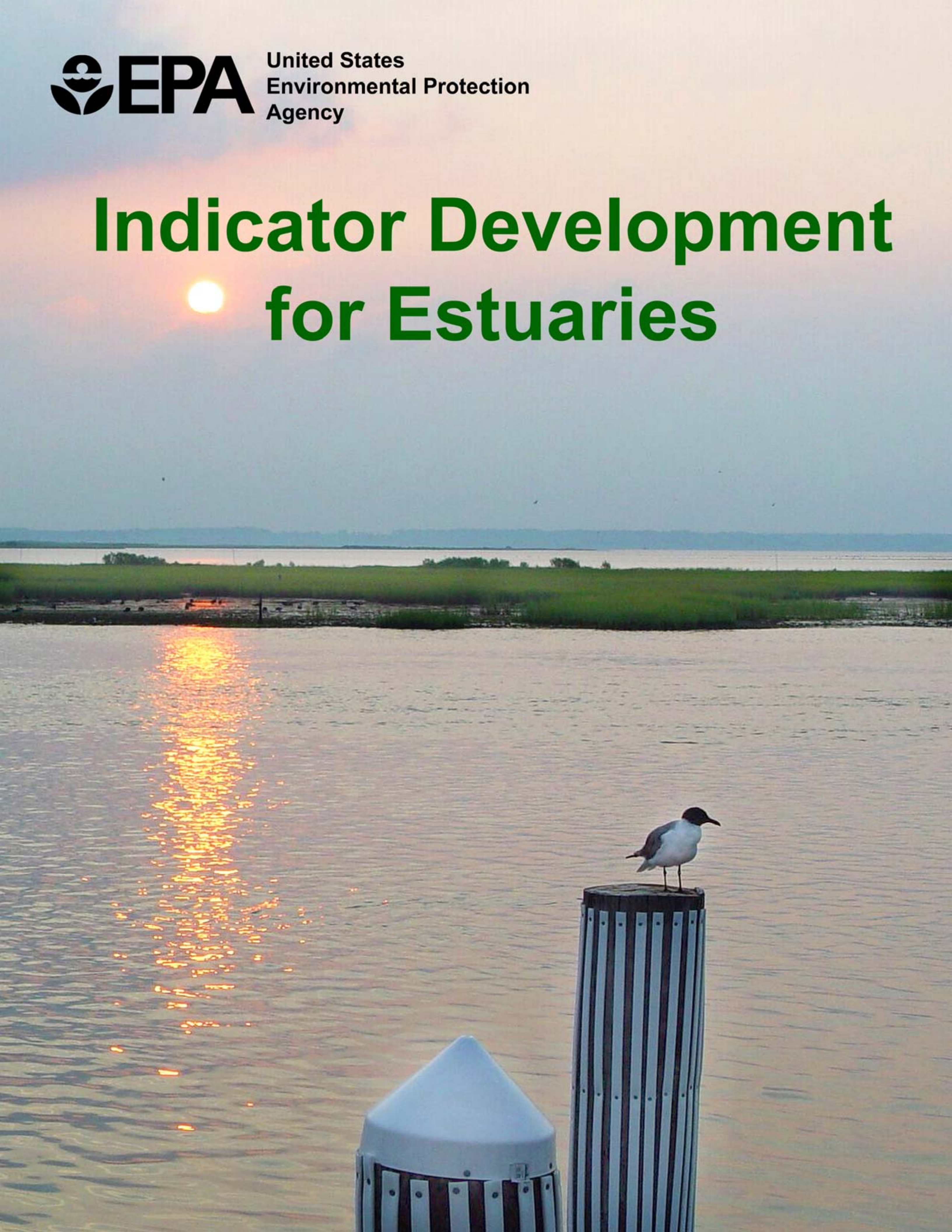
United States
Environmental Protection
Agency

# Indicator Development for Estuaries



Maryland Coastal Bays photo by Joe Hall

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## ACRONYMS

| | |
|---|---|
| ANCMS | Atlantic Northwest Coastal Monitoring Summit |
| BOD | biological oxygen demand |
| BTES | Barataria-Terrebonne Estuary System |
| BTNEP | Barataria-Terrebonne National Estuary Program |
| CBBEP | Coastal Bend Bays Estuary Program |
| CBEP | Casco Bay Estuary Partnership |
| CCMP | Comprehensive Conservation Management Plan |
| CHNEP | Charlotte Harbor National Estuary Program |
| CPUE | catch-per-unit-effort |
| CSO | combined sewer overflow |
| CWA | Clean Water Act |
| CZMA | Coastal Zone Management Act |
| CZMP | Coastal Zone Management Program |
| DDE | dichlorodiphenylethylene |
| DDT | dichlorodiphenyltrichloroethane |
| DO | dissolved oxygen |
| EMAP | Environmental Monitoring and Assessment Program |
| EPA | U.S. Environmental Protection Agency |
| FEMA | Federal Emergency Management Agency |
| GBEP | Galveston Bay Estuary Program |
| GIS | geographic information system |
| GLNPO | Great Lakes National Program Office |
| GOM | Gulf of Maine |
| GOMOOS | Gulf of Maine Ocean Observing System |
| GPRA | Government Performance and Results Act |
| LISS | Long Island Sound Study |
| LSU | Louisiana State University |
| LTEI | Long Term Environmental Indicators |
| MOU | Memorandum of Understanding |
| MWRA | Massachusetts Water Resources Authority |
| NCA | National Coastal Assessment |
| NCCR | National Coastal Conditions Report |
| NCIW | Northeast Coastal Indicators Workshop |
| NEP | National Estuary Program |
| NERR | National Estuarine Research Reserve |

| | |
|---|---|
| NGO | non-governmental organization |
| NHEP | New Hampshire Estuaries Project |
| NMFS | National Marine Fisheries Service |
| NOAA | National Oceanic and Atmospheric Administration |
| NPS | National Park Service |
| NRC | National Research Council |
| OCPD | Oceans and Coastal Protection Division |
| OCRM | Ocean and Coastal Resource Management |
| OECD | Organisation for Economic Co-operation and Development |
| ORD | Office of Research and Development |
| PAH | polycyclic aromatic hydrocarbon |
| PCB | polychlorinated biphenyl |
| PNNL | Pacific Northwest National Laboratory |
| PSR | Pressure-State-Response |
| PSR/E | Pressure-State-Response-Effects |
| QA/QC | quality assurance/quality control |
| SCCWRP | Southern California Coastal Water Research Project |
| SFEI | San Francisco Estuary Institute |
| SJBE | San Juan Bay Estuary |
| SOLEC | State of the Lakes Ecosystem Conference |
| TAC | Technical Advisory Committee |
| TBT | tributyltin |
| TEP | Tillamook Bay Estuary Program |
| U.S. | United States |
| USGS | U.S. Geological Survey |
| VSP | visual sampling plan |

# EXECUTIVE SUMMARY

The National Estuary Program (NEP) was established by Congress in 1987 under Section 320 of the Clean Water Act, to promote and restore the health of nationally significant estuaries, while concurrently supporting beneficial uses of the estuary's natural resources. Under the NEP, the Administrator of the U.S. Environmental Protection Agency (EPA) is authorized to convene Management Conferences to identify priority problems within these estuaries and develop a Comprehensive Conservation and Management Plan (CCMP) to address those problems. Since the programs inception, 28 NEPs around the Nation have been nominated and accepted into the National Estuary Program.

Each NEP is responsible to track the progress of CCMP implementation and to monitor associated ecological conditions in the estuary. Many NEPs share common priority problems or key management issues including: habitat, pathogens, freshwater inflow, nutrients, fish and wildlife, invasive species and toxics. However, each NEP's goals and issue-specific management actions are unique and, therefore, the specific data collected to track CCMP implementation progress and monitor ecological conditions, varies widely among the NEPs. Indicators developed are unique ranging from horseshoe crabs in Delaware Estuary to alligator nests in Barataria-Terrebonne National Estuary Program. Most of the NEPs share two or more of the key management issues, but may approach them differently based on differing cultural, economic and political characteristics. Each NEP reports on the status of indicator development and implementation yearly.

***Overview of Environmental Indicators***

*"Environmental Indicators are specific, measurable markers that help assess the condition of the environment and how it changes over time. Both short term changes and general trends in those markers can indicate improved or worsening environmental health."(Based on Barbara Keeler, personal communication, April 18, 2006)*
"Monitoring the status of an estuary is a complex undertaking. Measuring water and living resource quality at all times, in all locations, and at all depths would be prohibitively expensive." (EPA, 1994) Tracked over time, indicators can provide cost-effective information on the status and trends of a system and the effectiveness of management actions. Indicators let us express complex information as simple and useful measures of status and trends. Indicators can provide measures of the success of management actions and allow for mid-course corrections. They can provide qualitative and quantitative measures that can be useful on local, regional or national scales both on a temporal and spatial basis. Indicators can be used to inform diverse audiences including: environmental managers, scientists, resource managers and the public.

EPA's Ocean and Coastal Protection Division (OCPD) evaluated the usefulness of data being collected by individual NEPs as national environmental indicators. EPA decided to focus an initial evaluation on two key estuarine challenges: habitat degradation/loss and nutrient overloading. To achieve this objective, OCPD formed an NEP Indicators Workgroup to review and assess NEP data. The Workgroup concluded that indicator information collected by the NEPs could be useful on a local, regional, as well as, a national scale.

As a result of this effort and the growing importance of indicator development, OCPD decided to offer technical support to the NEPs for indicator development. Once the NEP selects appropriate indicators and the Management Committee formally adopts them, they are incorporated into the Monitoring Plan. The broad experience of the NEPs in indicator development led to the preparation of this "Indicator Development for Estuaries" manual, which provides a framework and a logical, stepwise process for selecting, validating and implementing indicators. Based on the NEPs' expertise, it became clear that this valuable expertise could be shared with other NEPs currently developing indicators and with estuaries facing some of the same issues.

**The Manual**

The Manual is organized to provide the user with a logical, stepwise process in developing and implementing indicators for the estuarine environment. It is organized under seven major headings:

- **Introduction**
  Provides the background for the identification and use of indicators;

- **Planning the Program**
  Covers spatial scale, establishing a steering committee, key management issues, and baseline assessments;

- **Conceptual Models Development**
  Discusses conceptual model development and use;

- **Indicator Specification**
  Presents concept, feasibility, response and interpretation, and usefulness of indicators;

- **Monitoring Plan Development and Modification**
  Covers development and revision of the monitoring plan;

- **Indicator Implementation**
  Formal adoption, funding, communication, monitoring plan implementation, data collection and analysis plans;

- **Indicator Reassessment**
  Reassess every five-years or less, reevaluation of each indicator as needed.

The Manual is tabbed for easy access to the chapter of interest and allows the user to focus on the appropriate step in the process.

Case studies of the Barataria-Terrebonne NEP, New Hampshire NEP Indicator Development Process and Northeast Coastal Indicator Workshop are provided to give the reader examples of how other programs have approached indicator development following this process. Additionally, to provide the reader with a quick overview, further understanding of programs, and references to indicator development, a list of indicators selected by NEPs and other programs and a list of available indicator-focused resources have also been included.

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# INTRODUCTION

This manual has been prepared to provide information on indicator development and to offer a framework for the development of indicators for use in coastal waters. The goal is to provide:

- Background information on indicators and why indicators should be developed.
- Information on indicator development by Federal programs and the advantage of developing indicators for use on more than just a local or regional scale.
- Information on who should develop indicators.
- Lessons learned by programs.
- Step-by-step process of how to select indicators.
    - Program needs for indicator development as related to the stage of program development.
    - General information on developing monitoring plans for indicators, and incorporating and implementing indicator programs.

Throughout the document, statements and examples from the U.S. Environmental Protection Agency's (EPA) National Estuary Programs (NEPs) and other Federal, regional, and local programs are highlighted.

## WHAT ARE INDICATORS?

The definition of an indicator varies from program to program. The following are examples of the definitions of "indicator" used in differing applications:

> *"Environmental Indicators are specific, measurable markers that help assess the condition of the environment and how it changes over time. Both short term changes and general trends in those markers can indicate improved or worsening environmental health."(Based on Barbara Keeler, personal communication, April 18, 2006)*
>
> "6. *Ecol.* A plant or animal that indicates, by its presence in a given area, the existence of certain environmental conditions." (Random House, 2001)
>
> "An Indicator is a particular characteristic or reference marker used to measure whether an outcome is being achieved." (EPA, 1994)
>
> "*Indicators* are objective descriptions of a particular aspect of our natural, economic, or social environment." (The Heinz Center, 2003)

It is clear that the varied definitions of an indicator reflect the application, the complexity of language used, and the degree of precision required based on programmatic context.

Implementation of indicators depends on the systems to which the indicators are being applied.

Indicators are used to summarize complex information into a simplified and useful form to facilitate the measurement of status and trends. Indicators communicate information, quantify responses, and simplify information about complex data. Indicators can be a cost-effective, accurate alternative to monitoring the individual components of a system. Therefore, indicators can be an effective means of assisting groups in tracking the progress of their programs (EPA, 2003a).

"When tracked over time, an indicator can provide information on trends in the condition of a system. In order to develop an appropriate environmental indicator, it must be directly linked to the cause, effect, or action it is tracking. Ideally, indicator development should be preceded by the development of an assessment question" (EPA, 2003a). Specifically, indicators should be linked to the issues and goals specific to an estuary program's Comprehensive Conservation and Management Plan.

For NEPs: indicators should be linked to the issues and goals specific to the estuary program's Comprehensive Conservation and Management Plan.

As stated above, indicators can assist the programs in tracking progress toward their goals. Indicators that are not linked to an estuary program's goals and objectives will not support efforts to assess the progress of management actions. Where possible, local and regional indicators can augment national assessments; therefore, to the degree possible, comparable indicators should be developed to support all levels of objectives.

Indicators are invaluable for measuring the achievement towards milestones and progress in meeting environmental goals. Indicators can also function as early warning signals for detecting relatively small adverse changes in environmental quality. For example, the change in air and ocean temperatures throughout the world has been used for years as an indicator of global warming, while the change in land use within an area can be an indicator of changes in human activities. Although these require very different types of measurements, both are indicators of human influence on our ecosphere.

The following definitions illustrate the use of different levels and types of indicators:

***Worldwide Indicator***
An indicator with worldwide applicability as a response to a common stressor (*e.g.*, global warming) or as an indicator with value regardless of geographic location (*e.g.*, water temperature).

***Cultural/Societal Indicator***
An indicator that can measure human activity—specifically, the impact of human activity on ecosystem integrity or human response to ecosystem stressors. Examples of the former

include population, impervious land cover, and wetland filling; examples of the latter include fish consumption advisories and beach closure days.

***Economic Indicator***
An indicator that normally shows general trends in the economy. Examples of an economic indicator include unemployment levels, the Consumer Price Index, industrial production, bankruptcies, and stock market prices.

***Ecological Indicator***
An indicator that characterizes measurable (quantifiable) characteristics related to the structure, composition, or functioning of ecological systems (EPA, 2003b). Generally biotic in nature, these can be a specific individual measurements, an index of measures, or a model that characterizes an ecosystem or one of its critical components (EPA, 2003b). An important aspect of an ecological indicator is that it quantitatively estimates the condition of ecological resources, the magnitude of stress, the exposure of biological components to stress, or the amount of change in condition (EPA, 2003b).

***Environmental Indicator***
An indicator that measures the state of air, water, and land resources, pressure on those resources, and the resulting effect on ecological and human health. An environmental indicator shows progress in making air cleaner and water purer and in protecting the land (EPA, 2003b). This type of indicator measures environmental conditions (*e.g.*, human health, quality of life, and ecological integrity) or stressors that provide useful information on patterns and trends.

**Delaware Inland Bays Program—Definition of an Environmental Indicator**

"As commonly employed, an environmental indicator is a discrete measure of one aspect of environmental quality that can be used alone or in combination with other indicators to deliver a message or tell a story related to the overall environmental health of an ecosystem." (Price and Huerta, 2001)

**Charlotte Harbor NEP (CHNEP)—Definition of an Environmental Indicator**

"An environmental indicator is defined here as a measure, an index of measures or a model that characterizes the ecosystem or one of its components." (CHNEP, 2004)

***Programmatic Indicator***
A program, policy, or administrative response to an environmental problem. These performance measures may or may not lead to detectable improvements in environmental conditions.

Each of these indicator types can be broadly applied or can be useful in certain situations. In the examples given above, global warming is considered a worldwide indicator, while changes in human activities are considered a cultural/societal indicator. This manual focuses on the development of ecological or environmental indicators on a local, regional, or national level. Even so, the steps outlined can be used to develop indicators for other applications.

For more information on cultural/societal and economic indicators, the following websites are suggested:

- Cultural Indicators—Contact the United Nations Educational, Scientific, and Cultural Organization - http://www.unesco.org/culture/worldreport/html_eng/wcr5.shtml
- Societal Indicators—Government Performance and Results Act – http://www.ed.gov/offices/OUS/PES/gpra/OPM.html
- Economic Indicators—see http://www.investorwords.com/cgi-bin/getword.cgi?1643&economic%20indicator

## WHY SHOULD INDICATORS BE DEVELOPED?

In the late 1960s, the United States began to develop an awareness of the importance of preserving and protecting our nation’s coastal waters, including the Great Lakes. Data from all over the United States showed that industrial and human practices had degraded the nation’s coastal waters, along with the lives and livelihoods of populations living along the coast.

### Programs and Other Initiatives

For over 40 years, the nation has worked to improve its coastal waters by enacting important legislation (see below) and developing a range of programs and initiatives that protect the coastal environment. Among these are programs that focus attention on identifying impacts that degrade the U.S. coasts on an estuarine, regional, and national level. Once the impacts are identified and their causes understood, these same programs work to develop plans to prevent further degradation of the area and develop ways to improve these ecosystems to a desirable condition. One tool that is used to track the environmental response to implementation of these programs is the environmental assessment program; a key component of the environmental assessment program is the inclusion of indicators.

### Legislation

In 1972, Congress enacted both the Federal Pollution Control Act (renamed in 1977 to the Clean Water Act [CWA]) and the Coastal Zone Management Act (CZMA) to begin protecting and cleaning our coastal waters. These acts and their revisions also created several national initiatives to improve our estuaries of national significance, including the NEPs and National Estuarine Research Reserve (NERR) programs. Other agreements and acts have created other programs such as the Great Lakes Program to focus on specific bodies of water.

> ***Clean Water Act*****—**The CWA established a structure through the EPA for implementing and regulating discharges of pollutants into the waters of the United

States and to develop pollution control programs such as setting wastewater standards for industry. The CWA granted EPA the authority to set water quality standards for all contaminants in surface waters. A revision in 1987 created the NEP to (1) identify nationally significant estuaries that are threatened by pollution, development, or overuse, and (2) promote comprehensive planning for and conservation and management of nationally significant estuaries (for more information see http://www.epa.gov/region5/water/cwa.htm).

***Coastal Zone Management Act—***The CZMA established a program through the National Oceanic and Atmospheric Administration (NOAA) to "preserve, protect, develop, and where possible restore or enhance the resources of the coastal zone for this and succeeding generations" (CZMA of 1972 as amended by P.L. 104-105 The Coastal Zone Protection Act of 1996, Section 303(1); NOAA, 2005). The CZMA established the NERRs and a process for coastal states to develop Coastal Zone Management Programs (CZMPs). The CZMPs provide "mechanisms to improve the cooperation and coordination among state agencies and with other levels of government and the public" (The Heinz Center, 2003).

These two acts were, and still are, the leading legislation for the protection and restoration of America's coastal environment. Through the adoption of these acts, many programs have started to monitor, protect, and restore the U.S. coastal areas and marine resources.

Since the development of the CWA and CZMA, Federal agencies and states have been working to improve their coastal waters as specified by these acts, but no specific measurement of the improvements has been conducted. In 1993, the Government Performance and Results Act (GPRA) called for "Federal agencies to undertake efforts to measure their performance and the effectiveness of their programs" (The Heinz Center, 2003), including those programs mentioned above. The process focused on developing a series of indicators that could track the effectiveness of these programs and provide quantifiable measures that demonstrate the response of our nation's coastal waters overall. Since the enactment of GPRA, programs like the National Coastal Assessment (NCA) have been implemented by EPA to measure improvements nationwide (see http://www.epa.gov/emap/nca/ for more information on the NCA).

## WHO IS DEVELOPING INDICATORS?

Organizations throughout the world and the United States have begun developing indicators, including programs by the World Bank, the Organisation for Economic Co-operation and Development (OECD), and Federal, state, and local agencies. Some programs only develop indicators that can be used in a specific location, while others are developing indicators to track changes in ecological conditions throughout entire regions. Several Federal programs have initiatives to develop indicators. The following discussions provide short descriptions of some of these initiatives.

***EPA's Environmental Indicator Initiative***

On November 13, 2001, EPA Administrator Christine Todd Whitman announced an "Environmental Indicators Initiative" to improve EPA's ability to report on the status of and trends in environmental conditions and their impacts on human health and the nation's natural resources (EPA, 2005a). The Indicators Initiative also identified where additional research, data quality improvements, and information were needed. EPA's long-term goal is to improve indicators and the data that are used to guide the Agency's strategic plans, priorities, performance reports, and decision-making (EPA, 2005a). EPA's Office of Environmental Information and the Office of Research and Development (ORD) are the lead contacts for this program.

One of the key products of the Environmental Indicators Initiative is EPA's Draft Report on the Environment 2003 (EPA, 2003b). The document reports on the environmental conditions and human health concerns of the environment, using available national-level data and indicators. The report includes data on human health, ecological conditions, clean air, "pure water," and better-protected land. Under "human health," the report explores trends in diseases, human exposure to environmental pollutants, and diseases thought to be related to environmental pollution (EPA, 2003b). The nation's *"ecological condition"* is determined by looking at land use and cover, living resources, and pressures on living resources and our sustainable natural resources. To establish a national baseline for *"clean air,"* the report examines outdoor air quality—its impact on human health and ecosystems—and indoor air quality impacts on human health. The *"pure water"* theme examines drinking water and food safety, recreational water use, the condition of the nation's water resources, and the living resources sustained by them. To ensure *"better protected land"* in the future, the report explores existing land cover and use, activities that affect the condition of the American landscape, the location and condition of degraded land, and various conservation and management practices (EPA, 2003b). The 2003 report is available at http://www.epa.gov/indicators/roe/index.htm.

***EPA's National Estuary Program***

EPA established the NEP to promote and restore the health of nationally significant estuaries, while simultaneously supporting all beneficial uses of the estuaries' natural resources. Under the NEP, the Administrator of the EPA is authorized to convene Management Conferences to identify priority problems within these estuaries and develop a Comprehensive Conservation Management Plan (CCMP) to address those problems. At present, there are 28 NEPs throughout the United States and 27 NERRs. Figure 1 shows the biogeographic coverage of the NEPs and the general vicinity of the NERRs.

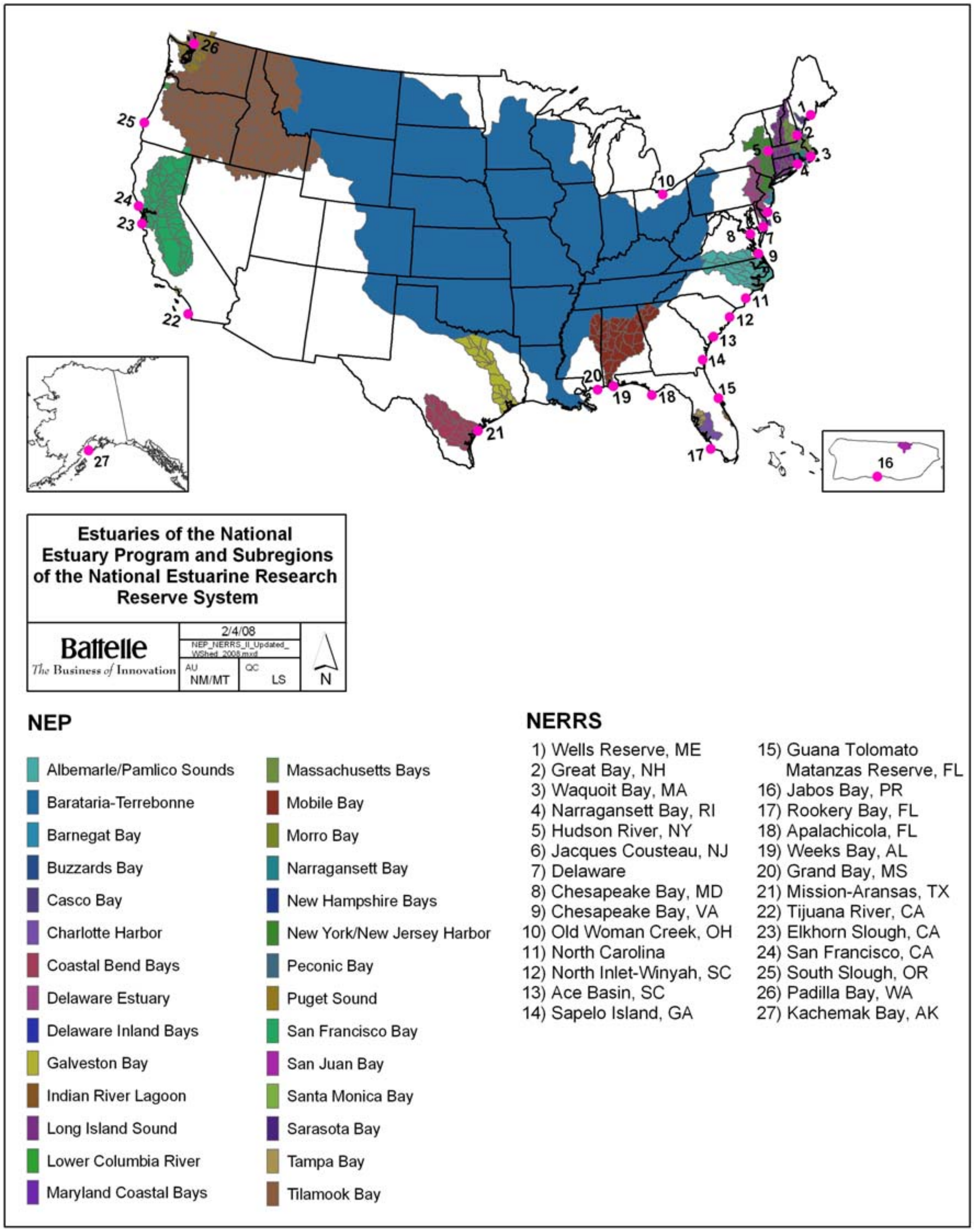



**Figure 1. Map of the estuaries in the National Estuary Program (NEP) and National Estuarine Research Reserve (NERR) System**

Over the past few years, EPA's Oceans and Coastal Protection Division (OCPD) determined the need to evaluate the usefulness of data being collected by individual NEPs as national environmental indicators—inclusive of indicators associated with restoration actions undertaken and changes in overall ecological condition—of NEP progress. NEP indicators must be directly linked to the cause, effect, or action that is proposed in the CCMP or monitoring plan. EPA considers the establishment of assessment questions and the development of a framework or model of the system relevant to the assessment question(s) important to the process of developing a suite of indicators. It is the responsibility of each NEP to track the progress of CCMP implementation and monitor associated ecological conditions in the estuary. Many NEPs share common priority problems; however, each NEP's goals and issue-specific actions are unique and, therefore, the specific data collected to track CCMP implementation progress and monitor ecological conditions varies widely among the NEPs (NCIW, 2004). Both the Barataria-Terrebonne NEP (Appendix A-1) and New Hampshire NEP (Appendix A-2) followed the process of developing indicators based on the goals and objectives of their CCMPs. Appendices A-1 and A-2 highlight the indicator development process of these two NEPs.

> NEP indicators must be directly linked to the cause, effect, or action that is proposed in the CCMP or monitoring plan. EPA considers the establishment of assessment questions and the development of a framework or model of the system relevant to the assessment question(s) important to the process of developing a targeted suite of indicators.

