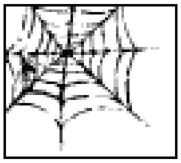
U.S. Environmental Protection Agency

National Estuary Program



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Monitoring Guidance for the National Estuary Program

EPA842-B-92-004

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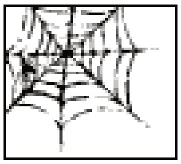

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Introduction

The Clean Water Act as amended by the Water Quality Act of 1987 establishes the National Estuary Program (NEP) to promote long term planning and management in nationally significant estuaries threatened by pollution, development, or overuse. Section 320 of the Clean Water Act describes the establishment of a management conference in each estuary to develop a Comprehensive Conservation and Management Plan. It also establishes requirements to monitor the effectiveness of actions taken pursuant to the plan.

This document provides guidance on the design, implementation, and evaluation of the required monitoring programs. This document should also be of use to others developing monitoring programs. The intended audience is the members of the management conference (i.e., the Management Committee, Scientific and Technical Advisory Committee, and the Citizens Advisory Committee) and the program coordinators and scientific staff of the individual estuary programs. The purpose of this document is to identify the steps involved in developing and implementing estuarine monitoring programs. Given the large number of participants in the management conference and the diversity of technical backgrounds, it is also intended to provide a technical basis for discussions on the development of monitoring program objectives, the selection of monitoring program components, and the allocation of sampling effort. Some of the issues addressed in this document are:

- What is the role of monitoring in the estuary programs?

- Why are monitoring programs necessary, and what are examples of goals and objectives?
- What criteria should be used to select components of the monitoring program, and what should drive the decision-making process?
- What is the importance of historical data, and how can ongoing monitoring programs be incorporated into the estuarine monitoring program?
- What is the relationship between estuary characterization and the monitoring program?

The key technical and programmatic aspects associated with each of these issues are described. This document also includes several examples. Two case studies are used to provide examples from existing estuarine monitoring programs. While these case studies focus on unique sets of problems and questions from individual programs, they provide illustrations of the process of monitoring program design, implementation, and evaluation. The lessons learned are of general applicability even though the political and institutional setting may be different from other estuaries.

The first case study from the Puget Sound Estuary Program (Appendix A1.0; not available electronically) provides an example of the process of developing an effective monitoring strategy. Key issues addressed include problem and goal definition, the process of monitoring program design and implementation, and options for funding estuary monitoring programs. The first case study also demonstrates how ongoing monitoring studies can be coordinated to develop a comprehensive basin-wide monitoring program. The second case study (Appendix A2.0; not available electronically) provides a detailed example of the application of methods for determining the effectiveness and feasibility of monitoring efforts in the Chesapeake Bay Program. Examples from other environmental monitoring programs are also described.

Appendix B of this document describes existing methods that may be used to monitor the effectiveness of management actions in the estuary. The National Estuary Program does not impose national requirements for standard methods. However, emphasis is placed on the importance of using standardized monitoring protocols within each estuary and developing performance-based criteria to evaluate the comparability of analytical methods. One long-term goal of the NEP is to develop a standardized set of key variables that, if measured in all NEP programs, will provide comparative data on nationally significant estuaries.

Funding is typically drawn from federal, state, and local sources for National

Estuary Program monitoring activities. Therefore, this document discusses the integration of existing monitoring efforts into the estuary monitoring program. It is also essential that National Estuary Program monitoring activities be coordinated with existing federal agency status and trends monitoring programs such as EPA's Ecosystem Monitoring and Assessment Program (EMAP), the National Oceanic and Atmospheric Administration's (NOAA) Status and Trends Program, and the U.S. Geological Survey's National Water Quality Assessment Program. If individual estuary monitoring programs will be measuring the same parameters as these federal programs, and the protocols in use provide adequate data, estuary programs should work to ensure compatibility of their data with the existing federal programs.

Data management, effective data analysis, and the communication of monitoring program results to a wide range of audiences at several technical levels are also essential to the success of the estuary program. This document discusses data management strategies and provides several examples of ongoing efforts to disseminate information developed by the National Estuary Program.

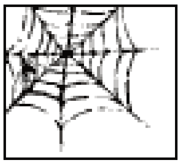
National Estuary Program

The purpose of the NEP is to identify estuaries of national significance and to promote the preparation of comprehensive management plans to ensure their ecological integrity. The process of identifying nationally significant estuaries and nominating estuaries to become part of the NEP is described in *A Primer for Establishing and Managing Estuary Projects* (U.S. EPA, 1989a) and *Final Guidance on the Contents of a Governor's Nomination* (U.S. EPA, 1990a). Following selection of an estuary to be included in the National Estuary Program, a management conference is convened by the EPA Administrator. The management conference has the responsibility to implement a four-phased program:

- Phase I: The Planning Initiative.
  The planning phase is intended to build the management framework for identifying and solving problems and defining the steps in the decision making process.
- Phase II. Characterization and Problem Definition.
  The goal of estuary characterization is to gather and summarize the existing knowledge concerning the state of the estuary as well as the physical, chemical, and biological factors controlling spatial and temporal changes. The characterization process focuses on identifying existing and potential problems and exploring probable causes of such problems. Such cause and

effect linkages between human activities and environmental changes provide the public and decision makers with the information necessary to develop priorities, set management strategies, and devise mitigating measures. However, information gaps do exist. Such information gaps can be filled by additional sampling and a subsequent monitoring program. The charac terization process is described in a separate EPA guidance document.

- Phase III. Development of a Comprehensive Conservation and Management Plan (CCMP).
  The CCMP is a major product of the estuary program. It is developed by the management conference to summarize findings, identify and prioritize problems, determine environmental quality goals and objectives, identify action plans and compliance schedules for pollution control and resource management, and to ensure that designated uses of the estuary are protected.

	Note: This information is provided for reference purposes only. Although the information provided here was accurate and current when first created, it is now outdated.

Background

- Phase IV - CCMP Implementation. When the final CCMP is submitted for approval to the administrator, the management conference and the governor establish a committee to coordinate the implementation of the CCMP. The development of a monitoring program to evaluate the effectiveness of actions specified in the CCMP is a required task of the manage ment conference.

The four phases of the NEP should *not* be viewed as sequential steps, where one phase cannot be initiated before another phase is completed. On the contrary, as the NEP has evolved, EPA has encouraged management conferences to proceed with the four phases simultaneously as often as possible. For example, early results of characterization (Phase II) may indicate obvious management actions that can be taken (Phase IV) prior to completion of the CCMP (Phase III), In these cases, implementation actions should proceed. In fact, EPA will base the selection of any new estuaries on an ability to streamline the NEP phases, focusing on estuaries that have a significant amount of the problem characterization done, that have a successful management framework that functions similarly to an NEP management conference already established, and that have clear commitments from key state and local agencies to participate in and support the NEP process.

Environmental sampling is required in Phases II and IV of the estuary programs. The studies conducted in Phase II are focused on filling identified data gaps, providing baseline data on point and nonpoint loadings of pollutants, and developing estimates of the degree of spatial and temporal variability. Sampling is conducted in Phase IV of the estuary programs as part of a long term environmental monitoring strategy.

Environmental *monitoring* that is conducted during PhaseIV is considered to be different from the *sampling* that is conducted during PhaseII. Monitoring involves repeated sampling over time. For example, short term sampling may be conducted in PhaseII to collect specific information on the concentration, distribution, and variability of chemical contaminants in sediments. The goal of the corresponding sampling that is conducted during PhaseIV is to evaluate trends in monitored variables and to link the observed patterns to specific management actions. A second distinction between PhaseII sampling and PhaseIV monitoring is that comprehensive environmental monitoring programs conducted during PhaseIV will require the integration of information from several concurrent sampling efforts. Since environmental sampling is costly and resources will be limited, there will be a need to evaluate the efficacy of different monitoring program components and to allocate sampling efforts accordingly. It will also be necessary to carefully plan and coordinate monitoring efforts among individual monitoring components and other preexisting monitoring programs to determine interactions and streamline monitoring efforts. A third distinction between environmental sampling and monitoring is the need to periodically analyze the monitoring program results and modify the level of sampling effort to maximize program effectiveness.

NEP Monitoring Program Goals

EPA is developing a programmatic monitoring system for NEP participants to use in tracking the progress being made in protecting NEP estuaries. While primarily aimed at tracking implementation of actions recommended by the management conferences in their CCMPs, the system will be helpful in the assessment of the NEP in its entirety. This programmatic monitoring system will:

- Assist estuary program managers to improve their programs by identifying current and emerging programs;
- Provide accountability to elected officials and the public relating to the progress toward estuary protection;
- Help identify the programs and projects that are working well; and
- Provide a framework for assessing the NEP as a whole.

This programmatic monitoring system will identify estuary management performance indicators that will track, on a regular basis, the status and progress of action-oriented efforts. Much of the input to this programmatic monitoring system will come from information generated by NEP environmental monitoring programs implemented under Phase IV of the NEP, as well as other environmental monitoring programs.

The two primary goals of the monitoring programs implemented in Phase IV by the management conferences are:

- To measure the effectiveness of management actions and programs implemented under the CCMP and
- To provide essential information that can be used to redirect and refocus the management plan.

These monitoring programs are an essential part of the management program review and evaluation process for each estuary, and they will be conducted throughout the implementation of the CCMP.

This document describes the steps involved in designing an environmental monitoring program to meet these two interrelated goals. For example, the goals of the Puget Sound Ambient Monitoring Program (described in Case Study 1) include the charac terization and interpretation of spatial and temporal patterns of conditions in Puget Sound, development of a permanent record of significant natural and human-caused changes in key environmental indicators, and the support of research activities through the availability of consistent, scientifically valid data. Such research will lead to a better understanding of the state of the estuary in question and, in turn, provide infor mation for making better resource management decisions.

