THE NATIONAL ESTUARINE RESEARCH RESERVE'S SYSTEM-WIDE MONITORING PROGRAM (SWMP): A SCIENTIFIC FRAMEWORK AND PLAN FOR DETECTION OF SHORT-TERM VARIABILITY AND LONG-TERM CHANGE IN ESTUARIES AND COASTAL HABITATS OF THE UNITED STATES

(2002; Revised August 2007)

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Executive Summary

Estuaries are among the most dynamic and productive environments known. They are transitional places where salt and fresh water mix and serve as nursery areas for numerous commercial fish and shellfish species. These habitats also act as rest stops for migratory birds, filters for pollution and buffers against coastal erosion. The high value that society places on estuaries for living, working and recreation has made these habitats among the most densely populated in the United States.

An increased awareness of estuarine degradation resulted in the passage of legislation aimed at protecting estuarine ecosystems. A landmark piece of legislation enacted by Congress was the Coastal Zone Management Act (CZMA) of 1972, which was the beginning of what became the National Estuarine Research Reserve System (NERRS). Currently, 27 reserves in 22 states and territories protect over 1 million acres of estuarine waters, wetlands and uplands. The NERRS was built on a foundation of partnerships among state and federal agencies and community groups. The reserves have a management framework in place that links stewardship, public education and scientific research and thus provide an ideal vehicle to establish a nationally coordinated monitoring program.

In 1992, the reserve system proposed the establishment of a coordinated monitoring program that would attempt to identify and track short-term variability and long-term changes in the integrity and biodiversity of representative estuarine ecosystems and coastal watersheds for the purposes of contributing to effective coastal management. The initial phase of the NERR System-wide Monitoring Program, known by its acronym SWMP (pronounced “swamp”), began in 1995. The focus was on monitoring a suite of water quality and atmospheric variables over a range of spatial and temporal scales. Water quality parameters measured include pH, conductivity, temperature, dissolved oxygen, turbidity and water level. This first phase of SWMP, designated Phase I is now operational and there are nominally four water quality monitoring sites in each reserve, of which, at least one is telemetered to provide near-realtime data through the NERRS Centralized Data Management Office (CDMO). In addition, each Reserve maintains at least one telemetered meteorological station that monitors weather parameters including temperature, wind speed and direction, relative humidity, barometric pressure, rainfall and photosynthetically active radiation (PAR) in near-realtime. Phase I data collection also includes monthly inorganic nutrient sampling at each water quality site and a single site monitoring of a diurnal nutrient and chlorophyll cycle that is measured once a month. Phases II and III of SWMP will incorporate Biological Monitoring and an assessment of Land Use and Habitat Change respectively within the Reserve System. Aspects of these later phases have begun to be tested in various pilot projects and programs throughout the NERRS.

The purpose of this document is to lay out a scientific framework and plan for the NERR SWMP that will assist in guiding the program. It is not a static document, especially regarding costs and implementation details, but it portrays priority activities for future SWMP efforts. This document describes a conceptual framework for NERR SWMP

laying out the steps that will assist in addressing coastal management problems. In addition, the SWMP plan contains some general areas for future monitoring including expansion of abiotic monitoring and a move towards operational status for Phases II and III Additional discussions on monitoring for invasive species, conducting benthic surveys and pore water chemistry are also presented.

The advantages of the NERRS monitoring program are that it will:

- Provide an ecosystem-based network for understanding the temporal and spatial variability of ecosystem components and their interactions.
- Provide a long-term database for the estuarine reserves' protected area network.
- Establish a baseline for measuring changes in environmental conditions and ecological processes.
- Provide a research framework for evaluating ecosystem conditions and interpreting and predicting responses to change.

The scientific value of NERR SWMP data increases over time because it is through the collection of long-term data that subtle changes in environmental conditions are identified. This monitoring program is an opportunity to increase our understanding of how various environmental factors influence estuarine processes by collecting high-quality, long-term data.

By understanding how estuaries function and change over time, we hope to predict how these systems respond to changes in climate and human-induced perturbations. Research is critical to the interpretation of monitoring results and for testing hypotheses generated by monitoring. Whereas monitoring determines whether and how much the environment has changed from its reference state, research helps establish causal relationships. The reserve system's monitoring program, coupled with NERR-supported research programs, provides a foundation for developing solutions to coastal management problems by answering how estuarine ecosystems change and why.

I. Introduction and History of the Program

Estuaries are among the most productive of ecological systems. Estuarine habitats, such as marshes, eelgrass meadows, oyster reefs, and mangrove forests provide critical nursery, feeding and spawning areas for many fish and shellfish species. Plentiful food and habitat make estuaries locations that migratory birds, waterfowl and mammals frequent on their annual journeys. These habitats provide a number of other valuable services, including sediment trapping, shoreline stabilization, and pollution removal (Costanza et al. 1997). Additionally, the ecological richness of estuaries translates to high economic value. Seventy-five percent of the nation's annual ten billion-pound seafood harvest comes from estuarine- and wetland- dependent species (Weber 1995). In 2005, over 10.2 million people made 32 million marine recreational fishing trips catching over 62 million fish, with most of the catch coming from inland waters (Personal communication from the National Marine Fisheries Service, Fisheries Statistics Division). Expenditures on fishing-related products and services associated with fishing for estuarine-dependent species also provide important revenue to local and state economies. Estimating the economic value of estuaries requires more than determining the market value of the goods and services (e.g., the commercial and recreation fishing industries) and evaluating non-market attributes that people value (aesthetics, scenic vistas, etc.). The importance of these revenues and their multiplier effects on the U.S. economy is significant (National Marine Fisheries Service 1999) as indicated in a recent estimation of the total value of estuaries at about \$23,000 ha^{-1} yr^{-1} (Constanza et al. 1997). In contrast, cropland was valued at \$92 ha^{-1} yr^{-1}.