***EPA's Great Lakes Program***

EPA's Great Lakes National Program Office (GLNPO) works with agencies in Canada to manage the shared resources of the Great Lakes under the Boundary Waters Treaty of 1909, the 1987 Great Lakes Water Quality Agreement, and portions of the CWA and the Clean Air Act. Through this program, EPA works with various Federal and state agencies to manage the ecosystems of the Great Lakes, including addressing issues such as "reducing toxic substances, protecting and restoring important habitats, and protecting human/ecosystem species health" (EPA, 2004). Each lake has its own Lakewide Management Plan, which has been developed to manage the top issues within that lake. Since 1994, the U.S. and Canadian governments have hosted biennial State of the Lakes Ecosystem Conferences (SOLECs), which have focused on reporting the health of the Great Lakes using indicators. "The SOLEC process is a rare opportunity to bring stakeholders together to identify common objectives and data needs, and to encourage cooperative data collection, evaluation, and reporting." (Environment Canada, 2005).

***NOAA National Coastal Management Performance Measurement System***

The National Coastal Management Performance Measurement System is part of an ongoing effort by the NOAA to work with coastal states to assess the effectiveness of the CZMA as carried out by coastal management programs and NERRs. This system responds to Congressional requests to assess the national impact of coastal management programs and to report to the Appropriations Committees on progress in meeting the objectives of the CZMA. NOAA's Office of Ocean and Coastal Resource Management (OCRM) is responsible for developing and implementing the performance measurement system. OCRM has worked with the coastal management programs and reserves to develop contextual and performance indicators related to coastal hazards, habitats, public access, coastal community development, coastal dependent uses, coastal water quality, government coordination and decision-making, education, stewardship, and research. In 2004, OCRM implemented a phased approach for collecting information on the identified indicators. Under Phase I of the coastal management programs, most of the performance indicators in a subset of states will likely be implemented. The reserves will phase in indicators over time, with Phase I limited to indicators with known data available. In addition to assessing management outcomes, NOAA will prepare annual assessments of activities funded under the CZMA. NOAA is also working with the states, other Federal agencies, and stakeholders to develop a consistent framework for a national state of the coast report that will serve as a report card on the condition of America's coastal resources (NCIW, 2004).

***National Park Service (NPS) Vital Signs Monitoring Program***

Fundamental to fulfilling the NPS mission of managing park resources "unimpaired for the enjoyment of future generations" is knowing the condition of natural resources in each national park. The National Parks Omnibus Management Act of 1998 established the framework for fully integrating natural resource monitoring and other science activities into the management processes of the National Park System. Section 5934 of the Act requires the Secretary of the Interior to develop a program of "inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources." In the Appropriations Bill for Fiscal Year 2000, Congress reinforced this message by calling on the NPS to implement a "systematic, consistent, professional inventory and monitoring program … that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data." The 2001 NPS Management Policies specifically directed the Service to inventory and monitor natural systems in national park units, and to use the results of monitoring and research to develop appropriate management actions. The NPS has implemented a three-tiered strategy to institutionalize natural resource inventory and monitoring throughout the agency: (1) completion of basic resource inventories upon which monitoring efforts can be based; (2) creation of experimental prototype monitoring programs to evaluate alternative monitoring designs and strategies; and (3) implementation of operational monitoring of critical parameters (*i.e.*, "vital signs") in all natural resource parks. To implement vital signs monitoring, all parks with significant natural resources (about 270 nationwide) have been grouped into 32 monitoring networks linked by geography and shared natural resource characteristics. Network parks share funding and professional staff to plan, design, and implement an integrated long-term monitoring program (NPS, 2003; NCIW, 2004).

## WHO SHOULD USE INDICATORS?

Any program that monitors a condition can develop an indicator. One example of a monitoring program that uses indicators is a weather forecast. Meteorologists use several measurements and techniques (*e.g.*, temperature, wind speed, and precipitation) to forecast the weather. Each item used is an indicator of something. If the temperature is below freezing and the radar says there is precipitation, then more than likely snow, sleet, or freezing rain is falling in the area. Thus, indicators can be used by anyone.

Today, a large percentage of the nation's population lives within coastal areas, which has created environmental pressure on coastal resources. Each coastal program that is developed to address these environmental pressures, such as the NEPs and NERRs, develops goals for its area. Along with these goals, measurement programs and indicators are established. The use of indicators supports the determination of whether an ecosystem is sustainable by helping to track the status and trends of an ecosystem. Typically, coastal programs choose indicators that track progress in a local area. However, several agencies may join their efforts, such as those instituted by the Gulf of Maine [GOM] Council, to develop indicators on a regional level. Federal agencies, including EPA, are interested in indicators that also determine the overall national health of coastal ecosystems. Although the application of indicators ranges in scale, the need for indicator development is the same depending on whether the indicators are being established for local, regional, or national efforts.

> Estuary programs should consider including indicators from the National Coastal Conditions Report (NCCR I and II [EPA 2001 and 2005b]) to assist in collecting data on the overall health of the nations coastal areas.

At the regional level, coastal programs such as the NEPs develop CCMPs. The purpose of a CCMP is to identify issues that require management strategies to best address and resolve the issues. As part of the CCMP development, program objectives are defined (for example, "Ensure public health associated with contact recreation and seafood consumption" [CBBEP, 1998]). To determine whether these objectives have been met, monitoring programs are developed to measure progress. As part of these monitoring programs, indicators are selected for measurement. Indicators provide the basis to answer the CCMP questions. Together, indicators and a monitoring plan ensure that policies and management efforts are effective in tracking the status of an ecosystem. Appendix A-1 and Appendix A-2 provide more details on the Barataria-Terrebonne NEP and New Hampshire NEP process of developing monitoring programs and indicators.

> For NEPs: Indicators should provide the basis to answer their CCMP questions.

Coastal waters are not defined by state borders, making it critical that neighboring communities cooperate to address environmental concerns. Joint efforts are required to identify and prioritize issues and questions. The need for regional indicators has become a forefront issue as the necessity for coordinated monitoring increases. Regional indicators serve to bring consistency to the process of informing decision-makers and the public on the status of the area or region. This type of effort helps address gaps between monitoring and management, such as consistent monitoring approaches, data reporting to ensure the work is relevant, and allocation of resources. For regional indicators to be successful, the use of the indicators must be consistent throughout the system to show overall trends.

A national approach to developing indicators will provide an integrated assessment framework for scientists, decision-makers, managers and, ultimately, the public. Federal agencies are required by the GPRA to report the status of the nation's coastal waters and their national programs. The nation's decision-makers want to know what the present conditions of estuarine resources are in the United States, how the conditions are changing, and what causes those changes. Therefore, a set of indicators must be developed to correlate data from the nation's coastal waters into one data set that can be analyzed for overall coastal ecosystem health. Federal, state, and local governments, as well as all interested parties, must be involved in developing a national effort. This type of alliance will then create a system that will be used locally and nationally.

> "The more information that can be supplied to managers and regulatory officials from a united approach with a common message, the more likely the message will be heard" (ANCMS, 2003).

Indicators offer a better understanding of a particular estuary, region, or the nation and provide a check of the health of valuable and productive resources. Whether indicators are developed at the local, regional, or national level, the need for them continues to grow as the nation's focus emphasizes the quality of life and the health of our coastal waters. The indicator development process is one of progress toward a shared vision or goal.

The NCA Program is just one effort to develop a national list of indicators on which to evaluate overall changes in the environmental health of U.S. waters. This effort is led by EPA's ORD and Office of Water, with support from NOAA, U.S. Fish and Wildlife Service, and the U.S. Geological Survey (USGS).

The NCA has prepared two National Coastal Condition Reports (NCCRs) (see http://www.epa.gov/emap/nca/index.html) which report on the quality of the nation's coastal waters, sediments, benthic communities, habitats, and fish species. To develop this report, the NCA prepared a list of indicators for which it collects data from a variety of local, regional and national programs. The callout box on page 12 lists indicators tracked by the NCA. Figure 2 is an example from the *National Coastal Condition Report II* of how the NCA synthesizes and reports the data collected (EPA, 2005b).

**National Coastal Assessment Indicators**

***Water Quality Index***

- Nutrients
  - Nitrogen (dissolved inorganic nitrogen)
  - Phosphorus (dissolved inorganic phosphorus)
- Chlorophyll-*a*
- Water clarity
- Dissolved oxygen (DO)

***Sediment Quality Index***

- Sediment toxicity—10-day toxicity test with the amphipod *Ampelisca abdita*
- Sediment contaminants
  - Metals—arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, zinc
  - Organic compounds—acenaphthene, acenapthylene, anthracene, fluorene, 2-methyl naphthalene, naphthalene, phenanthrene, benz(a)anthracene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene, pyrene, low-molecular-weight polycyclic aromatic hydrocarbon (PAH), high-molecular-weight PAH, total PAHs, 4,4’-dichlorodiphenylethylene (4,4’-DDE), total dichlorodiphenyltrichlorethane (DDT), total polychlorinated biphenyls (PCBs)
- Total organic carbon

***Benthic Index***

- Benthic community diversity
- Presence and abundance of pollution-tolerant species
- Presence and abundance of pollution-sensitive species

***Coastal Habitat Index***

- Average of the mean long-term decadal wetland loss rate (1780-1990) and the present decadal wetland loss rate (1990-2000).

***Fish Tissue Contaminants Index***

- Metals—arsenic, cadmium, mercury, selenium
- Organic compounds—chlordane, DDT, dieldrin, endosulfan, endrin, heptachlor epoxide, hexachlorobenzene, lindane, mirex, toxaphene, PAH (benzo(a)pyrene), PCB

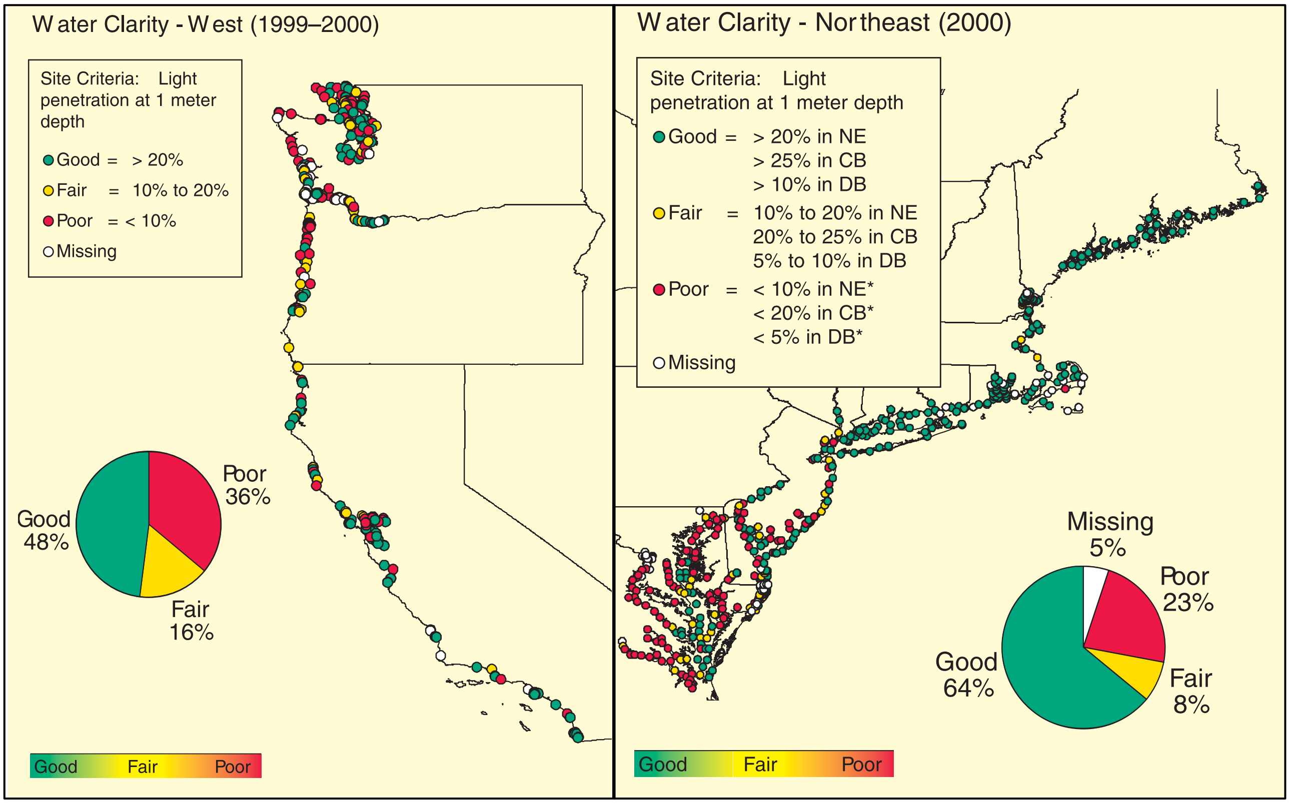



**Figure 2. National Coastal Assessment Synthesis of Water Clarity Data (EPA, 2005b)**

Although these indicators are reviewed on a larger (national) scale, the same indicators are also useful on the regional and local level (see the *Sneaker Index* callout box on page 35 for an example of how water clarity is used on a local level). It is suggested that these indicators be considered when developing local indicator sets, so that local data can be compared with this national data set.

## LESSONS LEARNED DURING PREVIOUS EFFORTS TOWARD INDICATOR DEVELOPMENT

A number of programs have spent considerable time and effort over several years to develop appropriate indicators. Since this process can be daunting to any new group, it is always helpful to find out what other programs experienced, especially any lessons learned. For the Northeast Coastal Indicators Workshop (NCIW), conducted in January 2004, the Maine State Planning Office prepared "Tapping the Indicators Knowledge-base" (Pidot, 2003). This document summarizes information on lessons learned collected from several Federal, state, and local programs throughout the United States. The key findings of this document are summarized below. The details can be found at http://www.gulfofmainesummit.org/docs/ Lessons_Learned_Report.pdf.

**Lessons Learned from the Northeast Coastal Indicator Survey**

- Developing indicators and indicator-based products is a lengthy process.
- Query the members of the target audience throughout the process.
- Involve a wide range of individuals from the beginning.
- Select indicators with good prospects for long-term monitoring.
- Replace an indicator if it does not produce meaningful results.
- Allow time for important decisions.
- Report clear and direct linkages between the indicators and the results/needs.
- Develop separate simplified reports developed for managers and policy makers.
- Indicators need to be sold to the managers and policy-makers.

Each lesson learned is important to every program attempting to develop indicators because they are all interconnected. As noted in the first bullet, development of indicators is not something that can be done in a day or two. To develop indicators that will be useful to the program, each group must carefully look at its issues, ecological system, and available data to determine the best indicator for that situation. It will take time to pull this information together in a way that can be reviewed. However, it is important so that the indicators selected have good prospects for long-term monitoring and effective results, but also so that the indicators are clearly linked to the items that need to be reported. Part of the reason indicator development takes time is because members of the target audience need to be queried, and a wide range of individuals must be involved to ensure that the questions the public and environmental managers need answered are addressed. In the case of the NEPs, this step is conducted for their CCMP development; however, the data necessary to choose indicators may not be consolidated during CCMP development.

Adequate information must be collected prior to indicator development so that indicators with good prospects for long-term monitoring and effective results are selected.

Another lesson learned is that once indicators are developed, the process does not stop. What looks good in theory does not always work in practice; therefore, once the data collection begins, the indicators should be further evaluated to determine whether the indicators are producing meaningful results and are useful to the end users. The indicators selected and information collected also need to be reported to the managers; therefore, the process of developing indicators should not be rushed, but it should also not be avoided. If the indicators supply useful information, indicator development can help save program funds or justify additional funds.

The last important lesson learned is that there are distinct advantages to indicator development; however, if poor choices are made, there can be some disadvantages and consequences. Indicators can help programs track changes efficiently, thus being more cost-effective and less time-consuming than monitoring a number of items. However, if the indicators selected do not communicate the information needed, then money can be wasted and important data needed to determine whether changes have occurred can be lost. Therefore, indicators must be selected wisely and reviewed often to ensure they meet the needs of the program.

**Long Island Sound Study (LISS)—Lessons Learned**

The biggest challenge during indicator development was the significant commitment of time necessary for developing indicators (Pidot, 2003).

**Casco Bay Estuary Partnership (CBEP)—Lessons Learned**

"...with a small budget and staff, Diane Gould reported that the CBEP staff has been challenged by the necessity of spreading itself out over all of the issues and topics deemed important (Pidot, 2003).

## INDICATOR DEVELOPMENT PROCESS

As noted in the lessons learned section, there are several necessary steps to follow when developing indicators. These steps generally fit into a consistent sequence (Figure 3) that, when followed, result in robust useful indicator sets. Each step in the process will be discussed in more detail throughout the remainder of this manual. In some instances, guidance documents previously developed by EPA provide greater detail on the steps. In cases where other documents already exist on these detailed processes, this manual will supply some of the highlights of the documents but will rely on the original documents to supply the entire process.

Many programs, such as the NEPs and NERRs, may have already completed a number of the steps outlined in this manual. Thus, to make this manual easier to follow and more user-friendly, we will use the flowchart in Figure 3 in the margins of the next few sections to show the step to which the accompanying text is referring. As the different steps in the process are explained in the text, a tab in the side margin will indicate where the text applies in the process (see example on page 16). This will allow groups to tab directly to the steps they are interested in.

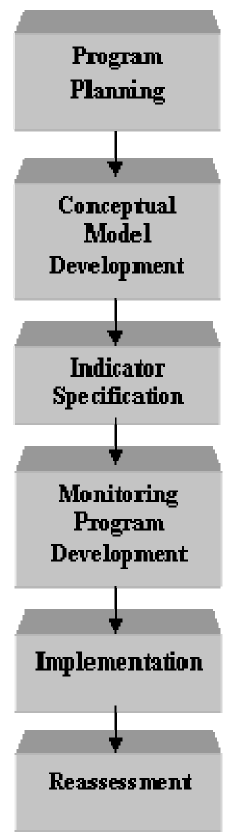
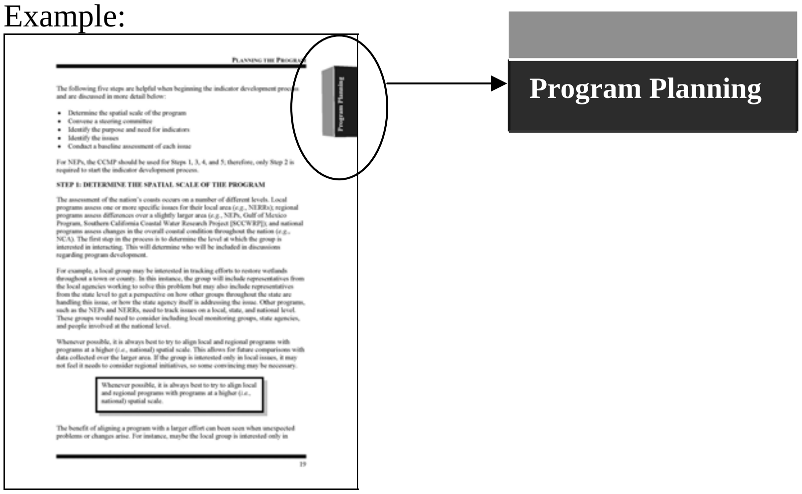


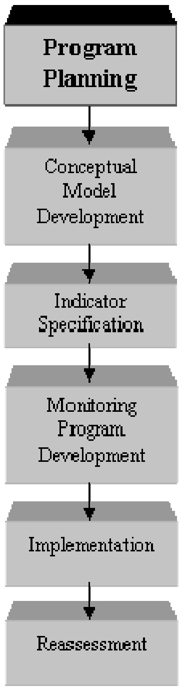

**Figure 3. Indicator Development Process**

Example:




Case studies have been included from the Barataria-Terrebonne Program (Appendix A-1), the New Hampshire Estuaries Project (NHEP) (Appendix A-2), and the NCIW (Appendix A-3). These case studies represent successful programs that developed indicators in a local and regional area. In addition, as we move through the steps toward indicator development, examples of additional programs will be given to assist new programs in understanding the process.

# PLANNING THE PROGRAM




For groups to be successful in their mission to improve or protect the ecosystems within their regions, programs must be created with a set of goals and the result in mind. Therefore, each program must be designed around a clear purpose. For example, a purpose might be to collect data that will inform scientists and managers about important aspects of a region they are working to protect.

Programs such as the NEPs, CZMPs, and NERRs were designed as partnerships between the Federal government and states working toward protecting, restoring, and sustaining development of the nation's coast through joint resources, funds, and management authorities. These programs also work to provide research, data, and education to sustain conservation and development of the coasts. When these collaborative efforts begin, a management plan is created to focus a program's efforts toward its goals.

In accordance with EPA Section 320 of the CWA (EPA, 2000a) requirement, NEPs develop a CCMP to document the partnership's plan for improving the estuary (see the callout box on the next page for more information on developing a CCMP). During development of the CCMP, the NEPs conduct a comprehensive review of the key management issues for their estuary. The CCMP identifies the estuary's priority problems, causes, and linkages to changes in the estuary. It also identifies the environmental quality goals and objectives of the program and explains the actions the NEP plans to take to abate or correct the problem. Background information on the estuary is included, such as "the status and trends of the estuary's water quality, natural resources, and uses" (EPA, 1992). The CCMP is not the indicator plan, but indicators are developed based on CCMP and monitoring plan management questions.

Similar steps are also followed when developing monitoring programs. In *Managing Troubled Waters,* the National Research Council (NRC) developed a seven-step process for developing and implementing monitoring programs:

1. Define program expectations and goals—This includes identifying public concerns along with current regulations and focusing the objectives on pertinent environmental and health regulations.
2. Define the strategy of the study—Developed by addressing specific questions to be answered. Scientists and managers must focus the questions being asked on the monitoring that is to be conducted, which will deliver the information required. These focus questions will vary from program to program.
3. Conduct relevant studies and research—Provide the groundwork for the construction of the monitoring design through development of methods, models, and techniques.

4. Develop a sampling and measurement program—The purpose of this step is to produce a sampling design that identifies what measurements should be monitored and where and when the measurements should be taken.
5. Implement the study—The implementation of the study will provide information and data for scientists and managers; however, the data will need to be analyzed and converted into useful information for managers and decision-makers to utilize.
6. Synthesize the data.
7. Report the results of a monitoring program to a varied audience consisting of managers, decision-makers, and the public (NRC, 1990).

The most important aspect of the process is that each step builds upon the previous steps. Therefore, when developing a program, it is important to revisit and rethink the steps in the process. Over time, the objectives and goals, monitoring techniques, and data available may change, as well as many other aspects of the process. When these changes occur, the plan should be updated to reflect the most current concerns.

The most important aspect of the process is that each step builds upon the previous steps.

**Steps to Develop a CCMP, Monitoring Plan, and Indicators**

The CCMP encompasses the management objectives established by the program. There are four phases to follow when developing a CCMP:

- **Phase 1:** Convening a management conference and establishing a structure of committees and procedures for conducting the group's work.
- **Phase 2:** Characterizing the estuary to determine its health, reasons for its decline, and trends for future conditions; assessing the effectiveness of existing efforts to protect the estuary; and defining the highest priority problems to be addressed in the CCMP.
- **Phase 3:** Specifying action plans in the CCMP to address priority problems identified through characterization and public input. The CCMP should build on existing Federal, state, and local programs as much as possible.
- **Phase 4:** Monitoring the implementation of the CCMP, reviewing progress, and redirecting efforts where appropriate.

Once the CCMP is developed, the NEP will draft a monitoring plan in accordance with its CCMP. The monitoring plan implements the management objectives and carries out action plans. Indicators are developed to address the specific estuary needs defined in the monitoring plan. NEPs work through a long process to develop and implement priority corrective actions and compliance to restore and maintain the health of an estuary. (EPA, 1993)

The following five steps are helpful when beginning the indicator development process and are discussed in more detail below:

- Determine the spatial scale of the program
- Convene a steering committee
- Identify the purpose and need for indicators
- Identify the issues
- Conduct a baseline assessment of each issue

For NEPs, the CCMP should be used for Steps 1, 3, 4, and 5; therefore, only Step 2 is required to start the indicator development process.

## STEP 1: DETERMINE THE SPATIAL SCALE OF THE PROGRAM

The assessment of the nation's coasts occurs on a number of different levels. Local programs assess one or more specific issues for their local area (*e.g.*, NERRs); regional programs assess differences over a slightly larger area (*e.g.*, NEPs, Gulf of Mexico Program, Southern California Coastal Water Research Project [SCCWRP]); and national programs assess changes in the overall coastal condition throughout the nation (*e.g.*, NCA). The first step in the process is to determine the level at which the group is interested in interacting. This will determine who will be included in discussions regarding program development.

For example, a local group may be interested in tracking efforts to restore wetlands throughout a town or county. In this instance, the group will include representatives from the local agencies working to solve this problem but may also include representatives from the state level to get a perspective on how other groups throughout the state are handling this issue, or how the state agency itself is addressing the issue. Other programs, such as the NEPs and NERRs, need to track issues on a local, state, and national level. These groups would need to consider including local monitoring groups, state agencies, and people involved at the national level.

Whenever possible, it is always best to try to align local and regional programs with programs at a higher (*i.e.*, national) spatial scale. This allows for future comparisons with data collected over the larger area. If the group is interested only in local issues, it may not feel it needs to consider regional initiatives, so some convincing may be necessary.

Whenever possible, it is always best to try to align local and regional programs with programs at a higher (*i.e.*, national) spatial scale.

The benefit of aligning a program with a larger effort can been seen when unexpected problems or changes arise. For instance, maybe the local group is interested only in studying invasive species in the local area. Aligning the program with a regional program may come in handy when a sudden unexpected change in species counts occurs with no apparent direct cause. Groups aligned with the regional sampling can then compare their local data with data collected on the regional level. This assists the program with determining whether the change was a local phenomenon that needs to be studied further or a regional issue experienced by other programs.

### STEP 2: CONVENE A STEERING COMMITTEE

Steering committees should be formed during the initial phases of the indicator development process so that they can be a part of the entire process. The earlier in the process the steering committee is involved, the more efficient and effective the indicator development process will be to achieve the desired program outcomes.

Steering committees are normally formed with a mix of people from different backgrounds, agencies, and organizations. Because the committee members are an integral part of the indicator development process, it is important that each person on the committee be included for a specific reason (for example, his or her expertise in a technical area or understanding of monitoring programs in the region). Committee members also must be actively involved in each step of indicator development, not only as reviewers of the final result. Groups that have an effective steering committee have found that it is easier to establish indicators and obtain the desired outcome by the end of the process.

The most important aspect of an effective steering committee is to convene the right balance of managers, policy-makers, researchers, and the public so that all are represented. Representatives from the area’s key monitoring and management groups should be included, along with members of local environmental groups and the public. The people involved do not have to be scientists with previous indicator knowledge. Members such as managers and policy-makers should be selected for their ability to inform decision-makers on funding and regulations and should be able to provide support for the future. Researchers, scientists, and educators who possess a strong knowledge of the ecosystem and science should be included on the steering committee to make informed decisions on indicators. It is also important to include the public for several reasons. Most important, public support is critical to the success of the indicator development process by providing public opinion on the ecosystem. Ultimately, the public is the final recipient of the program’s findings on the state of the ecosystem.

Once the steering committee is formed, members should be briefed on the goals of the indicator development process. If a definition of the word “indicator” has not already been developed, the committee members should be asked to do so based on the needs of their program. The committee should also assist in developing a list of topics, questions, and conceptual models to develop indicators. The members do not need to develop all of the information themselves, but they should agree on the topic areas and review the questions and conceptual models developed to ensure that they agree on what is included. In the case of the NEPs, the steering committee should use the topics and questions from the CCMP so that indicators will be developed to answer the NEP's management questions.

Workshops have been found to be successful events where steering committee members can gather with other participants to present the indicator development information that has been prepared and to receive feedback on whether they are on the right track. Just as it is important to have the right people as members of the steering committee, it is crucial to have the appropriate workshop participants to complete the indicator development process. Although the indicator development process continues long after the workshop has ended, everyone involved in the process has a responsibility to continue the work.

The key to a successful steering committee is communication. Regular communication of information on indicator development can be accomplished through e-mail distributions, conference calls, meetings, and workshops. Members should be required to commit to the development process, which could include bi-weekly or monthly meetings, whether through conference calls or attending the meetings in person. E-mail updates on the progress of the process should be distributed promptly based on a timeframe established by all members (for example weekly, bi-weekly, or monthly).