Monitoring Design Issues

Marine monitoring is the continued, systematic time-series observation of predetermined pollutants or pertinent components of the ecosystem over a period of time sufficient to determine (1) the existing level, (2) trends, and (3)natural variations of measured components (NOAA, 1979).

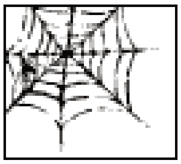
Recent reports by the National Research Council (NRC, 1990a and 1990b) evaluated current marine monitoring programs and practices, identified needed improvements in monitoring strategies, and made a series of recommendations to improve the usefulness of monitoring information.

The extensive NRC review of monitoring practices found numerous inadequacies in the design and use of monitoring data. Three broad problem areas were identified:

- Monitoring programs are often poorly designed because of failure to clearly define monitoring objectives and to apply available design tools. Some of the identified problems could be attributed to the inherent difficulty of separating the effects of human activities from natural variability.
- There is a lack of communication and coordination among the regulatory, scientific, and management entities sponsoring or conducting monitoring programs. Specific concerns include the inflexibility of regulatory requirements that limit opportunities to adapt programs to new needs and regional objectives. The need to adopt standardized sampling and quality assurance procedures to ensure data comparability has also beenidentified.
- The results of monitoring programs are notpresented in a form that is useful in developing broad public policy or evaluating specific control strategies. It is essential to link data management strategies and data analysis methods to the objectives of the monitoring effort. It is also necessary to devise a plan for effectively communicating monitoring results to the identified audience.Additionally, the NRC study found that poorly designed monitoring programs and the lack of communication and coordination among programs has often resulted in:
- Limitation of water quality and public health monitoring to areas adjacent to point-source outfalls and other known or potential problem areas, and to the sampling and analysis of conventional water quality and public health parameters
- Living resource monitoring programs restricted to assessment of a few higher-trophic levels of commercially or recreationally important species, without consideration of key prey species upon which these species depend
- Incomplete monitoring of living resources and habitats key to the determination of potential declines in living resources and water quality (i.e., near shore habitats, estuarine wetlands, plankton communities)

A wide range of guidance on the design of environmental monitoring programs is available in the literature. Important contributions have been made that address the principles and options for designing monitoring networks (Green, 1979; Segar and Stamman, 1986), the development of monitoring objectives (Beanlands and Duinker, 1983), the appropriateness of monitoring variables (Bilyard, 1987), and the application of statistical methods in the design process (Ferraro *et al*., 1989). The recent NRC study (NRC, 1990a) also provides comprehensive review of the steps involved in the design of marine environmental monitoring programs.

Outlined below is a systems approach to the design of the required NEP monitoring programs that incorporates existing information and that will ensure the collection, analysis and reporting of adequate information to meet the goals of individual estuary programs.



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Recommended Monitoring Design Procedures

Table 1-1. Elements of Systems Approach

- Define the Objective - The overall objective of the design process is stated in a succinct manner.
- Establish Information Needs - Information requirements to meet the objectives are established.
- Establish the Objectives of - The objectives of all possible monitoring
- Individual Program Components - Program components and performance criteria are established.
- Evaluation of Trade-Offs - The combination of monitoring components that best meet the overall objectives is selected.
- Feedback to Initial Design Step - Modifications to the system's design are made to improve the product's performance.

A systems design approach places emphasis on the optimum design of the overall monitoring program. The essential elements (shown in Table 1-1) are the assessment of trade-offs between individual aspects of the monitoring program and the use of feedback mechanisms to modify individual monitoring program components based on periodic assessments of overall program performance. This approach is well suited for design problems that involve complex, highly variable systems, such as estuaries, and that involve a large number of investigators that must interact as a group to produce the product. The plan for implementing this approach to designing the monitoring program is shown in Figure 1-1. It involves the specification of monitoring objectives, the completion of a series of steps to translate these objectives into clearly defined monitoring activities, and the use of feedback mechanisms to refine the objectives and adjust the sampling effort.

The overall objective of monitoring undertaken during Phase IV of the estuary programs will be to measure the effectiveness of management actions implemented as part of the CCMP. Meeting this broad program objective will require the specification of several individual, highly interrelated *monitoring objectives*. Examples of individual monitoring objectives (shown in Figure 1-1 as Objectives 1 through n) include: to determine the response of key water quality variables to management actions; to determine trends in sediment contaminant concentrations; and, to evaluate the persistence of PCBs in the tissue of recreational and commercial fish.

Each monitoring objective represents a separate component of the overall estuary monitoring program. The individual steps involved in designing each component of the monitoring program are shown on the right-hand side of Figure 1-1:

- *Step 1.* Develop Monitoring Objectives and Performance Criteria. Clear objectives and corresponding performance criteria must be developed for each component of the monitoring program. Performance criteria specify the level of change or trend that the monitoring program must be able to detect. For example, in the Chesapeake Bay Program, a target of 40% reduction in nutrient loads to the bay was established based on modeling results. One of the predicted benefits of nutrient reduction is the alleviation of anoxic conditions in the bay and an increase in the minimum dissolved oxygen to approximately 1.5mg/l. Therefore, the corresponding objective and performance criterion for the water quality component of the monitoring program would be to detect a long term change in dissolved oxygen concentration in the bottom waters of the bay equal to 1.5mg/l.

- *Step 2*. Establish Testable Hypotheses and Select Statistical Methods. The study objectives must be translated into statistically testable hypotheses; for example, no trend exists in measured values of dissolved oxygen concentration. Establishing testable hypotheses ensures that the results of the monitoring program will be unambiguous and that the objectives of the program can be met. The establishment of testable hypotheses also guides the development of statistical strategies for determining sample locations and times as well as the selection of statistical tests that will be used to analyze the resulting data.

- *Step 3.* Select Analytical Methods and Alternative Sampling Designs. Detailed specifications for each monitoring variable (measurable endpoint) of the monitoring program must be developed. These include: field sampling and laboratory procedures, and QA/QC procedures. Additionally, alternative sampling designs that specify the number and location of stations must be devised for input to the next step in the des ign process.

- *Step 4.* Evaluate Expected Monitoring Program Performance. It is essential to evaluate the expected performance of the initial sampling design to determine the minimum difference that can be detected over time or between locations. Without this evaluation there is a risk of collecting and analyzing too few samples to detect statistically significant temporal or spatial trends or of analyzing an excessive number of samples (with associated high costs). As indicated by the feedback loop shown in Figure1-1, the results of this evaluation are used to identify modifications to the initial design in order to increase monitoring program effectiveness. Information from this evaluation will also be used to assess the ability of monitoring components to provide information used to modify the management plan.

- *Step 5.* Design and Implement Data Management Plan. The development of a data management system is an essential task that is often overlooked in the design of monitoring programs. The data management system should be operational prior to implementation of the monitoring program. Data analysis methods and a timetable for analyzing the data, assessing CCMP implementation progress and monitoring program performance, and reporting program results should also be specified. The results of the performance assessment are used to refine program objectives and modify individual study elements to satisfy these objectives.

These individual steps in the monitoring design process shown in Figure 1-1 are described in Sections 2 through 6 of this document.

Peer review of the monitoring program is recommended to evaluate and assess program design. Critical review by technical experts without a vested interest in the estuary program will ensure that the monitoring objectives are meaningful and that the monitoring strategy adequately addresses these objectives with the most appropriate methods. This review should take place after the initial development of specific objectives and performance criteria and as part of periodic reviews that are conducted to evaluate the success of the monitoring program.

Overall program performance must be assessed at periodic intervals, and the results should be used to refine monitoring program objectives and methodologies. The original monitoring design must remain open to modification. The monitoring program should take advantage of new information and innovative sampling approaches as they are developed, and the link between modeling and monitoring efforts should be fully exploited. The results of the monitoring program should be used to refine and modify conceptual and mathematical models of the system, and modeling results should be used to guide changes in individual monitoring program components, variables monitored, the frequency of sampling, and overall monitoring strategies. It is essential that new information, from both independent research and the monitoring program results, is integrated into the monitoring program.

There are a number of management issues related to the design, implementation, and maintenance of NEP monitoring programs that must be addressed early by the management conference. These include setting the timetable for the design and implementation process, assigning responsibilities for coordinating the design effort, and planning for the long term success of the monitoring program.

Monitoring Program Management

Timetable for the Design and Implementation of the Monitoring Program

The design and implementation of the Puget Sound Ambient Monitoring Program (PSAMP), described in Case Study 1, required four years of uninterrupted effort. The development of the monitoring program was a consensus building effort among numerous agencies and organizations, and several iterations were required to finalize the initial design plans. In addition to the decisions regarding the basic sampling strategy, agreement was required on numerous interrelated issues, such as sampling protocols, appropriate quality assurance/quality control methodology, and the selection of an information management system.

Planning for the monitoring program should be initiated during the first year of the management conference. Milestones for the monitoring program effort should be clearly stated in the State-EPA Management Conference Agreement (a three to five year action plan for CCMP completion that is negotiated shortly after a management conference is convened). Development of the monitoring program should be given a high priority by the management conference after it is convened. It is important to begin early planning of the monitoring program to ensure that it is in place at the time the CCMP is implemented. A detailed monitoring program plan must accompany the CCMP that is submitted to the EPA Administrator for approval. The monitoring plan must contain the following elements that are described in this document:

- Definition of program objectives and performance criteria (parameter values needed to guide management decisions)
- Identification of testable hypotheses
- Detailed specifications for each monitoring variable, including sampling locations and frequency, field sampling procedures, field and laboratory analytical procedures, quality assurance and control procedures
- Specification of the data management system and statistical tests that will be used to analyze the monitoring data
- Description of the expected performance of the initial sampling design (i.e., the minimum difference that can be detected in measured variables over time and between locations)
- Plan and timetable for analyzing data and assessing program performance

Management Tasks for Developing the Monitoring Program

The first management task in developing the monitoring program should be the establishment of an organization or committee, such as a monitoring subcommittee of the Scientific and Technical Advisory Committee (STAC), to develop the monitoring program. The STAC is one of three committees that make up the NEP management conference. The other two committees are the management committee and the Citizen's Advisory Committee. Membership in the monitoring subcommittee should not be limited to STAC members but should include representatives from federal, state and local agencies, universities, industry, environmental groups and others currently conducting monitoring or planning monitoring programs within the estuary or surrounding waters. The subcommittee should be charged with the following tasks:

- Define the goals and objectives of the monitoring program.
- Propose an initial design that includes recommendations for sampling and analytical protocols, data management system specifications, quality assurance guidelines, data reporting requirements and cost estimates.
- Develop the final monitoring design using workshops and other mechanisms to solicit comments and suggestions from the public and scientific community.
- Coordinate the activities of the numerous interested and participating agencies and develop interagency agreements that will promote the monitoring effort.
- Identify funding mechanisms and opportunities to contain costs.