Intrinsically fragile and vulnerable under natural conditions, the high value that society places on estuaries for living, working and recreating has made them among the most densely populated and heavily used areas in the nation, and has resulted in a plethora of symptoms indicating declining ecological conditions. As of 2003, approximately 53% of America's population, or an estimated 153 million people, lived in United States coastal counties. This represents an increase of 33 million since 1980 and an additional 7 million are expected to reside along the narrow coastal fringes of the United States by 2008 (NOAA 2005) At least 37% of the population in the US is located within 100 km of major estuaries or the oceans (Cohen et al. 1997). The upward trend in population growth within coastal areas is expected to continue as coastal population grows apace with trends in the national population (NOAA 2005). Most coastal water-quality problems result from waste associated with high densities of the human populations along the coasts and from land-use practices in coastal watersheds.

NERRS History

An increased awareness of such problems during the 1960s and 1970s, resulted in the passage of several pieces of legislation aimed at protecting estuarine ecosystems. One of these new landmark statutes, was the Coastal Zone Management Act (CZMA) of 1972. Section 315 of the CZMA authorized the establishment of protected areas or "estuarine sanctuaries" to augment the federal coastal zone management program, which is dedicated to comprehensive, sustainable management of the nation's coasts. These

sanctuaries, administered by the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce, were to serve as natural field laboratories for the conduct of research related to coastal management. As defined by the Act, "These sanctuaries were to be research areas which could include any or all of an estuary, adjoining transitional areas and adjacent uplands, set aside to provide scientists and students the opportunity to examine over a period of time the ecological relationships within the area." Congress re-authorized the CZMA in 1985, and changed the name of the National Estuarine Sanctuary Program to the National Estuarine Research Reserve System (NERRS). The NERRS also contributes to the implementation of the Executive Order 13158 which calls for an expanded and strengthened system of Marine Protected Areas.

This national system of estuarine reserves is purposely designed to represent different types of estuaries within the 11 biogeographic regions across the nation (Figure X, picture of NERRS w/biogeo regions). The intent of the program is to establish a state-federal partnership that supports a common mission to practice and promote coastal and estuarine stewardship through innovative research and education (NERRS Strategic Plan, 2006). Since the first designated site in 1974 in Oregon, the NERRS' programs in monitoring, research, education and public outreach, and stewardship have provided timely information about the environmental quality of our nation's estuaries.

Currently, 27 reserves have been designated in 22 states and territories and protect over 1.3 million acres of estuarine waters, wetlands and uplands (Appendix A: List of reserves and designation date). NOAA establishes standards for designating and operating the reserves; provides base funding for operation, research, monitoring activities, and education; sponsors a graduate fellowship program; and integrates information from individual reserves to support decision-making at the national level. The role of the coastal states that manage reserves is to gather scientific information through research and long-term monitoring programs within the reserve and its watershed; to provide scientific information to target audiences through education, public awareness, and training programs; to address resource management needs; and to promote stewardship of resources.

Wetlands (e.g., marshes, mangrove forests, bogs) and submerged aquatic vegetation (SAV) are important habitats in estuarine ecosystems. They provide food and refuge for a high diversity of organisms, and they play major roles in sustaining living resources, in the maintenance of shoreline stability, and in controlling fluxes of nutrients, contaminants and sediments from land to coastal ecosystems. Although wetlands and SAV are important to humans for flood control, improving water quality, and sustaining fisheries, approximately 50 percent of these habitats have been destroyed or degraded in recent decades. These losses exacerbate the effects of nutrient enrichment and water quality problems. Poor water quality, increased levels of contaminants, modifications to important habitats, increased incidence of marine pathogens, and changes in relative abundance of estuarine resources are all widely reported ecological effects that have been

linked to changing land use patterns on adjacent watersheds and physical alterations to the estuaries themselves.

Monitoring in the NERRS

Complicating efforts to characterize the ecological status of estuaries is their great physical diversity. Estuaries are technically defined as semi-enclosed bodies of water with a free connection to the open sea where freshwater input dilutes the seawater (Pritchard 1967). This broad definition encompasses bays, sloughs, lagoons and other inlets into which freshwater enters via rivers and groundwater, swiftly or slowly, seasonally or sporadically. Along with differences in tides (from a few cm to about 15 m), these differences create habitats that change spatially and temporally over very different time scales. Different climates and different geographic locales further confound attempts to classify estuarine ecosystems.