**Great Lakes Program—Steering Committee**

"The process involved over 130 people that could be identified by name." "Experts, including researchers, academics, and managers, were included in each working group. They sought out individuals for inclusion in these groups based [on] expertise, rather than attempting to equally represent all sectors of the environmental world (policy, research, industry, etc…)." (Pidot, 2003)

## STEP 3: IDENTIFY THE PURPOSE AND NEED FOR INDICATORS

Step 3 in the process should answer the following questions: (1) Why are we developing indicators? and (2) Why is there a need for it? The answers to these questions are the starting blocks for the rest of the program, so getting consensus on these answers is important.

Normally, the purpose and need for the program are not difficult to determine because most groups were motivated by a specific issue or group of issues that needs to be addressed. Some programs have their purpose and need specified as part of their charter. For example, the NEPs have their purpose and need specified by Section 320(b)(6) of the CWA, which states that NEPs must "…monitor the effectiveness of actions taken in pursuit of the plan." In this particular instance, "plan" refers to the CCMP developed by each NEP. Other programs have similar goals under GPRA and other statutes. The important step is agreeing on and documenting the purpose and need.

For NEPs: the purpose and need for indicator development is to track progress towards the goals outlined in their CCMP.

The actual purpose of the program will depend on the complexity and scope of the issues the group is attempting to address. If the group is addressing only a single issue, then the purpose and need statement will focus on just that issue. For example, maybe the group is focused on lowering the concentration of fecal coliform throughout the estuary. In that case, the purpose and need statement for the program might be:

> **Purpose:** To monitor the change in fecal coliform levels throughout the estuary.
>
> **Need:** At present, the amount of fecal coliform entering the estuary is causing a health hazard to the local population that is exposed to the water. This program is needed to track changes in fecal coliform levels throughout the estuary to determine whether levels are increasing or decreasing based on recent efforts to prevent fecal coliform contamination.

The following is an example of a purpose and need statement developed for a program aimed at monitoring more than one issue.

> **Purpose—**To give the region the ability to compare data, assess the regional status of the environment, and provide early warning of potential problems.
>
> **Need—**To track the status and trends in ecosystem integrity throughout the region through collaborative partnerships. To provide information for policy, management and advocacy decisions at regional and local scales.

The more focused the purpose and need statements are, the more focused the resulting program will be. In addition, it is important that all parties involved in the program development understand the purpose and need statements clearly and are reminded of them throughout the process, so that a program can be developed to meet these goals.

**Great Lakes Program—SOLEC Goal**

"The goal of [SOLEC] is to assemble a basin-wide suite of scientifically valid indicators that will be most useful and understandable in determining the health of the Great Lakes ecosystem to the interested public." (Bertram and Stadler-Salt, 2000)

## STEP 4: IDENTIFY THE KEY ISSUES

Step 4 in the process uses the purpose and need statements to identify the issues, management objectives, and questions the program will address. For many programs, this was addressed when their management plans (*i.e.*, NEP CCMPs) were developed. Critical attributes for issue identification are:

1. The issues must directly link to the purpose and need statements;

2. Consider public, scientific, and management concerns in a measurable fashion; and
3. Details on the issues should be stated in terms of management objectives and questions that point to the critical information needs (EPA, 1993).

For NEPs: the key issues for indicator development should be the same as those identified in their CCMP.

The process of identifying issues can be simple or intricate, depending on the program goals. If the program has only one goal, such as eliminating hypoxia events from occurring within the estuary, then it will develop management objectives around this one issue. For more complex programs, the number of issues addressed will depend on the key issues affecting the ecosystem and what the program plans to cover. In this instance, the steering committee will need to define the priority issues within the estuary along with the coinciding management objectives. The document *Successful Coastal Management Solutions* outlines seven key management issues that estuaries should consider (EPA, 2003c):

1. Habitat
2. Pathogens
3. Freshwater in flow
4. Nutrients
5. Fish and wildlife
6. Introduced species (invasive species)
7. Toxics

**Develop Management Objectives**

Management objectives are specific actions designed to quantify/qualify the changes intended by the program for each priority issue. For example, if the issue is coliform contamination within the estuary, the management objectives for that issue might be:

- To decrease the number of boats discharging their holding tanks within the boundaries of the estuary by 70 percent within the next 3 years.
- To decrease the number of failing septic systems throughout the estuary's watershed by 50 percent within the next 15 years.
- To decrease the number of overflow instances from municipal sewer plants in the area by 25 percent within the next 10 years.
- To decrease the amount of runoff containing animal waste entering the estuary by 25 percent within the next 10 years.

Each of these management objectives has a specific goal and time period against which progress can be measured. In some instances, a quantitative value may not be associated with an issue. In these instances, it is important to be as specific as possible in order to ensure the program has some baseline condition to measure against.

These management objectives are then used to form questions that the selected indicators will address. The goal of the NEP is to determine the effectiveness of its CCMP and the implementation of the management objectives. Both the Barataria-Terrebonne and New Hampshire NEPs developed indicators based on questions formed from their CCMP management objectives; details on this process are provided in Appendix A-1 and Appendix A-2.

**Basic Steps for Action Plan Development**

- State the problem, identifying the probable causes and sources.
- State the program goals related to the problem and its sources.
- Set specific, measurable objectives to attain the goals.
- Determine the universe of possible management activities, both new and existing, for consideration.
- Select the activity that will work, that the public will support, and that can be implemented within a reasonable time and with reasonable resources.
- Establish specific action plans needed to abate and control the problem or to protect the resources.
- Implement and monitor results, collecting data on measurable indicators of progress.
- Report on progress, costs, and results.
- Review, re-evaluate, and redirect efforts as needed (EPA, 2005c).

### Define Questions to be Answered by Indicators

Under each management objective, a question or series of questions is used to answer whether the management objective has been met or how much progress has been made toward accomplishing the objective. The questions can be developed by simply turning the management objective into a question or a series of questions that look at different aspects of the objective.

For NEPs: Management objectives and question definitions should have been conducted in the CCMP. If not, these should be connected with issues identified in the CCMP.

Question development is an important task because the selected indicators must answer the questions. Therefore, the questions must be specific enough that someone can look at a series of data and develop an answer to that question.

For example, the management objective might be:

To determine the health of fisheries with regard to ecosystem integrity.

The associated questions could be:

1. What are the trends in and the status of commercially important fisheries stocks?
2. What are the effects of fishing on non-commercial species and their associated communities?
3. What are the effects of fishing and non-fishing activities on marine habitat and fisheries productivity?
4. What are the trends in the socioeconomic characteristics of fishing?

If the indicators being developed will be used at more than one level (i.e., nationally and locally), then there may be separate questions for each level of use of the indicator.

It is important that each question be clear and understandable. This will allow an appropriate indicator to be selected—*i.e.*, one that will answer the question. That answer will then be used with information from the other questions to answer whether the management objective was met.

**New Hampshire Estuaries Project—Goals and Objectives**

"Those charged with developing indicators for the New Hampshire Estuaries began by considering the goals and objectives written into the estuary management plan. Each objective was rephrased as a monitoring question – for which one or more indicators were selected based on their ability to appropriate answers. The hypothetical data required to track each of those indicators was then described and compared with actual data sets produced by existing monitoring programs." (Pidot, 2003)

## STEP 5: CONDUCT A BASELINE ASSESSMENT OF EACH ISSUE

Once the management issues and objectives are selected and outlined, the next step in the process is conducting a baseline assessment of each issue. Mature programs have normally already accomplished this task, but should review the information to make sure it is up to date. For new programs, how well this task can be accomplished will depend on how well the issue has been studied in the area.

A baseline assessment of an issue compiles and analyzes all available information on that subject for that area. It defines the present conditions of that issue for that particular area. If the issue is a new one, then an initial monitoring program might need to be conducted to determine the starting point; for others, the baseline assessment may only need to consist of a review of the most recent reports on the issue. It is important to understand current conditions so that trends can be identified. For example, if the group were concerned about changing dissolved oxygen (DO) levels within the estuary from year to year, the baseline assessment would need to include information on DO levels throughout the estuary over the past year and, if possible, from previous years, so that it can be determine how levels have changed over time.

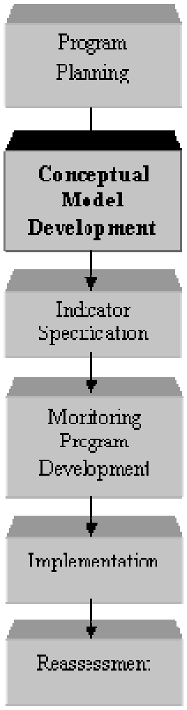
The baseline assessment should also include information on current monitoring being conducted, including what is measured; when, where and how often it is measured; how it is measured; and who conducts the monitoring. It is also helpful to know how often the monitoring programs report their data. When choosing an indicator, it is important to understand whether current monitoring conducted in the area will adequately answer the objectives. A number of programs have focused their indicator development on parameters currently measured through mandatory monitoring programs. The reason for this approach is that the baseline data are already available and the organization or agency already has a mandate to conduct the sampling, sample analysis, and data analysis. Other programs choose their indicators based on best scientific knowledge, then determine whether monitoring occurs in the area for that parameter. If the parameter was not monitored and was determined to be a priority, a monitoring plan could then be developed for it.

A high-profile baseline assessment was conducted by the Massachusetts Water Resources Authority (MWRA) in conjunction with the construction of a sewage treatment plant outfall in Massachusetts Bay. The outfall, which was brought on-line in September 2000, discharges secondary-treated effluent into Massachusetts Bay. MWRA has been monitoring the bay and Boston Harbor since 1992. The monitoring conducted prior to September 2000 was part of the baseline assessment of Massachusetts Bay and Boston Harbor. The baseline monitoring conducted allowed managers and scientists to gain vast knowledge about water quality, nutrients, benthos, sediment quality, and fish and shellfish in Massachusetts Bay and Boston Harbor. The extensive baseline assessment that MWRA conducted, which led to the comparison of pre- and post-outfall conditions within Massachusetts Bay and Boston Harbor, enabled scientists, managers, and decision-makers to make informed decisions on regulatory issues and responses needed.

There is a strong national push to establish a consistent effort in conducting baseline assessments and monitoring. Establishing a national monitoring effort would allow data to be easily compared and provide practical value for scientists and managers. To be fully effective, monitoring data collected by state, territorial, tribal, and local governments, non-governmental organizations (NGOs), and volunteers will need to be coordinated with the national monitoring network (U.S. Commission on Ocean Policy, 2004). Currently, the responsibility for monitoring and assessing marine resources is divided among a number of Federal, state, and local agencies, and other NGOs. A more unified approach with comprehensive monitoring can provide scientists and managers with the knowledge to facilitate ecosystem change and understand whether their goals and objectives are effectively being met.

**San Juan Bay NEP—Baseline Information**

"The proposed study will concentrate on establishing detailed Long-Term Environmental Indicators for the SJBE (LTEI-SJBE) by initially collecting baseline information from the system, establishing the indicators, and further enabling the analysis of achieved programmatic goals." (Otero, 2002)




# CONCEPTUAL MODEL DEVELOPMENT



The purpose of an indicator is to summarize complex information into a simplified and useful manner and facilitate the identification of status and trends. In a common analogy to the field of medicine, the patient represents a system or phenomenon of interest. Indicator development is conducted by linking a complex collection of subsystems with many compartments and interactions, just like the multitude of physiological systems of the human body. Indicators act as “vital signs” used to measure the state of the system, just as temperature and pulse are used to assess the overall health of a patient.

Indicators are used to convey information, quantify responses, and simplify information about complex ideas. They are assumed to be a cost-effective and accurate alternative to monitoring individual components of a system. Indicators can be quantitative or qualitative in nature and are useful at many scales, both temporally and spatially. When tracked over time, an indicator can provide information on trends in the condition of a system.

Perhaps the most well-known indicators are those describing the condition of the U.S. economy, such as the Dow Jones Industrial Average. To capture the complexity of a system, multiple relevant indicators can be aggregated into an “index.” The Dow Jones Industrial Average, for example, serves as a measure of the entire U.S. market, covering a diverse mix of businesses in each market sector – financial services, technology, retail, entertainment, and consumer goods (Figure 4).

To be useful, indicators must answer the questions being asked (see page 24) while being grounded within a conceptual framework that conveys not only what is being measured, but why and in what context. The Dow Jones, for instance, is an index within the framework of the U.S. stock market. In general, the higher the value of the Dow Jones index, the better the U.S. stock market is doing.

Following up on the management goals/objectives/questions developed under the previous section—this section focuses on the use and development of conceptual models in indicator identification and development.

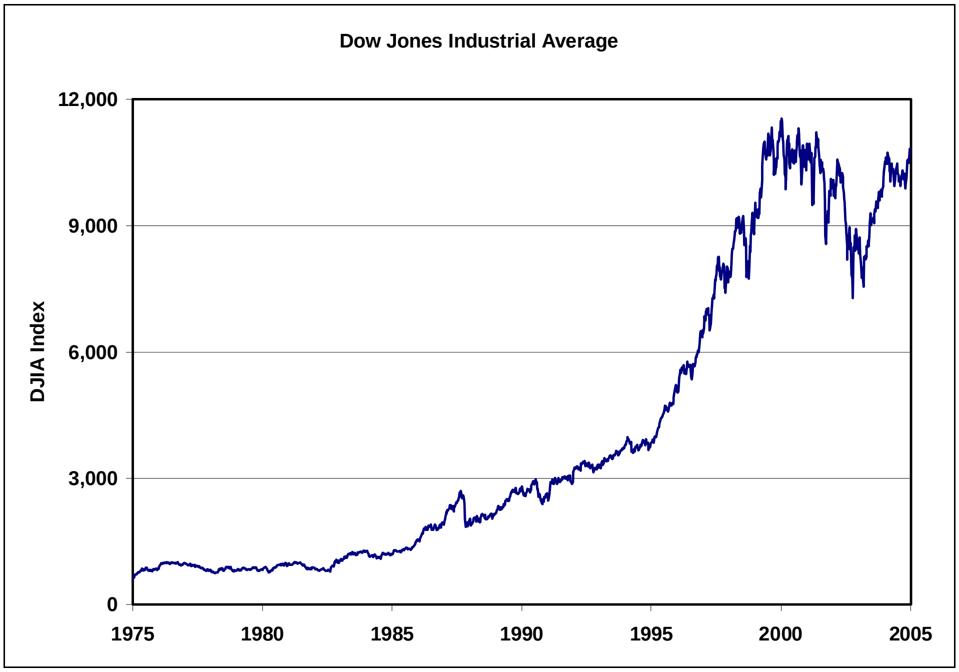



**Figure 4. Example of a Common Economic Indicator—Dow Jones Industrial Average from 1975 to 2005 (weekly mean index data compiled from http://www.djindexes.com)**

## USE OF CONCEPTUAL MODELS IN INDICATOR DEVELOPMENT

Conceptual models interpret systems by organizing information on the structure and interactions of the system into an easily understood and sometimes visual format, which simplifies the process of identifying appropriate indicators. These models identify key ecological compartments and linkages between those compartments. Within the conceptual model, the various perturbations (Pressures) are put into context with system ecology and potential responses. Several types of conceptual models can be used to organize and identify environmental indicators. These models run the gamut from simple text describing an ecological system to complex, multifaceted flow charts that detail many of the compartmentalized aspects and interactions occurring within a particular ecosystem (see Figure 5 for an example).

**New York/New Jersey Harbor Estuary Program—Indicator Development**

"There is no program that monitors habitat function directly. However, one indirect way to determine whether habitats are functioning properly is to examine the population sizes of organisms that those habitats support." (Steinberg, Suszkowski, Clark, and Way, 2004)

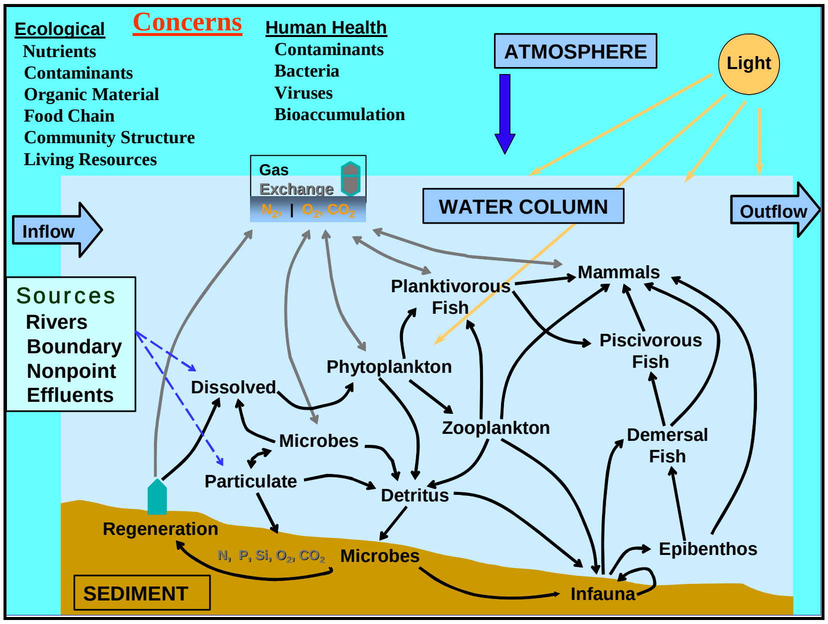



**Figure 5. Conceptual Model of Estuarine Ecosystem with Multiple Stressors and Responses**

## DEVELOPMENT OF CONCEPTUAL MODELS

Several different types of frameworks have been created for developing conceptual models. One of the more prominent frameworks categorizes (1) environmental indicators as pressures and stressors that degrade ecological condition, (2) the state of ecological conditions, and (3) society's responses at improving ecological condition. As seen in this categorization, environmental indicators can be used to measure ecological condition, but may be used to measure progress towards meeting goals, milestones, and objectives. These indicators are often referred to as "programmatic indicators," measuring implementation of actions, funding milestones, and changing laws, policies, and regulations. The following section presents several frameworks that can be used to organize environmental—both programmatic and ecological—indicators to monitor and track estuarine health and restoration efforts. As noted previously, this manual focuses on ecological indicators, but similar frameworks and processes apply to the development of other types of indicators.

### Pressure-State-Response (PSR) and Pressure-State-Response-Effect (PSR/E) Frameworks

Used internationally and nationally, the PSR framework is a conceptual framework developed by the OECD for environmental monitoring. The PSR framework (see Figure 6) represents the associations among the pressures exerted by human activities on the environment (Pressure); the changes in the quality and quantity of natural resources (State); and the societal responses to these changes through environmental and other polices (Response) (OECD, 1993).

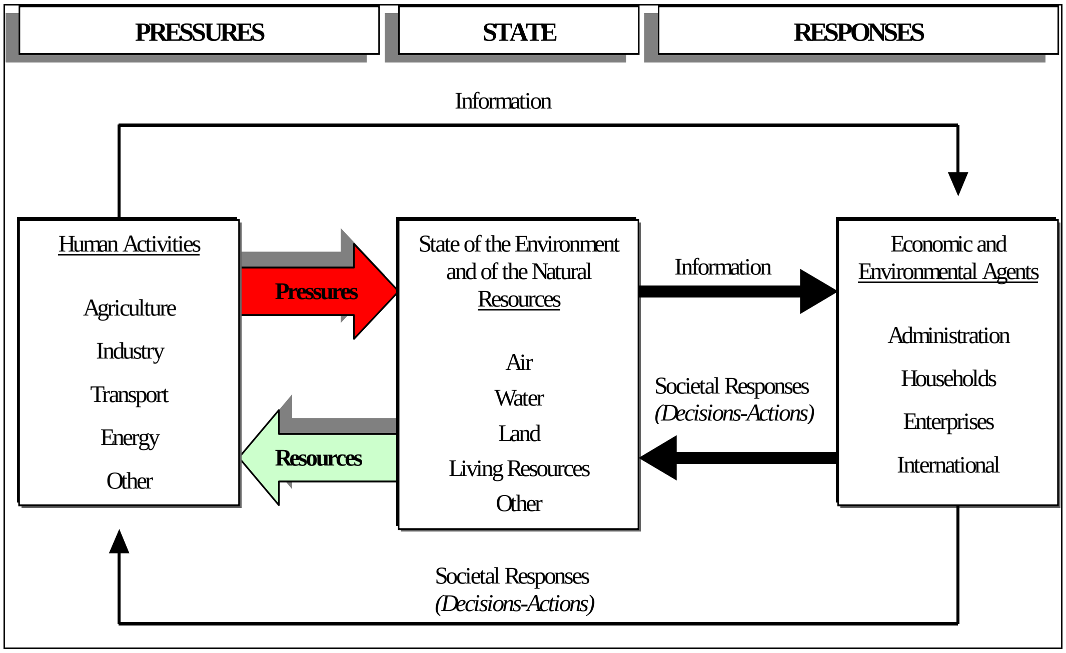



**Figure 6. The PSR Conceptual Model (OECD, 1993)**

Pressure indicators are measurements of the pressures exerted on the environment by human activity, whether direct (*i.e.*, proximate pressures) or indirect (*i.e.*, indirect pressures). Examples of pressure indicators include emissions from cars, discharges from municipal wastewater treatment plants, and runoff from agricultural operations. State indicators describe the quality of the environment and the quality and quantity of natural resources. State indicators generally are measurable quantities, such as water quality parameters, concentrations of air or water toxicants, the extent of viable wetlands, or the functionality or productivity of wetlands. Response indicators relate how society is responding to environmental changes and concerns by protecting and restoring the environment and preventing environmental damage. Societal responses may range from economic incentives such as taxation and subsidies to enforcement with legislative and management programs. The framework assumes that there is a causal relationship between each of the components that links human activity to environmental impacts.

Building on the existing PSR framework, the EPA Office of Policy, Planning and Evaluation modified the PSR framework to include interactions among pressure, state, and response indicators, called “effects” indicators (PSR/E) (EPA, 1995). The principles of the PSR/E framework have been adopted by EPA’s ORD, which focuses its indicator research on the state and effects components of the PSR framework. ORD’s indicators are science-based, rather than policy-based, and the guidance document *Evaluation Guidelines for Ecological Indicators* presents examples of three different types of indicators (EPA, 2000b).

With regard to the PSR and PSR/E approaches, the models can be relatively simple, focusing on only primary or secondary effects/interactions, or they may be more complex, including many factors influencing and being impacted within a system. The simpler the model, the more clearly defined the relationship between PSR and PSR/E. The main drawback in using a simple model is that a component of the real ecosystem that is not taken into account may play a critical role in how the ecosystem responds to or is affected by pressures or response actions.

It is important that conceptual models be easily understandable by both scientists and managers and that the models include enough information to make educated choices on what might be used as an indicator. For example, nutrients are a crucial ingredient in the biogeochemical functioning of an estuarine system. However, too much of a good thing, in this case anthropogenic nutrient inputs, could drive the system toward eutrophication with elevated biomass (organic material) and, eventually, lower bottom-water DO levels or even hypoxic conditions. This is just one example of the interactions of pressures on the state of an estuarine system, but it conveys the simple idea that additional input of nutrients could lead to low DO. In this case, the annual point source nutrient load may be a useful indicator of the pressures on the system. The annual or seasonal phytoplankton biomass or DO minima would be an indicator of the state of the system. If the management response is to decrease point source loading, then all three might be useful in understanding the success of the action both directly (nutrient loading) and indirectly on the effect on the system (biomass and DO).

> It is important that conceptual models be easily understandable by both scientists and managers and that the models include enough information to make educated choices on what might be used as an indicator.



> **Tillamook Bay Estuary Program (TEP)—State Indicators**
>
> "TEP made a conscious decision to focus on "state" indicators. State indicators were selected because they best describe the quality of the environment, and integrates the effects of pressures and responses over time." (TEP, n.d.)

This example is presented in Figures 7 and 8 within the more formal PSR and PSR/E frameworks. The primary difference between these frameworks is that the PSR/E framework formalizes the effects of the response actions into the conceptual model. Although it is not a specified component in the PSR framework, continued monitoring of pressure or state variables/indicators is implicit and serves to provide an understanding of the effect of management responses. In Figure 7, the management actions result in some change in both pressures and state as signified by the returning arrows. In Figure 8, the impact of these actions is specified as expected effects to both pressure and state variables (bottom box). A more complex version using multiple variables would follow the same process but would have many more interconnections between pressures, states, responses, and effects. At some point, the model becomes less useful and it would be preferable to use an ecological framework to describe the conceptual model, as discussed in the next section.

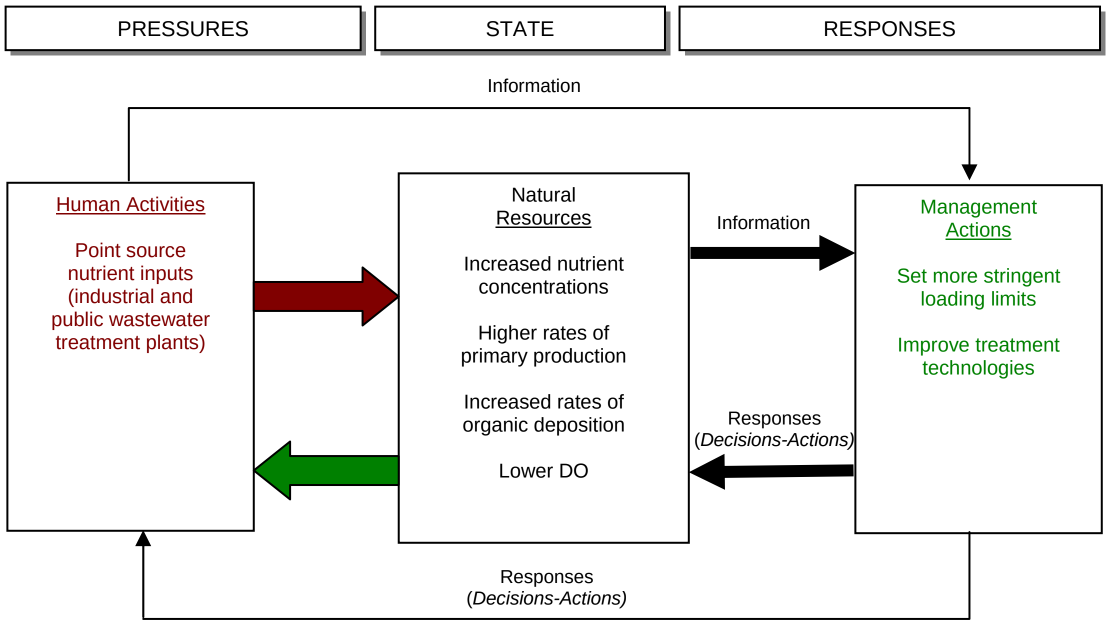



**Figure 7. Example of a PSR Conceptual Model for Nutrient Inputs and Aspects of Eutrophication.**

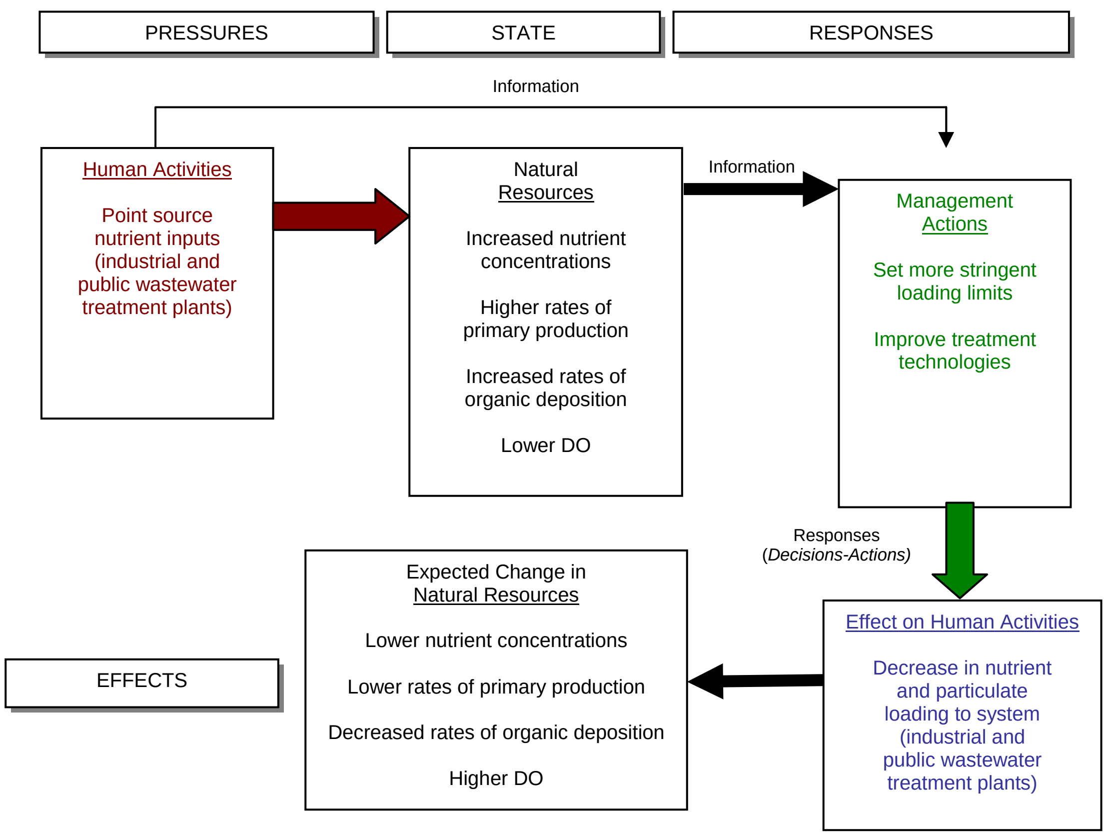



**Figure 8. Example of a PSR/E Conceptual Model for Nutrient Inputs and Aspects of Eutrophication.**

Note: Figures 7 and 8 were developed for this manual using example indicators.

