responding to public inquiries, such as those associated with the return of lost equipment and requests for detailed information about sampling activities.

Each crew will consist of a Crew Chief and three crew members. The Team Leader will act as Crew Chief for one of the two crews comprising a team. Field sampling will be directed by the Crew Chief, who will be the captain of the boat and the on-site decision maker regarding safety, sampling activities, and communication with the Operations Center. The Team Leader is responsible for overseeing all activities including tracking progress and maintaining equipment.

Qualifications for Team Leaders and Crew Chiefs are an M.S. degree in Biological/Ecological Sciences and three years of experience with small boat operations and data collection activities in marine/estuarine ecosystems, or a B.S. degree in a related field and five years of relevant experience. The three crew members will be required to have a B.S. degree or equivalent and, preferably, at least one year of experience in small boat operations and data collection in marine/estuarine ecosystems.

On any sampling day, three crew members, one of whom is a Crew Chief, will be on the boat collecting data, sediments, benthic organisms, and fish, and deploying and retrieving the water quality monitors at the designated sampling stations. The other crew member will remain on shore in a mobile laboratory and will prepare samples for shipment to processing laboratories, service and calibrate

water quality monitors, repair damaged equipment, and provide general support, including communication between the boat crew and the Operations Center.

Each team will have two substitute crew members who have undergone the same training as regular crew members. Each team will also have a crew member who, based on experience or performance, will be designated as a backup Crew Chief. These people will be available to the Team Leader in the event that illness, injury, or family emergency requires replacement of a crew member. Should additional crew members be needed for any reason, the Team Leader will contact the Operations Center, and arrangements will be made for a replacement crew member from another team. A fourth sampling team, composed of backup personnel, may be activated to assist primary teams in maintaining the sampling schedule. The fourth team most likely would be activated during the second sampling interval to assist with collecting supplemental samples.

7.3 Equipment

Each sampling team will be equipped with a 24-foot boat and trailer, all necessary sampling equipment, a pickup truck, and a mobile laboratory/service center. In addition, each crew will have a small van available to transport crew members to and from staging areas during crew changes. A fully equipped spare boat, trailer, and pickup truck will be available at the Operations Center for emergency use or to augment field collection.

The boat will be equipped with twin 150 horsepower outboard engines (to ensure crew safety in case one engine fails), a mast and boom with a hydraulic winch and capstan, Loran C, radar, VHF radios, a portable cellular telephone, a depth finder, all required safety equipment, maintenance tools, nautical charts for all sampling stations, and repair parts for sampling gear and outboard motors. The boat, engines, and trailer are estimated to weigh approximately 8,000 pounds. Because many of the ramps that will be used are likely to be of marginal quality, a full-size four wheel drive pickup truck, equipped for heavy-duty towing, will be used for towing. The truck bed will be covered by a camper shell that provides a secure area for storing equipment and supplies.

Each team will have the following equipment for collecting samples:

- A SeaBird CTD water profiling instrument outfitted with dissolved oxygen and pH sensors, transmissometer, fluorometer, and a photosynthetically active radiation (PAR) sensor

- Up to 14 Hydrolab DataSonde 3 recording units for measuring continuous dissolved oxygen and other water quality data at the 30 long-term dissolved oxygen monitoring sites
- Several 16 m high-rise fish trawls with detachable cod-end liners
- One stainless steel Young-modified Van Veen grab for sampling benthic organisms and sediments
- One rocking-chair dredge for collecting large (> 1 inch) bivalves
- Two lap-top personal computers (one computer will be maintained on the boat and one in the mobile laboratory).

The mobile laboratory will be used for servicing and calibrating water quality monitors, repairing equipment, storing supplies and backup equipment, and preparing samples for shipment to processing laboratories. It will be equipped with a workbench, shelving, and general supplies (e.g., shipping containers, labels, spare equipment, expendable supplies, and materials necessary to service field gear and water quality monitors). It will also have a VHF radio for communication with the boat and a lap-top computer for entering, recording, and transferring data to the Operations Center.

The field computers will serve as the primary means of capturing, storing, transmitting, and tracking electronic data from the Hydrolab and SeaBird instruments. In addition, they interface with the navigation instruments through custom software, assisting the Crew Chiefs to locate stations and record station coordinates during sampling activities (e.g., at the beginning and end of on-station activities). Data and information on the lap-top computers are transmitted to the Operations Center via modem over commercial telephone lines. These data also will be transferred on floppy disks. In addition, a complete copy of all sampling activities and data will be maintained on the hard disk of both computers. Field crews will "flag" any data or collections they consider to be questionable and will include an explanation of why the data were flagged. Because information is lacking on the ability of computers to withstand the abuse to which they may be subjected on the boats, data sheets will serve as the primary means of recording all but the electronic data. However, where feasible, field data will be entered onto the field computers and electronically transmitted to the Operations Center to provide a basis for evaluating the system.

As previously noted, the boat and the mobile laboratory will be equipped with a marine band VHF radio. The radios will be used as the primary means of communication between the land-based crew member and the boat during field operations.

7.4 Sampling Logistics

Equipment and supplies required to support field operations will be stored at two locations: Narragansett, Rhode Island, in the northern portion of the sampling area, and Columbia, Maryland, in the southern portion of the sampling area. Field crews will use these local bases as resupply points for mobile laboratories, as meeting places for crew changes, and as locations to prepare for or stage down from field trips.

Each sampling team will be responsible for sampling a defined geographic area (Fig. 7-1). Team 1 will sample stations from Cape Cod south to New York Harbor, including Long Island Sound and the Hudson River as far north as Albany, New York. Team 2 will be responsible for the area from New York Harbor, south to the upper Chesapeake Bay, including stations in the mainstem of the Bay north of Annapolis, Maryland. Team 3 will be responsible for sampling stations in the Chesapeake Bay and its tributaries south of Annapolis, Maryland, and the Delmarva Peninsula (Eastern shore of Delaware, Maryland, and Virginia).

Site reconnaissance will be conducted by the Crew Chiefs before actual sampling begins to identify inaccessible sites and potential hazards to sampling activities. Facilities necessary to complete data collection activities, including boat ramps, marinas, hotels, dry ice vendors, and overnight shipping depots, also will be located as a part of reconnaissance activities. During reconnaissance, the stations will be located using the protocols described in the Field Operations Manual (Strobel 1990). If the station location is found to be unacceptable for specific sampling activities (e.g., too shallow for deployment of water quality monitors, located in a busy navigational channel), the Operations Center will be notified. The Operations Center will work with the sampling design team to identify an alternative sampling site. Information obtained during reconnaissance will be stored in a computerized data base and included as an addendum to the Field Operations Manual.

Each team must sample approximately two stations per day to complete all required sampling activities, including travel by boat and car, time on station collecting samples, and launching and hauling the boat. The normal workday

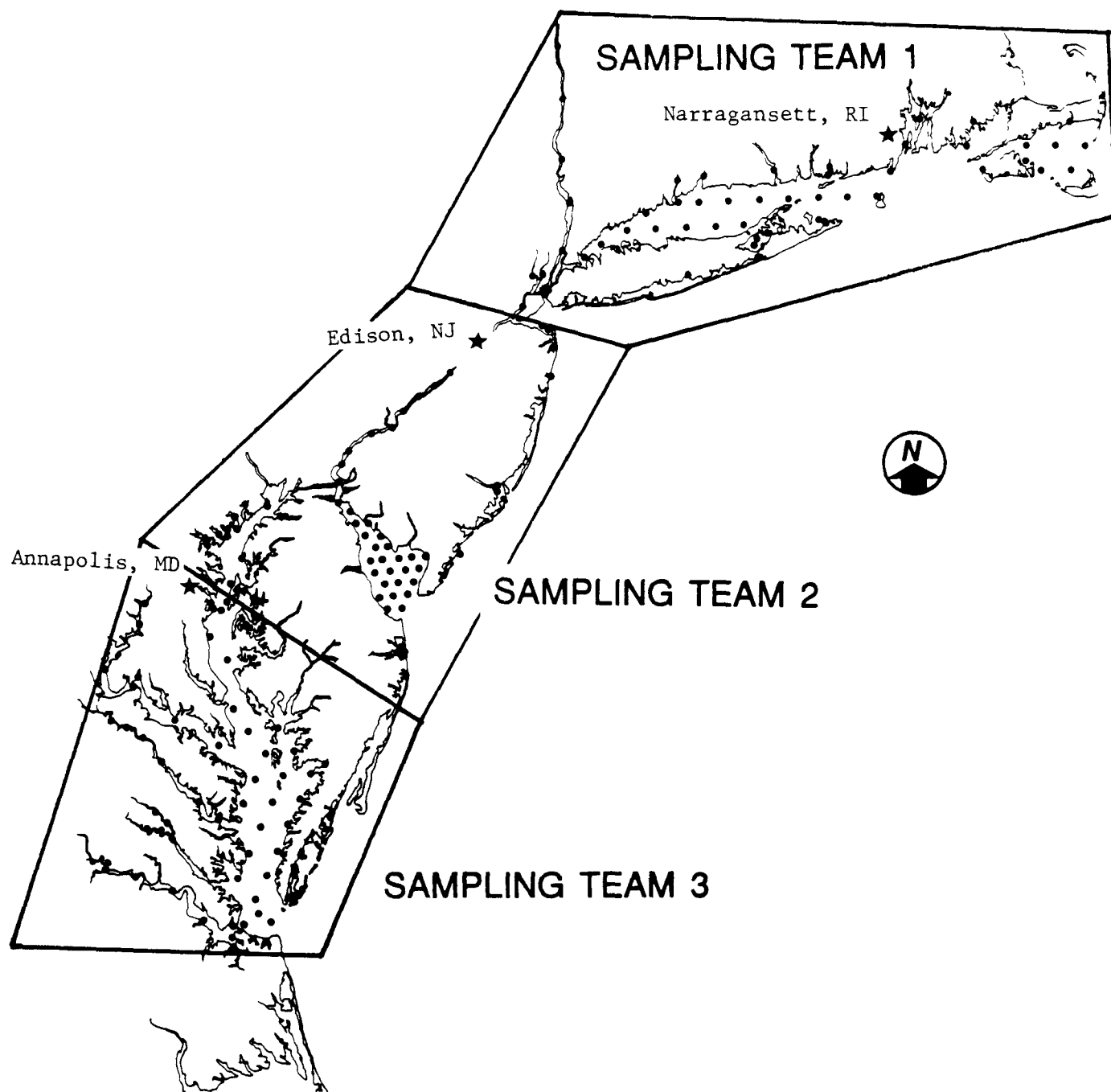


Figure 7-1. Areas to be sampled by each team during the 1990 Demonstration Project in the Virginian Province. Base Stations are indicated by stars.

for field crews will be approximately 12 hours. However, during the early part of the program when crews are becoming familiar with sampling operations (e.g., sampling Interval 1) many 16- to 18-hour days are anticipated. After the initial learning phase, crews will be required to plan their days to be off the water by about 1800 hours. Table 7-2 provides an example of the scheduling process.

During the first two sampling intervals, each team will be responsible for sampling 9 to 11 continuous dissolved oxygen monitoring stations. These stations must be revisited once every 10 days to service and replace the Hydrolab DataSonde 3 water quality monitors. To maintain this schedule, each team must complete a circuit of its designated sampling area every 10 days. Collection of data from continuous dissolved oxygen monitoring sites is the major factor affecting when other stations are visited.

On the day of a visit to a continuous dissolved oxygen monitoring site, Crew Chiefs will have the option of selecting any nearby site that has not been sampled. This selection will generally be based on local weather conditions. The adjacent site that is most likely to be adversely affected by inclement weather will be sampled as early in the schedule as possible. For example, all stations in Nantucket Sound are clustered into one group. On the first visit to Nantucket Sound, Team 1 will attempt to sample the site that is farthest from shore. If weather does not permit this, the team will sample a more accessible site nearer to shore. Ten days later, when the crew returns to Nantucket Sound, it will try again to sample the site most likely to be adversely affected by weather that remains to be sampled.

7.5 Sample Shipment and Processing

The expertise of several laboratories will be required for sample processing. During the Demonstration Project, chemical contaminant analyses will be conducted at the EPA Environmental Monitoring Systems Laboratory in Cincinnati, Ohio; fish histopathology will be conducted at the Environmental Research Laboratory in Gulf Breeze, Florida; sediment and water column toxicology testing will be conducted at the EPA Environmental Research Laboratory in Narragansett, Rhode Island; and benthic sample processing will be conducted by private contractors. A detailed description of sample handling procedures that will ensure timely processing of samples with limited holding times is provided in the Field Operations Manual (Strobel 1990). An EMAP-NC Laboratory Manual has been prepared to ensure that standardized laboratory protocols and procedures are used to process samples (Graves 1990).

Table 7-2. Example of the proposed sampling schedule for Team 1 for the first 10 days of Sampling Interval 2 (July 20- July 30). [BS = Base Station activities, I = Index Station activities, SUPL = Supplemental Station activities, TEST = Indicator Test Station activities, DOV = DO Revisit activities, and DOM = DO Monitoring activities]

Date	Location (Station Number)	Activity	Time On Station (hrs)	Travel by Boat (hrs)	Travel By Car (hrs)	Launch/ Hauling (hrs)
7/20/90	Buzzards Bay (2)	DOV + BS	5	1	2	1
	New Bedford (3)	DOV	1	1		
TOTAL TIME = 11 HOURS						
7/21/90	Nantucket Sound (223)	BS	3	3.5	2.5	1
	Nantucket Sound (225)	BS	3			
TOTAL TIME = 13 HOURS						
7/22/90	Narragansett Bay (212)	DOV	1	1	2	1
	Block Island Sound (8)	BS	3	1	1	1
TOTAL TIME = 11 HOURS						
7/23/90	Mystic River (203)	DOV	1	1	1	
	Connecticut River (206)	TEST	6.5	0.5	1	1
TOTAL TIME = 12 HOURS						

Table 7-2. Continued

Date	Location (Station Number)	Activity	Time On Station (hrs)	Travel by Boat (hrs)	Travel By Car (hrs)	Launch/ Hauling (hrs)
7/2/90	Long Island Sound (193)	DOV	1	1		1
	Quinnipiac River (207)	TEST	6.5	0.5	1	
TOTAL TIME = 11 HOURS						
7/25/90	Long Island Sound (201)	DOV	1	0.75	F 1	1
	Long Island Sound (191)	BS	3	1	3.25	1
TOTAL TIME = 12 HOURS						
7/26/90	Hudson River (186 and 187)	BS + I	4.25	1	3.5	1
TOTAL TIME = 9.75 HOURS						
7/27/90	Hackensack River (169)	DOV	1	2		1
	Arthur Kill (164)	TEST F	6.5		3	
TOTAL TIME = 13.5 HOURS						
7/28/90	Great South Bay (188)	DOV	1	0.5	2	1
	Napeague Bay (162 and 163)	BS + I	4.25	1	1	1
TOTAL TIME = 11.75 HOURS						
7/29/90	Great Peconic Bay (158 and 159)	DOV + BS + I	5	0.5	6	1
TOTAL TIME = 12.5 HOURS						

Table 7-2. Continued

Date	Location (Station Number)	Activity	Time On Station (hrs)	Travel by Boat (hrs)	Travel By Car (hrs)	Launch/ Hauling (hrs)
Begin Second Cycle						
7/30/90	Buzzards Bay (2)	DOV	1	2	2	1
	New Bedford (3)	DOV + BS	5			

TOTAL TIME = 11 HOURS

Sample tracking and data transfer will be a complex coordination task involving a wide variety of sample types shipped by any of three or four crews from a large number of possible shipping locations to the different processing laboratories. EMAP-NC has developed a computer-based sample tracking system to assist with this task (see Section 6.2). This system documents that a sample has been collected and placed in a shipping container. The destination of the shipment is also recorded. When a shipment is received, the receiving laboratory will record the shipment identification number and the identification numbers of all the samples inside the shipping container. Receiving laboratories will notify the Operations Center via the EPA network of receipt of all shipments and the identification number, type, and condition of all samples in each shipment. Most receipt notifications will be made within 24 hours. The Demonstration Project Manager will use information on sample collection and processing activities to assess the overall progress of the project and to identify problems (e.g., when samples have not been shipped or received on time). The software will flag any samples that were shipped but not received within two days of shipment. On a periodic basis, processing laboratories will be provided a list of the sample identification numbers they have received and data on the bottom salinity of the site at the time of collection. Analytical labs will not be provided any other information (e.g., location) about samples.