In addition to physical diversity, the great temporal variability associated with estuarine ecosystems can often make it difficult to separate natural change from change induced through human activities. Such variability may occur over timescales ranging from diurnal to seasonal and identifying natural patterns thus requires sustained, long term monitoring efforts. The value of coordinated monitoring efforts was recently acknowledged in the final report of the U.S. Commission on Ocean Policy (USCOP, 2004) which stated that "Long term environmental monitoring is essential to determine baselines, measure change, and assess overall ecosystem health.". Monitoring may be defined in many ways and has many historical uses (National Research Council 1990). Compliance monitoring is conducted to ensure that activities are carried out in accordance with regulations and permit requirements. Monitoring is also done to check the validity of assumptions and predictions in models. Trends monitoring can identify and quantify longer-term environmental changes that may result from natural variability and human activities. Most of the monies spent nationally for monitoring each year is for compliance monitoring. Much less is spent for monitoring status and trends at the regional level, and still less for national trends monitoring. The USCOP Final Report (2004) found that the United States largely lacks an effective comprehensive national program for measuring and evaluating the status of marine environmental resources and trends in marine environmental quality and that monitoring is especially lacking in coastal waters.

Formation of SWMP

Historically, research and monitoring efforts have varied widely within the NERRS as a result of the amount of funding available and the type of baseline scientific data available at a given reserve. Some reserves had a long history of scientific research prior to designation. The North Inlet/Winyah Bay NERR in South Carolina was a participant in the Long-Term Ecological Research program of the National Science Foundation prior to its designation as a NERR. Thus, there already existed strong baseline data for that reserve, thereby enabling subsequent monitoring efforts to be directed at filling data gaps. Other reserves had very little existing scientific information about their site, so their

research program entailed collecting baseline data on biotic resources and basic water quality conditions. At each reserve baseline ecological data were collected to characterize the reserves' ecology and ultimately become part of a published ecological characterization or profile of each site (Appendix B).

In 1995 NERRS developed and initiated the System wide Monitoring Program or SWMP as an integrated long-term national program whose primary focus was to track the short-term variability and long-term changes in estuarine ecosystems. This coordinated monitoring throughout the NERRS provides information about the status and condition of estuaries on a national scale. In addition, under the Code of Federal Regulations (15 CFR Part 921 Subpart G) NOAA provides funds to support basic monitoring programs conducted through the NERRS. For these reasons, the reserve system provides an ideal vehicle to implement and support a nationally coordinated monitoring program. Essentially, the reserves already have a framework in place that links stewardship, public education and scientific research.

The NERRS Strategic Plan outlines four priority coastal management issues including: land use and population growth, habitat loss and alteration, water quality degradation, and changes in biological communities (NERRS, 2006a). Additionally, the NERRS recently published a five-year Research and Monitoring Plan that highlights five priority research areas that support the NERRS Strategic Plan goals including: habitat and ecosystem coastal processes, anthropogenic influence on estuaries, habitat conservation and restoration, species management, and social science and economics (NERRS, 2006b). The NERRS SWMP is intended to support the goals and guiding principles outlined in both of these system-wide planning documents including the integration of research, education and outreach to improve coastal management decisions.

II. Program Overview

Mission Statement

The principal mission of the NERR System-Wide Monitoring Program (SWMP) is to:

> *Develop quantitative measurements of short-term variability and long-term changes in the water quality, biotic diversity, and land-use / land -cover characteristics of estuaries and estuarine ecosystems for the purposes of contributing to effective coastal zone management.*

Long-term monitoring and iterative habitat assessments conducted within the network of 27 NERR sites are intended to improve our fundamental understanding of the temporal and spatial dynamics of estuarine processes, and also to provide baseline information to evaluate subsequent changes in the ecological status of estuarine ecosystems in response to natural perturbations and anthropogenic disturbance. Federal coordination of the NERR SWMP allows for the recognition of significant ecological trends (improvement or degradation) in estuaries at national, regional, and local levels. Moreover, continued operation of the long-term monitoring effort within the network of representative NERR

sites will provide valuable data that will inform assessments and/or models on the cumulative effects of environmental stressors in estuarine ecosystems located throughout the coastal zone of the United States.

Goals

The NERRS SWMP will work to achieve its mission by meeting the following goals:

> ***Coordination, Cooperation, and Support:*** Maintain national-level coordination, interoperability, and the institutional infrastructure required to develop, improve, and sustain the monitoring program within NOAA and in cooperation with the network of coastal states and NERR sites;
> ***Data Collection:*** Provide continuous on-site operation of the monitoring program at the NERR field sites including provision of adequate financial support, personnel, training, equipment, facilities;
> ***Database Management, Informatics, and Access:*** operation of a centralized programmatic database that meets national standards for data archival, metadata, and quality assurance, and provides an efficient and effective portal for data access and interpretation;
> ***Understanding and Data Synthesis:*** periodic data synthesis and analysis to address coastal management questions and provide analytical information that is relevant to address national, regional, local issues;
> ***Legacy for the Future:*** adoption of rigorous quality control standards, collection protocols, and archival procedures to ensure that data are available in the future for retrospective analyses, modeling, and ecological forecasting; and
> ***Communication, Education, Technical Transfer, and Outreach:*** promote and facilitate internal communications as well as awareness, training, and utility of the products generated by the monitoring program to a broad external audience of scientists, resource managers, policymakers, school groups, and public stakeholders.