## Ecological Framework

Another environmental indicator framework that is related to the PSR/E framework is presented in the NRC's guidance document *Ecological Indicators for the Nation* (NRC, 2000). The NRC proposes national indicators of ecological condition that are influenced by multiple stressors. These indicators may be used to estimate the ability of a nation's ecosystems to continue to provide goods (*e.g.*, food and building materials) and services (*e.g.*, flood protection and recreation) for the survival of the society. These indicators fall into three categories:

1. Indicators of ecosystem extent and status;
2. Indicators of ecological capital;
3. Indicators of ecosystem functioning.

Indicators of ecosystem extent and status include measurements of land cover and land use. Indicators of ecological capital measure the biotic and abiotic natural capital, or raw materials, of the nation. Biotic raw materials include the number and distribution of native species, and the number of introduced or exotic and invasive species, while abiotic raw materials include soil and nutrients. Indicators of ecosystem functioning measure ecosystem processes or end results of processes, such as productivity and nutrient-use efficiency and nutrient balance. The interactions between raw materials and the ecosystem process are initially developed in a conceptual model of the estuarine ecosystem in order to develop relevant indicators to model the system.

In order to develop an appropriate environmental indicator, it must be directly linked to the cause, effect, or action it is tracking. Ideally, indicator development should be preceded by the development of an assessment question. An example assessment question relevant to the objective of this report is "What percent of the estuary is hypoxic?" The next critical step is the development of a framework or model of the system relevant to the assessment question. In the example, the estuary may be exhibiting hypoxic conditions due to lack of oxygen from algae growth, loss of seagrass, industrial pollutant discharges, invasive species changing ecosystem dynamics, or nutrient overloading.

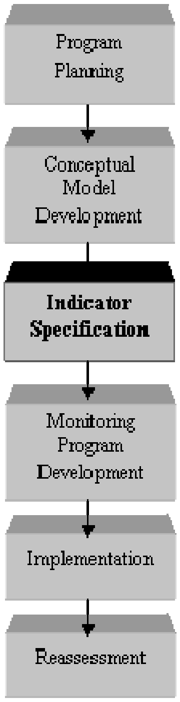
Ideally, a conceptual model should be developed based on the current understanding of the structure and function of the system in question (an estuarine ecosystem example is provided in Figure 5). The model considers temporal and spatial dynamics, evaluates recuperative capacities of the resource to combat stressors, and identifies where stressors are introduced to the system and may potentially impact resources. The model should present a thorough understanding of the inputs and outputs of the system that will lead to a selection of indicators in which to perform the research. Common mistakes encountered while developing indicators include

Ideally, a conceptual model should be developed based on the current understanding of the structure and function of the system in question

selecting indicators that are not linked to the assessment questions, developing indicators prior to posing an assessment question, and settling for indicators based on the currently available data.

> Common mistakes encountered while developing indicators include selecting indicators that are not linked to the assessment questions, developing indicators prior to posing an assessment question, and settling for indicators based on the currently available data.

# INDICATOR SPECIFICATION




Once the management goals/questions have been defined and at least one conceptual model has been developed, the process focuses on selecting appropriate indicators for addressing each question and model compartment. These indicators can be either quantitative measures (*e.g.*, DO levels) or qualitative measures (*e.g.*, aesthetics; see the *Sneaker Index* callout box below). Indicators can also be direct measurement indicators, index indicators, or complex multi-metric indicators. Direct measurement indicators, such as DO or nutrient concentrations, directly correlate the measurements of the indicator (DO) to the effect on the environment (hypoxia). Index indicators (multiple indicators), such as the index of benthic condition, integrates measures of community composition and diversity and discriminates between impacted and unimpacted areas. Complex, multi-metric indicators are a composite index, which integrates various structural and functional attributes of an ecosystem and provides an overall assessment of ecosystem condition (EPA, 2000b). An example of a multi-metric indicator is the characterization of a stream fish assemblage that measures the effects of a variety of stressors across different time scales and levels of ecological organization and evaluates the impact of fish consumption by the general public. The development of this type of indicator is based on the multi-metric Index of Biotic Integrity originally developed by Karr (Karr, 1981; Karr *et al.*, 1986). Therefore, each of these indicator types varies by the type of information and extent of analysis involved in its development.

> "The symbolic value of an indicator may outweigh its value as a literal measure."
> (Cobb and Rixford, 1998)



**Sneaker Index**

"The name *Sneaker Index* was originally coined by Sen. C. Bernard (Bernie) Fowler, around 1988. Sen. Fowler was deeply concerned about the future of Maryland's Patuxent River. To evaluate the condition of the river water, he began to measure how deep he could wade into the water and still see his sneakers—thus came the name 'Sneaker Index'. People understood this form of assessment very easily. Consequently, the public accepted it." (Price and Huerta, 2001)

A range of possible indicators stemming from eutrophication issues is presented in Figure 9. In this case, the input of nutrients to a system can have a variety of impacts that range from primary, to secondary, to even tertiary symptoms. Each level of symptoms in Figure 9 carries with it additional effects from other stressors. These indicators integrate impacts not only across multiple stressors, but often across wide spatial areas, over time, due to cumulative effects. A number of factors must be considered for the selection of indicators suitable for each area/region of interest (parameters and metrics).

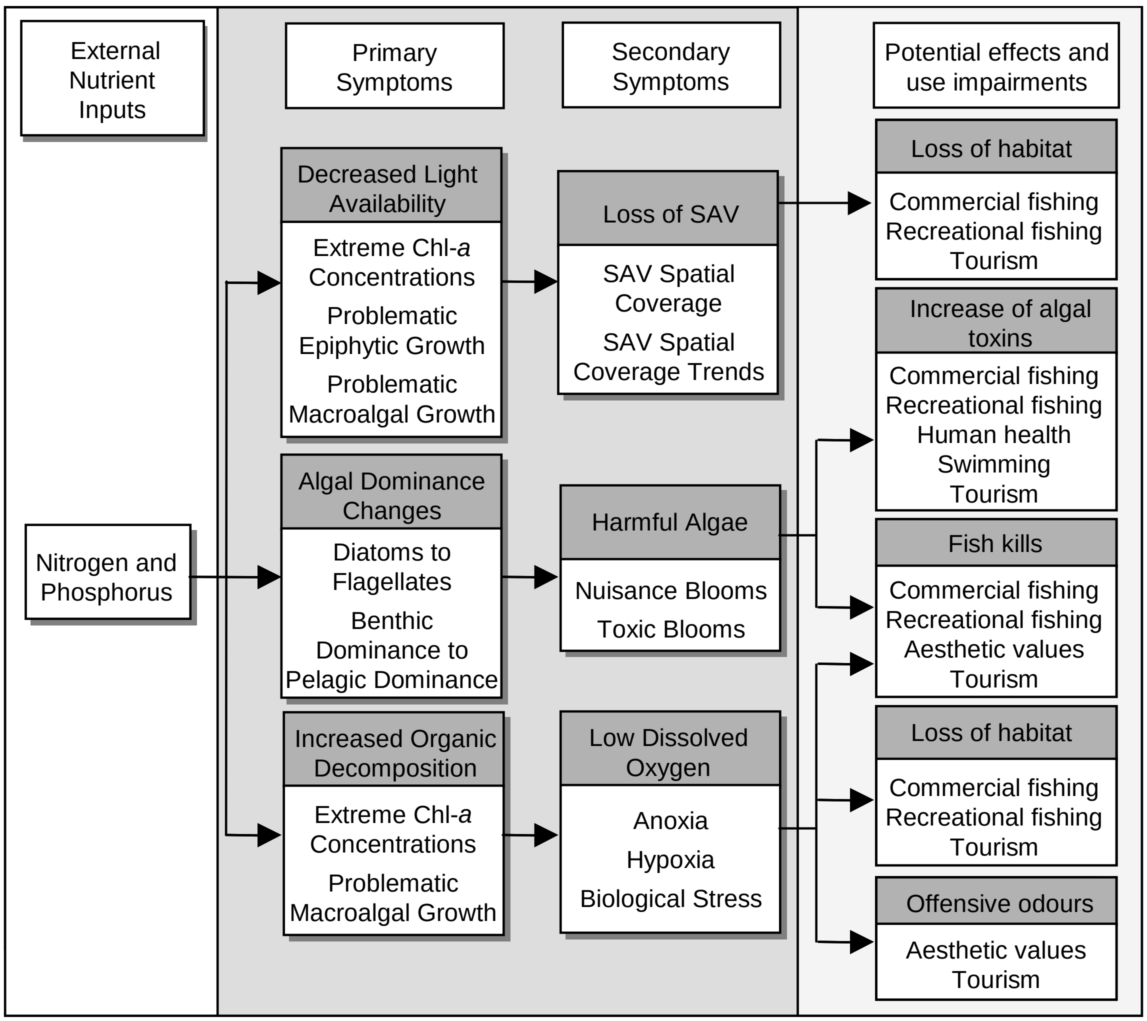



**Figure 9. Example of Multiple Levels of Indicators Associated with Eutrophication and the Inputs of Nutrients (Bricker, Ferreira, and Simas, 2003)**

**Great Lakes Program SOLEC 1996—Science Based Indicators**

At SOLEC 1996, constituents decided to create "a basin-wide, systematic framework using science-based indicators." "Small working groups of experts were assembled and asked to both 'extract' indicators from Great Lakes studies pertinent to their topic, and to identify new indicators to fill crucial gaps. According to the interviewees, breaking the indicator development process into manageable topic areas, and assigning each piece to a separate working group, made for a fairly efficient process." (Pidot, 2003)

To determine whether an indicator provides consistent information for evaluating both short- and long-term conditions and supporting management decisions, EPA has established guidelines using a four-phase approach for evaluating potential and acknowledged indicators (EPA, 2000b). The four-phase criteria are as follows:



1. ***Conceptual Relevance or Soundness***
   Is the indicator relevant to the assessment question and to the resource at risk? The choice of indicators is dependent upon initial questions and conceptual models for the relevant area.

2. ***Feasibility of Implementation (Current and Future)***
   Are the methods for long-term sampling and measuring the environmental variables technically feasible, appropriate, and efficient for use in a monitoring program? Evaluation of the indicators must focus on both the short- and long-term feasibility of monitoring, the associated costs, and the complexity of analysis and data interpretation.

3. ***Response Variability***
   Are human errors of measurement and natural variability over time and space sufficiently understood and documented? Indicators will likely integrate both anthropogenic and natural factors—can the spatial and temporal variability of each factor be determined (regional vs. local, short-term or long-term, etc.)?

4. ***Interpretation and Utility***
   Will the indicator convey information on resource conditions that is meaningful to environmental decision-makers? In addition, is the indicator currently monitored or likely to be easily monitored in the future?

These phases describe an idealized progression for indicator development that flows from fundamental concepts, to methodology, to examination of data from pilot or monitoring studies, and finally to consideration of how the indicator serves the program objectives. The guidelines are presented as sequential steps that can be used iteratively to refine the selected indicator.

Both the NRC and EPA's Environmental Monitoring and Assessment Program (EMAP) have put forth their own sets of criteria for evaluating the appropriateness of indicators for environmental systems (EMAP, 1994; NRC, 2000). Table 1 compares indicator evaluation criteria recommended by these two programs with those suggested in EPA (2000b) guidelines. Although some of the individual criteria vary between the three sets of guidelines, all of the criteria share the four phases described above, with several of the criteria in these groups overlapping across programs. The essential elements for evaluating the suitability of an indicator are whether the indicator is measurable using available technology, is relevant and responds to the assessment question, and provides information for management decision-making. Additionally, the best indicators are able to quantify information so its significance is more readily apparent and simplify information about complex phenomena to improve communication between researchers, managers, and ultimately the public.

**Long Island Sound Study—Indicator Development**

Indicator development began with a review of monitoring programs already collecting data in the Long Island Sound region. First, developers exclusively looked at existing programs and did not consider which information might be most useful to managers or scientists. LISS also reviewed the work of other groups that had completed indicator-based State of the Environment Reports to gain a sense of what choices were made by others with similar projects. A list of approximately 100 potential indicators was created from the review. Indicators were selected from this list based on the extent and quality of data immediately available, as well as their relevance to Long Island Sound management objectives. (Pidot, 2003)

**Tillamook Bay—Indicator Selection Criteria**

In addition to the selection criteria noted above, Tillamook Bay applied the following criteria:

1. Correlated to environmental conditions and/or responses
2. Representative of system-wide conditions
3. Understandable and relevant to audience
    a. Directly applicable to resource management
    b. Linked to public concern or interest
4. "Monitorable"
    a. Quantifiable
    b. Repeatable
    c. Affordable
    d. Practical

(TEP, n.d.)

**Table 1. Examples of Various Indicator Evaluation Guidelines[1]**

| General Criteria Group | EPA (2000b) | NRC (2000) | EMAP (1994) |
|---|---|---|---|
| Conceptual relevance or soundness | *Relevance to the assessment* | *General importance* | *Unambiguously interpretable* |
| | *Relevance to ecological function* | *Conceptual basis* | |
| Feasibility of implementation (current and future) | *Data collection methods* | *Necessary skills* | *Available method*<br>*Minimal environmental impact* |
| | *Logistics* | | *Amendable to synoptic survey* |
| | *Information management* | *Data archiving* | |
| | Quality assurance | | |
| | *Monetary costs* | *Cost, benefits, and cost-effectiveness* | *Cost effective* |
| | | Data requirements | |
| Response variability | Estimation of measurement error | | |
| | *Temporal variability – within the field season*<br>*Temporal variability – across years*<br>*Spatial variability* | *Temporal and spatial scales of applicability* | *Index period stability* |
| | *Discriminatory ability* | *Robustness*<br>*Statistical properties* | *High signal-to-noise ratio*<br>*Ecologically responsive* |
| Interpretation and utility | *Data quality objectives* | *Data quality* | |
| | *Assessment thresholds* | | *Nominal-subnominal criteria* |
| | Linkage to management action | | |
| | | | Retrospective |
| | | | Anticipatory |
| | | *Reliability* | *Historical record* |
| | | | New information |
| | | International compatibility | |

[1]Criteria that are common to more than one program are italicized.

## CONCEPTUAL RELEVANCE

*The indicator must provide information that is relevant to societal concerns about ecological condition. The indicator should clearly pertain to one or more identified assessment questions. These, in turn, should be germane to a management decision and clearly relate to ecological components or processes deemed important in ecological condition. Often, the selection of a relevant indicator is obvious from the assessment question and from professional judgment. However, a conceptual model can be helpful to demonstrate and ensure an indicator's ecological relevance, particularly if the indicator measurement is a surrogate for measurement of the valued resource. This phase of indicator evaluation does not require field activities or data analysis. Later in the process, however, information may come to light that necessitates re-evaluation of the conceptual relevance, and possibly indicator modification or replacement. Likewise, new information may lead to a refinement of the assessment question*. (EPA, 2000b)

The first step in indicator identification and development flows directly from the appropriate conceptual models identified for the specific estuary, ecosystem, or regional area of concern. These models may be specific to a particular segment of the ecosystem or more detailed, including multiple trophic levels and habitats. The suite of possible indicators also covers a wide range from parameter-specific to integrations of multiple metrics/parameters. In all cases, however, the indicator needs to be directly relevant to the resources at risk or the management questions being addressed. A compendium of indicators is included in Appendix B. This list, although quite comprehensive, is not necessarily complete; additional indicators may be valid in a particular system.

The strategies for selecting indicators based on conceptual models are as varied as the programs themselves, but most focus on some form of brainstorming. This activity can occur internally with NEP or other groups, externally utilizing the experience and knowledge of area scientists who are brought together as a Technical Advisory Committee (TAC) or similar types of advisory groups, or publicly with a wide range of stakeholders participating. Each level of involvement has benefits and drawbacks. Internal staff discussions can be focused, expedient, and driven by knowledge of the next three steps in the process. Expanding discussions to include a TAC will likely extend the timeframe of the process; however, it will also expand the knowledge base and may provide a more comprehensive list of indicators. Public workshops are certain to take the most time, but in addition to the benefit of likely producing a more comprehensive list of indicators that will be easily communicated, workshops also provide a mechanism of public education and a buy-in to the process.

## FEASIBILITY OF IMPLEMENTATION

*Adapting an indicator for use in a large or long-term monitoring program must be feasible and practical. Methods, logistics, cost, and other issues of implementation should be evaluated before routine data collection begins. Sampling, processing and analytical methods should be documented for all measurements that comprise the indicator. The logistics and costs associated with training, travel, equipment and field* *and laboratory work should be evaluated and plans for information management and quality assurance developed*. (EPA, 2000b)

The factors that determine the feasibility of indicator implementation fall into two general categories—available infrastructure/expertise and costs. The availability of the infrastructure necessary for sample/data collection, analysis, and management is directly related to costs, but such costs likely have been covered by previous budgets. If existing monitoring program infrastructure is not present, then the feasibility of implementing a wide variety of indicators is limited. It is expected that most systems will have a modicum of ongoing monitoring activities and that the current system in place not only provides data relevant to some of the selected indicators, but also has the capacity to be modified to implement additional monitoring efforts. Again, the cost/benefits of each indicator will need to be evaluated based on available funding sources, both current and with an eye to the future for any long-term metrics.

## RESPONSE VARIABILITY

*It is essential to understand the components of variability in indicator results to distinguish extraneous factors from a true environmental signal. Total variability includes both measurement error introduced during field and laboratory activities and natural variation, which includes influences of stressors. Natural variability can include temporal (within the field season and across years) and spatial (across sites) components. Depending on the context of the assessment question, some of these sources must be isolated and quantified in order to interpret indicator responses correctly. It may not be necessary or appropriate to address all components of natural variability. Ultimately, an indicator must exhibit significantly different responses at distinct points along a condition gradient. If an indicator is composed of multiple measurements, variability should be evaluated for each measurement as well as for the resulting indicator*. (EPA, 2000b)

There are two primary sources of variability in environmental data—analytical and natural. Although it is important to understand the variability inherent in specific analyses/measurements, that variability is not described herein. EPA (2000b) provides a detailed discussion of analytical variability and its context in indicator development. For this manual, it is expected that the variability from most methods of data/sample collection and analysis can be minimized or at least quantified by following explicit quality assurance/quality control (QA/QC) protocols. To this end, it is critical to have a QA/QC plan in place for any monitoring activity. Not only will it allow for assessment of field and laboratory variability, but the data quality objectives outlined in a typical QA/QC plan will also be useful during subsequent interpretation activities.

Natural variability occurs over many temporal and spatial scales, and a comprehension of natural variability is crucial to both understanding the system and selecting appropriate indicators. Ecosystem characteristics vary over time scales from hourly to interannual; selection of the optimal time scale is important in developing monitoring approaches and interpreting the data.

In most cases, the spatial scale that is of most concern to managers is their local area, but this may be as small as a localized area within an embayment, an entire embayment, a larger bay, or a large regional coastal area. Not only is the scale of the area of concern important, but important factors influencing localized areas are also often regional (*e.g.,* coastal currents), hemispheric (*e.g.,* North Atlantic Oscillation, El Niño/Southern Oscillation), or even global (*e.g.,* climate change) in scale.

In these contexts, the expectation is that the natural variability over time and space is such that an anthropogenic signal can be discerned. The natural variability either has to be relatively small or well-defined in comparison to expected changes due to human pressures. To this end, when selecting indicators to track ecosystem health and response to management actions, numerous questions should be considered concerning the temporal and spatial scale variability of environmental data. For example:

1. Are there natural seasonal patterns in the data?
2. What is the most representative time period from which to measure or average data?
3. Is the local expression of the indicator indicative of localized impacts or driven by larger regional forces?



## INTERPRETATION AND UTILITY

*A useful ecological indicator must produce results that are clearly understood and accepted by scientists, policy makers, and the public. The statistical limitations of the indicator's performance should be documented. A range of values should be established that defines ecological condition as acceptable, marginal, and unacceptable in relation to indicator results. Finally, the presentation of indicator results should highlight their relevance for specific management decisions and public acceptability*. (EPA, 2000b)

In this last step for indicator evaluation, the expected needs that the indicator must fulfill become a bit more diverse (see Table 1). The main need is for an *a priori* understanding or establishment of a threshold level or range of values that is considered 'good' or 'bad' with which to evaluate current conditions or trends based on a particular indicator. In the best-case scenario, this level or range of values would be based on a long-term data set—baseline or historical.

In the absence of data specific to the system of interest, comparisons to other systems may suffice. These comparative systems could be impaired or pristine or likely somewhere in between, but should have enough similarities to be germane to the system of interest. Best professional judgment can also be a valid source when no other data are available. Regulatory levels or management goals could also serve as a threshold for many quantitative indicators.

The selection of indicators will always be site-specific, but the process by which indicators are selected is nearly always the same and more or less follows the four steps described above.

Table 2 lists a sampling of potential indicators and their relevance, feasibility, expected variability, and interpretation utility. Although the details in the table are limited, these examples provide a starting point and model for this approach.

For example, DO is a key indicator and integrator of water quality in coastal waters. As a basic necessity for aquatic life, DO levels directly affect ecosystem health. Diaz and Rosenberg (1995) state that no other environmental variable of such ecological importance to coastal marine ecosystems has changed so drastically in such a short period of time as DO. These authors argue that while hypoxic environments have existed through geological time, their occurrence in shallow coastal and estuarine areas appears to be increasing and the cause seems most likely to be accelerated by human activities (Nixon, 1995; Bricker *et al.*, 1999). Thus, DO is obviously relevant to understanding human impacts on our coastal ecosystems.

The measurement of DO is straightforward for both *in situ* sensors and water samples (Winkler titrations), and the methods are quite accurate. DO is typically measured as part of coastal water quality monitoring programs and is relatively inexpensive in comparison to other data-gathering efforts. Historic data are often available, current monitoring programs are normally measuring DO, and data will continue to be easily and economically obtained into the future. All these factors indicate that DO is a very feasible indicator.



As mentioned, the analytical variability in DO analysis is tightly constrained, as methods are quite accurate and precise. The amount of DO contained in marine waters at saturation is a function of physical, chemical, and biological conditions. Cold waters hold more DO than warm waters at a given salinity. Seawater at equilibrium at a given temperature contains substantially less DO than freshwater. Thus, DO concentrations naturally follow a seasonal pattern of winter maxima and summer minima that is directly related to temperature but is influenced by biological processes. This aspect of natural variability in DO concentrations, and the fact that historic and present data monitoring programs further describe these trends or provide a baseline, suggests that it is likely that an anthropogenic signal in this indicator could be observed.

Biological production and utilization of DO in coastal waters has a well-known theoretical relationship to nutrient supplies. Increased nutrient supplies often lead to increased photosynthetic production of organic matter by phytoplankton or other algae. This increase in production often results in super-saturated DO levels in the upper water column. Alternatively, a dominance of heterotrophic activity, especially microbial respiration, can lead to greatly under-saturated conditions. Highly productive waters may experience super-saturated conditions during the day and under-saturated conditions at night, especially just before sunrise as respiration has been occurring for maximum duration.

**Table 2. Sampling of Indicators and their Respective Aspects under the Four Criteria—Relevance, Feasibility, Variability, and Utility**

| Indicator | Relevance | Feasibility | Variability | Utility |
|---|---|---|---|---|
| Nutrient loading | Point and non-point source inputs are one of the primary factors in eutrophication. | Point sources are required to measure nutrients by permits, and most monitoring programs include these relatively inexpensive measures. | Analytical variability is minimal and known. The inputs are also well-constrained (large natural variability in ambient waters, but not loading). | One of the responses of management is to set loading limits. Thus, baseline and post-action changes can be measured and changes in the ambient waters measured. |
| Dissolved oxygen | Integrator of many water quality processes and directly relevant to marine species (and fishermen). | Easily measured and among normal suite of measurements. | Analytical variability is minimal and known. Natural variability can be large, but seasonality of signal is typically known and changes in seasonal DO minima could be detected. | Given the understanding of this parameter, interpretation of the data is relatively straightforward (though ancillary information on physical current structure and bathymetry is very helpful). |
| Frequency of toxic/nuisance phytoplankton blooms | Public health and aesthetic issue. Shellfish closures also a monetary incentive for monitoring these species. | Often part of state monitoring programs (*e.g.*, Maine Department of Marine Resources). Local researcher with experience – otherwise can be very expensive. | Little analytical variability, assuming counts and identifications are made by experienced personnel. Natural variability can be large, but often well-known due to historical data and shellfish closures or other public health records. | Frequency of these blooms has increased—unclear from literature whether due to increase monitoring effort or as a result of anthropogenic impacts. |

**Table 2 (continued). Sampling of Indicators and their Respective Aspects under the Four Criteria—Relevance, Feasibility, Variability, and Utility**

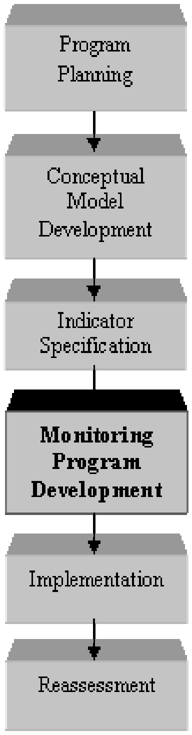
| Indicator | Relevance | Feasibility | Variability | Utility |
|---|---|---|---|---|
| Acres of existing seagrass and habitat restored | Importance to fisheries and sensitive to nutrients. Integrator of eutrophication processes (decreased light, increased epiphyte growth) and other anthropogenic pressures (trawling, development, increased sedimentation, etc.). | Established direct (divers) and indirect (*in situ* instruments and remote sensing) methods exist for mapping the density and extent of seagrass beds. Can be expensive, but can be conducted on a cyclical basis to minimize annual costs. | Increased variability with the indirect measurements that quantify over a larger range, but can be minimized by ground truthing sampling. Interannual variability a direct indicator of habitat loss or gain. | Necessary for establishing baseline conditions and to monitoring the effectiveness of restoration programs. Once a baseline distribution map is available, can revisit at 3- to 5-year intervals to gauge changes in this valuable habitat resource. |
| Benthic indices (health, abundance, taxonomic identification and diversity) | Benthos is an integral part of the ecosystem and tends to be the repository of much of the organic material and contaminants from anthropogenic inputs. Need to develop linkages between stressors and benthic impacts. | As with the phytoplankton, this type of indicator can be very expensive if not part of an ongoing monitoring plan. Unlike plankton, the benthos could be monitored less frequently if appropriate and still provide a clear indication of improvement or degradation. | The benthos is a highly variable environment, and this is reflected in the data. This variability can be minimized by implementing a QC program, by understanding the relative temporal and spatial variability across the system. and by tailoring the sampling schema to capture only the specific time and area of interest to both focus the effort and minimize these sources of variability. | Many types of indices listed in the literature. The more effort taken in selecting an appropriate index, the more useful the results will be. Critical in establishing 'baseline' conditions and for managers tasked with both assessing ecological condition and mitigating impacts caused by anthropogenic inputs. |

**Table 2 (continued). Sampling of Indicators and their Respective Aspects under the Four Criteria—Relevance, Feasibility, Variability, and Utility**

| Indicator | Relevance | Feasibility | Variability | Utility |
|---|---|---|---|---|
| Fish/shellfish consumption warnings | Designed to protect public health—usually using a risk-based approach to contaminant levels. Directly impact public's perception of water quality and toxics. | Typically issued by a state agency—the monitoring, analysis and assessment of risk all conducted by the state. Data publicly available (historic and into the future). | Primary sources of variability are controlled or at least taken into account in the risk-based system. State-to-state variability may exist, but relative numbers will likely be comparable over time. | One of the end-of-the-line type indicators—if warnings increase or decrease, a clear message is understood by the public. The more localized the range of the animals, the more pertinent to individual estuaries or locations. |



Another factor that affects DO concentration in estuarine and coastal waters is mixing (or lack thereof). Deeper waters, where vertical density differences exist (especially sub-pycnocline waters), may become hypoxic during the summer when DO solubility is lowest and ample supplies of labile organic carbon are available (due to sinking of senescent phytoplankton) to support microbial respiration and benthic respiration in the bottom waters. DO utilization in deeper stratified waters may outpace DO replenishment through transport of atmospheric DO and mixing and any potential net gains of DO from photosynthesis. DO concentration in coastal waters is a dynamic property that varies spatially and temporally, depending on physical, seasonal, biotic, and anthropogenic influences. Thus, the foundation for interpreting the DO indicator is sound and readily available. Not surprisingly, DO is one of the most widespread indicators in use for water quality objectives.