7.6 Project Management

Figure 7-2 outlines the organizational structure for the 1990 Virginian Province Demonstration Project.

The Associate Director for Near Coastal is responsible for program planning, budget management, program management, quality assurance, interagency coordination and constituency building. The major activities that must be conducted by the Associate Director include preparation and revision of multiyear implementation and operating plans, preparation and justification of budgets to EPA management, personnel management, resolution of organization conflicts, review of technical proposals and products for scientific rigor, establishing cooperating agreements with other agencies, informing key audiences (e.g., the scientific community, the public, special interest groups, other agencies) about EMAP activities, accomplishments, and plans.

The Technical Director will provide the technical leadership for EMAP-NC. The Technical Director's major responsibilities are research planning, including preparing and defending budgets; revising plans to reflect changes in policy, priorities, technical findings, and resources; developing and revising schedules; and synthesis and integration of the collected data into products. The Technical

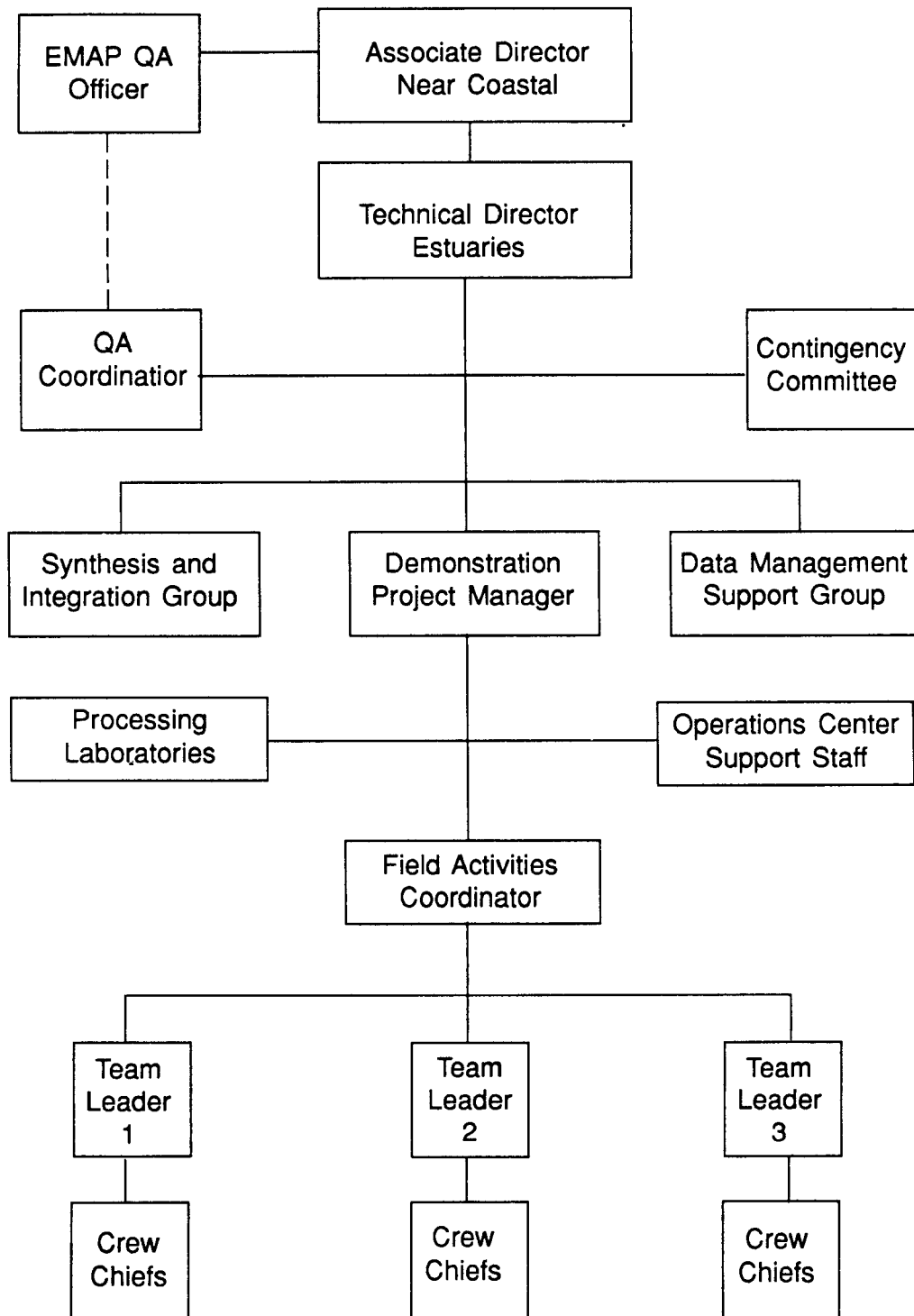


Figure 7-2. Management structure for the 1990 Virginian Province Demonstration Project

Director also will assist the Associate Director with interagency coordination. The activities of the Technical Director are supported by a Quality Assurance Officer, a data management staff, and a synthesis and integration staff.

The Demonstration Project Manager directs day-to-day operation of the 1990 Virginian Province Demonstration Project. The Demonstration Project Manager's major responsibility is to ensure that the needed samples are collected and processed. Major activities that the Demonstration Project Manager must conduct are selection and procurement of equipment and supplies, testing and evaluation of equipment, identification and selection of technical staff and contractors to perform the field program, training of field crews, management of the Operations Center, maintenance and storage of equipment, and tracking the progress of field and laboratory processing activities. The Demonstration Project Manager will make weekly progress reports to the Technical Director and other EMAP management. These reports will include the following:

- A list of the sites successfully sampled,
- A list of sites not sampled, the reasons why, and what plans have been made for obtaining these samples at a later time,
- The status of supplies and equipment,
- A general overview of data collection activities, and
- A brief evaluation of the quality of the data that were collected.

The Demonstration Project Manager will be supported by a Field Coordinator and the staff of the Operations Center. The Field Coordinator will be the major point of contact between field crews and other individuals within EMAP-NC.

7.7 Contingencies

Most regional monitoring programs are adversely affected by unpredictable events (e.g., inclement weather, equipment failure) that delay schedules. The success of the 1990 Virginian Province Demonstration Project is to a large degree dependent upon the efficiency with which acceptable contingency plans are developed and problems resolved.

The Crew Chief has the responsibility for determining whether sampling can be accomplished with an acceptable margin of safety and represents the lowest level at which decisions about alterations to the sampling activities and schedule will be made. The primary reason for cancellation of a sampling event most likely will be inclement weather. If inclement weather is anticipated, Crew Chiefs will sample only at sheltered sites that are minimally affected by inclement weather. Detailed procedures that Crew Chiefs will follow to ensure the safety of crew members are described in the Field Operations Manual (Strobel 1990).

Unforeseen circumstances, such as Coast Guard restrictions resulting from an accident or other regulations that close an area to boat traffic, may cause field crews to reschedule or cancel sampling activities at a specific location. If this should occur, the Crew Chief will contact the Operations Center immediately for instructions. The Demonstration Project Manager will have a list of sampling sites that can be moved without adversely affecting the sampling design (e.g., indicator testing and evaluation sites), as well as the protocol for choosing an alternative site. If the site is one that can be moved, the Operations Center will inform the Crew Chief of the location of the "new" site. If the site cannot be moved, the Demonstration Project Manager will contact the Technical Director, who will determine on appropriate actions.

Most equipment malfunctions and repairs will be handled by Crew Chiefs, using repair facilities within their specific sampling area. Crew Chiefs will coordinate this activity with their Team Leader and the Field Coordinator. In the event that a piece of field equipment (e.g., boat engines) fails and requires extensive repair beyond what can be provided locally within one day, the Operations Center will be notified. The Operations Center will take the actions required to ensure that replacement equipment is transported to the crew as rapidly as possible. The Demonstration Project Manager will be responsible for the rapid repair of damaged or malfunctioning equipment. Team Leaders will maintain an equipment log containing information on the performance and status of each major piece of equipment. This information will be communicated to the Operations Center on a routine basis.

When logistical problems that threaten the integrity of the project occur, the Technical Director will convene a meeting of the Contingency Committee, which will provide advice on potential alternative sampling designs or strategies. The Technical Director will be responsible for making decisions that alter the sampling design or field/laboratory/QA procedures. The committee will be composed of experts who are familiar with the sampling design, analysis scheme, indicators, sampling methodologies, and logistics and will advise the Technical Director on topics related to their respective areas of expertise.

Decisions of the Contingency Committee will be relayed to field crews by the Operations Center.

8.0 QUALITY ASSURANCE

The 1990 Virginian Province Demonstration Project will use 40 to 50 staff members to collect samples; and five different laboratories to process samples. The size of the staff involved in data collection and the number of organizations involved in laboratory processing will increase proportionately when EMAP-NC programs are implemented in other regions. Monitoring programs that involve multiple field crews and laboratories frequently encounter problems in obtaining data that are comparable among the many individuals and laboratories involved (Taylor 1978, 1985; Martin Marietta Environmental Systems 1987; NRC 1990a). Such problems usually result because, in the haste to initiate the data collection program, the field crews are not adequately trained in applying standardized collection methods and the comparability of the laboratory processing methods and capabilities are not evaluated (Taylor 1985).

EMAP-NC will implement a quality assurance (QA) program to ensure that the data produced are comparable and of known and acceptable quality. This program will consist of two distinct but related sets of activities: quality control and quality assessment. Quality control includes design, planning, and management actions to ensure that the appropriate types and amounts of data are collected in the manner required to address study objectives. Examples of some quality control activities that will be employed by EMAP-NC are the development of standardized sample collection and processing protocols and the requirement for specific levels of training for field crews and technicians who will collect and process samples. The goals of quality control procedures are to ensure that collection, processing, and analysis techniques are applied consistently and correctly; the number of lost, damaged, and uncollected samples is minimized; the integrity of the data record is maintained and documented from sample collection to entry into the data record; data are comparable with similar data collected elsewhere; and study results can be reproduced.

Quality assessment activities will be implemented to quantify the effectiveness of the quality control procedures. These activities ensure that measurement error and bias are identified, quantified, and accounted for or eliminated, if practical. Quality assessment consists of both internal and external checks including repetitive measurements, internal test samples, interchange of technicians and equipment, use of independent methods to verify findings, exchange of samples among laboratories, use of standard reference materials, and audits (Taylor 1985; USEPA 1984).

8.1 Data Quality Objectives

While quality assurance (QA) is a necessary part of any sampling program, defining the proper level of QA is difficult. If QA is defined too rigorously, it can consume a disproportionate share of program resources; if QA is defined too leniently, the data collected may be of insufficient quality to meet program objectives. Within EMAP, the balance between cost and uncertainty will be established using the Data Quality Objective (DQO) process (Fig. 2-4).

Developing DQOs is a multistage, iterative process that involves individuals at all levels of the project (Fig. 8-1). The first stage is initiated by the manager or decision maker, who identifies the central question to be addressed and the degree of acceptable uncertainty associated with the answer. In identifying acceptable uncertainty, the manager must weigh the cost of collecting samples against the "cost" of reaching incorrect decisions based on the sampling effort. The second stage is conducted by the project scientific staff, who formulate a sampling strategy for addressing the question and then estimate the cost of developing an answer with the satisfactory level of accuracy, precision, representativeness, comparability, and completeness. If the cost estimates are acceptable to the decision maker, then the project proceeds to the third stage, in which the technical staff develops quality control and quality assessment procedures for each aspect of the program (e.g., field collection, laboratory analysis and processing, data management analysis) that are consistent with the desired level of quality. If cost estimates are too high, then the scientific staff and the decision makers jointly modify the design and expectations of the proposed program until a proper balance of cost and uncertainty is achieved.

Two sources of error are considered in establishing DQOs: sampling error and measurement error. Sampling error is the difference between the sampled value and the true value and is a function of natural spatial and temporal variability and sampling design. The temporal variability relevant to EMAP-NC is that which occurs within the index period. Measurement error is the difference between the true sample values and the reported values, and can occur during the act of sampling, data entry, data base manipulation, etc. While "good" data are available to estimate measurement error for all of the parameters that will be measured by EMAP-NC, data for estimating sampling error are either unavailable or inaccessible for many, if not most, of the indicators to be measured. Acceptable estimates of variability are unavailable because EMAP is the first program to measure most of these parameters on a regional scale, using standardized methods and a probability-based sampling design.

Reliable estimates of temporal and spatial variability are essential to the DQO process because they are required for quantifying the degree of uncertainty

STAGE	1	2	3
Purpose	Develop Major Questions Refine Questions	Establish Design Constraints Refine Constraints	Design Program to Meet Constraints
Personnel With Lead Role	Data User (decision makers)	Project Management Staff	Technical Staff

Figure 8-1. The three stages of developing Data Quality Objectives

that will be produced by the sampling design. Without them, the scientific staff cannot provide the decision makers with an estimate of cost for a desired level of uncertainty (Fig. 8-1). For this reason, DQOs will not be implemented in the 1990 Demonstration Project. Rather, a major goal of the Demonstration Project will be to gather the data to establish DQOs when the program is implemented in subsequent years. The Demonstration Project will be implemented using Measurement Quality Objectives (MQOs). MQOs establish acceptable levels of uncertainty for each measurement process but differ from DQOs in that they are not combined with sampling error to estimate programmatic uncertainty. In subsequent years, DQOs will be developed to replace the MQOs. MQOs were established by obtaining estimates of achievable data quality based on manufacturer specifications, the judgment of knowledgeable experts, and available literature information. Each measured parameter will have an associated MQO for each of the attributes of data quality: representativeness, comparability, completeness, accuracy, and precision. Data quality attributes are defined below, along with the MQO established for each measured parameter within EMAP-NC.