Conceptual and Scientific Framework

The NERR SWMP is designed to operate as a network of intensive coastal and estuarine monitoring and research sites where datasets are collected with a high degree of temporal and spatial resolution. The conceptual design for the series of estuarine index sites, or reference areas, is in close alignment with key attributes identified by the joint USEPA / NOAA / USGS Coastal Research and Monitoring Strategy (2000) which include co-funding by federal and state programs, nested designs to allow state-specific issues to be addressed in a national context, collective reporting, and cross-system comparisons. The Coastal Research and Monitoring Strategy was developed to replace traditional single-issue, single-discipline problem solving with a coordinated interdisciplinary approach to address larger-scale problems of coastal water quality and declining coastal resources. The strategy provides a context to integrate the nation's monitoring programs across multiple natural resources at different temporal and spatial scales for coherent natural resource policy development that is based on sound scientific understanding.

Information generated by the NERRS network of research and monitoring sites should contribute to nationwide efforts that address fundamental questions about the functions, status and condition of the nation's estuaries and coastal resources. These fundamental questions have been adapted specifically for estuaries, and include:

- Do the environmental conditions in the network of NERR sites exhibit measurable signs of improvement or deterioration? Are there substantial regional and site-specific differences in the dynamics and functions of the estuarine ecosystems?
- Are the changes observed in estuaries the result of natural variability or anthropogenic activities? Do some activities have a greater impact than others?
- What management actions can be implemented to correct existing problems or prevent future problems?

The NERR SWMP also fits well within the hierarchical framework proposed by the Coastal Research and Monitoring Strategy (2000) to address coastal resource questions:

- Tier 1 : Characterization of Problems –monitoring programs that characterize broad-scale ecological properties as representative benchmarks for large regions by simultaneous and spatially intensive surveys, automated sampling, and/or remote sensing for the entire region;
- Tier 2 : Diagnosis of Causes – monitoring programs that characterize specific properties of large regions by sampling a subset of the region, and concentrate on specific resources and observations for a focused set of variables; and
- Tier 3 : Diagnosis of Interactions and Forecasting - programs that focus on integrated research and monitoring for specific issues and properties within intensively-studied index sites.

Along with the NERR research program, the NERR SWMP operates as within the hierarchical framework as a Tier 3 program. The intent of data acquisition activities is to understand estuarine processes that occur at local scales, to understand the variability of estuarine environmental change, and ultimately to develop and test predictive models of estuarine environmental responses.

The conceptual framework of the NERR SWMP includes 10 sequential steps and 3 important feedback loops. The sequential design follows recommendations by the National Research Council (1990) and the National Water Quality Monitoring Council (2004) to allow for the deliberate flow of information and commitment of effort through a series of integrated steps to ensure that data collection, analysis, and interpretation address important coastal management problems and objectives. The 10 sequential steps are as follows:

1. Development of Coastal Management Questions

The initial step in the SWMP is to formulate a series of coastal management questions. Each question should be posed to contribute fundamental information to

improve our collective understanding of estuarine processes and address an important local, regional, or national management issue (i.e. coastal non-point source pollution).

2. Identification of the Appropriate Monitoring Strategy and Sampling Design

The SWMP will incorporate sufficient feedback loops to ensure that the management problems and questions are refined to reflect the best available scientific information, including monitoring data generated by the SWMP and from outside sources.

3. Evaluation of SWMP Program

The initial phase of the SWMP program (SWMP I: Abiotic Monitoring) has been ongoing since 1995. Periodic synthesis of data products generated by the SWMP are used to realign focus areas, streamline operations, and evaluate program effectiveness.

4. Selection of Estuarine Sampling Variables

The suite of estuarine sampling variables monitored by the SWMP are carefully selected to ensure that information generated by the SWMP is directly linked to appropriate coastal management questions. A potential feedback loop (Figure 3) demonstrates how the sampling program can produce relevant information on a time-scale to answer specific management questions, and critical evaluation of the program within the feedback loop also ensures that the SWMP has the technical capability to measure meaningful environmental change within estuaries and estuarine ecosystems.

5. Identification of Natural Perturbations and Anthropogenic Disturbance

Estuaries and coastal embayments are highly variable coastal ecosystems that respond readily to natural perturbations and anthropogenic disturbance. The high levels of natural variability in estuaries (on sub-meter, meter, decimeter, and kilometer spatial scales and hourly, tidal, diel, seasonal, annual, and interannual temporal scales) creates a complicated background of changing environmental conditions that make it difficult to directly relate ecological responses to human activities.

6. Statistical Consideration of the NERR – SWMP Sampling Design

Statistical measures of natural and anthropogenic variability will provide valuable input for optimization of the SWMP, and it is important that numerical power analyses be conducted to predict whether the SWMP monitoring design can detect meaningful levels of coastal environmental change.

7. Quality Assurance and Quality Control of Data collection and management

The SWMP includes a rigorous Quality Assurance / Quality Control (QA/QC) program undertaken to ensure that the type, amount, and quality of data and ancillary numerical information are adequate to meet the study objectives. Development of supporting metadata is also a critical element of the monitoring program.

8. Data Analysis, Interpretation, and Application

Analysis of the SWMP datasets will be undertaken on a regular basis to summarize and simplify the acquired numerical information, conduct statistical tests of inherent

variability and significant differences, evaluate alternative hypotheses, determine the consequences of ecological observations, and assess levels of uncertainty associated with the conclusions drawn from the SWMP datasets.