As discussed in Section 1.2, the process of developing a comprehensive monitoring program must begin with a clear statement of the objectives. The explicit statement of objectives, and options for obtaining these objectives, is necessary as a starting point for describing the problem areas in the estuary and developing the consensus among interested agencies and other parties that is essential to the success of the monitoring effort.

The primary goals of the monitoring program will be to measure the success of the CCMP and to provide information that can be used to redirect and refocus the management. However, it will also be the responsibility of this subcommittee to develop secondary goals and program objectives that will be used to focus the sampling effort.

These objectives could include: continued characterization of spatial and temporal patterns of change in water quality, sediment and biological resources of the estuary; development of a permanent record of significant natural and human-caused changes in environmental indicators in the estuary over time, and support for research activities through the availability of consistent, scientifically valid data. The process of developing these objectives is described in Section 2.0.

There are several options for initiating the design process. The PSAMP began with an initial monitoring design developed by consultants to EPA Region 10. The initial design included goals and objectives, plans for operation of the program, and methods for sampling, analysis, and reporting the data. The first draft of the monitoring program design was refined by EPA Region 10 through a process involving meetings and discussions among managers and scientists working in the Puget Sound region. The Puget Sound Monitoring Management Committee then proceeded to review, modify, and refine the proposed monitoring design. This resulted in the development of a revised draft that was released for public and further scientific review. The Santa Monica Bay Restoration Project began the development of the monitoring program with an "Assessment of Monitoring and Data Management Needs Workshop;" to develop and evaluate monitoring options. In preparation for the workshop, background information was compiled and used to develop a "strawman;" to guide work shop discussions. In both the Puget Sound and the Santa Monica programs, public and scientific workshops were held to discuss the proposed monitoring options and to build the required consensus among participating entities.

The next task following the adoption of the monitoring program design is to ensure that it is implemented as planned. The implementation of a regional or basin-wide monitoring program requires the development of commitments and the coordination of activities among the participating agencies. This was achieved in the Puget

Sound Ambient Monitoring Program by negotiating memoranda of agreement(MOA) with each of the participating agencies. The MOAs specified commitments that each agency carry out its responsibilities identified in the monitoring program design, and that each agency maintain monitoring program funding levels and staff support for the monitoring program committees. As described in Case Study1, the negotiating of the MOAs was essential to the success of the PSAMP, but the complexity of the process was underestimated. It is recommended that the coordination efforts begin as soon as possible in the design process.

It is also important that the monitoring subcommittee begin to identify, early in the process of monitoring program development, the costs associated with existing monitoring in the basin, the costs of additional monitoring that will be needed, potential sources of additional funds to support the monitoring program, and appropriate mechanisms to fund the monitoring program. Costs of the Puget Sound Ambient Monitoring Program were calculated by a technical costing subcommittee of the monitoring management committee with the assistance of a technicalconsultant.

The estimates provided by this subcommittee demonstrate that the costs of comprehensive monitoring programs can be substantial. In addition to the $200,000 in staff and consultant time required to develop the monitoring program design, the calculated costs of full implementation of the PSAMP are approximately $3.2 million per year (in 1987 dollars). The initial sampling program was reduced in scope due to resource constraints, and costs for the program have been $250,000 to $350,000 over the first two years. The projected costs of implementing the monitoring plan submitted as part of the Buzzards Bay CCMP are $750,000 per year. This includes $200,000 funded by the estuary program to supplement ongoing state and citizen monitoring programs. The costs of the comprehensive water quality monitoring in the mainstem of the Chesapeake Bay are on the order of $900,000 annually. This monitoring includes the sampling of 20 variables at 49 stations, 20 times. In addition to mainstem sampling, the states surrounding the bay have undertaken their own extensive sampling programs in the bay's tributaries.

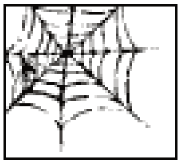
The substantial costs of these programs require equally substantial efforts to secure long term funding. Most of the costs of monitoring should be borne by the state and local agencies that will complete specific monitoring tasks. Therefore, the best opportunity for securing the required funding is indirectly by incorporating existing federal, state and local monitoring programs into the o verall design. The critical step will be to motivate the participating agencies to make modifications to existing monitoring efforts to meet the goals of the estuary program. The best way to achieve this objective is to involve these agencies in the estuary program and the monitoring design process as early as possible and to demonstrate the benefits of a regional / basin-wide monitoring program to the scientific and regulatory community. If state and local funds are not immediately available for full implementation of the monitoring pro gram, a plan for phased implementation can be developed through a priority setting process involving the monitoring management committee and other technical experts.

Section 4.0 of this document discusses the incorporation of individual components of ongoing local monitoring programs into the National Estuary Program monitoring efforts. Opportunities for taking advantage of monitoring programs of national scope, such as EPA's Environmental Monitoring and Assessment Program (EMAP) and NOAA's Status and Trends Program, as well as locally coordinated citizen monitoring programs, are also discussed.

Financing Marine and Estuarine Programs: A Guide to Resources (U.S. EPA, 1988a) provides guidance for obtaining direct financing of marine and estuarine monitoring programs. This document provides a primer on basic financing concepts and explains the initiatives needed to begin financial planning for long term resource management activities. Case studies are also included that provide examples of local financial efforts.

Planning for the Long Term Success of the Monitoring Program

A structure for managing the monitoring prog ram must be recommended to the management conference by the monitoring subcommittee or its equivalent. A lead coordinating agency or organization must be identified and given the responsibility for implementing the monitoring design as planned, mainta ining the monitoring effort, and reviewing the monitoring program results. The lead agency or organization should provide a full-time manager/coordinator and a staff that is responsible for keeping all the implementing agencies and other participants informed of progress, resolving disputes, carrying out technical and administrative duties, and reporting the results of the program.



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Develop Monitoring Objectives and Performance Criteria

The overall objective of the estuary monitoring program is to assist in determining the effectiveness of the implementation of the CCMP. However, this overall objective may encompass several specific monitoring objectives. The identification of these specific objectives begins during *Estuary Characterization.* The characterization process identifies public concerns and formulates a series of corresponding management issues. During characterization, conceptual and predictive models are developed and research results are evaluated to provide a basic understanding of important physical, chemical and biological processes in the estuary. This information is used in the design of the monitoring program to specify a set of variables and ecological processes that can be used to detect changes in the estuary in response to management actions.

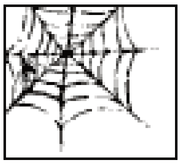
Regardless of the scope of the proposed monitoring program, *it is essential to develop explicit statements of the monitoring objectives as well as to establish performance criteria with which to measure monitoring program success*.

The development of the monitoring objectives is the culmination of the estuary characterization and the preparation of the CCMP. The characterization process is described in a separate technical guidance document (U.S. EPA, 1992). It involves the identification of public concerns and potential water quality, biological and public health problems in the estuary. A unique approach for identifying these concerns and ecological problems is based on previous work summarized in the National

Research Council's *Managing Troubled Waters* (Clark, 1986; NRC, 1990a and 1990b). The key to this approach is the construction of the matrix, shown in Figure 2-1 (not available electronically), which identifies Valued Ecosystem Components (VECs) and sources of perturbation. This matrix also summarizes the understanding of the relative importance of each source of perturbation and the degree of scientific certainty associated with knowledge about each impact. Each cell in the matrix summarizes the effects of each perturbation on a single ecosystem component. For example, the information summarized in Figure 2-1 indicates that wastewater out falls are a controlling factor of soft-bottom benthos communities and that there is a moderate degree of certainty regarding the scientific understanding of the effects of these outfalls in the Southern California Bight. The effects of each identified source of perturbation (e.g., storm water runoff) on all identified resources (VECs) are summarized along a single row. Similarly, each column summarizes the existing knowledge of the impacts on a single resource caused by the complete range of ident=ified sources of perturbation.

This matrix summarizes existing information on the resources of the estuary and potential impacts in an easily accessible manner. The process of developing this matrix also provides an effective tool for building consensus among the wide range of interested parties in the estuary program on the relative priority of monitoring objectives and the different components of proposed monitoring programs. Bernstein *et al*. (1991) describe an Integrated Assessment methodology based on the work by Clark (1986) that guides the selection of monitoring objectives based on the relative importance of the identified resources, the understanding of the underlying controlling processes, and the ability to detect changes in monitoring variables.

Simple conceptual and predictive models developed in the characterization process may also be used to summarize the physical, chemical, geological and biological status of the estuary and identify the factors controlling spatial and temporal changes. Finally, it is necessary to quantify the identified ecological relationships. Existing data should be analyzed to evaluate the strength and direction of identified relationships and to determine the magnitude of uncertainty associated with the existing information. The products of the characterization process should include the identification of the primary management issues. These management issues are used



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Monitoring Program Objectives

Figure 2-1, *Impacts on the marine environment of the Southern California Bight (Bernstein et al., 1991).* is not available electronically

The monitoring program is designed to verify the predicted results and evaluate the effectiveness of the CCMP implementation, and to recommend corrective actions. When insufficient information is available for estuary characterization and/or CCMP development, a monitoring program may also be designed to fill the information gaps.