- Representativeness is the degree to which the data represent a characteristic of a population parameter. In EMAP-NC, representativeness is most germane to the proper siting of a sampling location, and the MQO will be to ensure that all samples, with the exception of fish trawling, are within 100 meters of the planned sampling site. Fish trawling should occur within 500 meters of the planned site.
- Completeness is a measure of the amount of valid data (i.e., data not associated with some criterion of potential unacceptability) collected from a measurement process compared to the amount that was expected to be obtained. The MQO completeness criteria for EMAP-NC will range from 75 to 90 percent, depending on the measurement process. The specific completeness criterion for each measured variable is presented in Table 8-1.
- Comparability is defined as "the confidence with which one data set can be compared to another" (Stanley and Verner 1985). Comparability of reporting units and calculations, data base management processes, and interpretative procedures must be ensured if the overall goals of EMAP are to be realized. The MQO for the 1990 Virginian Province Demonstration Project is to apply accepted methods in a standardized way and to generate a high level of documentation to ensure that future EMAP efforts can be made comparable.

Table 8-1. Measurement Quality Objectives for EMAP-NC indicators and associated data

Indicator/Data Type	Accuracy Goal	Precision Goal	Completeness Goal
Sediment Contaminant Concentration			
Organics	30%	30%	90%
Inorganics	15%	15%	90%
Sediment Toxicity	NA	NA	90%
Benthic Species Composition and Biomass			
Sample collection	NA	NA	90%
Sorting	10%	NA	90%
Counting	10%	NA	90%
Taxonomic identifications	10%	NA	90%
Biomass	NA	10%	90%
Sediment Characteristics			
Grain size			
Sand, silt, clay	NA	20%	90%
Gravel	NA	50%	90%
Total organic carbon	20%	20%	90%
% water	NA	20%	90%
Acid volatile sulfides	20%	20%	90%
Dissolved Oxygen Concentration	± 1.0 mg/l	NA	90%
Salinity	± 2 ppt	NA	90%
Temperature	± 2 °C	NA	90%
Depth	1 m	NA	90%
Fluorometry	NA	NA	90%
Water Clarity	NA	NA	90%
pH	± 0.2	NA	90%

Table 8-1. Continued

Indicator/Data Type	Accuracy Goal	Precision Goal	Completeness Goal
Contaminants in Fish Flesh			
Organics	30%	30%	90%
Inorganics	15%	15%	90%
Gross Pathology of Fish	NA	NA	90%
Fish Community Composition			
Sample collection	NA	NA	75%
Counting	10%	NA	90%
Taxonomic identifications	10%	NA	90%
Length determinations	± 5 mm	NA	90%
Relative Abundance of Large Burrowing Bivalves			
Sample collection	NA	NA	75%
Counting	10%	NA	90%
Taxonomic identifications	10%	NA	90%
Tissue Contaminants in Large Bivalves			
Organics	30%	30%	90%
Inorganics	15%	15%	90%
Histopathology of Fish	NA	NA	NA
Sediment Mixing Depth	± 5 mm	NA	90%
Water Column Toxicity	NA	40%	90%

- Accuracy is defined as the difference between a measured value and the true or expected value and represents an estimate of systematic error or net bias (Kirchner 1983; Hunt and Wilson 1986; Taylor 1985).
- Precision is defined as the degree of mutual agreement among individual measurements and represents an estimate of random error (Kirchner 1983; Hunt and Wilson 1986; Taylor 1987).

Together, accuracy and precision provide an estimate of the total error or uncertainty associated with measured value. Accuracy and precision goals for the indicators to be measured are provided in Table 8-1. Accuracy and precision cannot be defined for all parameters because of the nature of the measurement type. For example, accuracy measurements are not possible for toxicity testing, sample collection activities, and fish pathology measurements. In addition, accuracy and precision goals are not established for stressor indicators. Control of the data quality attributes of stressor indicators is beyond the scope of EMAP-NC.

8.2 Quality Control

Establishing MQOs is of little value if the proper quality control activities are not undertaken to ensure that program objectives are met. Quality control in EMAP-NC will be achieved in three ways:

- Developing standardized sampling protocols for all sampling activities that are consistent with MQOs and the associated data quality attributes,
- Documenting those protocols in a manner that allows for easy reference and evaluation by all personnel involved in the project, and
- Training personnel responsible for each protocol to ensure that they are qualified to conduct assigned tasks using the specified method.

Most of the indicators that will be measured during the Demonstration Project are those for which standardized protocols, with known and acceptable levels of error, already exist. The first year (or more) of the program will be used to develop, refine, and standardize the measurement methods for indicators for which standard methods presently do not exist.

Although standard protocols are being used for many of the measurements that will be made, an essential aspect of the EMAP-NC QC program is written documentation of all sampling, laboratory, and quality assurance protocols. EMAP-NC has produced three documents to accomplish this objective:

- Laboratory Operations Manual -- A document containing detailed instructions for laboratory and instrument operations, including all procedures designed to ensure quality control of the measurement process.
- Field Operations Manual -- A document containing detailed instructions for all field activities.
- Quality Assurance Project Plan -- A document that specifies the policies, organization, objectives, and functional activities for the project. The plan will also describe the quality assurance and quality control activities and measures that will be implemented to ensure that the data produced will meet the MQOs established for the project.

A critical aspect of quality control is to ensure that the individuals involved in each activity are properly trained to conduct the activity. Laboratory personnel involved in the Demonstration Project do not require extensive training, since most of the samples will be processed by established laboratories, using the standard protocols presently employed on a production basis. The field sampling personnel, who are being assembled specifically for this project and who are being asked to conduct a wide variety of activities in the same manner consistently, will receive approximately one month of training.

Training for sampling crews will begin in late May and will continue for about one month, until the beginning of the data collection phase. The first part of this training will be oriented toward classroom and laboratory work. Qualified Crew Chiefs must have previous experience in small boat handling and of most of the required sampling equipment (e.g., trawls, dredges, sediment samplers). Therefore, training of Crew Chiefs will emphasize project objectives and design, sampling protocols, computer use, and navigation protocols required to locate sites. In addition, the Crew Chiefs will be instructed in public relations and policy issues relating to EMAP-NC. The Crew Chiefs will help to train the remaining crew members in boat operations, navigation, use of sampling gear, and general sampling protocols. The final portion of training will involve "hands-on/in-field" application of sampling methods.

Classroom training will be conducted jointly by the University of Rhode Island's Marine Resources Department and EMAP-NC management and QA

personnel based at the EPA Environmental Research Laboratory in Narragansett, RI. All instructors have wide-ranging experience in training scientific personnel in routine sampling operations (e.g., collection techniques, small boat operations). Their expertise will be supplemented by that of recognized experts in such specialized areas as fish pathology (Dr. Linda Despres-Patanjo NMFS, Woods Hole, Massachusetts, and Mr. John Ziskowski, NMFS, Milford, Connecticut), fish identification (Dr. Don Flescher, NMFS, Woods Hole), first aid including CPR (American Red Cross), and field computer/navigation system use (Mr. Jeffrey Parker, Science Applications International Corporation, Newport, Rhode Island).

All EMAP equipment (e.g., boats, sampling gear, computers) will be used during the training sessions, and by the end of the course, all crews members must demonstrate proficiency in the following areas:

- Towing and launching the boat,
- Making predeployment checks of all sampling equipment,
- Locating stations using the navigation system,
- Entering data into and retrieving data from the lap-top computers,
- Using all the sampling gear,
- Administering first aid, including CPR, and
- Using general safety practices.

In addition, all field crew members must be able to swim and will be required to demonstrate that ability.

The first several weeks of Sampling Interval 1 will be an extension of formal training. At this time, the Crew Chiefs will be given the opportunity to become thoroughly familiar with their crews and equipment. During this period, EMAP-NC scientists with expertise in boat operations, field collection methods, and quality assurance will accompany the crews and provide intensive training in areas where the crews exhibit deficiencies. This intensive "on-the-job-training" will continue until all crews have demonstrated that they can conduct all aspects of the sampling program proficiently.

Some sampling activities (e.g., fish taxonomy, gross pathology, net repair, etc.) require specialized knowledge. While all crew members will be exposed to these topics during the training sessions, it is beyond the scope of the training program to develop proficiency for each crew member in all of these areas. For

each of the specialized activities, selected crew members, generally those with prior experience in a particular area, will be provided intensive training. At the conclusion of the training program, at least one member of each crew will have been provided detailed training in fish taxonomy, mollusk taxonomy, fish gross pathology, net repair, gear deployment, and navigation.

All phases of field operations will be detailed in the Field Operations Manual. Copies of this manual will be distributed to all trainees prior to the training period. The manual will include a checklist of all equipment, instructions on the use of all equipment, and procedures for sample collection. In addition, the manual will include a schedule of activities to be conducted at each sampling location. It will also contain a list of potential hazards associated with each sampling site.

8.3 Quality Assessment

The effectiveness of quality control efforts will be measured by quality assessment activities, including quality assessment samples and audits. The goal of these activities will be to quantify accuracy and precision, but most importantly, they will be used to identify problems that need to be corrected as data sets are generated and assembled. Details of the quality assessment activities that will be conducted during the 1990 Demonstration Project can be found in the Quality Assurance Project Plan. A brief overview of these activities is provided below.

Quality assessment procedures will include using standards and check samples to verify instrument calibrations in the field, as well as collecting duplicate samples, field blanks, and performance evaluation samples. Quality assessment samples generally will be blind or double blind. The expected values of blind samples are not known to the analyst, while double blind samples cannot even be identified by the analyst as a control sample (Taylor 1985). The type and frequency of quality assessment activities that will be performed for each sampling activity are summarized in Table 8-2.

Field/laboratory technicians and analysts will be apprised routinely of their performance on quality assessment samples. Actions taken upon failing an assessment sample will depend on the magnitude of the problem. Criteria will be established for both warning and control limits. Exceeding warning limits will require only rechecking of calculations or measurement processes, but exceeding control limits will require that all samples processed since the last assessment sample be reanalyzed. Field/ laboratory technicians and analysts who repeatedly fail criteria will be removed from their positions and retrained. Examples of the warning and control limits that will be used in conducting chemical analyses of sediments and tissue samples collected during the Demonstration Project are

Table 8-2. Quality assurance sample types, type of data generated, and measurement quality expressed for all measurement variables

Variable	QA Sample Type or Measurement Procedure	Frequency of Use	Data Generated for Measurement Quality Definition
Sediment Toxicity	Reference toxicants tests	Each experiment	Variance of replicated toxicity results
Benthic Species Composition and Biomass			
Sorting	Resort of complete sample including debris	10% of each tech's work	Number of animals resorted
Sample counting and ID	Recount and ID of sorted animals	10% of each tech's work	Number of count and ID errors
Biomass	Duplicate weights	10%	Duplicate results
Sediment Characteristics	Splits of a sample	10% of samples	Duplicate results
Dissolved Oxygen Concentration	Air-saturated sea water and/or side by side collection/measurements with Winkler determinations	One at each sampling location	Replicated difference from expected
Salinity	Known check standard in mid-range of calibration	One at each sampling location	Replicated difference from expected

Table 8-2. Continued

Variable	QA Sample Type or Measurement Procedure	Frequency of Use	Data Generated for Measurement Quality Definition
Temperature	Thermometer check of instrument	One at each sampling location	Replicated difference from expected
Depth	Check bottom depth against depth finder on boat	One at each sampling location	Replicated difference from actual
Fluorometry	Check sample	One at each sampling location	Replicated difference from actual
Water Clarity	Check sample	One at each sampling location	Replicated difference from actual
pH	Known check standard in mid-range of calibration	One at each sampling	Replicated difference from actual location
Gross Pathology Fish	Examination by expert pathologist	Each trawl	Percentage of misidentifications
Fish Community Composition	I.D. of voucher specimens by taxonomic experts	Each trawl	Percentage of misidentifications

Table 8-2. Continued

Variable	QA Sample Type or Measurement Procedure	Frequency of Use	Data Generated for Measurement Quality Definition
Relative Abundance of Large Burrowing Bivalves	Expert I.D. of voucher specimens	Each trawl	Percentage of misidentifications
Water Column Toxicity	Reference toxicant tests	Each Experiment	Variance of replicated toxicity results

shown in Table 8-3. Recommended detection limits for chemical analyses are shown in Table 8-4.

Field and laboratory aspects of the 1990 Virginian Province Demonstration Project will be subjected to audits. Initial review of the field team will be performed during the training program. Following training, a site assessment audit will be performed by a combination of QA, training personnel, the Demonstration Project Manager, and the Technical Director. This audit will be considered a "shakedown" procedure to assist field teams in obtaining a consistent approach to collection of samples and generation of data. At least once during the field sampling program, a formal site audit will be performed by QA personnel to determine compliance with the Quality Assurance Project Plan, the Field Operations Manual, and the Laboratory Methods Manual. Checklists and audit procedures will be developed for this audit that are similar to those presented in USEPA (1985).

EMAP-NC QA personnel will conduct a performance audit of all laboratory operations at the outset of the project to determine whether each laboratory effort is in compliance with the procedures described in the Quality Assurance Project Plan. Additionally, once during the study, a formal laboratory audit will be conducted following protocols similar to those presented in USEPA (1985). Checklists that are appropriate for each laboratory operation will be developed and approved by the EMAP-NC QA Officer prior to the audits.

8.4 Quality Assurance of Data Management Activities

EMAP-NC must ensure and maintain the integrity of the large number of values that eventually will be entered into the data management system (NRC 1990; Risser and Treworgy 1986; Packard et al. 1989). EMAP-NC will use the procedures highlighted below to ensure the quality of the data in the EMAP Near Coastal Information Management System (NCIMS).

To minimize the errors associated with entry and transcription of data from one medium to another, data will be captured electronically to the degree possible. When manual entry is required, a hard copy of the entered data will be checked against the original by a second data entry operator to identify non-matches and correct keypunching errors. When data are transferred, the transfer will be done electronically, if possible, using communications protocols (e.g., Kermit software) that check on the completeness and accuracy of the transfer. When data are transferred using floppy disks or tapes, the group sending the information will specify the number of bytes and the file names of the transferred files. These data characteristics will be verified upon receipt of the data. If the file can be verified,

Table 8-3. Warning and control limits for quality control samples

Analysis Type	Recommended Warning Limit	Recommended Control Limit
Method Blanks (organic and inorganic)	-	Less than detection limit
Matrix Spikes	50% ^(a)	Not specified
Laboratory Control Sample		
Organic	80% - 120% ^(b)	70% - 130%
Inorganic	90% - 110%	85% - 115%
Laboratory Duplicate (organic and inorganic)	-	$\pm$ 30% relative percent difference
Ongoing Calibration Check (organic and inorganic)	-	$\pm$ 15% of the initial calibration
Standard Reference Material ^(b)		
Organic	80% - 120%	70% - 130%
Inorganic	90% - 110%	85% - 115%

^(a) Units are percent recovery

^(b) Units are percent of true value

Table 8-4. Recommended detection limits (in ppm/dry weight) for EMAP-NC chemical analyses

Analyte	Tissue Sample	Sediment Sample
<u>Inorganics</u>		
Al	10.0	1500
Si	100	10000
Cr	0.1	5.0
Mn	5.0*	1.0
Fe	50.0	500
Ni	0.5	1.0
Cu	5.0	5.0
Zn	50.0	2.0
As	2.0	1.5
Se	1.0	0.1
Ag	0.01	0.01
Cd	0.2	0.05
Sn	0.05	0.1
Sb	0.2*	0.2
Hg	0.01	0.01
Pb	0.1	1.0
<u>Organics</u>		
PAHs	20.0*	5.0
PCBs	1.0	0.1
PCB congeners	1.0	0.1
DDD, DDE, DDT species	1.0	0.1

* Not measured in fish tissues

it will be incorporated into the data base. Otherwise, new files will be requested. Whenever feasible, a hard copy of all data will be provided with transferred files.