9. Translation and Dissemination of Monitoring Results and Findings

Significant results and findings generated by the SWMP should be translated and disseminated on a regular basis to a broad audience of coastal managers, resource decision makers, technical experts, and academic investigators. Dissemination products will be designed to be used and accessed by their intended target audiences, and the monitoring program outputs will be focused to inform specific interest groups and the public regarding the status of their shared resources.

10. Re-Formulation of Management Questions and Monitoring Approach

Statistical summaries, analyses of system variance, and other quantitative descriptions of the time-series of SWMP parameters will be evaluated to address the appropriate coastal management questions posed at the onset of the monitoring program (feedback loop). Levels of inherent risk and uncertainty associated with the conclusions and recommendations will be identified, and particular care will be taken not to overstate the intended utility of the monitoring information. At this definitive and decisive point in the framework of the SWMP, the opportunity will be taken to refine the overriding study objectives, re-formulate the central management questions, generate new hypotheses, and redirect the overall monitoring approach.

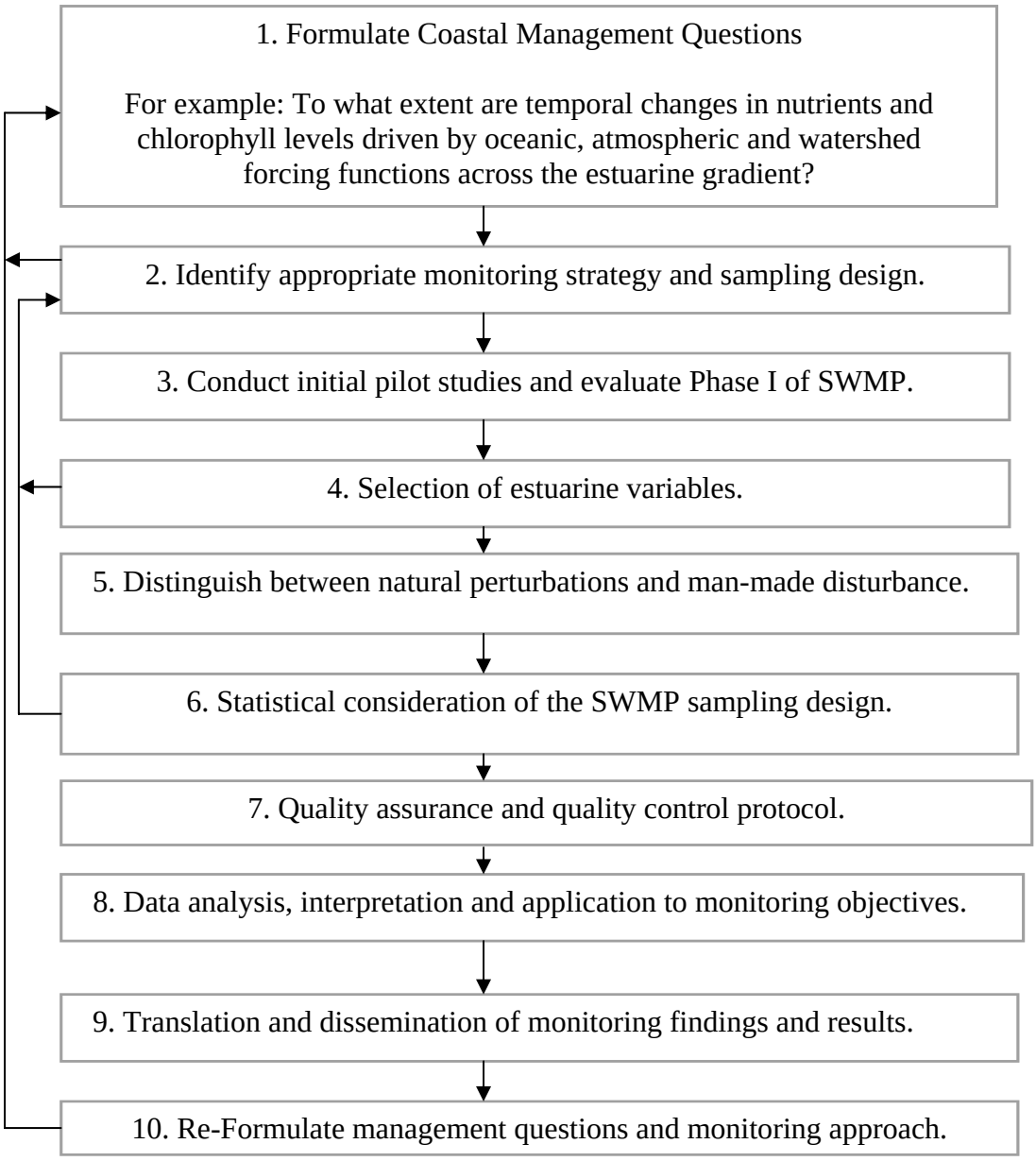

Figure 3. A conceptual framework for the NERR System-wide Monitoring Program.

The scientific framework and design of the NERR SWMP was initially developed over 1995-2000 in consideration, consultation, and cooperation with the NOAA – NS&T Program, the US EPA –EMAP, the National Park Service Inventory and Monitoring Program, and the NSF –LTER Program. The initial phase of the NERR SWMP was tested on a system-wide basis at 21 NERR sites, and the multi-state / federal partnership effort has received review and critical input on an annual basis from participating state coastal resource agencies and academic research programs.