Case Study 1 (Appendix A1.0; not available electronically) describes the process that led to the development of the goals of the Puget Sound Ambient Monitoring Program. The essential steps were:

- The development of the Puget Sound Water Quality Management Plan - a comprehensive management plan for Puget Sound and its related waterways. In developing this plan, nine issue papers were prepared. One of these, Comprehensive Monitoring of Puget Sound (PSWQA, 1986), reviewed existing monitoring programs and described the process of developing a comprehensive water quality, sediment, and biological monitoring program.
- During the same period of time, the Office of Puget Sound (EPA Region 10) developed a proposed sound-wide monitoring program which included goals and objectives, sampling design, operation of the program and methods for sampling, analysis and reporting of the data (Tetra Tech, 1986a). This

document provided a basis for discussions between members of the Puget Sound Estuary Program (PSEP) technical advisory committee, scientists, agency staff, and other interested parties.

- The Puget Sound Water Quality Management Plan appointed a Monitoring Management Committee to define the goals and objectives of the monitoring program and to modify the monitoring strategy proposed by the Office of Puget Sound. Key aspects of the monitoring program development included workshops that were held for public and scientific peer review, including the Technical Advisory Committee (TAC) of the Puget Sound Estuary Program.

  The final report of the Monitoring Management Committee (PSWQA, 1988) summarized the proposed monitoring program and provided explicit statements of the goals and objectives and expected performance.

Objectives and Rationale

Measuring toxic chemicals of concern will provide data to:

- Assess the potential for sediment toxicity to resident biota.
- Identify areas of Puget Sound that have been, or are, accumulating substantial amounts of toxic chemicals.
- Evaluate temporal changes of toxic chemicals accumulating in sediments.
- Interpret biological and sediment toxicity bioassay data.

Methods

Samples for sediment chemistry will be collected from the upper two centimeters (cm) of sediment, using either a 0.06m2 box corer or a 0.1m2 van Veen grab. Three grab samples will be taken at each station and composited. The same composite will be used for sediment toxicity bioassays and conventional sediment variables. A minimum of the upper 5 to 10cm of sediment will be collected for benthic macro-invertebrate abundance determination. Each sampling device has advantages and disadvantages. Although a box corer takes a deeper and possibly less disturbed sample than does a van Veen grab, the box corer is more difficult and more expensive to use. An evaluation of benthic sampling equipment for use in PSAMP is in progress.

Variables to be monitored will include selected EPA priority pollutant metals and selected EPA priority pollutant organic compounds, as well as additional compounds of concern in Puget Sound.

Miscellaneous organic acids and volatile organic compounds will be measured only where a suspected source is present. Intensive surveys conducted by individual agencies under other programs may be triggered by results from this program.

Tributyl-tin has recently been implicated as a human health risk (U.S. EPA, 1985). Studies from other parts of the country have shown accumulations in sediments and animal tissue around large marinas and harbors. The present concern warrants a comprehensive survey for tributyl-tin in sediments and bottom fish tissue in Puget Sound, but it is not included in the monitoring program at this time due to inconclusive sampling results from other parts of the country. Periodic spot checks for this and other contaminants are recommended. Costs of such analyses have not been included in cost estimates for the ambient monitoring program.

Replication and statistical sensitivity

Replicate samples will not be collected for sediment chemistry, thereby precluding statistical analyses among individual stations within a survey. Replicated sampling at all stations was precluded because of the high cost of laboratory analysis and has not been recommended by Puget Sound Estuary Program sampling and analysis protocols. The variability of sediment chemistry estimates will be reduced, however, by the compositing technique recommended. Field and laboratory replication will be required for sediment chemistry samples as part of the quality assurance program. Stations for field replicates will be chosen so as to be representative of certain areas or embayments and sediment types.

Statistical analyses may be performed for related groups (clusters) of stations within a survey or for selected stations over time.

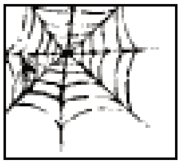
Replicate data from studies on the chemical composition of sediments within the Commencement Bay waterways indicated that coefficients of variation for several groups of organic chemicals ranged from 17-61 percent (Tetra Tech, 1985). Given a coefficient of variation of 30 percent and three to four replicates (in space or time), the minimum detectable difference in mean chemical concentration among stations, at the 95 percent confidence level with a power of 0.8, would be equal to about 100 percent of the overall mean among stations.

Protocols

Field and Laboratory References: Tetra Tech (1986b, 1986c , 1986d). Supporting literature: U.S. EPA (1983), Plumb (1981), U.S. EPA (1982). A summary of the design specifications for the sediment monitoring component of the Puget Sound Ambient Monitoring Program is presented in Table 2-1 (not available electronically). These design specifications provide an example of PSAMP efforts to clearly state the monitoring objectives and to establish performance criteria. Four major objectives are stated for the sediment chemistry component of the monitor ing effort: assess the potential of sediment toxicity, identify toxic accumulation areas within Puget Sound, evaluate temporal changes, and provide supplemental data that will be used to interpret bioaccumulation data and bioassay test results.

The establishment of program requirements, i.e., performance criteria, in terms of the level of precision and accuracy that is necessary to make decisions regarding the success of the monitoring effort will define the expectation of the monitoring program. Issues that must be addressed include: 1) What level of detail will be necessary to make decisions regarding the success of the CCMP? 2) What level of difference must be detected in the monitoring program to initiate modifications in the design and implementation of the monitoring program? This concept of explicitly stating performance criteria is the cornerstone of the systems design approach that is described below. The explicit statement of the monitoring program requirements provides a basis for evaluating expected and actual monitoring program performance (Section 5.0). Evaluation of the effectiveness of alternative monitoring designs also provides a basis for discussion of alternative monitoring approaches and sampling layouts.

Performance criteria are addressed in the design specifications for the sediment chemistry sampling of the Puget Sound Ambient Monitoring Program (Table 2-1; not available electronically). Under the discussion of replication and statistical sensitivity, basic information is provided on background variability and the minimum detectable difference between groups of stations. However, the specification of *performance criteria* associated with monitoring program designs *should be made more explicit* than those presented in these design specifications. For example, one of the stated objectives is to evaluate temporal changes in toxic accumulation. Corresponding performance criteria should be developed by determining the magnitude of trend that can be expected to be detected with the planned level of sampling effort and the period of time that will be required to detect statistically significant trends. The use of historical data and the application of statistical methods to evaluate and establish decision criteria are addressed in Section 5. An example of the use of statistical methods to determine the magnitude of trends that can be measured in a particular monitoring design is presented in Case Study 2 (Appendix A2.0; not available electronically).



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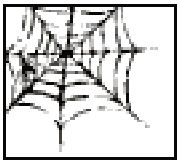
Performance Criteria

The Quality Assurance Management Staff (QAMS) of EPA has developed an approach to designing data collection programs based on the development of Data Quality Objectives (DQOs). This approach has many of the same elements as the systems approach for designing monitoring programs that are discussed in this document. The DQO process places emphasis on defining the objectives of data collection programs, specification of the decisions that will be made with the data collected, and the possible consequences of the decisions being incorrect (QAMS, 1986). A key aspect to the development of DQOs is the evaluation of the desired degree of certainty in conclusions to be derived from the data. This evaluation is similar to the process described in this document for the development of decision criteria. In both methods, the decision criteria are developed to ensure that adequate information is obtained for making decisions. A case study describing the use of DQOs in Superfund Remedial Investigations is presented by Neptune *et al*. (1990).



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Establish Testable Hypotheses

It is clear that the monitoring program must be designed to address a wide range of alternative hypotheses. *The recommended procedure for ensuring that sufficient information and the right type of information is developed in the monitoring program is to specify, prior to the collection of any samples, the statistical model that will be used to analyze the resulting monitoring data, and to specify testable (null) hypoth eses.*

TABLE 3-1.

Examples of Monitoring Program Objectives and Associated Questions

Objective	Questions
Document response of water quality variables to management actions	Are nutrient reduction strategies effective? Is the risk of hypoxia reduced? Is there a decrease in phytoplankton biomass? Is light transmittance affected? Is fish community structure affected?

Characterize spatial and temporal patterns in bioaccumulation products	What is the risk of consuming seafood from within the estuary? Are there trends in fish and shellfish contaminant concentrations? Do toxic hot spots exist and what are the influences on bioaccumulation? What is the relationship between sediment concentrations of contaminants and observed tissue concentrations? What is the relative contribution of different sources of pollutants?
Monitor the status of the ecosystem	What are the trends in selected indicators? What are the consequences of the physiological, morphological and molecular changes on which indicators are based on organism survival and population health? What is the status of species of commercial and recreational importance?

For example, expanding on the water quality issues above, the process of selecting the statistical model and testable hypotheses for detecting trends in dissolved oxygen concentration is outlined below.

A regression model is used to partition field observations (X_{ij}) between several factors that potentially influence dissolved oxygen concentrations:

$$X_{ij} = b_0 + b_1 t_i + b_2 l_j + b_3 t_i l_j + e_{ij}$$

where:

X_{ij} = field observation from time i and location j of dissolved oxygen concentration at a specified depth

b_0 = mean of all X_{ij} observations

$b_1 t_i$ = temporal component of the measurement

$b_2 l_j$ = spatial component of the measurement

$b_3 t_i l_j$ = location-time interaction component of the measurement

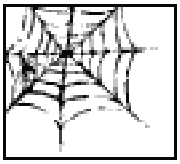
e_{ij} = random errors not accounted for by b_0, $b_1 t_i$, $b_2 l_j$, $b_3 t_i l_j$

One possible null hypothesis to be tested in this case is that there is no temporal trend in measured dissolved oxygen concentrations [H_o: $b_1 = 0$]. If it is concluded that Ho is false, then an alternative hypothesis [H_a: b_1 is positive (increasing trend) or negative (decreasing trend)] will be assumed to be true. The specification of this model also provides the basis for addressing other scientific hypotheses of interest. For example, is there evidence of location-time interaction [H_o: $b_3 = 0$]?