Erroneous numeric data will be identified using range checks, filtering algorithms, and comparisons to lists of valid values established by experts for specific data types (i.e., lookup tables). When data fall outside an acceptable range, they will be flagged in a report for the EMAP-NC Quality Assurance Officer (QAO). Similarly, when a code cannot be verified in the appropriate lookup table, the observation will be flagged and reported to the QAO.

All discrepancies and errors that are identified will be documented. This documentation will be a permanent part of the NCIMS. Data will not be incorporated into the NCIMS until all discrepancies have been resolved. The near coastal QAO will be responsible for resolving all errors. Data sets in which discrepancies have been resolved will be added to the appropriate data base. A record of the addition will be entered into the Data Set Index and kept in hard copy. Once data have been entered into the NCIMS, changes will not be made without the written consent of the QAO.

To ensure that complete records of all field activities are maintained, the field computer system will not allow modification of the data files. Instead, correction values will be entered into the data file and associated with the incorrect entry. Corrections will be made then and a record of the original data and the correction will become a permanent part of the file.

8.5 Quality Assurance Reports to Management

Control charts (an example of which is shown in Fig. 8-2) will be used extensively to document measurement process control. Control charts will be used with the following: (1) QC check standards for controlling instrument drift, (2) matrix spike or surrogate recoveries to measure extraction efficiency or matrix interference, (3) certified performance evaluation samples to control overall laboratory performance, and (4) blank samples. Control charts will be maintained at each participating laboratory and reported with the data.

The first Annual Statistical Summary for EMAP-NC is scheduled for June 1991, after completion of the 1990 Virginian Province Demonstration Project. Precision, accuracy, comparability, completeness, and representativeness of the data collected during the Demonstration Project will be summarized in this document, and detection limits will be reported. Interpretive Assessment Reports will be prepared every four years, and Special Scientific Reports will be produced periodically to address concerns raised about the program, such as the ability of

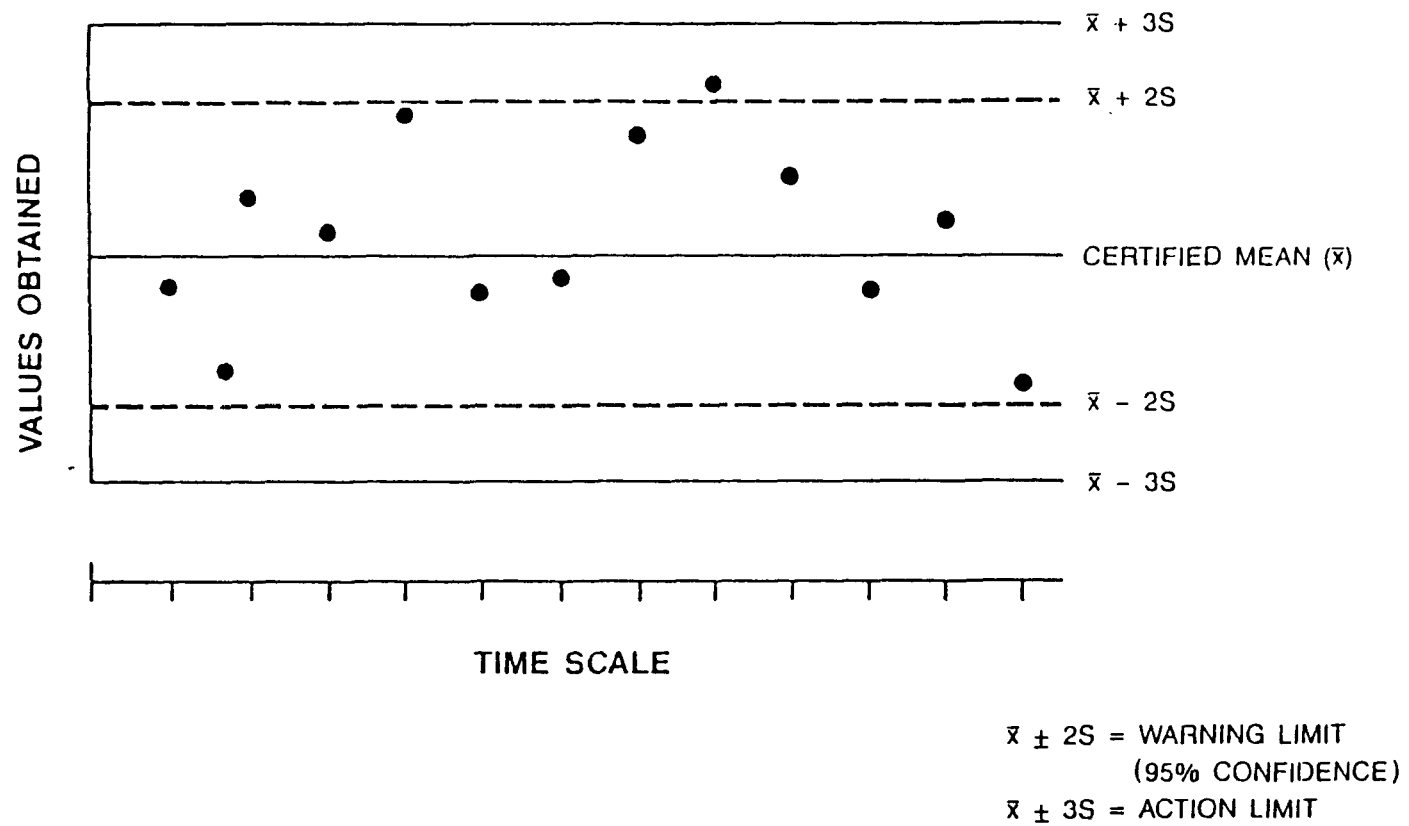


Figure 8-2. Example of a control chart

the sampling design to detect trends. The data quality attributes of precision, accuracy, comparability, completeness, and representativeness will also be provided for each of the reports.

9.0 REFERENCES

- Albert, R.C. 1982. Cleaning up the Delaware River. West Trenton, NJ: Delaware River Basin Commission.
- Aller, R.C. 1982. The effects of macrobenthos on chemical properties of marine sediment and overlying water. In: Animal-Sediment Relations: The Biogenic Alteration of Sediments, 53-102. P.L. McCall and M.J.S. Tevesz, eds. New York: Plenum Press.
- APHA. 1985. Standard Methods for the Examination of Water and Wastewater. 17th Ed. Washington, DC: American Public Health Association.
- Basta, D.J., B.T. Bower, C.N. Ehler, F.D. Arnold, B.P. Chambers, and D.R.G. Farrow. 1985. The National Coastal Pollutant Discharge Inventory. Rockville, MD: NOAA.
- Beanlands, G.E. and P.N. Duinker. 1983. An ecological framework for environmental impact assessment in Canada. Halifax, Nova Scotia: Institute for Resource and Environmental Studies, Dalhousie University.
- Beasley, B. and R. Biggs. 1987. Near coastal water segmentation. Report by the College of Marine Studies, University of Delaware.
- Bell, S.S. and B.C. Coull. 1978. Field evidence that shrimp predation regulates meiofauna. Oecologia 35:141-148.
- Biggs, R.B. and B.A. Howell. 1984. The estuary as a sediment trap: Alternate approaches to estimating its filtering efficiency. In: The Estuary as a Filter, 107-129. V.S. Kennedy, ed. New York: Academic Press.
- Bilyard, G.R. 1987. The value of benthic infauna in marine pollution monitoring studies. Mar. Poll. Bull. 18:581-585.
- Boesch, D.F. 1977. Application of numerical classification in ecological investigations of water pollution. Spec. Sci. Rpt. 77, EPA-600/3-7703.
- Boesch, D.F. and R. Rosenberg. 1981. Response to stress in marine benthic communities. In: Stress Effects on Natural Ecosystems, 179-200. G.W. Barret and R. Rosenberg, eds. New York: John Wiley and Sons.

- Boynton, W.R., W.M. Kemp, J. Garber, J.M. Barnes, L.L. Robertson, and J.L. Watts. 1988. Chesapeake Bay water quality monitoring program ecosystems processes component. Level 1 Report No. 5. Prepared for Maryland Department of Environment by University of Maryland Center for Environmental and Estuarine Studies.
- Breteler, R.J., K.J. Scott and S.P. Shepurd. 1989. Application of a new sediment toxicity test using the marine amphipod Ampelisca abdita to San Francisco Bay sediments. In: Aquatic Toxicology and Hazard Assessment, Volume 12. U.M. Cowgill, and L.R. Williams, eds. ASTM.
- Brongersma-Sanders, M. 1957. Mass mortality in the sea. In: Treatise on Marine Ecology and Paleoecology, 941-1010. J.W. Hedgpeth, ed. Mem. Geol. Soc. Am. 67.
- Broutman, M.A. and D.L. Leonard. 1986. National Estuarine Inventory: Classified Shellfish Growing Water by Estuary. Rockville, MD: NOAA.
- Broutman, M.A. and D.L. Leonard. 1988. The Quality of the Shellfish Growing Waters in the Gulf of Mexico. Rockville, MD: NOAA.
- Brown, A.C.,. 1964. Lethal effects of hydrogen sulfide on Bullia (Gastropoda). Nature 203:205-206.
- Bryan G.W. 1985. Bioavailability and effects of heavy metals in marine deposits. In: Wastes in the Ocean: Nearshore Waste Disposal, 41-79. B.H. Ketchum et al., ed. New York: Wiley.
- Buhler, D.R. and D.E. Williams. 1988. The role of biotransformation in toxicity. Fish. Aquat. Toxicol. 11:303-311.
- Cabelli, V.J. 1977. Clostridium perfringens as a water quality indicator. Special Technical Publ. 635. Philadelphia, PA: ASTM.
- Capuzzo, J.M., M.N. Moore, and J. Widdows. 1988. Effects of toxic chemicals in the marine environment: Predictions of impacts from laboratory studies. Aquat. Toxicol. 11:19-28.
- Carriker, M.R. 1967. Ecology of estuarine benthic invertebrates: A perspective. In: Estuaries, Publ. No. 83, 442-487. G.H. Lauff, ed. Washington, DC: American Association for the Advancement of Science.
- Chao, L.N. and J.A. Musick. 1977. Life history, feeding habitats, and functional morphology of juvenile sciaenid fishes in the York River estuary. Fishery Bull. 75:657-702.

- Chapman, P.M. 1988. Marine sediment toxicity tests. In: Chemical and Biological Characterization of Sludges, Sediments, Dredge Spoils, and Drilling Muds. J.J. Lichtenberg, F.A. Winter, C.I. Weber and L. Fredkin, eds. Philadelphia, PA: ASTM.
- Chesapeake Bay Panel. 1988. Marine Environmental Monitoring in Chesapeake Bay. Prepared for the Committee on A Systems Assessment of Marine Environmental Monitoring, Marine Board, National Research Council, Washington DC.
- Cloern, J.E. 1982. Does the benthos control phytoplankton biomass in South San Francisco Bay? Mar. Ecol. Prog. Ser. 9:191-202
- Connell, D.W. and G.J. Miller. 1984. Chemistry and Ecotoxicology of Pollution. New York: John Wiley and Sons.
- Conomos, T.J. and D.H. Peterson. 1976. Suspended-particle transport and circulation in San Francisco Bay: An overview. In: Estuarine Process, Vol. 2, 48-62. M.L. Wiley, ed. New York: Academic Press.
- The Conservation Foundation. 1988. Protecting America's Wetlands: An Action Agenda. Washington, DC: The Conservation Foundation.
- Costanza, R., F.H. Sklar, and M.L. White. 1990. Modeling coastal landscape dynamics. Bioscience 40:91-107.
- Crecco, V., T. Savoy, and W. Whitworth. 1986. Effects of density-dependent and climatic factors on American shad Alosa sapidissima recruitment: A predictive approach. Can. J. Fish. Aquat. Sci. 43:457-463.
- Cushing, D.H. 1982. Climate and Fisheries. London: Academic Press.
- Daiber, F.C. 1982. Animals of the Tidal Marsh. New York: Van Nostrand Reinhold.
- Daiber, F.C. 1986. Conservation of Tidal Marshes. New York: Van Nostrand Reinhold.
- Daiber, F.C. and C.T. Roman. 1988. Tidal marshes. In: The Delaware Estuary: Rediscovery a Forgotten Resource, 95-114. T.L. Bryant and J.R. Pennock, eds. Newark, DE: University of Delaware Sea Grant College Program.
- Dame, R., R. Zingmark, and D. Nelson. 1980. Filter feeding coupling between the estuarine water column and benthic subsystems. In: Estuarine Perspectives, 521-526. V.S. Kennedy, ed. New York: Academic Press.
- Dauer, D.M., T.L. Stokes, Jr., H.R. Barker, Jr., R.M. Ewing, and J.W. Sourbeer. 1984. Macrobenthic communities of the Lower Chesapeake Bay. IV. Bay-wide transects and the Inner Continental Shelf. Int. Revue Ges. Hydrobiol. 69:1-22.

- DiToro, D.M., J.D. Mahony, D.J. Hansen, K.J. Scott, M.B. Hicks, S.M. Mayr, M.S. Redmond. In press. Toxicity of cadmium in sediments: The role of acid volatile sulfide.
- Doering, P.H., C.A. Oviatt, and J.R. Kelly. 1986. The effects of the filter-feeding clam Mercenaria mercenaria on carbon cycling in experimental marine mesocosms. J. Mar. Res. 44:839-861.
- Donovan, M.L. and J.P. Tolson. 1987. Land Use and the Nation's Estuaries. Rockville, MD: NOAA.
- Downing, J.A. 1979. Aggregation, transformation and the design of benthic sampling programs. J. Fish Res. Bd. Can. 36:1454-1463.
- Elmgren, R., and J.B. Frithsen. 1982. The use of experimental ecosystems for evaluating the environmental impact of pollutants: A comparison of an oil spill in the Baltic Sea and two long-term, low level oil addition experiments in microcosms. In: Marine mesocosms: Biological and Chemical Research in Experimental Ecosystems, 109-118. G.D. Grice and M.R. Reeve, eds. New York: Springer-Verlag.
- Fava, J.A., W.J. Adams, R.J. Larson, G.W. Dickson, K.L. Dickson, W.E. Bishop. 1987. Research Priorities in Environmental Risk Assessment. Publication of the Society of Environmental Toxicology and Chemistry, Washington, DC.
- Fein, G.G., J.L. Jacobson, S.W. Jacobson, P.W. Schwartz, and J.K. Dowler. 1984. Prenatal exposure to polychlorinated biphenyls: Effects on birth size and gestational age. Pediatr. 105:315-320.
- Food and Drug Administration, Shellfish Sanitation Branch. 1971. National shellfish register of classified estuarine waters. Davisville, RI: Northeast Technical Services Unit.
- Food and Drug Administration, Shellfish Sanitation Branch, and National Oceanic and Atmospheric Administration, Strategic Assessment Branch and National Marine Fisheries Service. 1985. National shellfish register of classified estuarine waters. Rockville, MD.
- Forstner, U. and G.T.W. Wittmann. 1981. Metal pollution in the aquatic environment. 2nd revised edition. New York: Springer-Verlag.
- Frayser, W.E., T.J. Monahan, D.C. Bowden, F.A. Graybill. 1983. Status and trends of wetlands and deep water habitats in the conterminous United States 1950s to 1970s. National Wetlands Inventory, U.S. Fish and Wildlife Service, St. Petersburg, FL.