# MONITORING PLAN DEVELOPMENT AND MODIFICATION

The development of monitoring plans has been discussed in detail in other guidance manuals (EPA, 1992). This section highlights the steps discussed elsewhere, describes how monitoring activities fit into the indicator paradigm, and focuses on how ongoing monitoring programs may need to be modified to better address indicator program needs.

EPA's *Monitoring Guidance for the National Estuary Program* (EPA, 1992) specifies five steps for designing a monitoring program (Figure 10):

1. Develop monitoring objectives and performance criteria
2. Establish testable hypotheses and select statistical methods
3. Select analytical methods and alternative sampling designs
4. Evaluate expected monitoring program performance
5. Design and implement a data management plan



The first two steps are somewhat analogous to the processes outlined earlier in this manual for indicator development. The development of management goals for indicators and the indicators themselves can be used as the monitoring objectives and performance criteria for a monitoring program (Step 1). The conceptual models are in essence the basis for formulating testable hypotheses (Step 2). The selection of methods and sampling designs will be driven by available equipment/expertise, regulatory requirements, location of sensitive areas, and local geomorphology, to name a few factors (Step 3). Programmatic indicators will be critical in evaluating monitoring program performance (Step 4). The design and implementation of a data management plan (Step 5) is a key part of any monitoring program, but with regard to indicators, the only connection is the need for the data management schema to be able to record and track data associated with indicators and their calculation.

Many sources of information for developing a monitoring plan from scratch are available, such as EPA's 1992 guidance document and *Managing Troubled Waters* (NRC, 1990). These and other documents lay out the objectives, approach, and detailed examples for monitoring program development. Any new program should take into account current and potential future indicators and include measurements that are both directly and indirectly relevant to the indicators. Not only should the parameters included as part of specific indicators be measured, but also ancillary information pertinent to understanding the conceptual model and information necessary for interpreting trends in the indicators.

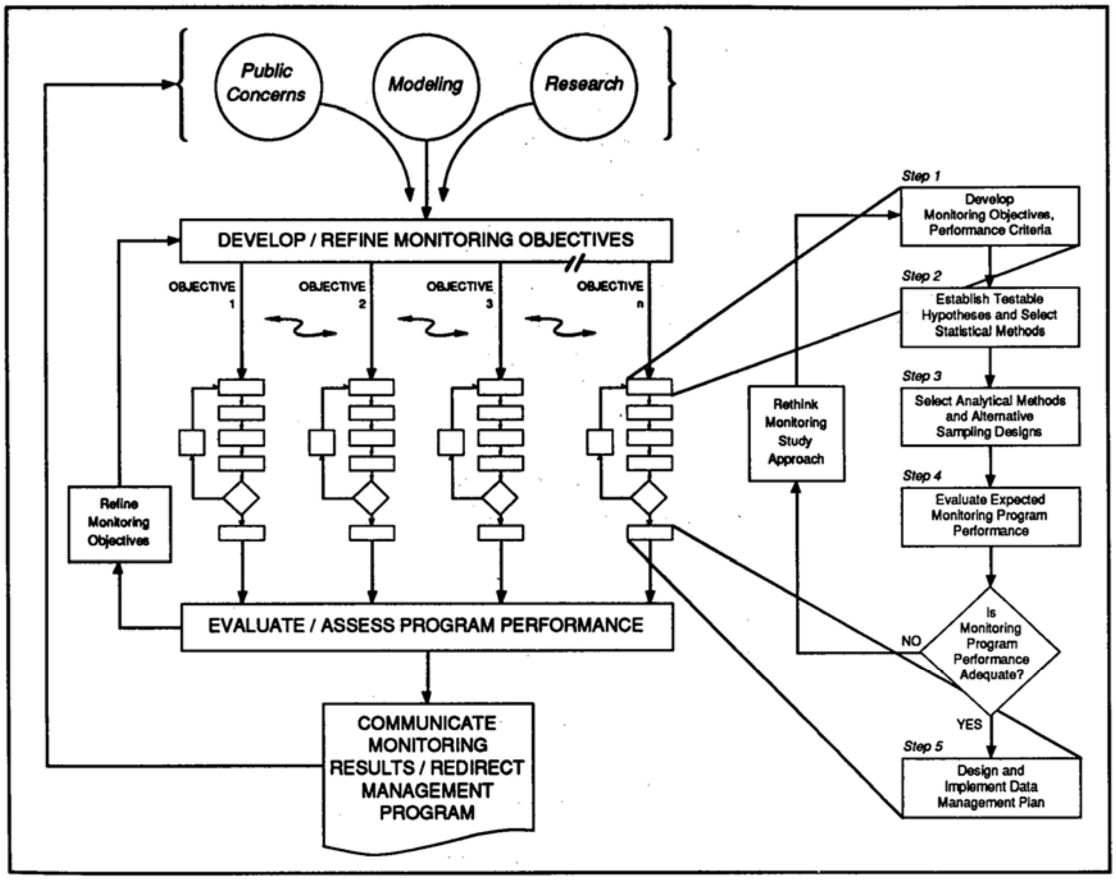



**Figure 10. Five Steps in Designing a Monitoring Program (EPA, 1992)**



Rather than revisit the steps involved with monitoring plan development, this section focuses on utilizing data from ongoing long-term programs and adapting current monitoring programs as necessary to fit the proposed indicator paradigm. Most groups looking at indicators begin the process by focusing on parameters that are already being monitored. What also needs to occur is a reevaluation of the monitoring plans to make sure the data being collected on the selected indicators are sufficient to answer the question. If not, programs could select indicators that will not address the scientific needs.

The expectation is that there is an existing, clearly defined, long-term monitoring program(s) in place in the area of interest. The first step is to list what variables are currently monitored and identify where, when, and how often they are monitored. Does the list of variables and the spatial and temporal extent of the sampling provide enough information and resolution to feasibly characterize an indicator(s)? If so, move on to the next indicator of choice and run through the same process. If not, decide whether the indicator warrants the cost of enhancing the monitoring program to make the additional measurements needed. At this point in the process, the scientific relevancy and utility of the indicator has already been established, but if the measurements are not made in the existing monitoring program, there may be limited historical data with which to compare.

This lack of data would diminish the overall worth of the indicator in question. If, however, it was still deemed a scientifically necessary component, then the decision comes down to relevance versus costs. Modification of indicators may be a viable and less costly approach when long-term data sets are available, but the necessary data are not available.

In many cases, there will be multiple monitoring programs from which to draw information for indicators. This is especially true for the development of regional indicators. The aspects of coordinating data and efforts across various monitoring programs not only provides a regional context for data and indicators, but also may provide significant cost savings to the agencies or groups currently conducting the monitoring. The steps are similar to the approach for an individual program. The first step is to obtain a list of what is presently monitored by each program. The next is to ensure that comparable methods have been used and that the units are standardized before the data are combined or compared. Whether comparing current data to historical data sets or one monitoring program's data to another, it is necessary to be aware of incongruent data sets. It may be possible to rectify data sets after the fact by conducting interlaboratory comparisons. This is recommended only in cases where different, yet valid, methods have been used. Interlaboratory comparisons are certainly recommended for ongoing monitoring programs to ensure comparability into the future (see the SCCWRP callout box on page 50).

Whether comparing current data to historical data sets or one monitoring program's data to another, it is necessary to beware of incongruent data sets.

**Long Island Sound Study—Data Comparison**

Two issues arose once the monitoring data were collected for assessment: (1) the monitoring protocols of New York and Connecticut were not consistent, and (2) information was needed on a watershed basis but collected by town and zip code. (Pidot, 2003)

At times, little thought is given to statistical design during the development of monitoring programs. This is often because there is a specific localized focus or interest. For example, water quality monitoring can focus on an outfall for permit compliance or seagrass monitoring at a specific resource location rather than more random coverage encompassing areas of that resource over an entire embayment. EPA's *Monitoring Guidance for the National Estuary Program* (1992), and references therein, provide details on statistical design of monitoring programs. In order to have a robust indicator, the monitoring data used need to appropriately describe the spatial and temporal scales of interest.

There are four basic spatial sampling schemes: random, systematic, stratified, and multistage. A random sampling design locates samples independently at random locations within an area of interest. This type of design is the easiest to implement but

## Southern California Coastal Water Research Project—Interlaboratory Comparison

SCCWRP was designed “to gather the necessary scientific information so that member agencies can effectively, and cost-efficiently, protect the Southern California marine environment” (SCCWRP, 2005). To characterize the area, several laboratories collect and analyze samples throughout the area; then SCCWRP compiles and compares the data to develop an overall picture of the ecosystem. At the beginning of the SCCWRP process, problems were noted with data inconsistencies. To ensure that the overall assessment of the area was correct, all laboratories submitting data to SCCWRP needed to be processing and analyzing sample in ways that resulted in compatible data. SCCWRP met this challenge by performing intercalibration exercises and in some instances, standardizing methods. The interlaboratory calibration data were used to compare the accuracy of data developed before and after the standardized methods. Prior to standardizing methods, the data ranged 20-fold between the lowest and highest values (top table), while data after standardization were more uniform (bottom table).

### Data Prior to Intercalibration and Standardization

**SANTA MONICA BAY SEDIMENTS – FIRST ROUND**

| | COMPOUND | LAB-1 | LAB-2 | LAB-3 | LAB-4 | LAB-5LAB-6 |
|---|---|---|---|---|---|---|
| Naphthalene | 54 | 171 | 279 | 27 | 139 | 259 |
| 2-Methylnaphthalene | 129 | 485 | 721 | 59 | 405 | 615 |
| 1-Methylnaphthalene | 61 | 172 | 272 | 23 | 181 | 222 |
| Biphenyl | 233 | 756 | 1140 | 97 | 606 | 770 |
| 2,6-Dimethylnaphthalene | 131 | 217 | 401 | 37 | 228 | 203 |
| Acenaphthylene | ND | 4 | ND | ND | ND | ND |
| Acenaphthene | ND | 15 | 46 | ND | ND | ND |
| 2,3,5-Trimethylnaphthalene | ND | 19 | ND | 4 | 15 | ND |
| Fluorene | ND | 38 | 75 | 2 | 24 | 69 |
| Phenanthrene | ND | 137 | 469 | 9 | 109 | 112 |
| Anthracene | ND | ND | 111 | 13 | 19 | 18 |
| 1-Methylphenanthrene | ND | 154 | ND | ND | 51 | ND |
| Fluoranthene | 76 | ND | 495 | 26 | 87 | 108 |
| Pyrene | 91 | ND | 1120 | 28 | 79 | 111 |
| Benz[a]anthracene | ND | ND | 284 | 30 | 65 | 38 |
| Chrysene | 60 | ND | 320 | 31 | 83 | 46 |
| Benzo[b]fluoranthene | ND | ND | 672 | 19 | 205 | 38 |
| Benzo[k]fluoranthene | ND | ND | 205 | 18 | 77 | 41 |
| Benzo[e]pyrene | ND | ND | 367 | 11 | 171 | 63 |
| Benzo[a]pyrene | ND | ND | 409 | 13 | 162 | ND |
| Perylene | ND | 249 | 183 | 5 | 72 | 32 |
| Indeno[1,2,3-c,d]pyrene | ND | ND | ND | ND | 69 | 23 |
| Dibenz[a,h]anthracene | ND | ND | ND | ND | ND | 38 |
| Benzo[g,h,i]pyrene | ND | ND | 60 | ND | 109 | 30 |
| Total PAHs | 835 | 2420 | 7630 | 453 | 2960 | 2840 |

12/10/2002-New Hampshire

### Data After Intercalibration and Standardization

**SANTA MONICA BAY SEDIMENTS – FINAL ROUND**

| COMPOUND | LAB-1 | LAB-2 | LAB-3 | LAB-4 | LAB-5 | LAB-6 |
|---|---|---|---|---|---|---|
| Naphthalene | 173 | 162 | 170 | 191 | 139 | 193 |
| 2-Methylnaphthalene | 388 | 435 | 480 | 532 | 336 | 525 |
| 1-Methylnaphthalene | *** | 145 | 185 | 166 | 153 | 144 |
| Biphenyl | 650 | 644 | 850 | 800 | 535 | 796 |
| 2,6-Dimethylnaphthalene | 365 | 212 | 255 | 343 | 214 | 269 |
| Acenaphthylene | *** | 8 | ND | ND | ND | ND |
| Acenaphthene | *** | ND | 25 | 15 | ND | ND |
| 2,3,5-Trimethylnaphthalene | *** | 22 | ND | 119 | 47 | ND |
| Fluorene | ND | 25 | 49 | 40 | 39 | 52 |
| Phenanthrene | 114 | 131 | 145 | 130 | 142 | 141 |
| Anthracene | *** | 33 | 34 | 58 | 41 | 29 |
| 1-Methylphenanthrene | ND | 62 | 27 | 68 | 73 | 128 |
| Fluoranthene | 183 | 280 | 150 | 135 | 146 | 183 |
| Pyrene | 211 | 196 | 155 | 230 | 125 | 185 |
| Benz[a]anthracene | 93 | 126 | 145 | 118 | 37 | 114 |
| Chrysene | 115 | 88 | 120 | 152 | 127 | 145 |
| Benzo[b]fluoranthene | *** | 164 | 330 | 179 | 60 | 92 |
| Benzo[k]fluoranthene | *** | 63 | 103 | 167 | 60 | 90 |
| Benzo[e]pyrene | 117 | 115 | 155 | 183 | 51 | 115 |
| Benzo[a]pyrene | 94 | 109 | 195 | 191 | 52 | 65 |
| Perylene | ND | 91 | 78 | 110 | 70 | 26 |
| Indeno[1,2,3-c,d]pyrene | *** | 44 | ND | ND | 88 | 66 |
| Dibenz[a,h]anthracene | *** | 26 | ND | ND | ND | ND |
| Benzo[g,h,i]pyrene | 34 | 100 | ND | ND | 80 | 97 |
| Total PAHs | *** | 3280 | 3650 | 3930 | 2610 | 3450 |

12/10/2002-New Hampshire

(Weisberg, 2002)

may not provide the most cost-effective approach or achieve a true understanding of the entire system, as the coverage is random (fine for standard error and other statistics, but not when clear geographic gradients are known *a priori*). A systematic design has sampling locations spread over equal intervals across the region and provides representative coverage of an area. Stratified sampling separates a region into multiple areas and allows for different sampling intensity in each area based on the expected variability or areas of concern. This approach allows for more cost-effective sampling as more resources can be applied to known areas of concern and less in areas that are relatively homogeneous (*e.g.,* many stations in a confined area in the vicinity of an outfall, but fewer in a larger area further offshore). See the *Visual Sampling Plan* (VSP) callout box below for information on a helpful software developed specifically for designing statistically based sampling plans.

**Visual Sampling Plan (VSP)**

If a program needs help assessing the spatial schemes of sampling the area of interest, free software is available that can help. EPA, in conjunction with the U.S. Department of Energy and U.S. Department of Defense, has developed a program called *Visual Sampling Plan*, which provides "simple, defensible tools for defining an optimal, technically defensible sampling scheme for characterization" (PNNL, 2005). VSP, which can be downloaded from http://dqo.pnl.gov/vsp/, can be used to design a cost-effective monitoring program to meet specific statistical criteria or can be used to evaluate a current monitoring program. One benefit of using VSP to design monitoring programs is that it "provides immediate feedback of the projected results of selected statistical sampling plans by overlaying random sampling locations or grids directly onto the site map" (PNNL, 2005). In addition, it "provides graphic decision tools such as graphs of probability of hot spot detection vs. total sampling costs" (PNNL, 2005). See http://dqo.pnl.gov/vsp/ for more details.



The last strategy described in EPA (1992) is multistage, or tiered, sampling. This applies to both the areas sampled—the first stage might be the entire region, the second stage representative areas within the region, and the third stage specific areas of concern. Not only could sampling be done on one or more of the stages, but also the types of parameters measured could be spread over different stages. This is often the case with monitoring programs. There are many stations where a basic suite of measurements are collected (low effort and low costs), and then a subset where more costly and time-intensive measurements are made. An example of this is provided in Figure 11, which shows the sampling design for the MWRA water quality monitoring program. This multistage sampling design spreads out the parameters measured across multiple stations and also has different frequencies with which stations are sampled. The nearfield stations, which are within a 10-kilometer-square area of concern around the MWRA outfall, are sampled 17 times per year, while the remaining 'farfield' stations are visited only 6 times per year.

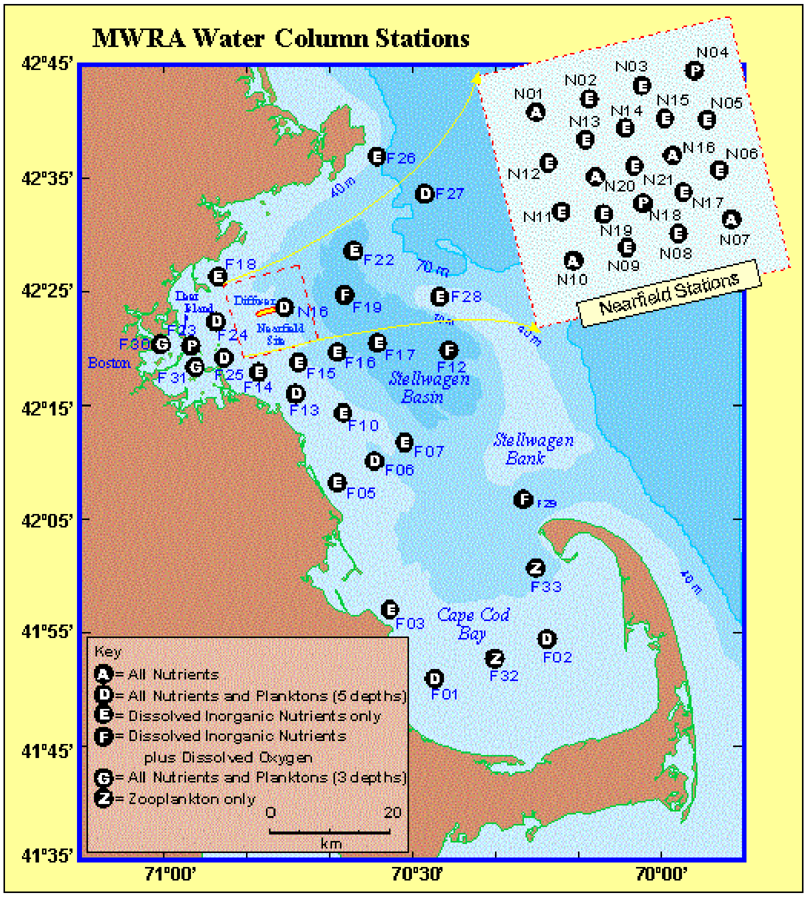
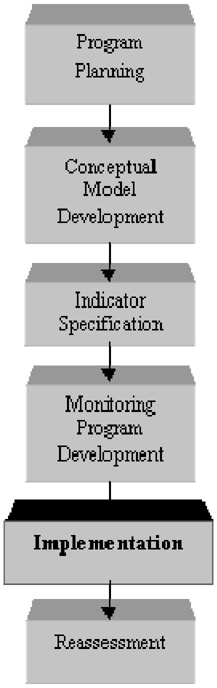



**Figure 11. Multistaged or Tiered Sampling Design of the MWRA Water Quality Monitoring Program**




# INDICATOR IMPLEMENTATION

Once indicators have been selected and a monitoring plan developed, the indicator program needs to be implemented. The process of implementing an indicator program will vary, depending on how many organizations are involved in the process and the overall goals of the program. In some instances, indicator programs are implemented by a group of organizations working toward the same goals; in a few instances, only a single organization is involved. This section focuses on some of the important aspects of implementing an indicator program that involves more than one organization, but several of these steps also apply if only one organization is implementing the program. The steps that will be covered under implementation are:

> The success of indicator development depends on how the program is implemented and involves many steps.

- Formal adoption and funding of the program
- Communication among organizations
- Monitoring plan implementation
- Data collection and analysis plans
- Reporting of indicator findings

**FORMAL ADOPTION AND FUNDING**

The first step in implementing an indicator program is getting it formally adopted by the organization(s). This means that the organization plans to do its best to implement the program using available funds. Most programs implemented by agencies and groups have been mandated in some way by an act of Congress, through a state legislature, or as part of an agreement with another organization that supplied the funding. Thus, the goals and reasons for conducting the work are set by what the group has been tasked to accomplish. In the NEP, formal acceptance by the management or TAC is required for formal acceptance of indicator implementation. The agreements sometimes include signed Memorandums of Understanding (MOUs), which specify the goals and obligations the groups have agreed to try to reach. MOUs are particularly useful when trying to implement an indicators program that stretches beyond the area of one monitoring group. It allows members of regional programs to have an exact understanding of what they have agreed to when joining the program. It also gives a regional group an understanding of what it should expect from its constituents. Each MOU is written based on the individual programs and groups involved. Either way, the important point is that someone in each organization agrees to seek the funding and staff to implement that organization’s portion of the program so that it can deliver the necessary data to reach the end result.

MOUs are particularly useful when trying to implement an indicators program that stretches beyond the area of one monitoring group.

Formal adoption of a program is important, but so is funding. It is unlikely that any single agency or organization will have enough funding to accomplish every task. One goal for many indicator programs is to reduce the amount of money spent by determining whether questions raised for that program have already been answered elsewhere and, if so, obtaining the answers to those questions from those other sources. Programs developing indicators for additional questions should plan to find the funding to cover the new work. Get buy-in on plans from agencies so that they can help fund programs. Try to find other groups that may already be monitoring the parameter and see if data can be shared. Other programs have used the development of a list of indicators to negotiate for additional monitoring funds. Lack of funds for monitoring does not have to be a reason to forgo developing indicators.

**Great Lakes Program—Management Involvement**

"The interviewees strongly suggest bringing managers into the process early on, both so that the product is as useful to them as possible, and to create a sense of ownership which might increase managerial use." (Pidot, 2003)

## COMMUNICATION AMONG ORGANIZATIONS

Communication among all parties within any program is one of the most important aspects of a successful indicators program. Communication must occur in order to develop an appropriate list of indicators, implement the monitoring plans, and report results. Successful programs result because everyone involved knows exactly what needs to be done, when it needs to be accomplished, and who is doing the work. Most importantly, if a problem arises, it is important that it be discussed early on and that all parties work to solve the issue. For instance, if an indicator is selected to monitor a situation, but someone discovers that the indicator is not properly documenting the changes as intended, this should be immediately communicated to the group so that the situation can be evaluated and money is not spent on an indicator that does not work. Another problem that must be communicated is lost or unavailable data. If the program is relying on the data to make a judgment about a portion of the environment, the entire group should be notified that the data are not available or that help is needed in collecting it. It is important that communication occur freely and openly within the program to ensure its success.

Communication among all parties within any program is one of the most important aspects of a successful indicators program.

Communication with stakeholders throughout the area is also important. This includes not only the organizations or agencies involved in the program, but also the public. Programs that demonstrate usefulness and answer questions that environmental managers and the public are interested in tend to get more funding. Therefore, from the beginning of the program, those involved with its development need to sell its usefulness. The group also needs to show timely results. Thus, the results of the indicators program need to be analyzed and reported promptly so that area managers can use the information to make decisions on next steps. Data from a couple of years past may not even be reviewed by an environmental manager or the public because it is considered outdated. Thus, the indicators program needs to develop a communication plan to ensure that information flows easily within the program and that data can be used by others outside of the program.

## MONITORING PLAN IMPLEMENTATION

As previously noted, once the indicators have been selected and a monitoring plan developed, the program needs to be implemented. In some instances, the monitoring is already being conducted under other programs and the data only needs to be collected and analyzed for their intended use. In other instances, the monitoring will need to begin in new areas or for new parameters. It is assumed that the developed monitoring plan specifies who will be monitoring which parameters and when. If it does not, then a plan should be developed. Some indicator plans may call for the collection of a number of new parameters. In these cases, depending on the funding available, a tiered approach to implementing the monitoring plans may need to be taken.

When developing a monitoring program, one important aspect is that, depending on how the indicators are selected, the indicator may or may not be monitored at that time and the program may or may not be able to afford to monitor all of the indicators at once.
A monitoring plan can still be written to include all of the indicators selected, but should point out that new indicators will be implemented as funding becomes available. A plan could also be developed to add sampling for one or more of the selected indicators to the monitoring program during each future year of sampling or at other specified times. This tiered approach can then be used to negotiate for additional funding from other programs and the state legislature.

Ongoing monitoring is essential to assess the health of ocean and coastal ecosystems and detect changes over time. More than any other measure, monitoring provides accountability for management actions (U.S. Commission on Ocean Policy, 2004).

Ongoing monitoring is essential to assess the health of ocean and coastal ecosystems and detect changes over time.

## DATA COLLECTION AND ANALYSIS PLANS

Within the monitoring plan and MOUs, statements should be included regarding how data will be collected and analyzed. Sometimes it is easy to collect and analyze the samples, but difficult to compile the final data in one place for analysis. These steps need to be part of the plan. Groups collecting data for indicators have used both centralized and distributed data locations successfully. The form selected depends on program needs, funding, and accessibility to the databases. Evaluation of secondary data is critical.

## REPORTING OF INDICATOR FINDINGS

Accurate and appropriate reporting of indicator results and data is critical to justify the program and to ensure that it is credible. Moreover, data collected and analyzed, but not properly reported, are of no value to scientists, managers, regulators, or the public.

Early in the program planning process, each indicator and monitoring project should develop a plan for reporting and communicating findings that supports the program's objectives. The plan may include a range of documents that convey the project's activities, data, and findings. These can range from brochures and flyers for public dissemination and relatively simple data reports to comprehensive interpretive reports that focus on progress and convey information to management and scientists. The plan should clearly convey the purpose of the different reports and modes of communication, their focus and content, the timeframes for publication, and distribution mechanisms.

Reporting plans differ for each program, as project objectives and communications needs vary. Reports will generally need to be customized for different stakeholders (*e.g.*, scientists, managers, the public). It is important to get the information to the stakeholders in a format they can understand and that will be useful for their particular needs. Formats such as scientific reports, report cards, science meetings, and newspaper articles and news conferences have been used successfully in different estuary programs. Each estuary program should plan on including this broad range of documentation to report on its indicators and progress.

The audience for which the indicator reporting may be intended generally falls into three general categories.