New revisions to the SWMP reflect recommendations for improvement to coastal environmental monitoring programs articulated by the National Science and Technology Council (Committee on Environment and Natural Resources, 2000), the National Ocean Service - Coastal Environmental Monitoring Committee (2000), the Heinz Center for Science, Economics, and the Environment (2002), the Pew Oceans Commission (2003), the US Commission on Ocean Policy (2004), the National Water Quality Monitoring Council (2004), and the US Integrated Ocean Observing System - Implementation Plan (IOOS, 2005). Moreover, the SWMP has also been updated and revised to address several additional issues recently identified by the US Council on Environmental Quality - Joint Subcommittee on Ocean Science and Technology (2006). In particular, the SWMP has strengthened its level of coordination and support at the national level while retaining sufficient flexibility at the site level to address local and regional differences in species, habitats, and coastal management issues. In addition, the SWMP has also developed close links in its observational capacity and data management protocols with the US IOOS program. As an example of an integrative and multidisciplinary estuarine monitoring program, the NERR SWMP is in compliance with the National Coastal Monitoring Act (33 USC sec 2801-2805; long term study of the environmental quality of the coastal environment). These revisions and improvements include maturation of the SWMP from its operational beginnings as a single-issue program with a focus on estuarine water parameters, to a more coordinated and integrative program that takes an interdisciplinary approach to systematic assessment of estuarine water quality conditions, nutrients, biotic diversity, habitats, and land use patterns in the adjacent watersheds.

The scientific framework for the NERR SWMP has been designed and consistently revised to ensure that data collection efforts, analysis, and interpretation address important coastal management problems and objectives. The NERRS is fully aware that many federal and state monitoring programs have preceded SWMP. It is widely recognized that failure to commit adequate resources of time, personnel, funding, and technical expertise to up-front program design and the synthesis, interpretation, and reporting of information will result in failure of the entire monitoring program (National Research Council, 1990).

Program Components

The broad geographic range of ecosystems and estuarine habitat types represented across the NERR system provides a network ideally suited to implement a long-term monitoring

program to address a variety of coastal management issues. In 1993, a group of dedicated staff and scientists in the NERR system proposed a nationally coordinated monitoring program that would attempt to identify and track short-term variability and long-term changes in representative estuarine ecosystems and coastal watersheds (Wenner and Geist 2001, Ross 2003). In 1995, the individual reserves and NOAA established the SWMP as a phased monitoring program to focus on three aspects of coastal ecosystem characteristics:

* **Phase 1** – Abiotic Factors, including: atmospheric conditions and water quality (nutrients, salinity, contaminants, etc.);
* **Phase 2** – Biological Monitoring, including: biodiversity, habitat and population characteristics;
* **Phase 3** – Watershed and Land Use Classifications, including: changes in human uses and land cover types.

The initial phase of SWMP focuses on monitoring a suite of abiotic factors to collect water quality and atmospheric information over a range of space (local, regional, national) and time (minutes, hours, days, months, years). Phase one began at reserves in Mid-Atlantic States and was ultimately adopted by all reserves. In 2004, NERRS initiated the second phase of SWMP with the central objective of characterizing biotic diversity in the reserves' estuarine ecosystems by assessing community composition and species abundance and distributions. Phase two builds on phase one monitoring capabilities by developing inquiry-based research projects that explore patterns of inter-annual variability and spatial distribution of estuarine communities. Phase three, the SWMP land use and habitat change initiative, focuses on tracking and evaluating changes over time in coastal and estuarine habitat as they relate to changes in watershed land use practices. Phase three is well-aligned with phase two, as both of these efforts utilize remote sensing imagery and ground truthing.

Challenges of Delivering a National Program at a Local Scale:

There are a number of major challenges in establishing and maintaining long-term nationally comprehensive monitoring programs. The need for long-term financial support to define variability and trends, the absence of communication and coordination among the entities conducting monitoring, and the difficulty in designing programs that not only track natural variability but detect change and separate human impacts are just a few examples of these implementation and sustaining obstacles. Additionally, there have been only limited efforts to inform and actively involve the public and elected officials in monitoring goals and decisions. If support for monitoring is to be gained and maintained, then the public must be involved in a meaningful way. The NERRS has developed the infrastructure and public support needed to conduct long-term monitoring projects and establish its national System-wide Monitoring Program (SWMP). It is anticipated that the close ties of the reserve system with local and regional coastal zone management agencies will facilitate integration of results based on SWMP data into decision-making and planning efforts by coastal zone managers.

The NERRS federal-state partnership offers both opportunities and challenges in implementing national level monitoring programs. NERRS staff are not employed by NOAA, rather, they are generally employees of either state agencies (such as state departments of natural resources or fish and game departments) or academic institutions. These partnerships have been successful in leveraging additional capacity at the local levels in terms of sharing costs associated with equipment, maintenance and operation of monitoring programs as well as expanding monitoring efforts appropriately to address local needs. The challenges in developing any monitoring program that meets both local needs while occurring in such a way as to be a component of a nationally comparable program include recognizing that long-term monitoring efforts already in place at the local level may not be amenable to changes in sampling design or changes in monitoring parameters. For example, state partners of the NERRS often support the field sampling efforts associated with SWMP as a component of a larger state monitoring program. NERR national recommendations on changes in sampling parameters, sampling gear and sample replicates that could enhance the national products of compiling SWMP data across the nation may not be able to be implemented easily at the state level if they are not already a component of that state's program and deviate from historically collected operational monitoring already in place.