- Frithsen, J.B. 1989. The benthic communities within Narragansett Bay. An assessment completed for the Narragansett Bay Project. Kingston, RI: University of Rhode Island.
- Frithsen, J.B., A.A. Keller and M.E.Q. Pilson. 1985. Effects of inorganic nutrient additions in coastal areas: A mesocosm experiment data report. Volume 1. MERL Series, Report No. 3. Kingston, RI: The University of Rhode Island.
- Goldberg, E.D., V. Hodge, M. Koide, J. Griffin, E. Gamble, O.P Bricker, G. Matisoff, G.R. Holdren, and R. Braun. 1978. A pollution history of Chesapeake Bay. Geochim. Cosmochim. Acta 42: 1413-1425.
- Grassle, J.F., J.P. Grassle, L.S. Brown-Leger, R.F. Petrecca, and N.J. Copley. 1985. Subtidal macrobenthos of Narragansett Bay. Field and mesocosm studies of the effects of eutrophication and organic input on benthic populations. In: Marine Biology of Polar Regions and Effects of Stress on Marine Organisms, 421-434. J.S. Gray and M.E. Christiansen, eds. New York: Wiley.
- Graves, R.L. 1990. Draft Environmental Monitoring and Assessment Program Near Coastal Demonstration Project Laboratory Methods Manual. U.S. Environmental Protection Agency, Office of Research and Development.
- Gray, J.S. 1982. Effects of pollutants on marine ecosystems. Neth. J. Sea Res. 16:424-443.
- Gunter, G. 1967. Some relationships of estuaries to the fisheries of the Gulf of Mexico. In: Estuaries, 621-638. G.H. Lauff, ed. Amer. Assoc. Adv. Sci. Pub. No. 83, Washington, DC.
- Haedrich, R.L. and S.O. Haedrich. 1974. A seasonal survey of the fishes in the Mystic River, a polluted estuary in downtown Boston, Massachusetts. Estuarine Coastal Mar. Sci. 2:59-73.
- Hall, L.W., Jr., D.T. Burton, L.H. Liden. 1982. Power plant chlorination effects on estuarine and marine organisms. CRC Critical Reviews in Toxicology, 10(1):27-47.
- Hargis, W.J., Jr. and D.S. Haven. 1988. Rehabilitation of the troubled oyster industry of the lower Chesapeake Bay. Journal of Shellfish Research 7:271-279.
- Hedgpeth, J.W. (ed.). 1957. Treatise on marine ecology and palaeoecology. Geol. Soc. of Am. Mem. 67, Washington, DC.
- Helz, G.R. 1988. Responses of estuarine and coastal marine waters to changing climate. A paper prepared during the author's tenure as an Environmental Science & Engineering Fellow. USEPA, Washington, DC.

- Hinga, K.R. 1988. Seasonal predictions for pollutant scavenging in two coastal environments using a model calibration based upon thorium scavenging. Marine Environmental Research 26:97-112.
- Holland, A.F., N.K. Mountford, and J.A. Mihursky. 1977. Temporal variation in upper bay mesohaline benthic communities: I. The 9-m mud habitat. Chesapeake Sci. 18:370-378.
- Holland, A.F., A. Shaughnessy, M. Hiegel, L. Scott. 1986. Long-term benthic monitoring for the Maryland Portion of Chesapeake Bay: July 1984-December 1985. Prepared for Maryland Department of Natural Resources Power Plant Siting Program, by Martin Marietta Environmental Systems.
- Holland, A.F., A.T. Shaughnessy, and M.H. Hiegel. 1987. Long-term variation in mesohaline Chesapeake Bay macrobenthos: Spatial and temporal patterns. Estuaries 10:227-245.
- Holland, A.F., A.T. Shaughnessy, L.C. Scott, V.A. Dickens, J. Gerritsen, J.A. Ranasinghe. 1989. Long-term benthic monitoring and assessment program for the Maryland portion of Chesapeake Bay: Interpretive report. Prepared by Versar, Inc. for Maryland Department of Natural Resources, Power Plant Research Program. CBRM-LTB/EST-2.
- Holme, N.A. and A.D. McIntyre. 1984. Methods for Study of Marine Benthos. London: Blackwell Scientific Publications.
- Homer, M., P.W. Jones, R. Bradford, J.M. Scoville, D. Morck, N. Kaumeyer, L. Hoddaway, and D. Elam. 1980. Demersal fish food habits studies near the Chalk Point Power Plant, Patuxent Estuary, Maryland, 1978-1979. Prepared for the Maryland Department of Natural Resources, Power Plant Siting Program, by the University of Maryland, Center for Environmental and Estuarine Studies, Chesapeake Biological Laboratory, Solomons, Maryland, UMCEES-80-32-CBL.
- Honeyman, B.D. and P.H. Santschi. 1988. Metals in aquatic systems: Predicting their scavenging residence times from laboratory data remains a challenge. Envir. Sci. and Tech. 22:862-871.
- Horvitz, D.G. and D.J. Thompson. 1952. A genealization of sampling without replacement from a finite universe. J. Amer. Statist. Assoc. 47:663-685.
- Huggett, R.J. 1989. Kepone and the James River. In: Contaminated Marine Sediments -- Assessment and Remediation, 417-424. Washington, DC: National Academy of Sciences, National Academy Press.
- Huggett, R.J. and M.E. Bender. 1980. Kepone in the James River. Environ. Sci. Technol. 14:918-923.

- Hunsaker, C. and D. Carpenter, eds. 1990. Ecological indicators for the environmental monitoring and assessment program. Technical Report for the U.S. Environmental Protection Agency Office of Research and Development.
- Hunt, D.T.E. and A.L. Wilson. 1986. The Chemical Analysis of Water: General Principles and Techniques. 2nd ed. London: Royal Society of Chemistry.
- Jacobson, S.W., J.L. Jacobson, P.M. Schwartz, and G.G. Feine. 1983. Intrauterine exposure of human newborns to PCBs: Measures of exposure. *In: PCBs: Human and Environmental Hazards*, 311-343. F. M. D'itri and M.A. Kamrin, eds. Boston: Butterworth Publishers.
- Jeffries, H.P., and M. Terceiro. 1985. Cycle of changing abundances in the fishes of the Narragansett Bay area. Mar. Ecol. Prog. Ser. 25:239-244.
- Jorgensen, C.B., P. Famme, H.S. Kristensen, P.S. Larsen, F. Mohlenberg, and H.U. Riisgard. 1986. The bivalve pump. Mar. Ecol. Prog. Ser. 34:69-77.
- Kemp, W.M., W.R. Bounton, R.R. Twilley, J.C. Stevenson, and L.G. Ward. 1984. Influences of submerged vascular plants on ecological processes in upper Chesapeake Bay. *In: The Estuary as a Filter*, 367-394. V.S. Kennedy, ed. New York: Academic Press.
- Kirchner, C.J. 1983. Quality control in water analysis. Environ. Sci. and Technol. 17(4):174A-181A.
- Knox, G.A. 1986. Estuarine Ecosystems: A Systems Approach. Boca Raton, FL: CRC Press.
- Leonard, D.L., M.A. Broutman, and K.E. Harkness. 1989. The quality of shellfish growing areas on the east coast of the United States. National Oceanic and Atmospheric Administration OAD, Rockville, MD.
- Levin, S.A. and K.D. Kimball (eds.). 1984. New perspectives in ecotoxicology. Environmental Management 8:375-472.
- Lippson, A.J., M.S. Haire, A.F. Holland, F. Jacobs, J. Jensen, R.L. Moran-Johnson, T.T. Polgar, and W.R. Richkus. 1979. Environmental Atlas of the Potomac Estuary. Prepared for Maryland Department of Natural Resources, Power Plant Siting Program by Martin Marietta Corporation, Baltimore, MD.
- Livingston, R.J. 1987. Field sampling in estuaries: The relationship of scale to variability. Estuaries 10:194-207.

- Logan, B.E., R.G. Arnold, and A. Steele. 1989. Computer simulation of DDT distribution in Palos Verdes shelf sediments. *In: Contaminated Marine Sediments -- Assessment and Remediation*, 178-198. Washington, DC: National Academy of Sciences, National Academy Press.
- Long, E.R., and M.F. Buchman. 1989. An evaluation of candidate measures of biological effects for the National Status and Trends Program. NOAA Tech. Memo.
- Malins, D.C. 1989. Sediment contamination and marine ecosystems: Potential risks to humans. *In: Contaminated Marine Sediments -- Assessment and Remediation*. 155-164. Washington, DC: National Academy of Sciences, National Academy Press.
- Malins, D.C., B.B. McCain, D.W. Brown, S.L. Chan, M.S. Myers, J.T. Landahl, P.G. Prohaska, A.J. Friedman, L.D. Rhodes, D.G. Burrows, W.D. Gronlund, and H.O. Hodgins. 1984. Chemical pollutants in sediments and diseases in bottom-dwelling fish in Puget Sound, Washington. *Environ. Sci. Technol.* 18:705-713.
- Malins, D.C., B.B. McCain, J.T. Landahl, M.S. Myers, M.M. Krahn, D.W. Brown, S.L. Chan, and W.T. Roubal. 1988. Neoplastic and other diseases in fish in relation to toxic chemicals: An overview. *In: Aquatic Toxicology, Toxic Chemicals, and Aquatic Life: Research and Management*, 43-67. D.C. Malins and A. Jensen, eds. Amsterdam: Elsevier Science.
- Martin Marietta Environmental Systems. 1987. Statistical and deliverable analytical support contract: Final report. Prepared for the Chesapeake Bay Program Water Quality Data Analysis Working Group.
- May, R.C. 1974. Larval mortality in marine fishes and the critical period concept. *In: The Early Life History of Fish*, 3-19. J.H.S. Blaxter, ed. New York: Springer-Verlag.
- Mayer, F.L., Jr., L.L. Marking, L.E. Pedigo, and J.A. Brecken. 1989. Physiochemical factors affecting toxicity: pH, salinity, and temperature, Part I. Literature review. U.S. Environmental Protection Agency, Gulf Breeze, FL.
- Mearns, A.J., M.B. Matta, D. Simccek-Beatty, M.F. Buchman, G. Sigenaka, and W.A. Wert. 1988. PCB and chlorinated pesticides contamination in U.S. fish and shellfish. National Oceanic and Atmospheric Administration Tech. Memo. MOS/OMA 39 OAD, Seattle, WA.
- Morganthau, T. 1988. Don't go near the water: Is it too late to save our dying coasts? *Newsweek*, August 1, 42-47.

- Nacci, D., R. Walsh, and E. Jackim. 1987. Guidance manual for conducting sperm cell tests with the sea urchin, Arbacia punctulata, for use in testing complex effluents. Contribution No. X105. In: Users Guide to the Conduct and Interpretation of Complex Effluent Toxicity Tests at Estuarine/Marine Sites. S.C. Schimmel, ed. Environmental Research Laboratory, U.S. Environmental Protection Agency, Narragansett, Rhode Island. Contribution No. 796.
- National Oceanic and Atmospheric Administration (NOAA). 1987. A summary of selected data on chemical contaminants in tissues collected during 1984, 1985, and 1986. National Oceanic and Atmospheric Administration Technical Memorandum Nos OMA 38.
- NOAA. 1988. Federal plan for ocean pollution research development, and monitoring: Fiscal years 1988-1992. Prepared by the National Ocean Pollution Program Office for the National Ocean Pollution Policy Board. Rockville, MD.
- National Research Council (NRC). 1983. Fundamental Research on Estuaries: The Importance of an Interdisciplinary Approach. Washington, DC: National Academy Press.
- NRC. 1989. Contaminated Marine Sediments -- Assessment and Remediation. Washington, DC: National Academy Press.
- NRC. 1990a. Managing Troubled Waters: The Role of Marine Environmental Monitoring. Washington, DC: National Academy Press.
- NRC. 1990b (in press). Monitoring Southern California Coastal Waters. National Academy Press. Washington, DC.
- Nixon, S.W., C.D. Hunt and B.L. Nowicki. 1986. The retention of nutrients (C,N,P), heavy metals (Mn, Cd, Pb, Cu), and petroleum hydrocarbons in Narragansett Bay. In: Biogeochemical Processes at the Land-sea Boundary,99-122. P. Lasserre and J.M. Martin, eds. New York: Elsevier.
- O'Connor, J.S., J.J. Ziskowski, and R.A. Murchelano. 1987. Index of pollutant-induced fish and shellfish disease. National Oceanic and Atmospheric Administration Special Report, NDS, Rockville, MD.
- Odum, H.T. and B.J. Copeland. 1974. A functional classification of coastal systems of the United States. In: Coastal Ecological Systems of the United States,5-84. H.T. Odum, B.J. Copeland, and E.A. McMahan, eds. Washington, DC: The Conservation Foundation.
- Odum, W.E. 1988. Comparative ecology of tidal freshwater and salt marshes. Ann. Rev. Ecol. Syst. 19:147-176.

- Office of Technology Assessment (OTA). 1987. Wastes in Marine Environments. Washington, DC.
- Officer, C.B., T.J. Smayda, and R. Mann. 1982. Benthic filter feeding: A natural eutrophication control. Mar. Ecol. Prog. Ser. 9:203-210.
- Officer, C.B., R.B. Biggs, J.L. Taft, L.E. Cornin, M.A. Tyler, and W.R. Boynton. 1984. Chesapeake Bay anoxia: Origin, development, and significance. Science 223:22-27.
- Olsen, S., D.D. Robadue, and V. Lee. 1980. An interpretive atlas of Narragansett Bay. Coastal Resources Center, University of Rhode Island, Marine Bulletin 40.
- Orth, R.J., and K.A. Moore. 1983. Chesapeake Bay: An unprecedented decline in submerged aquatic vegetation. Science 222:51-53.
- Overton, W.S. and S.D. Stehman. 1987. Empirical investigation of sampling and other errors in the National Stream Survey: Analysis of a replicated sample of streams. Oregon State Tech. Report 119.
- Overton, W.S. 1989. Design report of the environmental monitoring and assessment program. U.S. EPA Environmental Research Laboratory, Corvallis, OR.
- Oviatt, C.A. 1981. Some aspects of water quality in and pollution sources to the Providence River. Report for Region I, EPA, September 1979-September 1980, Contract #68-04-1002.
- Oviatt, C.A., and S.W. Nixon. 1973. The demersal fish of Narragansett Bay: An analysis of community structure, distribution and abundance. Estuar. and Coastal Mar. Sci. 1:361-378.
- Pait, A.S., D.R.G. Farrow, J.A. Lowe, and P.A. Pacheis. 1989. Agricultural pesticide use in estuarine drainage areas: A preliminary summary for selected pesticides. Rockville, MD: Strategic Assessment Branch Office of Oceanography and Marine Assessment, NOAA.
- Panel on Particulate Wastes in the Oceans. 1989. Monitoring Particulate Wastes in the Oceans. Prepared for the Committee on A Systems Assessment of Marine Environmental Monitoring, Marine Board, National Research Council. Washington DC.
- Parker, C.A., J.E. O'Reilly, and R.B. Gerzoff. 1986. Oxygen depletion in Long Island Sound. Historical Trends Assessment Program, National Oceanic and Atmospheric Administration, OAD, Rockville, MD.