- Public. Reporting to the public requires information to be presented in a concise, public-friendly format with less technical content and with straightforward presentations. The objective is generally to keep the public informed, to conduct public relations, and to generate support for management activities.
  **Examples of Reporting to the Public**
  - "State-of-the-Bay" report
  - Report cards
  - Flyers
  - Newspaper articles
  - Web site

**Long Island Sound Study—Reporting to the Public**

"Mark Tedesco felt that the process of putting together a report that was primarily directed at the public was actually quite healthy for the project as it forced the developers to clearly and concisely describe the trends they had uncovered, and to draw some conclusions that could be easily presented." (Pidot, 2003)

**Casco Bay Estuary Partnership—Reporting to Management**

"Since many decision makers will often not read lengthy documents, it is essential, according to Diane Gould, to have a summary highlighting the report results and detailing their significance directed specifically at policy makers and managers. (Pidot, 2003)

**Great Lakes Program—Reporting Status and Trajectories**

"The assessment for each indicator…provide both a 'status' component (Good, Fair, Poor, Mixed) and a 'trajectory' component (Improving, Unchanging, Deteriorating, Undetermined)." (SOLEC, 2004)

- Management/Regulators. Reporting to program management and environmental regulators generally includes providing both highly concise summaries and "light" technical reporting. The objective is generally to provide updates that directly relate to past management actions by assessing the progress and success of management activities, and to provide recommendations and justification for future management activities, along with supporting information and data.
  **Example of Reporting to Management/Regulators**
  - "State-of-the-Bay" report
  - Progress report
  - Report cards
  - Technical summaries

- Scientific Uses. Reporting for scientific use generally includes scientific, technical interpretive reports, which provide data that can be used by the scientific community for detailed analysis. The objective of these reports is to make data available and develop an in-depth understanding of the environmental conditions—an understanding which, in turn, may also be used for public and management reporting.
  **Examples of Reporting for Scientific Uses**
  - Comprehensive data reports
  - Interpretive reports, with data appendices
  - Web sites with databases
  - Peer-reviewed papers and publications

The following sections are intended to provide broad guidance on how to make program findings available and the level of detail that is appropriate in various reports. They are not intended to prescribe ways to write a specific type of technical report or other document, or how to summarize indicator information for the public. No format or approach fits all programs. Fortunately, many programs and organizations are already actively reporting results from their environmental studies. The reporting and communication from these other programs and organizations can serve as excellent examples of reporting that can be considered, and modified to meet the needs of a specific program Again, each program should have its own well-considered reporting plan, to address specific well-defined objectives of the program. Some programs will emphasize scientific reporting of the results, while other may be more heavily weighted towards informing the public and public outreach. In the aggregate, experience from many programs demonstrates that successful programs incorporate the full spectrum of reports and written materials for communication to scientists, managers/regulators, and the public. Regardless of report type, a process of conceptualizing, outlining, annotating, drafting and polishing each report should be practiced.

### Reporting to the Public

There are many and varied examples of effective reports that convey the state of an estuary to the general public. Examples include the *State of the Bay* reports (Figure 12) by the CBEP (Casco Bay Estuary Partnership, 2005a) (http://www.cascobay.usm.maine.edu/SOTB.html); the Pulse of the Estuary reports by the San Francisco Estuary Institute (SFEI, 2005) (http://www.sfei.org/rmp/pulse/2005/RMP05_PulseoftheEstuary.pdf); and the State of Boston Harbor reports by the MWRA (2002) (http://www.mwra.state.ma.us/harbor/enquad/pdf/2002-09.pdf). These types of reports are useful for communicating to those in the public who are actively involved in issues related to the program and wish to receive more information than the general public. In many cases, these reports have helped define the key issues and been used to form the basis of more technically sophisticated reports to management and the scientific community.

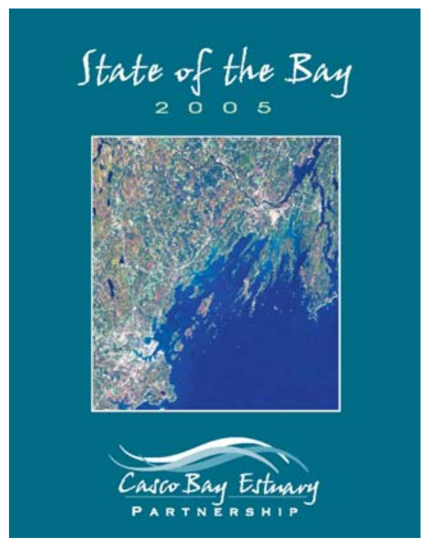



**Figure 12. Casco Bay Estuary Partnership 2005 State of the Bay Report**

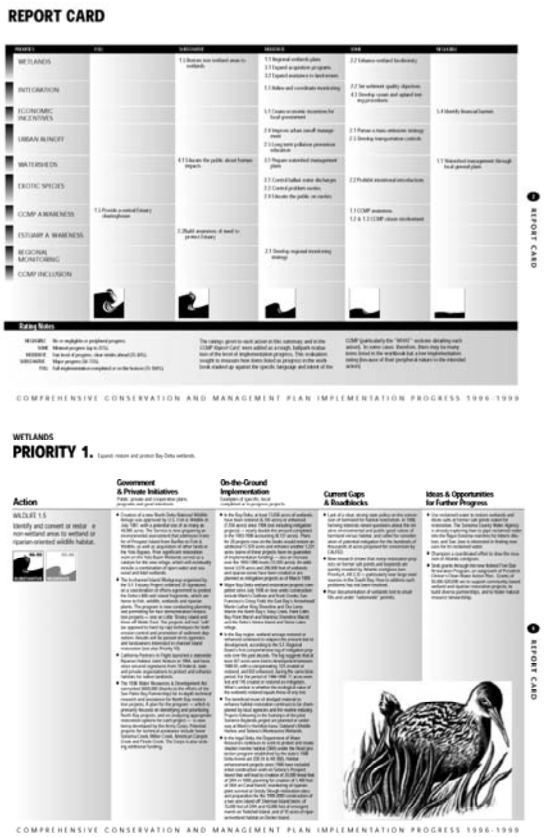



**Figure 13. San Francisco Report Card 1996-1999**

Report cards (San Francisco Estuary Project, 1999) (Figure 13) can be a valuable way to summarize program actions and related indicator responses. However, they can become tedious and carry the risk of oversimplification, which may result in misuse of the information presented. Thus, care must always be taken when simplifying information. Moreover, simplification must not happen at the expense of accuracy and should recognize the potential for misinterpretation. In addition to report cards, informational flyers can be highly effective in summarizing specific components of a program in a simple, eye-catching format that can reach a wide audience. Programmatic summaries (*e.g.*, annual updates) are also effectively communicated through concise flyers. Newspaper articles, news releases, and news briefings are other means of communicating to the public, as long as care is taken to ensure accurate representation of the information.

Finally, well-designed program web sites can be an excellent mode of communicating to the public, providing updates on activities, and providing an archive for access to historical documents. An example of an effective web site is the Chesapeake Bay Program's site (http://www.chesapeakebay.net/). Other examples include web sites by the MWRA (http://www.mwra.state.ma.us/), the St. Johns River Water Management District (http://sjr.state.fl.us/), the San Francisco Estuary Institute (http://www.sfei.org/), and the CBEP (http://www.cascobay.usm.maine.edu/).

***Developing Public Materials.*** Primary among the challenges associated with developing public materials is ensuring accurate communication of information in a manner the general public can understand. The suggested writing level for these reports is at an 8th grade level reading ability.

Often estuary program staff are challenged to find creative ways to present information. When developing public materials, it is important to focus on answering those questions that are foremost on the public's mind in straightforward language and with concise images. Reports for the public should emphasize, but should not be limited to, addressing concerns around the "what and why" questions, and less on "who, when, and how." For example:

- Is the water safe to swim in or drink? What has improved or gotten worse? Why?
- Is the fish/shellfish safe to eat? If why not, what can be done about it?
- Have the changes that estuary programs have requested worked toward defined goals? For example,
  - Have fertilizer reductions and sewerage plant upgrades focused at reducing nutrient levels worked towards improving DO levels in the estuary?
  - When the dam was demolished, did the fish return upstream?
  - Have the rebuilt wetlands or open lands that have been conserved helped the estuary program in any way?
- What needs to happen next to improve the estuary? How can the public help (besides providing more money)?

While many in the public primarily are interested in whether the financial investment and effort they have put in to save the estuary has merit, some will want more in-depth reports. They often want to know that there is a plan to move forward.

Suggested forms for public reports have been conveyed previously. How that information is communicated also must be carefully considered. Any graphs used should be simple and easy to follow. Simple one-dimensional bar or line graphs seem to be the best at showing changes over time. Limited and carefully prepared information on statistical considerations can be effective (*i.e.*, indicating a trend is statistically significant rather than a detailed explanation of the statistical methods). Pictures, diagrams, and artist renditions are also helpful in documents prepared for the general public (and also for more technically enlightened audiences), especially when describing various estuarine species and habitat restoration projects. Text should describe the problem's past history, the current situation, and the required actions to be taken to reach the "optimal" or a desired end. If the project is long-term, developing mid-progress milestones that can be celebrated will help maintain public interest and involvement.

Questions invariably arise on how to best handle questions from the news media. Depending on the circumstances of the interaction, but especially for formal press briefings or news releases, information sheets should be prepared in advance and should include details on the information being conveyed. This will help ensure that journalists have the correct numbers and other pertinent information, rather than having them rely solely on their notes.



**Reporting to Management/Regulators**

Different types of state-of-the-bay and state-of-the-estuary reports are often excellent guides for developing written and oral reports to management/regulators (Casco Bay Estuary Partnership, 2005a; SFEI, 2005; MWRA, 2002), and may by themselves be effective for communicating information. In contrast to reports for public consumption, reports prepared for management/regulators often include recommendations and require technical and other justifications to support these recommendations. The reports prepared for managers generally have more detail and content than public reports and support the more public-oriented reports. The level of detail provided in management reports will also vary, depending on the managers'/regulators' oversight responsibility. One example of such a report is the *5 Year Progress Report: 2000-2004*, prepared by MWRA for the governor and legislature of Massachusetts (MWRA, 2006) (Figure 14). Report cards (see Figure 13) can be valuable for providing summary-level information to management/regulators but have the same limitations and risks associated with disseminating such materials to the public.


**Figure 14. MWRA 5 Year Progress Report 2000-2004**

***Developing Management-/Regulator-Focused Reports.*** Management/regulator-focused reports address similar questions as those raised in public reports. They tend to provide more details and supporting information and focus on answering questions regarding whether environmental conditions or responses conform with an agency's mission or goals or a manager's oversight function. Reports for managers/regulators should address "what, when, where, and why" concerns and also address the "how" (either measurement, interpretive, or environmental) issues pertinent to the program's objectives. Depending on the specifics of the program, consideration of "who" (*e.g.*, responsible parties, ecological entities) may come into play. This means there normally needs to be an accounting of objectives as they relate to the agency's overall goals, the tasks that have been completed or started to date, the amount of funding that has gone toward these effort, and the status toward reaching the final goal. For estuaries within the NEP, this may mean linking progress made over a certain timeframe back to the specific goals outlined in the CCMP.

### Reporting to the Scientific Community

The different types of state-of-the-bay and state-of-the-estuary reports can also be an excellent resource for the scientific community, and often form the basis for further in-depth analysis. Conversely, in-depth scientific reports and peer-reviewed papers often validate the content of the higher-level interpretive and synthesized reports prepared for managers and the public. Typically, the flow of reports is from detailed scientific reporting to the higher-level syntheses and integration at the management and public levels. Regardless, each of these audiences has influence over the content and direction of reports across the entire program.

Generally, science-based interpretive reports provide the details of the monitoring, research, and assessments that take place within the program. While there are no standard formats for interpretive reports, each should include a section that introduces the report's subject and objective(s), describes the method(s) used to collect and analyze the data, presents the results and findings, discusses the results, and develops conclusions. A concise executive summary is a valuable tool for these reports, as they help inform managers and the interested public. Depending on the project, the reports should incorporate recommendations regarding changes to the project/program and further studies. The level of detail in a report depends on where and how it will be published. An interpretive report often includes in-depth considerations, while a peer-reviewed paper provides a succinct presentation of the findings, with the degree of detail depending greatly on the publisher.

Interpretive reports are also developed with many different formats, including highly graphical and “reader-friendly” formats that, in many ways, are an expansion of a state-of-the-bay report. One good example of such a report is the “Baywatchers II” report, prepared by the Coalition for Buzzards Bay (Buzzards Bay Project National Estuary Program, 1999). Examples of technical reports with additional technical rigor include the *National Coastal Condition Report II* (EPA, 2005b), the *State of the Estuary: A Report on Conditions and Problems in the San Francisco/Sacramento-San Joaquin Delta Estuary* document (San Francisco Estuary Project, 2002), and the *Regional Monitoring Program (RMP) for Trace Substances* report (SFEI, 1999). Technical reports are particularly valuable for the rest of the scientific community when raw and summarized data are included as appendices. Well-designed program web sites can also be valuable to the scientific community, both in terms of being a repository for documents and also for housing and making available for general use data that may be accessed and downloaded by scientists.

***Developing Scientific Community-Focused Reports.*** Unlike public- and management-focused reports, reports focused toward the scientific community are geared specifically toward reporting, interpreting, and synthesizing data in depth. These reports typically address in detail the “who, what, when, where, how, and why” questions. Scientists want to know everything, from the methods used to collect and analyze the samples, to how the data were treated for interpretation, to how the new data fit into scientific theories, hypotheses, and previously obtained data. These reports are normally highly technical, with figures and tables that support presentation of the findings, discussion, and conclusions. These reports are equally important as (some would say more important than) the public and management reports because they form the basis of future evaluations and conclusions regarding the overall condition, variability, and changes in the estuary. Reporting the actual data in these scientific reports is also crucial for future data comparisons. These reports often form the basis of peer-reviewed publications. Estuary programs should strive to ensure that reports prepared in support of their program maximize the development of information from the data collected.

Authors of scientific and technical reports that address environmental indicators should clearly communicate how the data from each selected indicator is linked to a specific outcome, represents broader environmental concerns, and supports decision-making. This documents how an indicator is useful to the estuary program and how it provides the necessary information to the program. If the authors and an indicator do not provide the necessary information, the link between the parameters and the interpretive results may result in estuaries spending unnecessary funds.

**Report Data Quality/Timeliness**

Inaccurate data and interpretation can lead estuary programs to make incorrect decisions based on those data or findings. It does not matter whether the report is for the public, management, regulatory, or scientific community, each report should be prepared carefully and should be based on accurate and complete data. An effective means of developing reports that meet program expectations is to have the authors develop an outline (preferably annotated) for each report in advance. Experience has also found that each report should be developed under a known level of data QA and interpretation verification (*e.g.*, peer review). To this end, technical, QA, and editorial reviews should be defined for each report and practiced by the estuary program.

It is also important that the reports be generated in a timeframe that will allow their findings/conclusions to be useful to management, regulators, and decision-makers. Data that is reported years after it has been collected can be useless if major changes are occurring within the estuary. Good practices are to have data available within 6 to 12 months of sample collection and interpretive reports completed within 1 year. An excellent example of the effective reporting schedules can be found under the MWRA Harbor and Outfall Monitoring Project, where data are required to be available within 3 months of collection and interpretive reports within 6 to 8 months of the end of the monitoring year. Such reporting enables implementation of preventative or corrective measures when a problem is just beginning to develop, not years later. Thus, it is important that estuary programs include in their reporting plans a schedule for reporting data. Another example of timely reporting is the 2006 draft Assessment Strategy developed for the Florida Everglades Restoration Monitoring and Assessment Plan. At a minimum, programs should provide data reports and preliminary findings at least every 2 years. This will provide the data needed for scientists to make decisions but will allow the program a little longer period (no more than every 5 years) to develop the larger programmatic or public reports.

The role of any report card, newsletter, management overview, or estuary data report developed is to make sure it conveys the intended message to the intended audience. A report that is useless to its audience will ultimately be useless to the estuary program that developed it.

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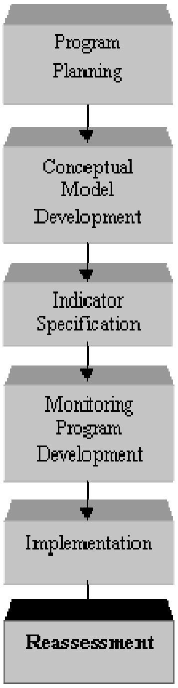
# INDICATOR REASSESSMENT




Most programs that develop a suite of indicators spend months, if not years, trying to select the most representative parameters and develop a robust monitoring program to support them. However, the process does not stop once the indicator measurement program is implemented. Continual assessment and reassessment of the performance of the program is the necessary next step. Reassessment of an indicator program ensures that the indicators are meeting expectations.

> It is important to reassess indicator programs a minimum of every 5 years to ensure that they are meeting expectations.

Reassessing an indicator program is not always a simple or clear-cut process. Some indicators answer specific questions (*e.g.,* monitoring DO levels to determine long-term increases/decreases in the water column or compliance with a state standard). Other indicators address the status of a broader question that cannot be easily answered (*e.g.,* monitoring catch of a species to estimate fish stock size). Even though an indicator was carefully selected, it is possible that it does not adequately address the question. For example, if a program is specifically concerned with metals inputs to sediment, a possible indicator may be to measure the amount of two or three key metals in the sediments of an area over time. If, after a period of time, the monitoring program finds that the concentration of metals in sediments is not changing as expected, concerns are raised as to why. In this case, the program needs to reassess the appropriateness of the metals monitored or conduct additional studies to determine why expected changes did not occur. These could be related to uncertainty in loading, physical changes in the sediment, geochemical processes, or the inappropriate selection of the indicator metal. Thus, the program needs to reassess and should potentially select a different indicator to effectively track changes in metals input to the sediment.

Each program should develop a reassessment plan that is designed to review the usefulness of the selected indicators. The reassessment should be conducted at a least every 5 years to ensure that funds are being spent economically and indicators are answering the intended questions. The initial step in the reassessment process is to review the current issues of importance. This review should allow issues that have been addressed to be removed, concerns to be modified, and new issues to be added.

**Galveston Bay NEP—Indicator Refinement**

"By consensus, the [Galveston Bay Council] will determine the final official set of indicators to be used by GBEP for inclusion on reports and public outreach materials. This is not to say that further refinements will not take place in the future as better datasets are found, monitoring programs improve or expand, and advances in research are made." (GBEP, 2004)

The next step in the reassessment process is to evaluate the questions the program must answer. Previous questions should be examined to determine whether they have been answered. New issues should generate specific questions. For the issues and questions that are still relevant, the next step is to determine whether the corresponding indicators remain valid. If so, the program should confirm the adequacy of the monitoring plan. If, during the review process, issues and questions were added, or if an indicator was no longer valid, the program needs to develop indicators appropriate to the questions and revise the monitoring plan. The key to any program review is relevant and recent information on the issues and questions. This includes selecting a new parameter whose measurement may be more cost-effective, or revising a methodology to provide a better understanding of the issue. Using outdated information may result in incorrect choices for the most appropriate indicators. Finally, the last step in the reassessment process is to implement the indicator program and revised monitoring plan.

# SUMMARY

Since the 1960s, the necessity of preserving and protecting our nation's coastal waters has been recognized. The nation has worked diligently to enact legislation (the CWA and CZMA) and develop programs (*e.g.*, NEPs and the NERR system) and initiatives to protect our coastal environment. As a result, plans and environmental assessment programs have been developed to prevent further degradation and address ways to improve ecosystems.

In 1993, GRPA called for "Federal agencies to undertake efforts to measure their performance and the effectiveness of their programs" (The Heinz Center, 2003). In response, a series of indicators were developed that could track the effectiveness of these programs and provide quantifiable measures that demonstrate the response of our nation's coastal waters. Since the enactment of GPRA, programs such as EPA's NCA have been implemented to measure improvement of coastal estuaries nationwide.

In support of programs and initiatives focused on preserving, protecting, restoring, and improving estuaries, EPA has developed this "Indicator Development for Estuaries" manual to help further those efforts. As previously stated, the intent of this manual is to provide an interactive process, considerations, and lessons learned to assist coastal and estuarine programs, including the NEPs, in ecological and environmental indicator development on a local, regional, or national level.

To summarize this manual and provide assistance to programs, the following checklist is provided as a supporting tool for indicator development, covering the important areas of program planning through implementation and reassessment. Additionally, three case studies have been included in Appendix A to demonstrate how local and regional programs have conducted their indicator development process.

Finally, Appendices B and C are included as supplemental information to assist programs with their indicator development. Appendix B lists some of the indicators chosen by various programs, including NEPs. Appendix C lists some available resources on indicator development. This list is not meant to be all inclusive, but rather a sampling of available documents.

| INDICATOR DEVELOPMENT CHECKLIST | |
|---|---|
| **Check Box** | **Steps/Considerations** |
| | **Program Planning (unless already conducted as part of the estuaries CCMP development)** |
| | • Decide on the spatial scale of the program |
| | • Convene a steering committee |
| | • Reach agreement or consensus on the purpose and need for indicators |
| | • Identify the key issues |
| | • Develop management objectives |
| | • Define questions to be answered by indicators |
| | • Conduct baseline assessment on each issue |
| | **Conceptual Models Development** |
| | • Determine the type of conceptual model to use |
| | • Develop conceptual models for each issue |
| | **Indicator Specification** |
| | • Collect information on monitoring programs being conducted in the area (*e.g.*, who, what, where, when, how often, using what methods) |
| | • Determine how indicators should be selected (*e.g.*, based on parameters already being monitored; scientifically sound parameters) |
| | • Develop possible indicators list |
| | • Select indicators to answer key questions based on the following criteria:<br>- Conceptual relevance/soundness—*Is the indicator relevant to the assessment question and to the resource at risk? Scientifically sound?*<br>- Feasibility of implementation (current and future)—*Are the methods for long-term sampling and measuring the environmental variables technically feasible, appropriate, and efficient for monitoring use?*<br>- Response variability—*Are human errors of measurement and natural variability over time and space sufficiently understood and documented?*<br>- Interpretation and utility—*Will the indicator convey information on resource conditions that is meaningful to environmental decision-makers? Is the indicator currently monitored and likely to be monitored in the future? Sustainable indicators.* |
| | **Monitoring Plan Development and Modification** |
| | • Develop or revise current monitoring plan to incorporate selected indicators |
| | • Identify indicators critical to the evaluation of monitoring program performance |
| | • Design and implement data management plan |

| INDICATOR DEVELOPMENT CHECKLIST (Continued) | |
|---|---|
| **Check Box** | **Steps/Considerations** |
| | **Indicator Implementation** |
| | • Formally adopt program |
| | • Obtain funding |
| | • Initiate communication among organizations |
| | • Convene an implementation oversight committee |
| | • Develop a data analysis and assessment plan |
| | • Implement the monitoring plan |
| | • Report indicator findings |
| | **Indicator Reassessment** |
| | • Reassess selected indicators a minimum of every 5 years |

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# APPENDIX A-1
# BARATARIA-TERREBONNE PROGRAM CASE STUDY

## PROGRAM OBJECTIVES AND HISTORY

In September 1990, the State of Louisiana and the U.S. Environmental Protection Agency (EPA) developed a cooperative agreement and formed the Barataria-Terrebonne National Estuary Program (BTNEP). The goal of the program is to launch a collaborative effort that focuses government, private, and commercial resources toward the protection of the basins.

One of the first actions the program initiated was the development of a Comprehensive Conservation Management Plan (CCMP), which detailed specific action plans to promote and preserve the Barataria-Terrebonne Estuary System (BTES). The plan identified issues, assessed status and trends, developed strategies, recommended corrective actions, and implemented and funded plans. Overall, the BTNEP CCMP outlined 12 goals:

- Preserve and restore wetlands and barrier islands
- Realistically support diverse, natural biological communities
- Develop and meet water quality standards that adequately protect estuarine resources and human health
- Promote environmentally responsible economic activities that sustain estuarine resources
- Generate national recognition and support
- Implement comprehensive education and awareness on and awareness programs that enhance public involvement and maintain cultural heritage
- Create an accessible, comprehensive database with interpreted information for the public
- Create clear, fair, practical, and enforceable regulations
- Develop and maintain multi-level, long-term, comprehensive watershed planning
- Be compatible with natural processes
- Forge common-ground solutions to estuarine problems
- Formulate indicators of estuarine ecosystem health and balance estuary use (BTNEP, 1996).

Along with these goals, BTNEP identified seven priority problems causing impacts to the estuary.

1. Hydrologic modification
2. Sediment reduction

3. Habitat loss
4. Eutrophication
5. Pathogen contamination
6. Toxic substances
7. Living resources

When the CCMP was approved by the EPA, an organizational structure was established for the implementation of the program. This included performing day-to-day tasks, reporting information to the public, making policy decisions, and developing meetings and workshops. In 2001, EPA requested that all National Estuary Programs (NEPs) develop indicators to measure the progress of their programs. Based on this request, BTNEP began to develop an indicator set.

## INDICATOR DEVELOPMENT PROCESS

### Steering Committee Involvement

BTNEP began the indicator development process by forming a planning committee with representatives from Federal, state, and university participants who volunteered their time toward the effort. The committee developed a workshop and formulated background materials. The background workshop materials included goals and objectives of the workshop, initial focus questions, and an indicator selection matrix. The planning committee included the following participants:

- Dean Blanchard, BTNEP
- Rex Caffey, Louisiana State University Agricultural Center
- Rod Emmer, Federal Emergency Management Agency (FEMA)
- Dianne Lindstedt, National Marine Fisheries Service (NMFS)
- Nancy Rabalais, Louisiana Universities Marine Consortium
- Kerry St. Pé, BTNEP
- Greg Steyer, U.S. Geological Survey (USGS)
- Glenn Thomas, Louisiana Department of Wildlife and Fish
- Monica Young, EPA
- Brent Ache, Battelle

### Identify the Purpose and Need for Indicators

BTNEP's indicator development effort focused on the following purpose and need.

> **Purpose:** To develop indicators to periodically review and report the vital signs of the BTES.
>
> **Need:** BTNEP needs to protect, restore, and sustain the BTES for today and for future generations. Indicators are needed to measure the amount of success BTNEP has accomplished toward these goals.

**Issues and Management Objectives**
The issues and management objectives were previously outlined in BTNEP's CCMP. There were then used to develop indicators.

**Baseline Assessment of Each Issue**
Prior to the workshop, the planning committee created an indicator matrix. The matrix was categorized by seven priority problems, and indicators were ranked on level of data availability as high, medium, or low. The matrix also included whether and what type of data were available to support the indicator, as well as the major pro and con considerations for choosing the indicator.

**Indicator Development Workshop**
On June 13-14, 2001, an indicator development workshop was held in Gonzales, Louisiana. The workshop assembled individuals with a vested interest in monitoring or managing BTES who could recommend a suite of indicators that best represents the environmental condition of BTES while also being meaningful to the estuary's residents and public officials.

Workshop participants were separated into four breakout groups for indicator development discussions. Three of the groups were based on the seven priority problems; the fourth group addressed regional demographics, sustained recognition, citizen involvement, and economic growth. The four breakout groups addressed the following issues:

- Hydrologic modification, reduced sediment flows, habitat loss
- Changes in living resources
- Eutrophication, pathogen contamination, and toxic substances
- Quality of life: community, economy, and awareness

Each breakout group was given the same set of goals to develop indicators. They were also instructed to identify indicators to address the specific focus questions. The goals were to:

- Develop a suite of ~20 indicators, maximum, that were both meaningful to the target audience and supported by datasets produced under the current monitoring efforts, that describe:
  - Key components representative of ecological condition related to the seven CCMP priority problems.
  - Key demographic, economic, and awareness components of the region's natural resource-based economy and quality of life.
- Identify potential indicator opportunities based on planned future monitoring in the BTES.
- Identify critical indicator (and associated monitoring) gaps and needs for the BTES.
- Discuss indicators based on the Pressure-State-Response (PSR) framework, which uses stressors, condition, and management actions to categorize environmental indicators.

- Discuss indicator presentation format to present indicators in the indicator report (Battelle, 2001).