Green (1979) emphasizes the importance of developing testable hypotheses during the design phase of environmental studies and points out that hypothesis formulation is a prerequisite to the application of statistical tests. As pointed out below in Section 5 , the development of testable hypotheses and the selection of statistical methods are also the first steps in evaluating the expected performance of the monitoring program. For the dissolved oxygen example, this means determining the minimum trend that can be detected for a specified level of sampling effort. The process of devising testable hypotheses should also be used to initiate discussions between the management committee and technical experts on the importance of individual monitoring objectives and the relevance of the associated questions. Platt (1964) provides an excellent review of the importance of hypothesis development in the design of scientific investi gations in general.

The statistical tests that will be used to analyze the resulting data must be specified for each hypothesis developed. The applicability of univariate, multivariate, parametric and nonparametric methods must be carefully evaluated. Selected references that provide background information on the use of various statistical methods are summarized in the annotated list presented in Table 3-2. These references will provide program coordinators and scientific staff with a basic understanding of the analytical options available. However, it is essential to involve the statisticians responsible for the analysis of the data in both the development of testable hypotheses and the selection of analytical methods.

The statistical software that will be used to analyze the data should also be identified at this step in the design process. Berk (1987) describes the attributes of effective microcomputer statistical software. Meads (1990) summarizes the results of a user's survey of six advanced statistical packages available for PCs. *The American Statistician*, a publication of the American Statistical Association, also regularly reviews new statistical software and updates to existing packages.



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Selection of Statistical Methods

Table 3-2.

References to Basic Monitoring Design and Statistical Texts

Reference	Description
Monitoring Design	
Sampling Design and Statistical Methods for Environmental Biologists (Green, 1979)	Introduction to principles and options for sampling and statistical design. Examples of monitoring design and application of statistical methods.
Statistical Methods for Environmental Pollution Monitoring (Gilbert, 1987)	General reference that describes a wide range of statistical methods and their application. Intended for nonstatisticians. Description of several statistical techniques that are not commonly seen in general references.

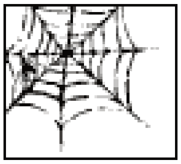
Sampling Techniques (Cochran, 1977)	Comprehensive review of sampling methods and theory. Detailed presentation of topics at an introductory level. Applicability not limited to environmental sampling and monitoring.
Statistical Principles in Experimental Design (Winer, 1971)	Description of hypothesis testing concepts.

General Statistics

Biometry (Sokal and Rohlf, 1981)	Basic reference to statistical techniques most frequently used in the biological sciences. Numerous examples of applications.
Biostatistical Analysis (Zar, 1974)	Basic reference to statistical techniques most frequently used in the biological sciences. Emphasis on analysis of variance techniques.
Applied Statistics, Principals and Examples (Cox and Snell, 1981)	In depth examples of many of the most common statistical applications.

Multivariate Statistics

Applied Multivariate Statistical Analyses (Johnson and Wichern, 1982)	General introduction to multivariate methods.
Applied Regression Analysis (Draper and Smith, 1981)	Detailed introduction to regression techniques. Includes section on planning large regression studies.
Multivariate Statistical Methods: A Primer (Manly, 1986)	Brief description of the most common multivariate techniques, with examples.



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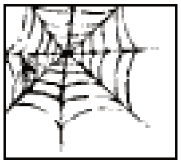
Select Analytical Methods and Alternative Sampling Designs

The goal of this step in the design process is to develop detailed monitoring program specifications. In addition to the statistical methods, these specifications include the field collection and laboratory analysis methods for individual monitoring variables, and the appropriate quality assurance/quality control procedures. Alternative sampling layouts including numbers and location of sampling points, sample frequency, and the level of sample replication should also be developed. This information will then be used in the next step (see Section 5) to evaluate expected monitoring program performance and to select the most efficient sampling layout among the alternatives.

Appendix B (not available electronically)of this document provides descriptions of numerous sampling methods that are routinely utilized in estuarine monitoring programs. These descriptions include information on how the data can be used to address the goals of the monitoring programs and to evaluate the success of the CCMP. The essential elements of quality assurance and quality control programs are also described. The purpose of selecting field and laboratory methods at this stage of the design process is to ensure: the feasibility of using the selected methods in conjunction with the proposed level of sampling effort; that any data used to evaluate expected monitoring performance, a crucial step in the design process, are directly comparable with data that would be collected in the proposed monitoring effort; and, that standardized methods are used. The development and application of an effective QA/QC program is discussed throughout the appendix.

The Chesapeake Bay Split-Sample Program (U.S. EPA, 1991) is presented as a valuable approach to maintaining QA/QC.

	Note: This information is provided for reference purposes only. Although the information provided here was accurate and current when first created, it is now outdated.

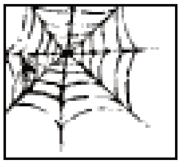
Selection of Field and Laboratory Methods

Standardized protocols or performance criteria should be developed to ensure that the data collected by the different groups participating in the estuary monitoring program are directly comparable. Becker and Armstrong (1988) describe the process of developing standardized sampling and analysis protocols for measuring selected environmental variables in Puget Sound. The key feature of the development of these protocols was a series of workshops at which regional scientists and managers worked together to develop standardized methodologies. The protocols that have been developed are described in the introduction to Appendix B (not available electronically). These protocols were also used as a primary source of information for the description of methods that are included in Appendix B.

In the development of alternative sampling layouts, consideration should be given to the trade-offs between the benefits of a comprehensive monitoring effort and available funding. In general, federal support for these programs will be limited both in the amount of funding available annually and the duration of funding. Consideration should be given to both limiting the scope of monitoring efforts and making the most efficient use of ongoing monitoring programs in the estuary.

Ideally, the scope of the program should be adequate to meet all identified monitoring objectives. Where the funding is not available to meet all the objectives, however, the individual monitoring components should be prioritized on the basis of the relative importance of related management issues and the availability of existing information. Generally, emphasis should be placed on focusing monitoring efforts in order to attain the level of precision necessary to evaluate the effectiveness of individual management actions, rather than implementing a comprehensive monitoring program that lacks the ability to detect the level of changes expected over time.

Given the wide variety of habitats in individual estuaries, the large variability generally associated with environmental samples, and the limit of funding, alternative sampling strategies should be investigated. Through design optimization, the sampling effort can be distributed spatially and temporally in such a way as to maximize the amount of information obtained within the area sampled. The strategy behind most sample design optimizations is either to minimize the detectabledifference or trend for a fixed cost or to minimize the cost for a specified minimum detectable difference or trend. The strategy adopted will depend upon the specific situation for each monitoring program. In either case, the goal is to obtain the maximum amount of information per dollar spent.



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Alternative Sampling Designs

The choice of a sampling design depends on several factors including the objectives of the monitoring program, the type of data that are required to test the null hypothesis, the underlying assumptions of statistical tests, and the spatial and temporal distribution of the monitoring parameters. These factors can affect both the validity of the test results and the efficiency of the monitoring program (cost to obtain a given level of detection). A brief summary of common sampling designs is presented in Figure 4-1.

Figure 4-1.

Description of various sampling designs.

- The most basic method of collecting monitoring data is simple random sampling. With this design, samples are selected ran domly and with equal probability. While this method is easy to implement, there are a variety of sampling designs that can be more efficient. Such designs will produce estimates with smaller standard errors for the same sampling effort, or require fewer samples to obtain the same standard error as would be obtained with simple random sampling.

- One such design is systematic sampling. In systematic sampling, sample units are selected at fixed intervals in space or time, usually with a random start. There are many variations of systematic sampling; however, they all share some common advantages and disadvantages. The even coverage obtained with systematic sampling tends to ensure that each sample, on average, is more representative of the population as a whole than a simple random sample. Therefore, such samples tend to have a smaller standard error associated with them. Problems can arise that lead to bias or increased variance if there is an underlying pattern or periodicity in the population over space or time, which is common with environmental data. In addition, it can be difficult to obtain a valid estimate of the standard error if the data cannot be assumed to be distributed randomly.

- Another design often used is stratified sampling. By dividing the study area into nonoverlapping homogeneous strata it is possible to optimize the sampling effort in several ways. First, the samples can be allocated to the different strata in proportion to the size of the strata and the variability within the strata, and in inverse proportion to the cost of sampling in those strata. This method will insure that the minimum variance will be obtained for a given cost. Other criteria, such as the ecologic importance of strata and the parameters being measured, can also be taken into account when allocating sampling effort. Stratified sampling also allows the use of the best sampling designs within strata to further increase the sampling efficiency. Stratified sampling works well in a tiered approach because it allows monitoring performance assessment and design modification to be made on a stratum by stratum basis. Stratified sampling also yields estimates for each stratum, providing information that better represents the area being sampled, and is therefore more ecologically meaningful. As an example, two strata may each have a significant trend for a given parameter, but the trends may be in opposite directions. If the data were combined (such as in systematic sampling), the trends might cancel each other out and result in a conclusion of no significant trend. Because stratified sampling ensures that some samples will be taken from each stratum, over the entire study area, it helps ensure that the overall estimate will be more representative on average than one obtained from a simple random sample. This advantage of stratified sampling will be realized even if optimal allocation is not used and the strata are defined arbitrarily with respect to the parameters of interest. In general, if the variability within individual strata is less than the overall variability in all combined strata, the standard errors obtained with stratified sampling will be less than those obtained from systematic sampling, which will be less than those obtained from simple random sampling. Applications of stratified sampling to environmental studies are found in U.S.EPA (1982a), Jensen (1973) and Reckhow and Chapra (1983).