- Pearl, H.W. 1988. Nuisance phytoplankton blooms in coastal, estuarine, and inland waters. Limnol. Oceanogr. 33:823-847.
- Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Ann. Rev. 16:229-311.
- Plumb, R.H. 1981. Procedures for handling and chemical analysis of sediment and water samples. Prepared for the U.S. Environmental Protection Agency/Corps of Engineers Technical Committee on Criteria for Dredge and Fill Material. Published by Environmental Laboratory, U.S. Army Waterways Experiment Station, Vicksburg, Mississippi. Technical Report EPA/CE-81-1.
- Polgar, T.T. 1982. Factors affecting recruitment of Potomac River striped bass and resulting implications for management. In: Estuarine Comparisons, 427-442. V.S. Kennedy, ed. New York: Academic Press.
- Polgar, T.T., J.K. Summers, R.A. Cummins, K.A. Rose, and D.G. Heimbuch. 1985. Investigation of relationships among pollutant loadings and fish stock levels in northeastern estuaries. Estuaries 8:20-29.
- Pollard, J.E., K.M. Peres, T.C. Chaing, R. Valente, C. Strobel, and J. Rosen. 1990. Environmental monitoring and assessment program near coastal demonstration project quality assurance project plan. Environmental Monitoring Systems Laboratory, U.S. EPA, Cincinnati, OH.
- Pomeroy, L.R., and R.G. Wiegert, eds. 1981. The Ecology of a Salt Marsh. New York: Springer-Verlag.
- Pritchard, D.W. 1955. Estuarine circulation patterns. Proc. Am. Soc. Civ. Eng. 81:1-11.
- Pruell, R.J., J.G. Quinn, J.L. Lake, and W.R. Davis. 1987. Availability of PCBs and PAHs to Mytilus edulis from artificially resuspended sediments. In: Oceanic Processes in Marine Pollution. Vol. 1. Biological Processes and Wastes in the Ocean, 97-108. J.M. Capuzzo, and D.R. Kester, eds. Malabar, FL: Krieger.
- Rabalais, N.N., M.J. Dagg, and D.F. Boesch. 1985. Nationwide review of oxygen depletion and eutrophication in estuarine and coastal waters: Gulf of Mexico. Louisiana Universities Marine Consortium, Data Report.
- Redfield, A.C. 1972. Development of a New England salt marsh. Ecol. Monogr. 42:201-237.
- Reilly W.K. 1989. Measuring for environmental results, EPA Journal 15(3):2-4.

- Reish, D.J. and J.L. Barnard. 1960. Field toxicity tests in marine water utilizing the polychaetous annelid Capitella capitata (Fabricius). Pacif. Nat. 1:1-8.
- Remane, A., and C. Schlieper. 1971. Biology of Brackish Water. New York: John Wiley and Sons.
- Rhoads, D.C. 1974. Organism-sediment relations on the muddy sea floor. Oceanogr. Mar. Biol. A. Rev. 12:263-300.
- Rhoads, D.C., P.L. McCall, and J.Y. Yingst. 1978. Disturbance and production on the estuarine sea floor. Amer. Scient. 66:577-586.
- Rhoads, D.C., and J.D. Germano. 1982. Characterization of organism-sediment relations using sediment profile imaging: An efficient method of remote ecological monitoring of the seafloor (REMOTS System). Mar. Ecol. Progr. Ser. 8:115-128.
- Rhoads, D.C., and L.F. Boyer. 1982. The effects of marine benthos on physical properties of sediments: A successional perspective, In: Animal-Sediment Relations: The Biogenic Alteration of Sediments, pp 1-52. P.L. McCall and M.J. S. Tevesz (eds.), New York: Plenum Press.
- Roesijadi, G., J.S. Young, A.S. Drum, and J.M. Gurtisen. 1987. Behavior of trace metals in Mytilus edulis during a reciprocal transplant field experiment. Mar. Ecol. Progr. Ser. 18:155-170.
- Rose, K.A., J.K. Summers, R.A. Cummins, and D.G. Heimbuch. 1986. The analysis of long-term multivariate ecological data using categorical times series. Can. J. Fish. Aquat. Sci. 43:2418-2426.
- Rosen, J.S. and J. Beaulieu, M. Hughes, H. Buffum, J. Copeland, R. Valente, J. Paul, F. Holland, S. Schimmel, C. Strobel, K. Summers, K. Scott, J. Parker. 1990. Environmental Monitoring and Assessment Program Data Management System for Near Coastal Demonstration Project. U.S. Environmental Protection Agency, Office of Research and Development. EPA-600/x-90/207.
- Sanders, H.K., P.C. Mangelsdorf, Jr., and G.R. Hampson. 1965. Salinity and faunal distribution in the Pocasset River, Massachusetts. Limnol. Oceanogr. 10:R216-R229.
- Sanders, H.L., J.F. Grassle, G.R. Hampson, L.S. Morse, S. Garner-Price, and C.C. Jones. 1980. Anatomy of an oil spill: Long term effects from the grounding of the barge Florida off West Falmouth, Massachusetts. J. Mar. Res. 38:265-380.
- Sanders, J.E. 1989. PCB pollution in the upper Hudson River. In: Contaminated Marine Sediments -- Assessment and Remediation, 365-400. Washington, DC: National Academy of Sciences, National Academy Press.

- Schimmel, S.C. 1990. Implementation Plan for the Environmental Monitoring and Assessment Program Near Coastal Demonstration Project. U.S. Environmental Protection Agency, Office of Research and Development.
- Schubel, J.R. and H.H. Carter. 1976. Suspended sediment budget for Chesapeake Bay. In: Estuarine Processes, Vol. 2, 48-62. M.L. Wiley, ed. New York: Academic Press.
- Schubel, J.R., and H.H. Carter. 1984. The estuary as a filter for fine-grained suspended sediment. In: The Estuary as a Filter, 81-104. V.S. Kennedy, ed. Orlando, FL: Academic Press.
- Schubel, J.R. and V.S. Kennedy. 1984. The estuary as a filter: an introduction. In: The Estuary as a Filter, 1-11. V.S. Kennedy, ed. Orlando, FL: Academic Press, Inc.
- Science Advisory Board (SAB). 1988. Future risk: Research strategies for the 1990s. The Report of the Research Strategies Committee. Science Advisory Board, EPA to Lee M. Thomas, Administrator, EPA.
- Scott, J., D. Rhoads, J. Rosen, S. Pratt, and J. Gentile. 1987. The impact of open-water disposal of Black Rock Harbor dredged material on benthic recolonization at the FVP site. Technical Report D-87-4. U.S. Army Engineer Waterways Experiment Station. Vicksburg, MS.
- Scott, K.J., and M.S. Redmond. 1989. The effects of a contaminated dredged material on laboratory populations of the tubificious amphipod Ampelisca abdita. In: Aquatic Toxicology and Hazard Assessment, 12th volume. U.M. Coughill and L.R. Williams, eds.
- Sea Bird Electronics, Inc. 1987. Sealogger CTD. Sea Bird Electronics, Inc. Bellevue, WA.
- Sharpe, J.H., J.R. Pennock, T.M. Church, T.M. Tramontano, and L.A. Cifuentes. 1984. The estuarine interaction of nutrients, organics, and metals: A case study in the Delaware Estuary. In: The Estuary as a Filter, 241-258. V.S. Kennedy, ed. Orlando, FL: Academic Press.
- Sinderman, C.J. 1979. Pollution-associated diseases and abnormalities of fish and shellfish: A review. Fish. Bull. 76:717-741.
- Sloan, R., B. Young, V. Vecchio, K. McKnown, and E. O'Connel. 1988. PCB concentrations in the striped bass from the marine district of New York State. Tech. Report 88-1. Department of Environmental Protection, New York.

- Smart, T., E. Smith, T. Vogel, C. Brown, and K. Wolman. 1987. Troubled Waters Business Week, October 12, 1987, 88-104.
- Sprague, J.B. 1985. Factors that modify toxicity. In: Fundamentals of Aquatic Toxicology. G.M. Rand and S.R. Petrocelli, ed. New York: Hemisphere Publication Corp.
- Stanley, T.W. and S.S. Verner. 1985. The U.S. Environmental Protection Agency's quality assurance program. In: Quality Assurance for Environmental Measurements, ASTM STP 867, 12-19. J.K. Taylor and T.W. Stanley, eds. Philadelphia: American Society for Testing and Materials.
- Stehman, S.D. and W.S. Overton. 1987. An empirical investigation of the variance estimation methodology prescribed for the National Stream Survey: Simulated sampling from stream data sets. Oregon State Technical Report 118.
- Stehman, S.V. and W.S. Overton. 1989. An empirical, general population assessment of the properties of variance estimators of the Horvitz-Thompson estimator under random-order, variable probability systematic sampler. Technical Report. 132, Dept. of Statistics, Oregon State University.
- Strobel, C.J. 1990. Environmental Monitoring and Assessment Program Near Coastal Component 1990 Demonstration Project Field Operations Manual. U.S. Environmental Protection Agency. Office of Research and Development. 68-C8-066.
- Summers, J.K. and K.A. Rose. 1987. The role of interactions among environmental conditions in controlling historical fisheries variability. Estuaries 10:255-266.
- Swartz, R.C. 1987. Toxicological methods for determining the effects of contaminated sediment on marine organisms. In: Fate and Effects of Sediment Bound Chemicals in Aquatic Systems, 183-198. K.L. Dickson, A. W. Maki, and W.A. Brungs, eds. New York: Pergamon Press.
- Swartz, R.C. 1989. Marine sediment toxicity tests. Contaminated sediments -- assessment and remediation. Washington, DC: National Academy Press.
- Swartz, R.C., W.A. DeBen, J.K. Jones, J.O. Lamberson, and F.A. Cole. 1985. Phoxocephalid amphipod bioassay for marine sediment toxicity. In: Aquatic Toxicology and Hazard Assessment: Seventh Symposium, 284-307. R. D. Cardwell, R. Purdy, and R.C. Bahner, eds. Philadelphia, PA: American Society for Testing and Materials.
- Tagatz, M.E. 1968. Biology of the blue crab, Callinectes sapidus (Rathbun) in the St. Johns River, Florida. Fish. Bull. 67:17-33.

- Taylor, J.K. 1978. Importance of inter-calibration in marine analysis. Thal. Jugo. 14:221.
- Taylor, J.K. 1985. Principles of quality assurance of chemical measurements. NBSIR 85-3105. National Bureau of Standards, Gaithersburg, MD.
- Taylor, J.K. 1987. Quality Assurance of Chemical Measurements. Chelsea, ME: Lewis Publishers, Inc.
- Terrell, T.T. 1979. Physical regionalization of coastal ecosystems of the United States and its territories. Office of Biological Services, U.S. Fish and Wildlife Service, FWS/OBS-79/80.
- Theede, H. 1973. Comparative studies on the resistance of marine bottom invertebrates to oxygen deficiency and hydrogen sulphide. Mar. Biol. 2:325-337.
- Thomas, L.M. 1988a. The E in Environmental Protection Agency. Environmental Protection Agency Journal 14(1):3-4.
- Thomas, L.M. 1988b. Environmental Regulation Challenges We Face. Environmental Protection Agency Journal 14(2):2-3.
- Thorson, G. 1957. Bottom communities. In: Treatise on Marine Ecology and Paleoecology, 461-535. J.W. Hedgpeth, ed. New York: Geological Society of America.
- Thursby, G.B., and R.L. Steele. 1987. Guidance manual for conducting sexual reproduction tests with the marine macroalga Champia parvula for use in testing complex effluents. Contribution No. X103. In: Users Guide to the Conduct and Interpretation of Complex Effluent Toxicity Tests at Estuarine/Marine Sites. S.C. Schimmel, ed. Environmental Research Laboratory, U.S. Environmental Protection Agency, Narragansett, Rhode Island. Contribution No. 796.
- Toufexis, A. 1988. Our filthy seas: The world's oceans face a growing threat from manmade pollution. Time, August 1.
- Turekian, K.K. 1977. The fate of metals in the oceans. Geo. et Cosmochimica Acta 41:1139-1144.
- Turgeon, D.D., B.W. Gottholm, K.D. McMahon, A. Robertson. 1989. Toxic Contamination in Long Island Sound. National Oceanic and Atmospheric Administration National Status and Trends Program for Marine Environmental Quality. National Oceanic and Atmospheric Administration, Ocean Assessments Division, Rockville, MD.

- U.S. Environmental Protection Agency (USEPA). 1983a. Chesapeake Bay: A profile of environmental change. Prepared for the U.S. Congress by the Environmental Protection Agency, Region 3, Philadelphia, PA.
- USEPA. 1983b. Technical support manual: Waterbody surveys and assessments for conducting use attainability analyses. Vol. II: Estuarine systems. Office of Water and Standards.
- USEPA. 1984. Chesapeake Bay: A framework for action. Prepared for the U.S. Congress by the Environmental Protection Agency, Region 3, Philadelphia, PA.
- USEPA. 1985. Standard Operating Procedures for Conducting Surplus and Sample Bank Audits. U.S. Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, OH. EPA/600/4-79/019.
- USEPA. 1987. Unfinished business: A comparative assessment of environmental problems. Vol. 1, Overview. U.S. Environmental Protection Agency, Washington, DC.
- USEPA. 1989. Briefing Report to the EPA Science Advisory Board on the Equilibrium Partitioning Approach to Generating Sediment Quality Criteria. EPA 440/5-89-002. USEPA, Criteria and Standards Division, Washington, DC.
- Vernberg, F.S. 1972. Dissolved gases. *In*: Marine Ecology, Vol. I, Part 3, 1491-1526. O.Kinne, ed. New York: Wiley-Interscience.
- Warwick, R.M. 1980. Population dynamics and secondary production on benthos. *In*: Marine Benthic Dynamics, Belle W. Baruch Library in Science Number 11. K.R. Tenore and B.C. Coull, eds. Columbia, SC: University of South Carolina Press.
- Weaver, G. 1984. PCB contamination in and around New Bedford, Mass. EST 18:22A-27A.
- Weinstein, M.P., S.L. Weiss, and M.F. Walters. 1980. Multiple determinants of community structure in shallow marsh habitats, Cape Fear River estuary, North Carolina, USA. Mar. Biol. 48:227-243.
- Whitledge, T.E. 1985. Nationwide review of oxygen depletion and eutrophication in estuarine and coastal waters: Executive Summary. Brookhaven National Laboratory, Upton, NY.
- Wolfe, D.A., M.A. Champ, D.A. Flemer, and A.J. Mearns. 1987. Long-term biological data sets: Their role in research, monitoring, and management of estuarine and coastal marine systems. Estuaries 10:181-193.