**Indicator Specification and Monitoring**

Indicators were developed based on the focus questions and availability of monitoring data; however, the indicators selected were not necessarily supported by a current dataset or monitoring program. Participants were asked to discuss indicators that either specifically addressed a focus question or were supported by monitoring data. Therefore, three categories were established to group indicators: Supported, Future Indicator, and Gap/Need.

- Supported: Potential indicator by existing status and trends monitoring and assessment.
- Future Indicator: Potential indicator will be supported by planned future status and trends monitoring and assessment.
- Gap/Need: Potential indicator not supported by existing or planned status and trends monitoring and assessment (Battelle, 2001).

The suite of indicators developed at the workshop constitutes the best indicators, currently supported by existing monitoring programs and associated datasets. All indicators selected followed the indicator selection criteria:

**Valid**

- Relevant: State, pressure, or response indicators relevant to one or more of the seven CCMP priority problems (or the region's natural resource-based economy and quality of life, as addressed in the CCMP).
- Appropriate Scale: Representative of the entire BTES (or some significant sub-unit) over an appropriate time scale.
- Sensitive / Responsive: Natural variability can be reasonably explained; quickly reflects changes in the environment (Battelle, 2001).

**Understandable**

- Meaningful: Interpretable and meaningful to BTES residents and their political representatives (*i.e.*, simple presentation format).
- Trend: Demonstrates or will demonstrate a trend (increase, decrease, or stable) from a reference condition.
- Measurable: Periodic assessment, on the scale of 1 to 2 years, is supported (Battelle, 2001).

**Available**

- Supported (or Future): Supporting dataset is long-term trend monitoring, immediately usable, and with a reasonable expectation that monitoring will continue.
- Data Quality: Supporting dataset quality is acceptable.
- Data Provided (Cost Issue): Dataholder agrees to provide the simple data aggregation or the analyzed/modeled results of the dataset (Battelle, 2001).

**Indicators Developed**
Below is a listing of the focus questions and indicators that participants identified based on available data in the region (Battelle, 2001).

***Hydrologic Modification, Reduced Sediment Flows, and Habitat Loss Indicators***

Question 1. Are we losing land in the BTES, and where?
Indicator(s):
- Land-water ratios in the BTES by fresh-, brackish-, intermediate-, and saltmarsh habitat type over time.

Question 2. Why are we losing land in the BTES?
Indicator(s):
- Marsh health and vigor (above and below ground)
- Flooding frequency and duration
- New vertical accretion
- Nutria damage

Question 3. Are fish and wildlife habitats being protected and restored?
Indicator(s):
- Number of acres restored in the BTES over time.

***Changes in Living Resources Indicators***

Question 1. Are fish and wildlife populations healthy?
Indicator(s):
- Shrimp abundance in the BTES over time (one of the three significant commercial species, or combined harvest).
- Oyster abundance on public seed grounds in the BTES over time.
- Red drum abundance in the BTES over time.
- Community diversity in the BTES over time (trawl samples).
- Mottled duck abundance in the BTES over time.
- Christmas bird counts over time (which combines both migratory and non-migratory bird species).
- Freshwater catfish abundance in the BTES over time.
- Largemouth bass abundance in the BTES over time.
- Alligator nests in the BTES over time.

Question 2. Are invasive species a problem?
Indicator(s):
- Nutria population and marsh damage estimates in the BTES over time.
- Cost of invasive species control in the BTES over time.

Question 3. Are seafoods safe to eat?

Indicator(s):

- Seafood safety indicator, to be selected from (1) area of oyster closures in the BTES over time; (2) health department fish consumption advisories in the BTES over time; or (3) mercury in edible fish tissue data collected in the BTES.

Question 4. What threatened or endangered species can we use to assess the health of our estuary?

Indicator(s):

- Bald eagle population and nests in the BTES over time.
- Brown pelican population and nests in the BTES over time.

***Eutrophication, Pathogen Contamination, and Toxic Substances Indicators***

Question 1. Are our waters healthy?

Indicator(s):

- Chlorophyll-*a* in the BTES over time.
- Area of dead zone (off coastal Louisiana) over time.
- Number of petroleum spills reports in the BTES area over time.

Question 2. Are pathogen and toxic substance concentrations increasing or decreasing?

Indicator(s):

- Fecal coliform bacteria concentrations at key recreational sites in the BTES over time.
- Fecal coliform bacteria concentrations at key oyster growing water sites in the BTES over time.
- Number of pumpout and dumpstation facilities in BTES over time.
- Number of fish advisories for mercury in the BTES over time.
- Atrazine concentration in BTES surface waters over time.

***Quality of Life: Community, Economic, and Awareness Indicators***

Question 1. How are natural-resource-based business patterns changing?

Indicator(s):

- Value of tourism in the BTES.
- Value of citrus, row crop, cattle, sugar cane agriculture in the BTES.
- Value of oil and gas infrastructure in the BTES and value of product moved through the BTES over time.
- Aggregate dockside value of commercial fisheries landed in BTES parishes over time and number of commercial fishing licenses over time.
- Aggregate landings of recreational fishing in BTES parishes over time.
- Number of recreational fishing guide/charter licenses in the BTES parishes over time.

Question 2. How are environmental changes affecting our quality of life and community's sustainability?

Indicator(s):

- Number and duration of unacceptably high-chlorides in source (input) water to regional drinking water plants (at least Lafourche Parish and Terrebonne Parish plants) over time.
- Value of flood insurance claims in BTES parishes from FEMA over time.

Question 3. How is public support for a healthy estuary changing?

Indicator(s):

- Number of educational brochures distributed annually by the BTNEP over time.
- Number of volunteers participating in the following four programs annually: beach sweep, storm drain stenciling, marsh grass planting, Christmas tree restoration over time.

**Reporting Indicator Findings**

The findings from the workshop were incorporated into an indicators report (2002), which was distributed to the public, Federal, state, and local agencies. Furthermore, BTNEP plans to release an updated indicators report every 3 years, and it is expected that the indicator list will grow over time as more monitoring data become available.

**Revision of the Monitoring Program and Indicators**

Prior to development of the indicator report, the focus questions were narrowed down to 10 questions rather than the 12 previous questions developed at the workshop. From the workshop, 38 indicators were developed. However, BTNEP narrowed the indicators to 34, which were reported in the indicator report. BTNEP plans to reassess its indicator program every 5 years.

The information noted throughout this case study came from the following documents and discussions with BTNEP staff.

Battelle. 2001. Workshop Summary: BTNEP Indicators Development Workshop, Holiday Inn, Gonzales, Louisiana, June 13-14, 2001. A publication of the Barataria-Terrebonne National Estuary Program, Thibodaux, Louisiana, June 2001,

BTNEP. 1996. The Executive Summary: Program objectives, action plans, and implementation strategies at a glance. CCMP – Part 1 of 4. June 1996. Available from http://www.btnep.org/default.asp?id=30.

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# APPENDIX A-2
# NEW HAMPSHIRE ESTUARIES PROJECT CASE STUDY

## PROGRAM OBJECTIVES AND HISTORY

The New Hampshire Estuaries Project (NHEP) was formed in July 1995 when the State of New Hampshire and the U.S. Environmental Protection Agency (EPA) developed a cooperative agreement. The program's mission is to protect, enhance, and monitor the environmental quality of the state's estuaries.

The first task that the NHEP initiated was the development of a Comprehensive Conservation Management Plan (CCMP). The plan identified the goals and objectives of the NHEP, assessed status and trends, included research and technical development needs, outlined plan implementation, and identified funding. Overall, the NHEP CCMP (2000) focused on five areas of concern:

- **Water Quality:** Identify and eliminate or reduce pollution sources that degrade water quality.
- **Land Use, Development, and Habitat Protection:** Work with municipalities within the estuaries watershed to ensure that land use policies and new developments consider impacts on estuarine water quality and habitats.
- **Shellfish Resources:** Open shellfish beds that have been closed due to pollution or lack of testing to certify shellfish safety for human consumption.
- **Habitat Restoration:** Protect and restore viable and diverse habitats in the estuarine region.
- **Outreach and Education:** Raise awareness and engage communities, government agencies, organizations, and individuals in responsible use and stewardship of the estuaries.

The CCMP was completed in 2000. The plan presented goals, objectives, and specific actions to protect, enhance, and monitor New Hampshire's estuarine resources. The plan also included a process for implementing the actions, which included organizing tasks, reporting information to the public, making policy decisions, developing meetings and conferences, and securing funds. In 2001, EPA requested that all National Estuary Programs (NEPs) develop indicators to measure the progress of their programs. Based on this request, NHEP began to develop an indicator set.

## INDICATOR DEVELOPMENT PROCESS

### Technical Advisory Committee Involvement

During the fall and winter of 2001-2002, the NHEP Coastal Scientist and Technical Advisory Committee (TAC) developed a suite of environmental indicators to track progress toward the NHEP's management goals and objectives.

The first step toward developing environmental indicators for the NHEP was to translate the goals and objectives from the management plan into questions that could be answered by environmental monitoring. For example, the management plan objective, "Achieve water quality in Great Bay and Hampton Harbor that meets shellfish harvest standards" was translated to the question, "Do NH tidal waters meet fecal coliform standards of the NSSP for approved shellfish areas?" For some management objectives, multiple monitoring questions were identified due to the complexity of the factors affecting attainment of the goal. For example, the objective related to achieving water quality that meets shellfish harvest standards depends on reducing both dry-weather and wet-weather pollution sources. Therefore, two additional monitoring questions were developed: "Has wet weather bacterial contamination changed significantly over time?" and "Has dry weather bacterial contamination changed significantly over time?"

The next step was to refine the monitoring questions into a suite of environmental indicators. The difference between environmental indicators and monitoring questions is that indicators have precise definitions of their hypotheses, statistical methods, measurable goals, data sources, data quality objectives, and data analysis methods. Establishing these definitions ensures that the indicators will be interpreted consistently and clearly. As indicators were proposed, they were vetted using the EPA's Office of Research and Development (ORD) guidelines for ecological indicators (EPA, 1999) to determine their level of development.

Finally, the NHEP Coastal Scientist gathered data and prepared a series of indicator reports. The process of working with the data provided more insight and opportunities to refine the indicator definitions.

### Purpose and Need for Indicators

NHEP needed environmental indicators for two purposes. First, indicators are used to report on progress toward management plan goals and objectives. Second, the indicators are used to report on status and trends in water quality and estuarine resources through periodic "State of the Estuaries" reports to the public and other coastal stakeholders.

### Indicator Specification and Monitoring

The TAC followed the ORD guidelines (EPA, 1999) as guidance for developing indicators. The guidelines included:

- **Conceptual Relevance—**Relevance to both the ecological condition and a management question.

- **<u>Feasibility of Implementation</u>—**Feasibility of methods, logistics, cost, and other issues of implementation.

- **<u>Response Variability</u>—**Exhibition of significantly different responses at distinct points along a condition gradient.

- **<u>Interpretation and Utility</u>—**Ability to define the ecological condition as acceptable, marginal, or unacceptable in relation to the indicator results.

**Indicators**

According to the NHEP's monitoring plan (2004), the indicators were classified into three tiers based on the above criteria and number of criteria that were met. The three tiers were developed to better define which indicators would answer the monitoring questions stated in the monitoring plan, which in turn report on the progress toward the management objectives.

- **<u>Environmental Indicator</u>—**A parameter that meets all four ORD criteria for developing indicators. The measurable goals set for these indicators are tied to the management goals and objectives. For cases where "baseline" was the measurable goal, the best available baseline data were used, not just data from 2000 (the start date for implementation of the NHEP management plan).

- **<u>Supporting Variable</u>—**A parameter that meets the first three of the ORD criteria but cannot be used to interpret environmental or ecological quality independently. Some of these variables were still considered essential to the NHEP monitoring plan because they provided important information for interpreting trends in other indicators. The difference between supporting variables and environmental indicators is that supporting variables lack measurable goals.

- **<u>Research Indicator</u>—**A parameter that meets the first ORD criteria for being "conceptually relevant" but lacks clear methods and means of interpretation at the present time. Some research indicators were retained in the monitoring plan because they have the potential to address monitoring questions that are not covered by other indicators. NHEP will research these potential indicators in the future.

For some NHEP management objectives, it was not possible to establish environmental indicators because the objective is administrative in nature. "Administrative objectives" describe actions that should be taken rather than environmental conditions to be achieved. Therefore, NHEP's progress on these objectives were tracked by "administrative indicators" that document the activities the NHEP or its partners have undertaken relative to the objective. For example, for the NHEP objective to "encourage 42 coastal communities to actively participate in addressing sprawl," the administrative indicator reports the number of communities engaged in smart growth activities and the NHEP actions to promote smart growth.

**Issue and Management Objectives**
Nearly all of the NHEP management objectives (35 of 38, or 92 percent) have been tied to at least one indicator, with a breakdown as follows: 20 of the 38 (53 percent) will be tracked using environmental indicators and 15 of the 38 (39 percent) will be tracked using administrative indicators. For the remaining three management objectives, research indicators have been identified. The NHEP also tracks 18 supporting variables that will be used to help interpret the indicators. In total, the NHEP reports on 34 environmental indicators, 14 administrative indicators, 18 supporting variables, and 10 research indicators. The reason why there are so many more indicators than management objectives (76 vs. 38) is that many objectives have been assigned multiple indicators and supporting variables to answer multiple monitoring questions or to report on different facets of the objective.

***Environmental Indicators***
The suite of indicators presented in the NHEP monitoring plan (2004) was chosen to answer the monitoring questions discussed in the plan. The indicator's numbers are not listed sequentially as the indicators provided below were chosen by the TAC from a larger set of indicators that were originally developed.

**A. Indicators of Bacteria Pollution**

*Monitoring Goal: To determine the status and trends of the sanitary quality of shellfish-growing and recreational waters.*

- BAC1. Acre-days of shellfish harvest opportunities in estuarine waters
- BAC2. Trends in dry-weather bacterial indicators concentrations
- BAC4. Tidal bathing beach postings
- BAC5. Trends in bacteria concentrations at tidal bathing beaches
- BAC6. Violations of *Enterococci* standard in estuarine waters
- BAC7. Freshwater bathing beach postings
- BAC8. Bacteria load from wastewater treatment plants

**B. Indicators of Toxic Contaminants**

*Monitoring Goal: To determine the status and trends of toxic contaminants in water, sediment, and biota of coastal New Hampshire.*

- TOX1. Shellfish tissue concentrations relative to Food and Drug Administration standards
- TOX8. Finfish and lobster edible tissue concentrations relative to risk-based standards
- TOX2. Public health risks from toxic contaminants in fish and shellfish tissue
- TOX3. Trends in shellfish tissue contaminant concentrations
- TOX4. Trends in finfish tissue contaminant concentrations

- TOX5. Sediment contaminant concentrations relative to National Oceanic and Atmospheric Administration (NOAA) guidelines
- TOX6. Trends in sediment contaminant concentrations
- TOX7. Benthic community impacts due to sediment contamination

**C. Indicators of Nutrients and Eutrophication**

*Monitoring Goal: To determine the status and trends of the eutrophic conditions in New Hampshire's coastal and estuarine waters*

- NUT1. Annual load of nitrogen to Great Bay from wastewater treatment facilities (WWTF) and watershed tributaries
- NUT2. Trends in estuarine nutrient concentrations
- NUT3. Trends in estuarine particulate concentrations
- NUT5. Exceedances of instantaneous dissolved oxygen (DO) standard
- NUT6. Exceedances of the daily average DO standard
- NUT7. Trends in biological oxygen demand (BOD) loading to Great Bay
- NUT8. Percent of the estuary with chlorophyll-*a* concentrations greater than state criteria

**D. Indicators of Shellfish Resources**

*Monitoring Goal: To determine the status and trends of molluscan shellfish populations in New Hampshire's coastal and estuarine waters.*

- SHL1. Area of oyster beds in Great Bay
- SHL2. Density of harvestable oysters at Great Bay Beds
- SHL3. Density of harvestable clams at Hampton Harbor flats
- SHL4. Area of clam flats in Hampton Harbor
- SHL5. Standing stock of harvestable oysters in Great Bay
- SHL6. Standing stock of harvestable clams in Hampton Harbor
- SHL7. Abundance of shellfish predators
- SHL8. Clam and oyster spatfall
- SHL9. Recreational harvest of oysters
- SHL10. Recreational harvest of clams
- SHL11. Prevalence of oyster disease
- SHL12. Prevalence of clam disease

**E. Indicators of Land Use and Development**

*Monitoring Goal: To determine the status and trends of land use and development in coastal New Hampshire.*

1. LUD1. Impervious surfaces in coastal subwatersheds
2. LUD2. Rate of sprawl—high impact development

3. LUD3. Rate of sprawl—low-density, residential development
4. LUD4. Rate of sprawl—fragmentation

**F. Indicators of Habitat Protection**

*Monitoring Goal: To determine the status and trends of habitat protections in New Hampshire's coastal and estuarine waters.*

- HAB6. Protected conservation lands
- HAB3. Protected, undeveloped shorelands
- HAB4. Protected, unfragmented forest blocks
- HAB5. Protected rare and exemplary natural communities

**G. Indicators of Critical Habitats**

*Monitoring Goal: To determine the status and trends of critical species and habitats in New Hampshire's coastal and estuarine waters.*

1. HAB1. Salt marsh extent and condition
2. HAB2. Eelgrass distribution
3. HAB11. Unfragmented forest blocks

**H. Indicators of Critical Species**

*Monitoring Goal: To determine the status and trends of critical species in New Hampshire's coastal and estuarine waters.*

1. HAB7. Abundance of juvenile finfish
2. HAB8. Anadromous fish returns
3. HAB9. Abundance of lobsters
4. HAB10. Abundance of wintering waterfowl

**I. Indicators of Habitat Restoration**

*Monitoring Goal: To determine the status and trends of habitat restoration in New Hampshire's coastal and estuarine waters.*

1. RST1. Restored salt marsh
2. RST2. Restored eelgrass beds
3. RST3. Restored oyster beds

**Reporting Indicator Findings**
The NHEP publishes four data reports ("indicator reports") that illustrate the status and trends in the various indicators. These reports are technical in nature. Each report focuses on a different suite of indicators: shellfish, water quality, land use and development, and habitats and species. All of the indicators are presented to the TAC, which selects a subset of indicators to be presented to the NHEP management committee. After the chosen indicators are presented to the committee, between 10 and 20 indicators are chosen to be included in the "State of the Estuaries" report. This report is published every 3 years.

The combination of the technical reports for the scientific community and the simpler State of the Estuaries report for other users is useful for getting indicator information to as many people as possible.

**Monitoring Program**
The NHEP developed a monitoring plan for each indicator. The data quality objectives for each indicator were matched to an appropriate sampling and analysis design using power analysis. Sampling design details are listed in the NHEP monitoring plan.

**Indicator Implementation**
The NHEP TAC is tasked with initiating, overseeing, tracking, evaluating, and updating the implementation of the monitoring plan. According to the NHEP monitoring plan (2004), the plan will be "fully implemented" when the NHEP is able report on at least one indicator for each management objective. Currently, 35 of 38 management objectives are tied to at least one indicator.

**Formal Adoption and Funding**
The latest version of the NHEP monitoring plan (version 4) was approved by the NHEP TAC in June 2004. This plan contains forecasts of funding needs through 2015. The NHEP uses these forecasts to allocate monitoring funds each year.

**Communication**
The NHEP's goal is to communicate the results of environmental monitoring to four audiences: the EPA, the NHEP Management Conference, the scientific community, and the public, which is broadly defined to include coastal decision-makers, watershed organizations, and interested citizens.

**Data Collection and Analysis Plan**
The NHEP monitoring plan contains information on data collection and analysis for each indicator. As with most of the NEPs, the NHEP coordinates with agencies and organizations who participate in monitoring activities in order to avoid duplication of effort. This coordinated effort makes the most of current monitoring efforts and available data. The NHEP maintains the inventory of all estuarine and coastal monitoring programs in the state. The NHEP monitoring plan incorporates data collected by over a dozen programs.

**Revision of the Monitoring Program and Indicators**
The NHEP Coastal Scientist and TAC review the monitoring programs and indicators each year. The monitoring plan is updated periodically as new indicators are developed or monitoring programs change.

The information noted throughout this case study came from the following documents.

NHEP. 2000. Comprehensive Conservation Management Plan. New Hampshire Estuaries Project. 2000.

NHEP. 2002. Environmental Indicator Report: Water Quality. New Hampshire Estuaries Project. December 27, 2002.

NHEP. 2003. Environmental Indicator Report: Land Use and Development. New Hampshire Estuaries Project. April 30, 2003.

NHEP. 2003. Environmental Indicator Report: Species and Habitats. New Hampshire Estuaries Project. April 30, 2003.

NHEP. 2003. Environmental Indicator Report: Shellfish. New Hampshire Estuaries Project. October 14, 2003.

NHEP. 2003. The State of the Estuaries. New Hampshire Estuaries Project. September 2003.

NHEP. 2004. Monitoring Plan. New Hampshire Estuaries Project. June 2004.

All NHEP documents can be downloaded from www.nhep.unh.edu.

# APPENDIX A-3
# NORTHEAST COASTAL INDICATORS WORKSHOP CASE STUDY

In 2001, representatives of Federal, state, local and non-governmental organizations (NGOs) from eastern Canada and the New England region met to discuss issues that were common throughout the Gulf of Maine region. Their vision was of a sustainable Northeast Atlantic ecosystem that ensures environmental integrity and that supports and is supported by economically viable, healthy human communities. Based on this initial discussion and the need for information on the ecosystem, an idea was spawned to form a coordinated regional program to monitor the coastal waters from eastern Canada to the Long Island Sound region of New York. This particular situation was unique because it was not mandated by Federal or state regulations, but a collaborative idea among environmental managers of the region. The overall goal that developed was a group, which would voluntarily coordinate their current monitoring programs to determine the overall ecological health of the northwest Atlantic region.

In 2002, the group began to formally discuss what the program would focus on and whether organizations throughout the region felt a coordinated program could be developed. The first step was development of a steering committee, which included staff from various Federal, provincial, and state governments throughout the northeast United States and eastern Canadian region. The committee initially chose to focus on three areas of coastal environmental monitoring: nutrient overenrichment; toxics/contamination; and habitat loss, degradation and restoration. Participants of the steering committee focused their efforts on developing a straw coordinated regional monitoring strategy and collecting information on current monitoring, regional concerns, and future focus areas (*e.g.*, questions that should be answered through the coordinated monitoring effort).

The information development step included the preparation of white papers and other documents by the steering committee for each of the three focus areas. This information was presented to a larger contingency of environmental managers, policy-makers, scientists, and the region's public at the first of two workshops held in December 2002. At the workshop, the steering committee presented its ideas for a regional coordinated monitoring program and why it thought such a program would be important to the region. The group was also brought together to:

- Develop an ecologically driven basis for coordinating selected monitoring programs in Atlantic Northeast coastal waters,
- Develop a framework for a regional monitoring network, and
- Identify new regional monitoring needs and corresponding research needs that respond to the region's pressing management needs.

The major conclusion from the workshop was that a coordinated regional monitoring network was needed and could be developed. Participants recommended that the coordinated regional monitoring network be set up with the following form and functions:

Form:

1. Geography—Nova Scotia/New Brunswick to Long Island Sound. Additional information from other areas may be needed to support some parameters (*e.g.*, atmospheric deposition).
2. Type of organization—regional public/private nonprofit or charitable organization that incorporates existing mandates.
3. Partners—government, NGOs, businesses, academics, regional organizations.
4. Structure—steering committee or board that includes state/provincial agencies, environmental groups, dischargers, researchers, and the public.
5. Governance/decision-making—where appropriate voluntary compliance, consensus, and legislative mandates (existing and new).
6. Operating budget—start with seed funding; then, after positive results have been shown, plan on incremental growth. If funding becomes available, move toward major initiatives.
7. Funding sources—new grants and contracts (*e.g.*, government, foundations). Larger monitoring groups involved would use some of their resources toward involvement in the program in return for additional information on areas of concern.
8. Staffing—focused full-time regional coordinator growing to additional staff.

Function:

1. Scope/reach—government, volunteer, and academic programs and more as appropriate to answer the questions.
2. Scale—depends on the final questions being asked.
3. Links to research—identifies priorities linked to monitoring; active proponent of regional research; identifies new issues and problems.
4. Program design and implementation/methods—coordinate programs to meet regional needs; apply performance-based standardized protocols as appropriate.
5. Data management—start with web links to databases with spatial references and metadata. As the program proceeds, standardized formats for data and policies for making data available and reported should be developed.
6. Data synthesis and communication—integrated multifactor regional assessments with links to management, public, and NGO needs; educational and marketing materials; and smaller-scale assessments or larger trends and assessments by selected issues.
7. Services provided—regional multivariate

Although other programs integrate regulatory and management needs and responsibilities into their programs, the consensus of the participants was that this regional program should not go beyond coordinating, collecting, and disseminating monitoring data. Instead, a coordinated monitoring group could first provide data that regulators would find useful in assessing water quality and management needs. If the regional program provides useful advice and creates a valuable forum for discussion on how each jurisdiction can better manage their waters or make recommendations for comprehensive management that cannot be handled at the state/province level, regulators should be more open to participation.

For this program to work, the participants felt that the major monitoring groups needed to be involved in this process. These included: the U.S. Environmental Protection Agency's (EPA's) National Coastal Assessment (NCA), the Gulf of Maine Ocean Observing System (GOMOOS), Gulfwatch, Plum Island Sound Long Term Ecosystem Research, the Massachusetts Water Resources Authority (MWRA), National Estuary Programs (NEPs), National Estuarine Research Reserves (NERRs), the National Park Service (NPS), aquaculture monitoring programs, and industry (*e.g.,* power plants, manufacturing). Participation by large monitoring programs was noted as being necessary to provide the critical mass needed to move forward. This does not mean that other smaller programs or new programs are not needed. However, due to the lack of funding in most areas, data will need to be extracted from existing programs, and then augmented where needed.

Based on the conclusions from this workshop, the steering committee was expanded and a set of goals created to further the development of the program. The expanded committee initially focused on getting the message of its efforts out to monitoring programs throughout the region. The committee also used the information collected at the workshop to develop conceptual models, questions, and information on possible indicators throughout the region. The committee refined the focus on the three issues addressed by the workshop to include fisheries, land use, and climate change issues.

This information was used to support a second workshop, conducted in January 2004, that focused on gaining consensus on a list of key indicators for which regional data would be compiled and used to track trends in ecosystem integrity through the Northwest Atlantic region. This workshop focused on:

- Reviewing current efforts to coordinate monitoring and indicator development throughout the region.
- Developing indicators that apply to the northeast coastal region of the United States (from New York to Maine) and Canada (Gulf of Maine) under six categories: fisheries, eutrophication, contaminants, coastal development, aquatic habitat, and climate change.
- Discussing how indicators could be created and managed, including incorporation into existing programs, in the near future.
- Informing area agency managers of the results of the workshop to get buy-in on the necessity of the coordinated program and to collect information on what the managers need from the program.

Participants discussed the progress made to develop the coordinated regional program and what should be done to get the program formally started. In addition, key managers from several of the top agencies and organizations throughout the region were invited to hear the findings and suggestions of the workshop and to provide input on next steps that might ensure successful program implementation.

After this workshop, a Memorandum of Understanding (MOU) was developed and distributed among interested programs. It focused on sharing data for the coordinated effort. Members of the steering committee also took on additional tasks to move the program forward.

## INDICATOR DEVELOPMENT PROCESS

### Steering Committee Involvement

For this effort, the steering committee was a key success factor in developing a coordinated monitoring network with indicators. Commitment of staff time by agencies and organizations from each of the states and provinces proved to be the major catalyst in the design and development of this program. The steering committee included participants from:

- Battelle
- Connecticut Department of Environmental Protection
- Environment Canada
- Maine Department of Environmental Protection
- Maine Sea Grant Program
- Maine State Planning Board
- Massachusetts Coastal Zone Management
- MWRA
- National Oceanic and Atmospheric Administration (NOAA)
- National Marine Fisheries Service (NMFS)
- EPA Headquarters
- EPA Region 1
- U.S. Geological Survey (USGS)
- Wells NERR

Members of the steering committee were responsible for assisting with the development and design of the regional network, but they also assisted in informing their managers and others of the importance and usefulness of this program. Each member worked hard to make this program a success. Some assisted by developing materials for the workshop to communicate the overall goals of the program, but also the necessary information to make decisions towards those goals. Others assisted by taking the message of coordination to others to get programs interested in being a part of the network; still others helped by trying to find funding for the program. Without the assistance of each person, the program would not have moved forward.