- Multistage sampling is another cost effective method of allocating sampling effort over large areas. In this design, large primary sampling units are composed of smaller secondary units. For large-scale studies, third stage units may also be used. Within each of the selected first stage units, one or more second stage units are selected. In addition to increased sampling efficiency, this method allows intensive sampling to be done only at the second stage, while parameters that are inexpensive to measure can be obtained for the first stage units. This provides some level of monitoring over a wide area, and if problem areas are detected, the distribution of second stage units can be reallocated. The information collected from the first stage units can also be used to implement variable probability sampling at the second stage to further increase the sampling efficiency.

Further information on these sampling designs and methods for calculating required sample sizes and optimal distribution of samples can be found in Gilbert (1987) and Cochran (1977).

A monitoring strategy that incorporates ongoing monitoring programs or elements from these programs can significantly reduce the cost of the monitoring effort. Existi ng compliance and resource monitoring programs may produce data that can completely satisfy, or augment, the spatial and temporal coverage required by an NEP monitoring program. Additionally, by adopting sampling and analytical methods of ongoing monitoring programs as standard protocols for NEP monitoring program components, data from these existing monitoring programs may be used in evaluating the effectiveness of the CCMP.

An inventory and evaluation of existing federal, state, local, and volunteer monitoring programs within the estuary drainage basin should be conducted in order to assess their usefulness and applicability in evaluating the effectiveness of the CCMP. Key tasks of this assessment process include:

- Identification of existing and planned programs as well as special projects that may contribute data useful in evaluating the effectiveness of the CCMP
- Determination of whether NEP monitoring program objectives could be cost-effectively met by incorporating sampling and analytical methodologies from these existing monitoring programs

Use of Existing Monitoring Programs

Specific monitoring variables, statistical and analytical methods, and quality assurance/quality control (QA/QC) protocols selected will depend upon the stated objectives and action plans outlined in the CCMP, and specific hypotheses to be tested in the monitoring program. Therefore, techniques from existing monitoring programs may not always be adopted. However, whenever possible, it is recommended that programs work to ensure comparability of their methods with existing programs.

Several specific opportunities for taking advantage of ongoing monitoring efforts are described below.

NOAA's National Status and Trends Program

NOAA's National Status and Trends Program is designed to assess the current conditions of environmental quality in the nation's coastal zone and to determine whether these conditions are improving or deteriorating (NOAA, 1989). In order to achieve this objective, NOAA currently supports the Benthic Surveillance Project and the Mussel Watch Program.

The Benthic Surveillance Project regularly measures concentrations of contaminants in sediments and tissues of bottom-dwelling fish. The occurrence of external and internal symptoms of disease (e.g., fin erosion and liver tumors) are also documented. The Benthic Surveillance Project currently collects and analyzes sediment and bottomfish samples at 75 estuary sites.

The Mussel Watch Program collects mussels and/or oysters once a year from approximately 200 sites nationwide (NOAA, 1989). Analyses of sediment and bivalve tissue concentrations of trace metals, DDE, PCBs, aromatic hydrocarbons, and radionuclides are conducted.

NS&T has developed standardized methods for analysis, quality assurance (QA), and quality control (QC) for fish and shellfish tissue and sediment contaminants. The methods employed in this program and sampling locations should be reviewed to determine the feasibility of their incorporation into the planned monitoring efforts in each estuary. For detailed information concerning analytical and QA/QCmethods, contact:

NOAA National Status and Trends Program
NOAA N/OMA32
6001 Executive Blvd
Rockville, MD 20852

In addition, NOAA is establishing a National Estuarine Reserve Research System (NERRS). National Estuarine Research Reserves are established and managed for long-term environmental monitoring and scientific research. The results of scientific research at the Reserves are important sources of information and data to support coastal zone management and decision making. For more information concerning the NERRS, contact:

Marine and Estuarine Management Division
Office of Ocean and Coastal Reserve Management
NOS/NOAA
1825 Connecticut Avenue, NW
Washington, D.C. 20235

EPA's Environmental Monitoring and Assessment (EMAP) Program

The goal of EMAP's Near Coastal (EMAP-NC) Program is to monitor the condition of near coastal ecosystems, evaluate the relationship between ecological condition and anthropogenic disturbance, and assess the effectiveness of pollution control actions and environmental policies on a regional and national scale. EMAP will provide information on biological and chemical indicators, sampling design and methods, analytical methods, and QA/QC protocols.

EMAP-NC sampling design consists of three schemes (U.S. EPA, 1990b). EMAP's regionalization scheme divides the nation's estuaries and coastal resources into biogeographical provinces (e.g., Virginian, Carolinian, Louisianian, Acadian, Columbian, and Californian provinces). EMAP's classification scheme classifies estuaries into three resource classes that have similar physical features:

- Large, continuously distributed estuaries (e.g., Chesapeake Bay, Long Island Sound)
- Large, continuously distributed tidal rivers (e.g., Potomac, Delaware, Hudson Rivers)
- Small, discretely distributed estuaries, bays, inlets, and tidal creeks and rivers (e.g., Barnegat Bay, NJ; Indian River, FL; Lynnhaven Bay, VA)

EMAP's sampling scheme consists of elements of systematic, random, and fixed location sampling. Large, continuously distributed estuaries are sampled using a randomly placed systematic grid, with grid points about 18 km apart. Large tidal rivers are sampled along systematically spaced lateral transects. Transects are located about 25 km apart. Two sampling points are located on each transect, one randomly selected, and one selected using scientific judgement to identify sampling locations that may be indicative of degraded conditions in the system. Small estuaries are sampled by partitioning them in groups of four, selecting one estuary randomly from each group of four, and sampling at two stations in each small estuary selected. EMAP will operate on a four year sampling cycle, with one-fourth of the sites in a region sampled each year. Sampling will be undertaken only during the months of July and August. Given this sampling design and schedule, it is clear that a very small amount of EMAP data, if any, is likely to be available to most NEP estuary programs in a particular year. The stratified random sampling approach developed by the EMAP program may be of use to some NEP estuary programs if applied on a much smaller scale. The EMAP program is currently evaluating the advantages of sampling on alternative spatial scales.

EMAP-NC indicators of environmental quality are described in EMAP's Near Coastal Program Plan for 1990 and Ecological Indicators documents (U.S. EPA, 1990b and 1990c). Ecological indicators include:

- Response indicators
    - Benthic species composition and biomass

    - Gross pathology of fish
    - Fish community composition
    - Relative abundance of large burrowing shellfish
    - Histopathology of fish
    - Apparent redox potential discontinuity
- Exposure indicators
    - Sediment contaminant concentration
    - Sediment toxicity
    - Contaminants in fish flesh
    - Contaminants in large bivalves
    - Water column toxicity
    - Continuous and point measurements of dissolved oxygen concentration
- Habitat indicators
    - Salinity
    - Sediment characteristics
    - Water depth
- Stressor indicators
    - Fresh water discharge
    - Climate fluctuations
    - Pollutant loadings by major category
    - Land use patterns of watershed by major category
    - Human population density/demographics
    - Fishery landings statistics

Methods for collecting many of these indicators are addressed in the methods section (Appendix B; not available electronically).

The information from EMAP-NC is intended to establish ecological trends over the time frame of decades. Although this information may not be immediately available to the National Estuary Program, EMAP-NC does provide valuable information and assistance in the areas of sampling design, indicators, sampling methods, quality assurance and information management. Additionally, EMAP-NC is implementing a secondary monitoring strategy that focuses on local and state issues. The objective is to foster the incorporation of EMAP-compatible monitoring efforts for near-coastal resources into sampling by state and local agencies. Such efforts are intended to build upon the present EMAP design to permit assessment of environmental conditions at spatial and temporal scales not presently addressed by EMAP.

For detailed information concerning EMAP analytical, statistical, and QA/QC meth ods, consult the Director of EMAP's Near Coastal Waters Monitoring Program at:

Environmental Research Laboratory
U.S. Environmental Protection Agency
27 Tarzwell Drive
Narragansett, RI 02882

Local Monitoring Programs

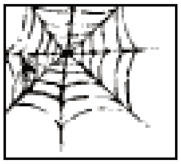
In addition to ongoing compliance and resource (e.g., fisheries) monitoring that is conducted in each estuary, there are also other opportunities to augment the estuary monitoring programs. For example, states are required under 305(b) of the Clean Water Act to conduct water quality assessments, and they are encouraged to include assessments of trends in their reports that are submitted biennially to EPA (U.S.EPA, 1989b). Other monitoring programs are conducted by state agencies, universities and pollutant dischargers. These programs should be evaluated to determine their use in monitoring CCMP implementation.

State sponsored and private volunteer monitoring programs have been shown to be very valuable in collecting data on estuarine water quality, beach litter, marine mam mal strandings, and the status of other estuarine resources (Armitage *etal*., 1989). Volunteers in the Chesapeake Bay watershed have collected data used to help verify water quality models and to identify correlations between measured variables, such as low dissolved oxygen, and the frequency of observed events such as fish kills and algae blooms (Ellett, 1988).

Volunteer monitoring programs have also been useful in developing an educated and involved constituency committed to protecting water resources (U.S. EPA, 1990d). Partnerships between the public and government agencies responsible for management must be developed if National Estuary Program CCMPs are to be effectively implemented. Establishment of volunteer monitoring programs has proven to be an effective way to build public commitment to achieving environmental quality goals and objectives in the CCMP. Through participation in monitoring programs, citizens learn how they contribute to pollution problems and develop a sense of stewardship toward the waters they are monitoring. Volunteer monitoring programs also help the public to understand the difficulties faced by the scientific community in linking water quality changes to impacts on living resources.