Woltering, D.M. 1984. The growth response in fish chronic and early life stage toxicity tests: A critical review. Aquat. Toxicol. 5:1-21.

APPENDIX A

Environmental Monitoring and Assessment Program Overview



United States
Environmental Protection
Agency

Office of Modeling,
Monitoring Systems and
Quality Assurance (RD-680)
Washington DC 20460

Research and Development

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Environmental Monitoring and Assessment Program

Overview

Overview

This document presents an overview of the rationale, goals, and primary elements of the Environmental Monitoring and Assessment Program (EMAP), which represents a long-term commitment to assess and document periodically the condition of the Nation's ecological resources. EMAP is being designed by the U.S. Environmental Protection Agency's (EPA) Office of Research and Development. 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.

Monitoring, Regulatory, & Policy Needs

Environmental regulatory programs have been estimated to cost more than \$70 billion annually, yet the means to assess their effect on the environment over the long term do not exist. While regulatory programs are based upon our best understanding of the environment at the time of their development, it is critical that long-term monitoring programs be in place to confirm the effectiveness of these programs in achieving their environmental goals and to corroborate the science upon which they are based.

The EPA, the U.S. Congress, and private environmental organizations have long recognized the need to improve our ability to document the condition of our environment. Congressional hearings in 1984 on the National Environmental Monitoring Improvement Act concluded that, despite considerable expenditures on monitoring, federal agencies could assess neither the status of ecological resources nor the overall progress toward legally-mandated goals of mitigating or preventing adverse ecological effects. In the last decade, articles and editorials in professional journals of the environmental sciences have repeatedly called for the collection of more relevant and comparable ecological data and easy access to those data for the research community.

Affirming the existence of a major gap in our environmental data and recognizing the broad base of support for better environmental monitoring, the EPA Science Advisory Board (SAB) recommended in 1988 that EPA initiate a program that would monitor ecological status and trends, as well as develop innovative methods for anticipating emerging problems before they reach crisis proportions. EPA was encouraged to become more active in ecological monitoring because its regulatory responsibilities require quantitative, scientific assessments of the complex effects of pollutants on ecosystems. EMAP is being initiated in 1990 by EPA in response to these recommendations.

EMAP's Purpose

EMAP is being designed to monitor indicators of the condition of our Nation's ecological resources. Specifically, EMAP is intended to respond to the growing demand for information characterizing the condition of our environment and the type and location of changes in our environment. Simultaneous monitoring of pollutants and environmental changes will allow us to identify likely causes of adverse changes. When fully implemented, EMAP will answer the following questions:

- ☐ What is the current status, extent, and geographic distribution of our ecological resources (e.g., estuaries, lakes, streams, wetlands, forests, grasslands, deserts)?
- ☐ What proportions of these resources are degrading or improving, where, and at what rate?
- ☐ What are the likely causes of adverse effects?
- ☐ Are adversely-affected ecosystems responding as expected to control and mitigation programs?

EMAP will provide the Administrator, the Congress, and the public with statistical data summaries and periodic interpretive reports on ecological status and trends. Because sound decision-making must consider the uncertainty associated with quantitative information, all EMAP status and trends estimates will include statistically-rigorous confidence limits.

Assessments of changes in our Nation's ecological resource conditions require data on large geographic scales collected over long periods of time. For national assessments, comparability of data among geographic regions (e.g., the Northeast, Southeast, and West) and over extended periods is

critical, and meeting this need by simply aggregating data from many individual, local, and short-term networks that are fragmented in space or time has proven difficult, if not impossible. EMAP will focus specifically on national and regional scales over periods of years to decades, collecting data on indicators of ecological condition from multiple ecosystems and integrating them to assess environmental change. This approach, along with EMAP's statistically-based design, distinguishes it from most current monitoring efforts, which tend to be short-term or locally-focused. A long-term, integrated, multi-ecosystem monitoring program offers the advantages of earlier detection of problems and improved resolution of their extent and magnitude, while enabling formulation of more cost-effective regulatory or remedial actions.

Environmental monitoring data are collected by EPA to meet the requirements of a variety of regulatory programs. Many federal agencies collect environmental data specifically to manage particular ecological resources. Efficient execution of EPA's mandate to protect the Nation's ecosystems requires, therefore, that EMAP complement, supplement, and integrate data and expertise from the regulatory offices within EPA and from other agencies. EMAP should not be perceived as a substitute for ongoing programs designed to meet objectives other than its own. Interagency coordination is actively being pursued with the Departments of Interior, Commerce, and Agriculture. This coordination avoids duplicative monitoring efforts, facilitates exchange of existing data for use in the refinement of monitoring networks, and increases the expertise available to quantify and understand observed status and trends. EMAP will also draw upon the expertise and activities of the EPA Regional Offices, States, and the international community.

Ecological monitoring programs of the 1990's and beyond must be able to respond and adapt to new issues and perspectives within the context of a continuing effort to detect trends and patterns in environmental change. These demands will be met by EMAP through a flexible design that can accommodate as yet undefined questions and objectives as well as changing criteria of performance and scientific capability. Further, EMAP's design will encourage analysis, review, and reporting processes that foster discovery of unanticipated results and promote the widespread dissemination of scientifically-sound information. Periodic evaluations of the program's direction and emphasis will be the key to maintaining its viability and relevance while retaining the continuity of the basic data sets. These evaluations will serve to preclude the "aging" that typically hinders long-term monitoring efforts.

Planning & Design

The major activities in 1990 around which EMAP is being developed are:

- ☐ **Indicator Evaluation and Testing**—evaluation and testing of indicators of ecological condition;

- ☐ **Network Design**—design and evaluation of integrated, statistical monitoring networks and protocols for collecting status and trends data on indicators;
- ☐ **Landscape Characterization**—nationwide characterization of ecological resources in areas within the EMAP sampling network to establish a baseline for monitoring and assessment; and
- ☐ **Near-Coastal Demonstration Project**—implementation of regional-scale surveys to define the current status of our estuarine resources.

Although the goal is to establish the program in all categories of ecosystems, the initial emphasis is on testing and implementing the program in estuaries, near-coastal wetlands, and inland surface waters, coordinating these activities with the National Oceanic and Atmospheric Administration, the U.S. Fish and Wildlife Service, and the U.S. Geological Survey. Because precipitation and air quality are two important factors influencing ecosystems, EMAP also will contribute to the evaluation and maintenance of the multiagency atmospheric deposition networks currently coordinated by the National Acid Precitation Assessment Program (i.e., the National Trends Network/National Dry Deposition Network). These ecosystems and deposition networks offer immediate opportunities to demonstrate the EMAP approach.

EMAP also will contribute to the development of a research program in environmental statistics. This program will refine the statistical framework for the remaining types of ecosystems in preparation for full implementation of EMAP in 1995 and beyond. Relying heavily on expertise from academia and industry, this program will develop methods and approaches for: (a) analyzing and interpreting spatial and temporal trends in indicators across regions; (b) incorporating and substituting historical data and data from ongoing monitoring programs into EMAP; (c) designing efficient quality assurance programs for ecological monitoring programs; and (d) diagnosing the likely causes of adverse conditions in ecosystems.

Indicator Evaluation & Testing

Purpose

EMAP will evaluate and use indicators that collectively describe the overall condition of an ecosystem. Measurements of ecosystem condition should reflect characteristics clearly valued by society. Measurement methods must be standardized and quality-assured so that spatial patterns and temporal trends in condition within and among regions can be accurately assessed.

Strategy

Indicators in three categories will be evaluated:

- ❑ **Response indicators**—which quantify the response of ecosystems to anthropogenic stress. Examples include signs of gross pathology (e.g., the appearance of tumors in fish or visible damage to tree canopies); the status of organisms that are particularly sensitive to pollutants or populations of organisms important to sportsmen, commercial interests, or naturalists; and indices of community structure and biodiversity.
- ❑ **Exposure indicators**—which show whether ecosystems have been exposed to pollutants, habitat degradation, or other causes of poor condition. Examples include ambient pollutant concentrations; acidic deposition rates; bioaccumulation of toxics in plant and animal tissues; media-specific field bioassays using test organisms; and measurements of habitat condition or availability (e.g., siltation of bottom habitat and vegetative canopy complexity).
- ❑ **Stressor indicators**—which are socio-economic, demographic, and regulatory compliance measurements that are suggestive of environmental stress. Examples include coal production, population figures, pesticide applications, pollutant emissions inventories, and land use.

Sets of indicators will be identified and measured in all categories for each ecosystem type. The set of response indicators should reflect adverse effects of both anticipated and unanticipated environmental stresses (e.g., new pollutants). Criteria must be developed for each response indicator to identify when conditions change from acceptable or desirable to unacceptable or undesirable. Criteria could be based on conditions attainable under best management practices as observed at "regional reference sites", relatively undisturbed sites that are typical of an ecoregion. A set of exposure indicators will be used to determine whether ecosystems have been exposed to environmental stress and what the causes of poor condition are likely to be. For example, undesirably low diversity in stream fish communities across a region might be related to the presence of toxics in sediments, siltation of bottom habitat, insufficient flow, low pH, or bioaccumulation of toxics. In this example, stressor indicators that might be examined in diagnosing the cause would include the number and type of industrial dischargers, farmed acreage or construction activity, water withdrawals, presence of mine spoils or acidic deposition, and regional pesticide application.

The goals of EMAP are quite different from those of the compliance monitoring most commonly conducted by EPA. While compliance monitoring involves identifying, with a high degree of confidence, pollutant concentrations that can be linked unequivocally to individual polluters, EMAP will use sets of indicators to assess the condition of multiple ecological systems across regions, coupled with an evaluation of associated pollutant sources or other anthropogenic environmental disturbance. EMAP's regional approach to environmental monitoring and assessment is quite unusual, and the expected benefits include an improved capability to detect

emerging problems and to identify those types of ecosystems most in need of research, assessment, or remediation. Regional monitoring and assessment is the only effective way to determine whether current environmental regulations are adequately protecting our ecological resources.

Activities

Many scientific questions remain to be answered. Is the natural variability in response indicators too large to make sufficiently precise estimates of regional conditions? Can ecosystem condition be compared among regions with different biota? What criteria will be used to determine acceptable versus unacceptable conditions? How are the data best interpreted for systems with response indicators in undesirable range and multiple, conflicting, or unknown exposure indicators? What, if anything, might be done when a system's range in response indicators is acceptable, but the range in exposure indicators is not? EMAP will seek short- and long-term answers to these questions through three types of activities:

- ❑ Reports evaluating the availability and applicability of indicators for all EMAP ecosystem categories;
- ❑ Workshops on ecological indicators; and
- ❑ Development of a long-term indicator research program for all EMAP ecosystem categories.

Network Design

Purpose

Meeting the goal of estimating status and trends in the condition of the Nation's ecosystems requires a monitoring framework that:

- ❑ Provides the basis for determining and reporting on ecological indicators at various geographic scales;
- ❑ Is adaptable to monitoring on regional as well as on continental and global scales;
- ❑ Enables the examination of correlations among spatial and temporal patterns of response, exposure, and stressor indicators;
- ❑ Enables the incorporation or substitution of data from ongoing monitoring sites and networks; and
- ❑ Is sufficiently adaptable and flexible to accommodate changes in spatial extent of the resource (e.g., the areal extent of wetlands) and to address current and emerging issues.

Strategy

A global grid will be constructed for identifying sampling sites. This grid will then be divided into sub-grids in accordance with whatever scale of resolution (e.g., national, regional, or subregional) is required for an assessment of the condition of ecological resources. Currently, a sub-grid for the United States and its surrounding continental shelf waters that includes approximately 12,500 sites is being evaluated. Within these sites, ecosystems will be identified and characterized and their number and areal extent will be determined. This initial characterization will be accomplished using existing maps, satellite imagery, and aerial photography. Field sampling of sets of indicators will be conducted on a subset of sites statistically selected from the 12,500 original sites.

Current EMAP research will determine the number of sampling sites needed for regional and national reports on the status, changes, and trends in indicators. Two alternative approaches for field sampling of approximately 3,000 sites are being considered. In the first, about one-fourth of the 3,000 sites across the continental United States would be visited in one year. The following year, a second one-fourth of the sites would be sampled and so on, such that all sites would be visited during a four-year period. In the second, data would be collected during a single year at all the sampling sites in a geographical area (e.g., the estuaries in the Virginian Province from Cape Cod to Cape Hatteras or all lakes and streams in the Northeast) and sampling efforts would shift to a new area during following years. The statistical, logistical, and reporting advantages of each option are being evaluated in light of EMAP's long-term goal to provide a national assessment of the status, changes, and trends in ecological resources. In addition, the timing of the sampling period, the statistical procedures for establishing where a measurement is to be made, and the number of samples that must be collected at each sampling site are being examined.

Activities

Current activities are focused on making the global grid final, applying it to the United States, and identifying rules for associating ecosystems with grid points and statistically selecting them for sampling. The EMAP design and sampling strategy will be reviewed by the American Statistical Association and appropriate ecosystem experts.

Landscape Characterization

Purpose

National assessments of status and trends of the condition of ecosystems require knowing not only what percentage of a particular resource is in desirable or acceptable condition, but also how much of that resource exists. Some types of wetlands are being lost at an alarming rate; conversion and loss of other types of ecosystems are also occurring. Such changes

may be of particular concern if statistically correlated with pollutant exposure or other anthropogenic stressors. For most ecosystems, few national data bases can currently be used to derive quantitative estimates of ecosystem extent and changes in condition on a regional basis with known confidence.

The technique that will be used to address these issues is landscape characterization. Landscape characterization is the documentation of the principal components of landscape structure—the physical environment, biological composition, and human activity patterns—in a geographic area. EMAP will characterize the national landscape by mapping landscape features (e.g., wetlands, forests, soils, and land uses) in areas associated with the EMAP sampling grid. Characterization uses remote sensing technology (satellite imagery and aerial photography) and other techniques (e.g., cartographic analysis and analysis of census data) to quantify the extent and distribution of ecosystems. Over time, periodic aerial and satellite photography will permit quantitative estimation of changes in landscape features that might be related to anthropogenic activities and pollutants. The results of these characterization analyses also permit more informed selection of systems for field sampling.

Strategy

The characterization strategy involves the application of remote sensing technology to obtain high-resolution data on selected sample sites and lower resolution data over broad geographical areas. Other data sources such as maps and censuses will be used to supplement the remote sensing data.

The remote sensing data also will furnish detailed information needed for the network design. For example, lakes, streams, wetlands, forests, and other types of ecosystems associated with each grid point will be identified so that a subset for field sampling can be statistically selected. Characterization also supplies a portion of the data needed to classify ecosystems into subcategories of interest (e.g., forest-cover types, wetland types, crops, and lake types).