**Purpose and Need for Indicators**

The steering committee determined the purpose of this program to be to track the status and trends in ecosystem integrity throughout the Northwest Atlantic region through collaborative partnerships. The need of the program was to provide information for policy, management, and advocacy decisions at a regional scale.

**Identify the Issues**

Several environmental issues are widespread in the region. Early in the development process, the steering committee decided to focus on a limited number of the issues. The plan was to start with a limited number and add additional topics as the program progressed. Initially three topics were chosen based on the *Gulf of Maine Council on the Marine Environment Action Plan 2001 to 2006* (http://www.gulfofmaine.org/council/action_plan/action_plan2001-06.pdf). Nutrient overenrichment, toxics/contamination, and habitat loss, degradation and restoration were covered at the first workshop in December 2002. Participants of the first workshop voiced concern with three additional topics: fisheries, land use, and climate change. Based on the request from workshop participants, these three additional topics were included in the second workshop held January 2004, along with the first three topics from the initial workshop.

**Assessment of Each Issue**

Each issue included in the process was assessed by reviewing available literature and compiling the information into a statement of present status. In most instances, monitoring programs throughout the region had reports noting the status of individual areas of the region, which were used to extrapolate an overall picture of the region. Although a measurable baseline could not be specified, in most instances enough information for the region was available to allow future changes, either beneficial or adverse, to be noted.

As noted earlier, the steering committee developed straw documents on the issues, questions, and possible indicators that could be used to track these issues throughout the region. They also collected information on monitoring programs throughout the region along with information on the types of data each program collected.

**Conceptual Models**

Conceptual models were developed by the steering committee in a variety of formats. Some were written descriptions, while others were tables or pictures. Common to each of the models was the fact that they noted pressures to the system, the current state of the system as it was known at that time, and the response of the system to the pressures exerted on that system. Figure 8 within the main body of this manual was one of the models developed.

**Indicators**

The focus of the January 2004 workshop was the review of questions that needed to be answered by the program and indicators that could possibly supply the necessary data to evaluate changes in each of the six topic areas. Below is a listing of the questions and indicators that participants suggested the network focus on answering in their initial efforts, based on available data from the region.

***Fisheries***

Overarching Question: What is the health of the fisheries with regard to ecosystem integrity, including targeted and non-targeted species, habitat, and fisheries activities?

Question 1. What are the trends in and the status of exploited fisheries stocks?

Indicator(s):

- Proportion of stocks at or above targeted abundance or biomass
- Age/size structure of species from surveys and/or landings
- Spatial distribution of fisheries species

Spatial and Temporal Scales: Range of species or stocks; annual to every 3-5 years

Question 2. What are the effects of fishing on non-targeted species and their associated communities?

Indicator(s):

- Characteristics of bycatch and discards
- Population levels for selected species
- Species diversity

Spatial and Temporal Scales: Regional based on populations or stock, biogeographic boundaries; seasonal

Question 3. What are the effects of fishing and non-fishing activities on marine habitat and fisheries productivity?

Indicator(s):

- Area closed to fishing, both pelagic and/or benthic
- Benthic diversity
- Spatial distribution of bottom fishing

Spatial and Temporal Scales: Region-wide (based on biogeographic boundaries); 1 to 5 years, depending on habitat to annually to continuous

Question 4. What are the trends in the socioeconomic characteristics of fishing?

Indicator(s):

- Days at sea
- Fleet composition
- Commercial and recreational fishing economic value
- Angler satisfaction
- Overcapitalized fleets
- Natural capital value
- Market value for consumers

***Contaminants***

Question 1. How are contaminants in the region changing?

Indicator(s):

- Area of sediments that have contaminant levels above sediment quality guidelines
- Level of contaminants in representative non-migratory organisms
- Area of shellfish bed closure by state by year
- Days of beach closure due to bacterial contamination by state by year

Spatial and Temporal Scales: Specific water body scales; event to annual to decadal

Question 2. How is the input of contaminants changing over time and space?

Indicator(s):

- Annual chemical load to water bodies by state
- Number of bacterial source investigations and sources eliminated by year by state

Spatial and Temporal Scales: Water bodies region-wide; annual to source specific

Question 3. Are management actions changing the extent and severity of human health effects?

Indicator(s):

- Incidences of human disease caused by consumption of fish and shellfish and recreational contact
- Level of contaminants in representative fish/shellfish and at-risk humans
- Annual number of beach and shellfish closures (reopenings)

Spatial and Temporal Scales: Water bodies region-wide; annual to source specific

Question 4. How well are contaminant management actions protecting ecosystem integrity?

Indicator(s):

- Sediment quality measure by triad approach
- Incidence of disease
- Reproductive success
- Quality of habitats as affected by contaminants

Spatial and Temporal Scales: Water bodies region-wide; annual to decadal scales

***Eutrophication***

Question 1. What are the extent, severity, and trends of eutrophication impacts?

Indicator(s):

- Dissolved oxygen (DO)
- Chlorophyll-*a*
- Submerged aquatic vegetation
- Water clarity

Spatial and Temporal Scales: Estuary-wide; seasonal to annual

Question 2. What are the sources of nutrients, can they be controlled, how are they changing?

Indicator(s):

- Measured and modeled loads
- Land use/cover (load proxy)
- Population (load proxy)

Spatial and Temporal Scales: Regional; seasonal to annual to decadal

Question 3. What is the state of management measures and how can they be optimized?

Indicator(s):

- DO
- Chlorophyll-*a*
- Submerged aquatic vegetation
- Water clarity
- Measured and modeled loads
- Land use/cover (load proxy)
- Population (load proxy)

***Aquatic Habitat***

Question 1. How is the extent, distribution, or use of coastal habitats (watersheds, estuaries, near, and offshore) changing over time?

Indicator(s):

- Extent per habitat type over time
  - Large-scale mapping, small-scale ground surveys
- Distribution per habitat type
- Inventory of human use
  - Area, percent of public vs. private
  - Area, percent designated for permanent habitat protection

Question 2. How is the ecological condition of coastal habitats changing over time?

Indicator(s):

- Community structure
  - Measure of change of relative abundance of species within habitat
- Trophic structure
- Species of concern

Question 3. What are the causes of coastal habitat change over time?

Indicator(s) of most important potential causes of habitat loss and degradation (physical and hydrologic alteration, nutrient loading, resource extraction, contaminants, climate change, sediment input)

- Extent and percent habitat area altered by tidal restrictions
- Boat registrations
- Seagrass Nutrient Pollution Index
- Indicators relating to other causes assumed covered by other groups

***Coastal Development***

Question 1. What is the type, pattern, and rate of land use change?

Indicator(s):

- Percent change in land cover to more intensive uses
- Demographic changes (population, etc.)
- Types of land uses and change

Question 2. How are these changes impacting the integrity of coastal ecosystems?

Indicator(s):

- Integrity of coastal ecosystems for:
  - Threatened and endangered coastal species
  - Migratory species
  - Invasive species

Question 3. How is the region responding to changes in coastal ecosystems?

Indicator(s):

- Type, location and pace of land conservation
- Type, location and pace of habitat restoration
- Land management (planning, regulatory, etc)

***Climate Change***

Question 1. What are the causes?

Indicator(s): None identified

Question 2. What are the impacts of climate changes to: weather, atmospheric & ocean circulation, ecosystems, and society?

Indicator(s):

- Precipitation trends
- Storm frequency and intensity
- Water temperature surface bottom
- Relative sea level rise

Spatial and Temporal Scales: Regional; annual to decadal

Question 3. What are the impacts of climate change on biotic ecosystems?

Indicator(s):

- Warm vs. cold water finfish species diversity
- Planktonic diversity
- Wetlands extent, distribution and composition
- Marine diseases indices (*i.e.*, multinucleated spore unknown, dermo, shell disease)

Spatial and Temporal Scales: Regional; annual

**Monitoring Program**

This program was not created to specifically monitor the indicators chosen. Participants plan to request cooperative assistance from programs already monitoring specific areas of the region. The data will be collected in one place so that they can be reviewed in total and a decision on the health of the regions ecosystem made. Thus, a monitoring program was not designed or implemented for this program, but programs may be asked to modify their present sampling schemes to include areas not currently monitored.

**Indicator Implementation**
To ensure that an integrated decision-making system is developed, several participants suggested that groups that are already developed and working (*e.g.*, Gulf of Maine [GOM] Council with financial support for the program coming from elsewhere, Long Island Sound Study [LISS]) be used to get the coordinated monitoring program started rather than starting from scratch. It was felt that these groups could assist in moving the group forward at a quicker pace. Once the common needs for the program are defined, monitoring programs not involved with the group will then be approached to join.

One important item that the participants identified is that when the program is started, a determination needs to be made of quality of data being collected and where data gaps may exist. Quality could be determined through an intercalibration exercise. Then, if needed, the program can move towards standardized methods. Everyone agreed that it is easier to compare data if they are collected in a consistent way. The other important aspect that the group will need to include is a feedback loop.

**Formal Adoption and Funding**
In most instances, it was agreed that it will be difficult to get ongoing monitoring programs (*i.e.*, GOMOOS, MWRA, LISS, Massachusetts Bay NEP) to change their focus and financially support a new effort. To make this a success, the group will need to secure "buy-in" from Federal (*i.e.*, EPA, Environment Canada, NOAA, and NMFS) and state agency leaders. It was felt that MOUs would need to be developed to ensure that programs do not back out of the group. It was also suggested that MOUs specify the agreement to standardize data collection and analysis methods (where needed).

**Communication**
The group suggested that this aspect could best be addressed through the use of various groups that are already working rather than having new groups created (*e.g.,* GOM's Gulfwatch program, GOMOOS, LISS, MWRA, NCA, Mercury Deposition Network). To assist with communication, an implementation plan, program inventory, program description including objectives, and monitoring and data management protocols should be developed to ensure that everyone involved understands how the group will proceed. Then, on a predetermined basis, indicator reports and status of the environment reports should be written to communicate the findings of the group.

**Monitoring Plan Implementation**
Not applicable.

**Data Collection and Analysis Plan**
For this program, the stakeholders will have to develop a fairly detailed data collection and analysis plan. Because data will be coming from a variety of programs, the plan will

need to include how the data will be supplied, to whom it will be supplied, how often, etc. At this time, the stakeholders are still working out these issues.

**Reporting Indicator Findings**
Most workshop participants felt that it is very important to communicate the findings of the program to managers and the public to show value in the efforts made. To support managers in making decisions, the groups noted that the following items would be of assistance:

- Develop periodic assessments and maps.
- Develop data integration and interpretation tools.
- Produce products that have integrated assessments that can draw conclusions and relate changes to stressors.
- Provide a vehicle for workshops, seminars, and other opportunities to share knowledge.
- Provide reports on the socioeconomics of impacts and actions/inactions.

The public, on the other hand, is more interested in knowing things such as “What is the status of the environment (encompasses a variety of spatial scales and ecological compartments); Is it improving or not? What are the scales of influence? What are the trends? What are the responses throughout the system? Are the responses local or regional? By what amount? How sensitive are various biogeographic areas? Are management strategies working? Reports directed at these answers will also be considered for publication.

Documentation of environmental condition may take the form of easily understood “state-of-the-environment” reports. These reports might be geographically based, issue-based, or both. The consensus of the group was that this regional program should not go beyond coordinating, collecting, and disseminating monitoring data. Data interpretation and management planning will be left to the regulators already managing the areas, but the coordinated monitoring group would provide data that regulators would find useful in assessing water quality and management needs. If the regional program provides useful advice and creates a valuable forum for discussion on how each jurisdiction can better manage their waters, or make recommendations for comprehensive management that cannot be handled at the state/province level, regulators should be more open to participation.

**Revision of the Monitoring Program and Indicators**
Participants of the workshops agreed that an assessment of the overall program should be done on a 5-year basis to ensure that the program is completing its overall goals. This would include an assessment of the issues being monitored, the questions being answered, the monitoring program being used, and the indicators being monitored. In addition to the 5-year reassessment, an internal assessment of the data could be conducted yearly or biyearly through external peer-reviews of products generated by the program.

The information noted throughout this case study came from personal knowledge of the process (personal communication Lynn McLeod, Battelle, 2005) and the following documents:

ANCMS. 2003a. ANCM Summit Fact Sheet #1. February 2003. Available from http://www.gulfofmaine.org/nciw/Fact_Sheet.pdf

ANCMS. 2003b. ANCM Workshop Summary Report. February 2003. Available from http://www.gulfofmaine.org/nciw/ancms2002.asp

NCIW. 2004. NCIW Workshop Summary. Available from http://www.gulfofmaine.org/nciw/FinalWorkshopSummary.pdf

# APPENDIX B
# INDICATORS DEVELOPED BY VARIOUS GROUPS

The following is a list of indicators chosen by various groups for monitoring progress within estuaries or coastal areas around the United States. The list is divided into six categories:

- Fisheries
- Contaminants/water quality
- Contaminants/sediments
- Land use change
- Aquatic habitat
- Other

**Fisheries**

- Trends, abundance, and diversity (total number of species, total number of individuals, and biomass) in fish, shellfish, and crustaceans
- Toxic tissue concentration and trends of contamination (metals, polycyclic aromatic hydrocarbon [PAHs], polychlorinated biphenyls [PCBs], pesticides, dioxins, furans, and dichlorodiphenyltrichloroethane [DDT]) in lobsters, shellfish, and fish
- Public health risks from toxic contaminants in fish and shellfish tissue
- Fish diseases (observation of fish diseases [fin erosion, tumor, etc.] or individual fish samples
- Changes in the health, ecology, or other effects on recreational fish
- Weights of fish populations
- Number of fish kills
- Biodiversity of bottom-dwelling species and mid-water species
- Status of shellfish beds (changes in acreage of closed and open shellfish flats)
- Changes in the health, ecology or other effects on landings (catch and effort, catch-per-unit-effort [CPUE])
- Shellfish habitat (acres of shellfish beds classified as suitable for harvesting and for seed stock)
- Shellfish harvest (bushels of oyster harvested annually and dollar value of the harvest)
- Density of harvestable clams flats
- Abundance of shellfish predators
- Weight of shellfish landings
- Disease linked to contaminated shellfish

- Recreational harvest of clams
- False mussel stands
- Oysters (population, restored beds [acres], bed acres restored with disease resistant American oyster stock, disease, bed acreage)
- Recreational harvest of oysters
- Oyster density on public seed grounds over time
- Oyster abundance and health on private leases
- Bacteriological water quality of oyster harvesting waters
- Lobster harvest (pounds of lobster harvested)
- Lobster permits (permits and licenses)
- Anadromous fish runs
- Anadromous fish returns
- Annual number of fish migrating down stream
- Number of stream miles opened through fish passage enhancement projects
- Stream miles opened to migratory fish
- Public use and access
    - fish advisories
    - fish tissue - persistent, bioaccumulative, and toxic contaminant levels
    - percent of streams impaired for fishing
    - shellfish bed closures
- Right whale populations: number of right whales
- Macroinvertebrates (freshwater)
- Biological production and respiration (phytoplankton and zooplankton productivity, abundance, and composition, bacterial production, respiration)
- Macrophyte abundance and composition
- Estimated economic impact of recreational fishing over time
- Value and number of licenses of commercial and recreational fishing
- Change in number of saltwater fishing licenses
- Acres of commercial shellfish areas (total acres of open, restricted, closed, and prohibited commercial shellfish areas)
- Commercial fishing pressure (weight [pounds] of commercial catch)
- Recreational fishing pressure (recreational CPUE for targeted resident fish species)
- Presence absence of disturbance indicator species, non-native fish
- Occurrence of non-native crabs

**Contaminants/Water Quality**

- Water quality (temperature, salinity, pH, turbidity, dissolved oxygen [DO], chlorophyll-*a*, total dissolved solids, total suspended solids, nutrients, phosphorus, nitrates, metals, organics)
- Light attenuation (secchi disk depths, or some equivalent measure of light attenuation)
- Point source and non-point source nitrogen loading
- Trophic state index of water
- Isohaline locations

- Atrazine concentration in surface waters over time
- Atmospheric deposition
- Number and duration of high-chloride events in source water to the Clotilda drinking water plant over time
- Occurrence of harmful algal blooms (species, extent, duration, ecological and human health effects)
- Water bodies on Department of Environmental Protections planning or verified lists for impairments
- Tributyltin (TBT) concentration levels (trends in TBT water column concentrations)
- Types and amounts of floatable debris (ocean-side barrier island and estuaries)
- Change in ambient shallow ground-water with respect to established drinking water standards
- Changes in specific conductance
- Amount of contaminant inputs from major point sources and tributaries
- Composition of aquatic debris (floating and in coastal areas)
- Regions of concern: areas with known chemical contaminant-related impacts
- Number of pumpout and dumpstation facilities over time (boat waste)
- Combined sewer overflow (CSO) abatement (frequency of CSO events and volume and duration of overflow events)
- Toxic contaminants in stormwater runoff and receiving waters
- Trends in permitted discharge flow and number of National Pollutant Discharge Elimination System permits
- Sewage disposal and septic tank loads
- Industry reported releases and transfers of chemical contaminants
- Releases and transfers of chemical contaminants from Federal facilities
- Dischargers in significant noncompliance
- Municipal facilities in the watershed using nutrient reduction technology
- Communities implementing stormwater best management practices
- Conversion of septic systems to central sewer
- Removal of direct discharges into the bays
- Concentrations of fecal bacteria (fecal coliform, Enterococci, E. Coli) in surface water as a proportion of criteria/screening levels
- Seagrass acreage change (temperature, pH, total suspended solids, DO, nitrogen, biological oxygen demand (BOD), phosphorus, secchi depth, salinity)
- Non-toxic sewage treatment plants
- Number of volunteer water quality monitoring stations
- Concentration of toxics in sediment and biota (number of water bodies on 303(d) list-in general or for contaminants of concern)
- Safety at swimming beaches: Enterococcus levels and number of beach closures
- Trends in dry weather bacterial indicator concentrations (fecal coliform, e coli, Enterococcus)
- Trends in wet weather bacterial indicator concentrations

- Bacteria load from wastewater treatment plants (fecal coliform, total coliform, flow)
- Macroalgal biomass (measure of benthic productivity)
- Pollution trends
- Acres of cropland under nutrient management
- Eelgrass nutrient pollution index
- Distribution of nuisance macroalgae
- Other toxic substances in groundwater (nitrate)
- Pesticides in ground and surface waters
- Number of petroleum and chemical spill reports over time (total volume spilled)

**Contaminants/Sediments**

- Sediment chemistry (using U.S. Environmental Protection Agency [EPA] National Coastal Assessment [NCA] data)
- Sediment toxic contamination (metals, PAHs, PCBs, pesticides, dioxins, furans, butyl Tins, and halogenated hydrocarbon)
- Sediment toxicity (toxicity of sediment elutriate to *Ampeliscus*)
- Benthic community structure, composition (species and numerical data), and health (total number of benthic species, total number of individuals [abundance], and biomass)
- Benthic index for mud flat, salt flats, and subtidal unvegetated (population density of selected infauna, concentration of contaminants of concern, salinity, grain size, and DO)
- Sediment trends in rivers entering the bay: flow adjusted concentration and monitored loads
- Water quality—contaminated sediment (benthic toxicity and organic toxicity)
- Concentrations of selected contaminants in sediment as a proportion of probable effects level
- Suspended sediments
- Freshwater macroinvertebrate community (wide array of sample statistics including a summary index of biotic integrity)
- Benthos (marine)
- Sediment contaminant concentrations relative to National Oceanic and Atmospheric Administration (NOAA) guidelines
- Trends in sediment contaminant concentrations
- Other toxic substances in biota (chlordane, DDT, metals, PCBs, polychlorinated dibenzodioxins, polychlorinated dibenzofurans, mercury, cadmium)
- Macroinfauna species
- Meiofaunal species
- Organic pollutants in sediment (volatile and semivolatile organic compounds, polychlorinated naphthalenes)
- Sediment composition
- Percent organic carbon in sediment

**Land Use**

- Land Use/land cover (riparian zones, wetland area, agriculture near water, amount of edges, dominance, miles of roads, amount of agriculture and urban area, contagion, fractal dimension, recovery time, edge amount per patch sized, land cover transition matrix, corridors between patches, diffusion rates, inter-patch distances, actual vs. potential vegetation, percolation thresholds, largest patch, loss of rare land cover, habitat for endangered species)
- Coastal habitat restoration (acreage and diversity of coastal habitats restored to healthy and historic ecological functions, tidal wetlands, freshwater wetlands, estuarine embayments, coastal and inland forest, beaches and dunes, cliffs and bluffs, coastal grasslands, intertidal flats, rocky intertidal zones, submerged aquatic vegetation and shellfish reefs)
- Habitat restoration (number of restoration projects (a) planned; (b) in progress; (c) implementation completed)
- Percent forest cover (acreage of tree cover)
- Habitat opportunity (number of reconnections between open water and diked or levied former tidal habitats)
- Habitat loss (number of dredging, fill and shoreline permits issued)
- Habitat protection and conservation (number of protection and conservation projects (a) planned; (b) in progress; (c) implementation completed) Environmental lands acquisition (acreage of wetlands and environmentally sensitive lands acquired)
- Net change in habitats (sum of number of completed restoration and compensatory mitigation projects minus the sum of all habitat loss projects from dredge, fill, diking, etc.)
- Location of land loss
- Protected open space
- Wetland loss (acres of wetlands lost and index of biological integrity)
- Trends in number, type, or location of wetlands created, enhanced, or preserved
- Land-water ratios by fresh-, brackish-, intermediate-, and saltmarsh habitat type over time
- Specific land-use delineation for developed and agricultural areas
- Change in shoreline habitat/sensitive areas
- Change in stream flow (freshwater inputs)
- Salt marsh extent and condition
- Acreage of land converted to alternate use
- Unfragmented blocks of land (unfragmented blocks of land > 250 acres and >2,000 acres)
- Indicators of freshwater wetland functions
- Population and land use trends
  - average lot size
  - number of households
  - farmland acres
  - public parkland
  - developed land

- Public use and access
  - public access points
  - potable water withdrawals
  - human and industrial water consumption
  - projected future water demands
- Extent of turf grass
- Number of sewered and unsewered homes
- Remediated stormwater sites
- Change in number of bay and tributary public access points/areas (boat launches, parks, fishing piers)
- Change in number and location of marine pumpout facilities
- Change in commercial landings and commercial boat licenses
- Change in recreational landings: number and size
- Change in amount of impervious surface (aerial photography and geographic information system (GIS) mapping)
- Interior to edge ratio
- Hydrologic/bathymetric change
- Municipal waste water permit violations
- Number of 303(d) listed streams
- Number and percentage of shorelines hardened-bulkheading
- Number of types of development permits
- Quality, quantity, and identification of outfalls
- Rate of sprawl-low density, residential development (road miles per capita in the coastal watershed)
- Estimated vehicle nitrogen oxide emissions vs. vehicle miles traveled
- Rate of sprawl-fragmentation (habitat fragmentation per capita in the coastal watershed)
- Population levels or relative abundance of key plant and animal species
- Number of listed, rare or endangered species by year as related to habitat acreage

**Aquatic Habitat**

- Submerged aquatic vegetation habitat (abundance, change, health, distribution, and density by species)
- Area of brown marsh
- Acres of marsh damage by non-native nutria in over time
- Change in base flow of tributary streams over time
- Saltwater intrusion
- Water levels
- Percent exotics within saltwater marshes and location
- Acreage of subbasins that no longer contribute flows to their historic receiving water bodies
- Acreage of subbasins returned to historic receiving water bodies
- Net difference between the acreage of subbasins that no longer contribute flows to their historic receiving water bodies and the acreage of subbasins returned to historic receiving water bodies

- Tidal wetlands, tidal wetlands buffer habitats (wetland acres restored/preserved, number of successful wetland mitigation sites, acreage of wetlands buffered, wetland acres, riparian buffer [miles])
- Overall restoration initiatives (number of acres preserved, restored, enhanced, habitat acres on corporate properties)
- Fish passage/blockages (stream miles opened, stream blockages removed)
- Sneaker index (water clarity and turbidity)
- Percent change in inflows from major tributaries
- Annual gaged freshwater inflows compared to inflow recommendations
- Riparian integrity (percent of riparian zone (50-meter and 100-meter buffer) with native vegetation)
- Distribution of coarse and soft bottoms
- Diversity and composition of Riparian insect assemblages
- Deposition in the estuary (sediment deposition and accumulation, changes in bay bathymetry and tidal prism)
- Erosion in the watershed (changes in channel cross sections due to aggradation and deposition of sediment)
- Portion of channels where newly deposited sediments pass suitability criteria (contaminants in sediments)
- Percentage of navigation projects that contain one or more of the following: environmental dredging for the purpose of toxics reduction, brownfields remediation, habitat acquisition, habitat restoration, improvement of appropriate public access, or beneficial reuse of dredged material
- Other toxic substances in sediments (PCBs, DDT, PAHs, arsenic, copper, lead, mercury, silver, radionuclides)
- Habitat quality
- Biological resources

**Other**

- Coastal, nesting, threatened, and endangered bird trends, abundance and diversity (population estimates of birds by species)
- Trends abundance, and diversity in waterfowl
- Change in number of waterfowl hunting licenses
- Population condition of endangered species (population size and/or reproductive success [breeding/fledgling pairs, etc.])
- Cost of invasive species control
- Species diversity (wildlife)
- Rare plant and animal populations
- Native species assessment (number of estuarine-linked species listed under Federal or state Endangered Species Act programs)
- Percent non-native species
- Number, frequency, and occurrence of non-native species
- Acreage of non-native sub-macrophytes
- Overall restoration initiatives (habitat acres impaired by invasive species, habitat acres controlled for invasive species)

- Invasive species (species composition and abundance)
- Seals (number of seals)
- Seal tissue toxics (PCBs, dioxins, furans, pesticides, and heavy metals)
- Boating use
- Water allocation
- Soil types
- Alligator nests
- Black bear abundance
- Reptile and amphibian population abundance
- Atmospheric and other pollution inputs (organic pesticides, PCBs, trace metals and byproducts of combustion)
- Population within 50 miles of the watershed (measure population growth and demographic trends to determine potential human use of the resources)
- Trends in shipping traffic versus vessel fuel spills and vessel incidents
- Value of shipping cargo, recreational boating, energy production wells, nature tourism
- Muck removal (volume and acreage of muck deposits removed)
- All dredged material being used beneficially
- Watershed population levels (measure population growth and demographic trends in the Long Island Sound watershed)
- Comprehensive Conservation Management Plan (CCMP) progress
- Best management practices activity
- Population of watershed municipalities
- Percent of communities implementing development that works
- Percent of communities implementing policies of public participation
- Beach clean-up volunteers (number of volunteers)
- Debris collected during International Coastal Cleanup (composition of debris, weight of debris, miles of shoreline cleaned)
- Website visitors (number of times the web site is accessed by the public per year)
- Number of environmental organizations (dates/times, participation numbers, and number of events)
- Number of environmental activities-specific (dates/times, participation numbers, and number of events)
- Number of environmental science courses/sections
- Number of kids reached in classrooms, field projects, on-river, service learning
- Number of school districts
- Number of teachers in estuary-related training courses
- Number of adults completing environmental science training
- Number of teachers working with estuary partnership or estuary partnership curriculum
- Number of non-formal K-12 environmental projects, events
- Number of partnerships between schools and outside entities
- Number of class visits to learning centers for an organized experience related to the estuary

- Number of educational materials distributed over time
- Number of volunteers involved: restoration projects, clean up projects, and water quality monitoring (number of projects, number of volunteers, number of first time volunteers, number of returning volunteers, and is the demand growing)
- Number of media hits
- Number of recycling programs
- Number of license plates sold
- Cumulative number of businesses recognized as stewards of the estuary
- Number and value of flood insurance claims over time
- Revenues and jobs generated by tourism over time

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# APPENDIX C
# RESOURCES ON INDICATORS


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