Each National Estuary Program Management Conference should establish a volunteer monitoring component as an integral part of its monitoring program. The experience of citizen monitoring programs throughout the country proves that volunteers can be trained to carry out a wide variety of environmental monitoring tasks, provided they are given the appropriate equipment and instruction. In estuaries, volunteers can be especially helpful in upstream areas not normally covered by a state's monitoring network. Basic water quality measurements such as pH, transparency, salinity, dissolved oxygen, and temperature can provide useful information to the comprehensive monitoring program. Trained volunteers can also be used to assess aquatic vegetation in the estuary and can provide information on acute problems such as spills, fish kills, and algae blooms. EPA has published a guidance document describing how to plan and manage effective volunteer environmental monitoring programs (U.S. EPA, 1990d). The document provides an overview of the use of citizen volunteers in environmental monitoring. It discusses how to plan and organize volunteer monitoring projects, how to involve the media, and how to prepare quality assurance plans for volunteer programs.

In general, estuary monitoring programs must select cost-effective methods that provide data essential to assessing the effectiveness of the CCMP. Whenever possible, programs should work to ensure comparability of their methods with applicable ongoing programs. Key aspects of the incorporation of existing state agency and volunteer monitoring programs into the overall design for the Puget Sound Ambient Monitoring Program are described in Case Study 1 (Appendix A1.0; not available electronically).



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Evaluate Monitoring Program Performance

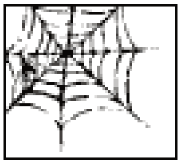
Although often overlooked and neglected, the evaluation of monitoring program performance is potentially the most important step in the design and review process. The performance evaluation motivates the development of explicit statements of program objectives as well as the specification of quantitative performance criteria during the design phase. During the course of the monitoring effort, performance evaluations provide a systematic procedure for measuring success in terms of the ability to meet program goals. The periodic evaluation process also identifies the need to modify sampling design and methods.

Evaluation procedures are essential because the information developed in the monitoring programs must be sufficiently precise and scientifically defensible. The monitoring programs will provide the primary source of information that will be used to evaluate the success of the CCMP. This information will be used as a basis for determining the efficacy of selected management strategies and the accuracy of model predictions upon which many management decisions have been based. The monitor ing programs will also provide quantitative information that will guide decisions regarding needed modifications to the management plan.

Additionally, the cost of the estuary monitoring programs will be substantial. In order to protect this investment, *it is essential to assess expected performance prior to collecting the first samples*. This performance information will provide the basis for determining the feasibility of proposed sampling strategies, selecting the most effec tive monitoring components and variables, and optimizing the overall monitoring effort.

The two types of performance evaluations are shown in Figure 1-1 and highlighted in the schematic on the next page. The first is the evaluation of the *expected performance of individual components* of the monitoring program (e.g., the evaluation of trends in toxic chemical accumulation in sediments). The first evaluation takes place during the design phase. The second type of performance evaluation is the *assessment of overall program performance*. This assessment takes place after the monitoring program has been implemented (e.g., after the first full year of data have been collected). The objective is to determine if the overall goals of the program are being met by the individual monitoring components and if the program should be modified by adding, deleting or expanding the scope of individual monitoring components. The essential feature of both types of evaluation is the existence of a feedback loop that provides the pathway for modifying the system's design based on monitoring program performance.

The establishment of performance criteria (e.g., the ability to detect a change in chlorophyll concentrations of 5 1/8 g/l over a period of five years) is a fundamental part of developing monitoring objectives. As indicated in Section 2.0, these performance criteria represent the level of change that must be detected in order to make management decisions regarding the effectiveness of the CCMP. It is these performance criteria that will be used to evaluate the applicability of individual components of the monitoring program. The specification of sampling methods for proposed monitoring program components described in Step 3 (Section 4.0) includes the development of alternative sampling strategies, including the monitoring variables/indicators and the level of sampling effort (numbers of sampling stations and sample replicates). The goal of the performance assessment is to evaluate the effectiveness of these alternative sampling designs in terms of the established performance criteria. The results will provide the basis for determining the relative benefits of individual monitoring components and selecting the final monitoring design.



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Evaluate the Expected Performance of Individual Monitoring Program Components

The questions that will be addressed in these analyses are:

- Can the proposed sampling effort meet the needs of the monitoring program as defined in the performance criteria associated with the stated objectives?
- How can the proposed program be modified to ensure that these objectives are met?

As indicated by the feedback loop shown in Figure 1-1, this is an iterative process. Proposed sampling designs are evaluated and modified, if necessary, to meet the overall objectives. The tools for conducting these analyses are described in Section 5.3.

>The overall performance of the monitoring program should be evaluated at periodic intervals. Initially, this evaluation should take place at the conclusion of the first year of sampling. This evaluation should compare the results with the expected monitoring performance, and a list of required modifications should be prepared. Opportunities for streamlining the program should be identified, and the performance criteria should be reviewed and revised, if necessary, for subsequent evaluations.

>The primary tool for conducting these analyses is statistical power analysis. Statistical power analysis provides an evaluation of the ability to detect statistically significant differences in a measured monitoring variable. The importance of these analyses can be seen in the examination of the possible outcomes associated with testing the null hypothesis (e.g., Ho: sampling location has no effect on observed sediment contaminant concentrations) shown in Figure 5-1:

- The null hypothesis is true, and it is rejected.
  This is referred to as a Type I error (a) and is commonly called the significance level of the test. By convention this value is routinely set at 0.05, i.e., the investigator accepts a small probability of incorrectly concluding that there are differences in sediment contaminant concentrations between sampling locations. Lower or higher values of the significance level of the test may be appropriate depending on the consequences of incorrectly rejecting a true null hypothesis.
- The hypothesis is true, and it is accepted.
  This is the complement of the Type I error (1- a).
- The hypothesis is false, and it is accepted. This is referred to as a Type II error (b). While the significance level of the test is consistently reported with the results of statistical tests, the probability of accepting the null hypothesis when it is not true (Type II error) is almost never reported with statistical test results. Moreover, the consequences of the Type II error are probably not fully comprehended by many investigators.
- The hypothesis is false, and it is rejected. This is the complement of the Type II error (1- b) and is referred to as the power of the test. Therefore, *statistical power is the probability of correctly detecting an effect*.

Consideration of these possible outcomes of a statistical test leads to three important conclusions. The first is that failure to reject the null hypothesis does not justify its acceptance. For example, the failure to reject the null hypothesis (e.g., that location has no effect on sediment contaminant concentrations) may occur either because there really is no effect (probability = 1 - a) or because the power of the test is so low (probability=b). In the later case, *a Type II error occurs because the statistical test is weak*. This may be due to the highly variable nature of the sampling environment or the low level of sampling effort. In either case, it is possible to evaluate the probability of the TypeII error for any statistical comparison of environmental data. Therefore, the second conclusion is that the probability of the Type II error should be reported with all statistical test results. The third conclusion is most relevant to the design of the NEP monitoring programs: the expected power of the statistical test should be evaluated prior to implementing the sampling program.

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Statistical Power Analysis Methods

Although statistical power analyses are not routinely conducted with statistical tests of significance, there is ample guidance available and the tests can be easily performed. Power analyses can be conducted using standard equations and tables or nomographs. The basic tools for conducting these analyses are provided by Cohen (1977), Dixon and Massey (1969), and Winer (1971). More comprehensive tables and nomographs are provided by Pearson and Hartley (1951), Tang (1938), Lehmer(1944), and Scheffe (1959), but the use of these references requires more advanced statistical training. There are also a wide range of computer programs available for conducting statistical power analyses. Goldstein (1989) reviewed several MS/PC-DOS power analysis programs and compared the methods they cover, their ease of use, graphics capabilities and their computational accuracy. Additionally, a statistical power analysis tool for analysis of variance is available on the EPA's Ocean Data Evaluation System (U.S. EPA, 1987a), and the U.S. EPA guidance for conducting fish histopathology studies (U.S. EPA, 1987b) provides nomographs for the power analyses associated with contingency table analysis.

Most basic statistical texts address hypothesis testing and the concepts of statistical power analysis. The statistical texts by Dixon and Massey (1969) and Winer (1971) provide introductory level descriptions as well as the tables for conducting these analyses. The statistical text by Scheffe (1959) provides a theoretical description of power tests for the analysis of variance. The Technical Support Document for the ODES Statistical Power Analysis Tool (U.S. EPA, 1987a) provides a detailed introductory level description of power tests for the analysis of variance.

The power of all statistical tests is dependent upon the following design parameters:

- significance level of the test (a)
- level of sampling effort (i.e., number of sampling stations and sample replicates)
- minimum detectable difference in the effect that can be detected
- natural variability within the sampling environment

This relationship between the power of a statistical test and the design parameters makes several types of power analyses possible. The power of the test can be determined as a function of any of these design parameters. Alternatively, the value of any individual design parameter required to obtain a specified power of a statistical test can be determined as a function of the other parameters.

The results of statistical power analyses are generally reported in two formats. In the first, shown in Figure 5-2, the minimum difference in the effect that can be detected is shown as a function of level of sampling effort (number of replicate samples). The results of this type of analysis provide a quantitative comparison of alternative sampling layouts, and they are especially useful in the evaluation of proposed NEP monitoring programs. Using these results, the level of sampling effort required to obtain a selected level of precision in the monitoring program can be determined. This example was taken from the evaluation of bioaccumulation monitoring strategies (U.S. EPA, 1987c). Historical data for liver concentrations of PCBs in winter flounder were used to evaluate the expected performance of alternative sampling designs.

Figure 5-2. Minimum detectable difference vs. number of replicates for fixed set of design parameters.

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Fixed Design Parameters

Statistical Significance (a)  = 0.05
Power (1-b)                   = 0.80
Stations                      = 4
Estimated Variance (s2)       = 2.06
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The results shown in Figure 5-2 were taken from the first phase of the analyses.