Certain types of landscape data assist in diagnosing the probable causes of undesirable conditions in response indicators. Characterization will describe the physical and spatial aspects of the environment that reflect habitat modification, for example, those that can amplify or counteract the effects of toxicants and other pollutants on plants and animals.

Finally, characterization will compile data on stressor indicators that can be identified from remote sensing and mapped data, including land use, mining activities, population centers, transportation and power corridors, and other anthropogenic disturbances.

EMAP will assemble, manage, and update these data in Geographic Information System (GIS) format. A standardized characterization approach and a landscape information network common to all ecosystems will be used to optimize cost and data sharing and to ensure common format and consistency. Through close work with other agencies, EMAP will

establish design requirements for the integrated characterization including acceptance criteria for baseline data, consistent classification detail and accuracy, and suitable spatial and temporal resolution to distinguish landscape features of particular interest.

Activities

The design of the characterization plan and the evaluation of potential characterization techniques are in progress. A prototype methodology for high-resolution characterization has been developed. Current activities include evaluating a range of methods, from landscape ecology to quantitative, multistage remote sensing (combined satellite and aerial photography) in widely different terrain types. EMAP characterization will begin in 1990 at approximately 800 sites, or about one-fourth of the 3,000 selected for field sampling.

Near-Coastal Demonstration Project

Purpose

Information obtained from the near-coastal demonstration project will be used to refine the EMAP design, and the study itself will serve as a model for implementing EMAP projects in other study areas and types of ecosystems.

The demonstration project has five goals:

- ☐ Evaluate the utility, sensitivity, and applicability of the EMAP near-coastal indicators on a regional scale;
- ☐ Determine the effectiveness of the EMAP network design for quantifying the extent and magnitude of pollution problems in the near-coastal environment;
- ☐ Demonstrate the usefulness of results for planning, priority-setting, and determining the effectiveness of pollution control actions;
- ☐ Develop standardized methods for indicator measurements that can be transferred to other study areas and made available for other monitoring efforts; and
- ☐ Identify and resolve logistical issues associated with implementing the network design.

Strategy

The strategy for accomplishing the above tasks is to work closely with the National Oceanic and Atmospheric Administration's National Status and Trends Program to field-test the near-coastal indicators and network design through a demonstration study in the estuaries and coastal wetlands of the Mid-Atlantic area of the United States. Estuaries were selected because their natural circulation patterns concentrate and

retain pollutants. Estuaries and coastal wetlands are also spawning and nursery grounds for many valued living resources, and estuarine watersheds receive a large proportion of the pollutants discharged to the Nation's waterways. The Mid-Atlantic study area was chosen because adverse pollutant impacts are evident; contaminants are present in the water, sediments, and biota; the vitality of many organisms is reportedly threatened; and seven of the area's larger estuaries are included in EPA's National Estuary Program.

Activities

During 1989, the major environmental problems associated with near-coastal systems were identified: eutrophication, contamination, habitat modification, and the cumulative impact of multiple stressors. A set of response, exposure, and stressor indicators applicable to each problem is to be identified, based on current understanding of how various environmental stressors affect ecosystem processes and biota. Near-coastal ecosystems have been classified for monitoring and assessment based on their physical and chemical characteristics and their susceptibility to environmental stressors. A monitoring network design that is compatible with the EMAP design is being developed. Several logistical and technical questions regarding the EMAP near-coastal project remain, including:

- ☐ What set of indicators will be measured?
- ☐ What specific methods will be used to sample each indicator?
- ☐ Will all indicators be measured at all sampling sites or can a sampling plan be developed that requires measurement of costly indicators only at selected sites? and
- ☐ To what degree should sources of variation be measured and accounted for in the network design?

The near-coastal demonstration project will be conducted in the estuaries and coastal wetlands of the mid-Atlantic area of the United States (from Cape Hatteras to Cape Cod) during mid-1990. A report on the results of the project will be prepared in 1991.

Information Contact

EMAP is planned and managed by ORD's Office of Modeling, Monitoring Systems, and Quality Assurance (OMMSQA). Inquiries may be directed to:

EMAP Director
ORD/OMMSQA (RD-680)
U.S. EPA
Washington, DC 20460
(202) 382-5767
Fax: (202) 252-0929

APPENDIX B

Memorandum of Understanding Between Environmental Protection Agency and National Oceanic and Atmospheric Administration

JOINT NOAA-EPA AGREEMENT TO DETERMINE THE STATUS,
TRENDS, AND ECOLOGICAL EFFECTS OF ANTHROPOGENIC STRESS IN
COASTAL AND ESTUARINE AREAS OF THE UNITED STATES

I. PURPOSE

The NOAA National Ocean Service and the U.S. EPA Office of Research and Development agree to coordinate their research and monitoring programs for assessing the effects of anthropogenic stress on marine and estuarine ecosystems. This agreement provides an initial mechanism for coordination of planning activities leading to the establishment of a joint NOAA/EPA program for monitoring the status and trends of near coastal environmental quality and ecological conditions. It also covers joint activities associated with the synthesis and integration of monitoring and characterization data into assessments of the effects of human activities on the Nation's near coastal ecosystems.

II. BACKGROUND AND SCOPE

Both NOAA and the U.S. EPA have regulatory mandates to conduct a broad range of research and monitoring activities to assess the effect of anthropogenic stress on marine and estuarine environments. Without coordination and cooperation, these activities could result in duplicative efforts. For example, both NOAA/NOS and the U.S. EPA/ORD have a need for and a requirement to conduct status and trends monitoring research on indicators of environmental quality and pollution assessment activities at regional and national scales in coastal areas.

Existing NOAA programs are focused on (1) assessing the status and trends of chemical contaminants, at national and regional levels, (2) characterizing existing environmental conditions and problems using available data and retrospective analyses, (3) development of indicators of the effects of chemical contamination on biota, and (4) development of information transfer capabilities (e.g., computerized information management systems that make a broad range of information on the characteristics and conditions of coastal areas available to decision makers and scientists).

Existing U.S. EPA/ORD programs are focused on (1) development and evaluation of indicators of marine and estuarine environmental quality and sampling methods that quantify and partition the extent and magnitude of cumulative and multimedia anthropogenic impacts on marine and estuarine environments; (2) establishment of the monitoring networks to obtain the data necessary to determine the status and trends in ecological condition of near coastal ecosystems, and (3) conduct of multimedia integrated assessments, including retrospective analyses, to evaluate the effectiveness of pollution control policies and practices and to

identify emerging pollution problems before they reach crisis proportions.

Although both commonalities and differences exist between NOAA and U.S. EPA programs, the combined results of both serve the national interest more than the results of either program. Therefore, it is the intention of NOAA/NOS and the U.S. EPA/ORD to cooperate and coordinate to the greatest possible extent to prevent duplication of efforts and to ensure that information produced by each program is used to the maximum extent possible, including joint synthesis and integration activities.

Cooperation has already begun in several areas including the following:

- 0 A schedule of monthly meetings for coordinating activities for the exchange of information has been set and honored since October 1989. The purpose of these meetings has been to avoid and prevent duplicative activities and to identify areas for joint activities. Information exchanged at these meetings has been used by both NOAA and U.S. EPA in developing future research and monitoring plans.
- 0 Combined NOAA/EPA quality control and assurance procedures have been developed, and a joint NOAA/EPA quality assurance program will be implemented in 1990 for the Near Coastal Demonstration Project of U.S. EPA's Environmental Monitoring and Assessment Program.
- 0 EPA has transferred funds to NOAA to begin data collection and synthesis efforts to characterize important aspects of estuaries in the Virginia Province.
- 0 NOAA has assisted EPA in development and evaluation of marine/estuarine environmental quality indicators by participating in workshops, providing data for retrospective analyses and review of EPA plans.
- 0 NOAA personnel have been assigned to and will participate directly in the FY 1990 EMAP Near Coastal field measurement program.

The desire to implement this agreement reflects the success of ongoing cooperation and the desire of both agencies to further enhance the exchange of information.

III. COOPERATIVE PLANNING

The NOAA/NOS and U.S. EPA/ORD agree to coordinate the planning and implementation of their research, monitoring, and assessment

programs for assessing the ecological condition of near coastal environments. This program shall include:

- 0 Research and monitoring to assess the effects of human activities on near coastal environment and the effectiveness of existing environmental regulations and policies.
- 0 Research related to testing and evaluating indicators of ecological condition.
- 0 Planning and establishment of status and trends monitoring networks.
- 0 Synthesis and integration of monitoring and assessment data, including retrospective analyses.
- 0 Identification of emerging coastal pollution problems.

IV. COORDINATION STRUCTURE

The framework for monitoring and research conducted under this memorandum shall be developed through the NOAA/EPA Joint Committee for Coastal and Marine Environmental Quality Monitoring. This committee was created to ensure coordination and exchange of information between the two programs on monitoring, research, and assessment activities.

The activities of this joint committee shall include:

- 0 Early and continuing communication about research and monitoring priorities.
- 0 Interactive planning and review of plans.
- 0 Exchange of funds for work on joint projects.
- 0 Interim review of results, discussions of areas of concern, and recommendations of actions.
- 0 Joint synthesis and integration of the data collected by each agency.
- 0 Planning and approval of joint documents assessing the status and trends of the ecological condition of near coastal environments and other projects deemed necessary.

V. OTHER ORGANIZATIONS

~~It is the intent of NOAA/NOS and EPA/ORD to interact with other organizations conducting monitoring and research programs within~~

the scope of the Agreement.

This agreement and subsequent Memoranda of Understanding shall be considered subject to revision by direction from either of the principal agencies.

Virginia K. Tippie

VIRGINIA K. TIPPIE
Assistant Administrator
for National Ocean Service
National Oceanic and
Atmospheric Administration

Erich W. Bretthauer

ERICH W. BRETTTHAUER
Assistant Administrator
for Research and
Development
U.S. Environmental
Protection Agency

APPENDIX C

List of Participants at the EMAP-NC Indicator Workshop

DISSOLVED OXYGEN INDICATORS

Denise Breitburg
Academy of Natural Science
Benedict Estuarine Research Lab
Benedict, MD

Robert Diaz
Virginia Institute of Marine Science
Gloucester Point, VA

Jeffrey B. Frithsen
Versar, Inc.
Columbia, MD

Jonathan Garber
U.S. EPA
Environmental Research Laboratory
Narragansett, RI

Michael Haire
Maryland Department of the Environment
Baltimore, MD

Fred Holland
Versar, Inc.
Columbia, MD

William Muir
U.S. EPA, Region III
Philadelphia, PA

William Nelson
U.S. EPA
Environmental Research Laboratory
Narragansett, RI

Joel S. O'Connor
U.S. EPA, Region II
New York, NY

John Paul U.S. EPA
Environmental Research Laboratory
Narragansett, RI

Nancy N. Rabalais
Louisiana Universities Marine Consortium
Chauvin, LA

Ananda Ranasinghe
Versar, Inc.
Columbia, MD

John Scott
SAIC
Narragansett, RI

Anna Shaughnessy
Versar, Inc.
Columbia, MD

Steve Weisberg
Versar, Inc.
Columbia, MD

BENTHIC INDICATORS

Robert Diaz
Virginia Institute of Marine Science
Gloucester Point, VA

Jeffrey B. Frithsen
Versar, Inc.
Columbia, MD

Jonathan Garber
U.S. EPA
Environmental Research Laboratory
Narragansett, RI

Fred Holland
Versar, Inc.
Columbia, MD

John Kraeuter
Rutgers University
Port Norris, NJ

Mark Luckenback
Virginia Institute of Marine Science
Gloucester Point, VA

Sam Luoma
U.S. Geological Survey
Menlo Park, CA

Foster "Sonny" Mayer
U.S. EPA
Environmental Research Laboratory
Gulf Breeze, FL

Joel S. O'Connor
U.S. EPA, Region II
New York, NY

Fred Pinkney
Versar, Inc.
Columbia, MD

Ananda Ranasinghe
Versar, Inc.
Columbia, MD

Donald C. Rhoads
SAIC
Woods Hole, MA

John Scott
SAIC
Narragansett, RI

John Stein
NOAA
Seattle, WA

Kevin Summers
U.S. EPA
Environmental Research Laboratory
Gulf Breeze, FL

Steve Weisberg
Versar, Inc.
Columbia, MD

FISH AND SHELLFISH INDICATORS

John Boreman
UMAS/NOAA CMER Program
University of Massachusetts
Amherst, MA

Linda A. Deegan
Marine Biological Laboratory
Woods Hole, MA

Tom DeMoss
U.S. EPA, Region III
Annapolis, MD

Frank Hetrick
University of Maryland
College Park, MD

Fred Holland
Versar, Inc.
Columbia, MD

James R. Karr
Virginia Polytechnic Institute
and State University
Blacksburg, VA

John Kraeuter
Rutgers University
Port Norris, NJ

Mark Luckenback
Virginia Institute of Marine Science
Gloucester Point, VA

Sam Luoma
U.S. Geological Survey
Menlo Park, CA

Foster "Sonny" Mayer
U.S. EPA
Environmental Research Laboratory
Gulf Breeze, FL

William Nelson
U.S. EPA
Environmental Research Laboratory
Narragansett, RI

Joel S. O'Connor
U.S. EPA, Region II
New York, NY

Tom O'Connor
NOAA
National Status and Trends Program
Rockville, MD

Fred Pinkney
Versar, Inc.
Columbia, MD

William Richkus
Versar, Inc.
Columbia, MD

John Scott
SAIC
Narragansett, RI

John Stein
NOAA
Seattle, WA

Kevin Summers
U.S. EPA
Environmental Research Laboratory
Gulf Breeze, FL

Steve Weisberg
Versar, Inc.
Columbia, MD

CONTRIBUTORS AND COMMENTS

Individuals who made significant contributions to the preparation of this document were, in alphabetical order:

Dr. Jeffrey Frithsen, Versar, Inc.
Dr. Jeroen Gerritsen, Versar, Inc.
Dr. Fred Holland, Versar, Inc.
Dr. John Paul, U.S. Environmental Protection Agency,
Environmental Research Laboratory, Narragansett, Rhode
Island
Mr. Jeffrey S. Rosen, Computer Sciences Corporation
Mr. Steven Schimmel, U.S. Environmental Protection Agency,
Environmental Research Laboratory, Narragansett, Rhode
Island
Dr. John Scott, Science Applications International
Mr. Charles Strobel, Science Applications International
Dr. Kevin Summers, U.S. Environmental Protection Agency,
Environmental Research Laboratory, Gulf Breeze, Florida
Dr. Stephen Weisberg, Versar, Inc.
Mr. Raymond Valente, Science Applications International.

This document greatly benefitted from comments received from the following:

Mr. John Baker
Mr. Dan Basta
Dr. Tudor Davies
Dr. Doug Heimbuch
Dr. Rick Linthurst
Dr. Jay Messer
Mr. David Marmoreck
Mr. Thomas DeMoss
Mr. Jim Pollard
Dr. Thomas O'Connor
Dr. Scott Overton
Dr. Andy Robertson