[Get the workgroup to feed in on other challenges that will help the review panel understand the constraints that the NERRS may have in the face of recommendations that move for changing SWMP methodology, etc—see Jeff Crooks for his context.]

Relevance to NOAA's Research Plan and Strategic Plan:

NOAA has recently redesigned its approach to research to follow a more interdisciplinary, cross-cutting strategy to address defined priority research areas (NOAA, 2005a). The new infrastructure for NOAA's research focuses on four mission goals: Ecosystem, Climate, Weather and Water, and Commerce and Transportation Goals. The NERRS is a strong contributing member of the Coastal and Marine Resources Program within the Ecosystems Goal Team. The reserve system also contributes indirectly to the Climate Goal as well as the Weather and Water Goal.

National Oceanic and Atmospheric Administration	NOAA's Ecosystem Goal Team Selected Outcomes
Vision: Societally relevant research that forms the scientific basis for more productive and harmonious relationships between humans and their environment. **Mission: To conduct research, develop products, provide scientific understanding and leadership and to conduct outreach towards fostering NOAA's evolving environmental and economic mission.**	• **Healthy and productive coastal and marine ecosystems that benefit society.** • **A well informed public that acts as stewards of coastal and marine ecosystems.**

The mission of the Ecosystems Goal is to protect, restore, and manage the use of coastal and ocean resources through an ecosystem approach to management. NOAA's Strategic Plan (2006-2011) outlines a mission "to understand and predict changes in Earth's environment and conserve and manage coastal and marine resources to meet our Nation's economic, social, and environmental needs" (NOAA, 2005b). NOAA's plan identifies a number of fundamental activities to meet the described mission including:

- Monitor and observe the land, sea atmosphere, and space to create observational and data collection network that tracks Earth's changing systems.
- Understand and describe how natural systems work together through investigation and interpretation of information.
- Assess and predict the changes of natural systems and provide information about the future.
- Engage, advise, and inform individuals, partners, communities, and industries to facilitate information flow, assure coordination and cooperation, and provide assistance in the use, evaluation, and application of information.
- Manage coastal and ocean resources to optimize benefits to the environment, the economy, and public safety.
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Through the integrative and collaborative efforts of reserve research, education, and training activities, the NERRS strives to meet NOAA's mandates to ensure that coastal ecosystems will be better understood and improved coastal decision making will lead to improved coastal conditions in the United States.

III. SWMP Phase I: Abiotic Monitoring Overview

In 1993, the NERR research coordinators proposed the establishment of a national coordinated monitoring program that would attempt to identify and track short-term variability and long-term changes in representative estuarine ecosystems and coastal watersheds. The first phase of the NERR SWMP began in 1995. The initial objective of the program was to monitor a suite of water quality and atmospheric variables over a range of spatial (local, regional, national) and temporal (minutes, hours, days, months, years) scales.

Water Quality Monitoring

The abiotic variables measured are not only indicative of habitat quality for numerous estuarine species, but they establish health criteria and determine human uses. All 27 reserves deploy at least four Yellow Springs Instrument Co. (YSI^{TM}) Model 6600's and 6600 EDS datasondes (Extended Deployment System) for continuous monitoring of water quality parameters including pH, conductivity, temperature, dissolved oxygen, turbidity and water level every fifteen to thirty minutes. One datasonde is placed at a control site, while another is placed at a site that is impacted by human activity and exemplifies a concern of the reserve (e.g., nonpoint source pollution). Two additional water quality stations are placed strategically within the estuary to provide additional long-term information along salinity, vertical, and land use or habitat gradients as appropriate to address local reserve research questions (Trueblood et al. 1996). Currently, at least one water quality station within each reserve is telemetered through the NOAA Geostationary Operational Environmental Satellites (GOES) to provide near real-time data to the CDMO. Each sonde takes measurements every 15 minutes and these observations are transmitted in batches once an hour.

Beginning in 2001, the NERRS incorporated monitoring of nutrient concentrations into SWMP in order to address coastal manager's needs to better understand nutrient conditions within estuarine systems. Nutrient monitoring consists of sampling at the four SWMP stations for at least monthly baseline grab samples and monthly diel (24-hour) samples at one SWMP station. Analyses for ammonium, nitrate, nitrite, ortho-phosphate and chlorophyll a are mandatory. Analyses for silica, particulate nitrogen, particulate phosphorous, dissolved total nitrogen, dissolved total phosphorous, particulate carbon, dissolved carbon and total suspended solids are currently optional. It is anticipated that within the next few years nutrient sampling for total nitrogen and total phosphorous will be included in the standard suite of sampling parameters at reserves that can support this additional sampling effort and cost.