They indicate that the minimum difference in tissue concentrations of PCBs that could be detected between sampling locations with the collection and analysis of tissue from five fish at each location was approximately 120 percent of the overall mean at all stations, or 4.9mg/kg. Additionally, these results also show that the sampling program would require the collection and analysis of tissue from seven fish at each location to detect a difference equal to the overall mean among sampling locations. Based on the results of these early analyses during the design phase of the monitoring program, alternative sampling strategies were evaluated. Additional power analyses were conducted to evaluate the compositing of fish tissue prior to laboratory analyses. The results indicated that the collection of replicate composite samples would permit the detection of substantially smaller differences in tissue concentrations of PCBs at a much lower cost.

Statistical power analyses may also be displayed as shown in Figure 5-3 (not available electronically). The power of the test (the probability of detection) is shown as a function of the minimum detect able difference that can be detected between locations or over time. These results, taken from Case Study 2 (AppendixA2.0; not available electronically), were obtained from the analysis of a subset of water quality data that were collected in Chesapeake Bay. As part of the 1987 Chesapeake Bay Agreement, a commitment was made to reduce the total inputs of nitrogen and phosphorus entering the mainstream of the Chesapeake Bay by at least 40% by the year 2000. The target of 40% nutrient reduction was developed by modeling the environmental conditions in the Chesapeake Bay with a two-dimensional, steady-state model. The modeling results indicated that, after full implementation of the 40% reduction goal, the lowest average dissolved oxygen would be 1.6 mg/l and no waters would be anoxic. Therefore, the minimum performance criterion for the monitoring program should be the ability to detect a difference in dissolved oxygen equal to 1.6m/l.

To test the ability of the existing monitoring program to meet the performance criterion, historical data were used to estimate measurement variability. Statistical power analyses were then conducted, using estimates of the maximum and minimum variance. The results shown in Figure 5-3 indicate that the minimum trend in dissolved oxygen concentration that can be detected with a probability of 0.80 and ten years of data is on the order of 0.06 to 0.13mg/l-yr. These results indicate that the existing monitoring program would meet the specified performance criterion.

The relationship between power and minimum detectable difference, shown in Figure 5-3, provides the information required to evaluate the probability of a Type II error and the probability of detecting specific levels of effects in a proposed sampling program. Recent examples of the application of this type of power analysis include: Parkhurst (1985); Toft and Shea (1983); and Rotenberry and Wiens(1985). The necessity for this type of analysis in the evaluation of statistical test results is provided by Peterman (1989).

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Design and Implement Data Management Plan

Data management and data analysis, two key components of the monitoring study that are often overlooked in the design of monitoring programs, are as important to the success of the monitoring effort as the collection and laboratory analysis of field data. Moreover, the cost of effective data management/data analysiscan be substantial. On the order of 20 percent of the budget allocated for the monitoring program should be reserved for data management and data analysis activities. Failure to plan for these costs can result in the loss of information due to inadequate data preservation and limited analysis of the monitoring data that are collected.

Recent characterization efforts conducted by individual estuary programs, at considerable expense, found that historical data are not readily available and that essential quality assurance information necessary to evaluate the comparability of data sets is often not preserved. Generally, it was found that although large expenditures are often made on data collection, the amount of funding allocated to data management and data analysis is relatively small and inadequate.

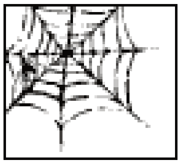
The need to assimilate and integrate historical information, as well as planned monitor ing efforts, should drive the development of a data management strategy. Failure to plan for data management can result in the loss of the information due to inadequate data preservation.

The development of a data management strategy must consider the following questions:

- Where will the data go?
- How will these data be stored?
- Who will maintain the data base?
- How will data be checked and loaded into the database?
- How accessible will the data be?
- Will statistical, graphical, and report generating tools be available?
- How much will it cost?

A computer system will be essential for the management of the data collected by the estuary monitoring programs. It should be operational prior to implementation of the monitoring program and should have the following attributes:

- Centralized storage of raw data
- Easy access and use
- System documentation
- Quality assurance procedures
- Linkage to graphical, statistical and report generation routines
- Long term availability and flexibility



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Data Management

A centralized data source provides the ability to transfer data between investigators and to conduct analyses that utilize data from different monitoring program components. An additional feature of a centralized data management approach is the ability to designate a system administrator who has responsibility for system documentation and data quality assurance.

The quality assurance information that must be reported with each data set must be defined prior to implementation of the monitoring effort. The objective is to identify key field, laboratory and quality assurance information that would allow future users of the data to make informed decisions regarding the comparability of historical data sets. This set of basic reporting requirements should be developed for all data types collected. The Ocean Data Evaluation System (ODES), supported by EPA's Office of Water, and the data system developed for the Puget Sound Ambient Monitoring Program provide good models for the implementation of data quality assurance procedures. Each data set that is submitted to ODES, for example,undergoes an extensive quality assurance review, and the results of this review are summarized in a report that is accessible from within the system. Extensive documentation for ODES is available (U.S. EPA, 1987d and 1988b).

The data management system that is adopted by the estuary programs must also provide basic graphical, statistical and report generation capabilities and/or the ability to download data easily to data analysis packages. It must also be flexible enough to address new data types and analytical needs. Finally, a long term financial commitment must be made to the system in order to establish user confidence in the ability to store and access data over a long time period.

The NEP has developed a data management policy to ensure that all potential users, both inside and outside the NEP, have access to environmental data generated under the program. Responsibility for identifying and selecting data management support remains with the NEP Management Conferences. The selection of a data management system by each program should be based on an evaluation of characterization and monitoring requirements for the estuary. Use of existing systems, where possible, is encouraged.

>As indicated in Section 5.0, an essential element of the monitoring plan will be the specification of a timetable for analyzing the data and assessing monitoring program performance. The assessment of monitoring program performance should be used to refine monitoring program objectives and modify individual monitoring program elements to satisfy these objectives. Initially, monitoring program evaluations should be conducted after the first year of data collection. Subsequent interim evaluations should be conducted at two or three year intervals.

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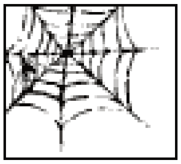
Data Analysis

The primary purpose of other data analysis activities will be to test the hypotheses developed in Step 2 of the design process (see Section 3.1). Additional goals are to summarize the data, generate new hypotheses, and evaluate the uncertainty associated with the measurements and conclusions. Additional analyses should be designed to produce information for use by groups with diverse technical backgrounds.

A wide range of statistical and graphical tools are readily available for use in meeting these goals. Recently, there has been an increased interest in the development of Geographical Information System applications for graphical analysis and information display. The National Estuary Program is currently funding projects to demonstrate the use of this tool to synthesize a broad range of data collected by the estuary programs, and to effectively communicate this information to interested groups.



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Communicate Program Results

One of the primary goals of the monitoring program is to provide information that can be used to redirect and refocus the CCMP. To achieve this goal, emphasis should be placed on distributing the data that are collected in the estuary monitoring programs. The data collected by individual investigators should be made readily available to the scientific community for comparative studies that relate information from different components of the program. Section 6.0 discusses the need for the development and implementation of an effective data management strategy. Emphasis should also be placed on the analysis of these data. The dissemination of the recorded monitoring data is not a sufficient mechanism for communicating the monitoring results. Statistical analysis of the monitoring data is essential, and graphical and written summaries should be produced for agency managers charged with implementing the CCMP. The results must be effectively communicated to an audience with a wide range of technical backgrounds and interests.

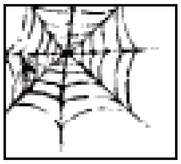
Figure 1-1 and the schematic above show two feedback loops associated with the evaluation of monitoring data. One provides direct feedback of analytical results that are used to modify and refine the monitoring program to increase efficiency (see Section 5.0). The other provides feedback to three basic factors that influence the design, development and refinement of monitoring program objectives: public concerns, modeling, and research. Data analyses must provide information that addresses the needs of program managers, scientists and the public.

Graphical and written summaries should be produced that demonstrate the results of individual components of the monitoring program as well as the relationships between monitoring activities. These summaries should serve as tools to effectively communicate information on the effectiveness of the actions taken under the management plan, and to build public awareness of actions taken by the estuary program. Demonstration materials that summarize program results should be produced for use in newsletters, workshops, poster sessions, and public forums. The results of the monitoring effort and the data analyses should also be made available to the scientific community, and use of the monitoring data should be encouraged. Data analyses should be conducted to test for trends, test and generate new hypotheses, evaluate the uncertainties associ ated with the data, and to identify the source of these uncertainties. These analyses should serve as a basis for extending existing knowledge of the estuary, making refinements to conceptual and numerical models of the system developed in the characterization phase of the program, and identifying new research. Collectively the analytical results should provide the necessary information for redirecting and refocus ing the CCMP.

There are several examples of publications by estuary programs to generate public interest and support, and to disseminate information on monitoring results. In addition to preparing annual technical reports on monitoring efforts, the Puget Sound Estuary Program produces a quarterly newsletter - *Puget Sound Notes* (Figure 7-1; not available electronically). This technical newsletter has a distribution of 2,750 individuals and organizations. It is intended to report on recent program results and to inform interested individuals about events that affect the estuary. The *Chesapeake Bay Barometer* is a one page monthly publication of the Chesapeake Bay Program. The *Barometer* provides a summary of dissolved oxygen concentration and water clarity in the bay during the previous month. It also includes short, nontechnical summaries of topics of general interest (Figure 7-2; not available electronically). Previous topics have included: salinity in the bay, boat pollution, bald eagle populations, and the striped bass fishery. The Santa Monica Bay Restoration Project is producing a series of paired reports on pathogens (Figure 7-3; not available electronically). These reports summarize the results of the long term assessment of inputs of fecal indicators and enteric viruses from storm drains. The results of each phase of the study are summarized in both a *Technical Report* and a*Public Summary*.

U.S. Environmental Protection Agency

National Estuary Program



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