Meteorological Monitoring

Every Reserve in the NERRS must maintain at least one meteorological station as part of the SWMP. The meteorological stations were originally purchased in 1996, but the monitoring was not fully standardized and implemented until 2001. All SWMP meteorological stations were originally based on the Campbell Scientific CR10X

datalogger, currently the CR10X are being replaced by the upgraded Campbell Scientific CR1000 datalogger. Readings of all the measured parameters are taken every 5 seconds with averaged or totaled values of the data output every 15 minutes. As with the water quality stations, these data are transmitted hourly via satellite to a central receiving ground station for near real-time display. Both data streams contribute to the IOOS initiative.

The parameters measured include maximum and minimum temperature and time of the extremes, relative humidity, rainfall, and barometric pressure. Also measured is wind speed, including maximum speed and time, wind direction and the standard deviation of the wind direction. The standard deviation of wind direction is an indicator of the variability of the direction over the 15 minute measurement interval. The final required measured parameter is photosynthetically active radiation (PAR). Individual reserves may monitor additional parameters if desired, and several reserves already measure total solar radiation. The stations are sited at locations typical of natural conditions in the area and installed according to National Weather Service guidelines.

Meteorological data was originally measured primarily as to provide ancillary information for the water quality measurements initiated during phase one of SWMP. Weather data can provide insight into antecedent conditions that may have affected the water quality parameters. The addition of telemetry capability now allows SWMP data to support additional users such as local weather forecast offices associated with the National Weather System and search and rescue efforts associated with the US Coast Guard. Additional benefits with near real-time data delivery include the ability of various weather forecasters to better predict storm tracks and properly warn coastal residents in the path of the storm.

Next Steps: Expanding Abiotic Monitoring

Funding limitations since inception of the monitoring program have limited the scope of the abiotic monitoring aspects of the program. The NERRS proposes to improve and expand the existing water quality and weather monitoring by upgrading equipment, increasing spatial coverage, increasing parameters monitored, adding personnel, and incorporating an analytical piece to the program. These components are viewed as necessary to fully implement the water quality and weather monitoring aspects of SWMP. Where there is consensus, these additional components of the monitoring program are given priority according to whether they should be implemented as soon as funds are available (High priority) or whether they may require further evaluation or will be implemented later (Medium priority).

Upgrades and Maintenance of Equipment (High Priority)

In order to minimally continue the abiotic monitoring portion of SWMP, it will be necessary to continually upgrade equipment as necessary. Aging instruments increase maintenance and replacement costs and upgrading the instruments with new probes can only occur if the dataloggers are upgraded (Appendix C: matrix of reserves sonde status).

Additional costs associated with the new telemetry system must also be incorporated to sustain the NERRS role as an IOOS backbone component with the consistent delivery of near real-time data (Ocean.US 2006).

Spatial Expansion of Monitoring Sites (High Priority)

In the initial phase of SWMP, the NERRs have concentrated on intensive measurements at four sites within each reserve in order to focus on temporal variability and periodicity. At some reserves the data are collected from only four sites, which may not adequate to represent the diverse array of habitats, land use and environmental conditions that occur in the NERRS. There are other reserves that support additional monitoring stations that may or may not follow the same sampling protocols as the required four SWMP stations (Appendix D). The incorporation of existing non-SWMP stations into the SWMP program will require a discussion regarding protocols, QA/QC, and data management for additional sites that either meet or do not meet current SWMP standards. Simultaneous and intensive sampling at multiple sites within a reserve that are more spatially representative of a reserve and its watershed may provide new insights into variation, especially when linked with habitat change. An additional goal of spatial expansion will be to more fully better characterize reserves for purposes of addressing coastal management issues and determining the response of estuarine ecosystems to natural and human induced change. At a minimum, it would be ideal to increase spatial coverage of SWMP water quality monitoring at two additional locations along a physical gradient within each reserve with locations of these sites to be determined by the research coordinator based on the site specific coastal monitoring issue being addressed. Funding for additional weather stations at reserves is also sought to support improved coverage within the reserve and its watershed. Some reserves already have additional water quality and meteorological monitoring stations (in addition to the required SWMP stations) which may address this need. Additional resources would likely be required to support for the NERRS Centralized Data Management Office as this office could potentially process this additional data or enable access to additional datasets as possible.

Personnel Needs (High Priority)

Implicit in any expansion of the SWMP is a substantial increase in the necessary technical and data management personnel. At minimum, a full time Research Coordinator and a full time technician must be dedicated to the current abiotic sampling phase of SWMP at each Reserve. An expansion of the abiotic phase of the SWMP may require additional staff time.

Analytical Component (High Priority)

Twelve years after the commencement of the SWMP, only a few efforts have been made to determine the value and use of the data on national and regional scales (Appendix E). Up to now, funding for these syntheses has been provided solely through the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET). The NERRS proposes that funds be allocated every two years to analyze and synthesize the enormous amount of data being collected by the SWMP. Such syntheses will determine the similarities/dissimilarities among reserves, as well as provide much of the information needed to determine the range of water quality and meteorological conditions represented

by the NERR system (e.g., severity and frequency of hypoxia, salinity ranges, tidal periods, and other habitat attributes). Regular syntheses would provide information on the status of the NERRS and any trends occurring by comparing the frequency, duration, severity, periodicity, and explanatory environmental factors for hypoxia and other "key" water quality indicators among reserves, regionally, and nationally. Additionally, incorporating ancillary data sources within an analysis of SWMP data (i.e., USGS and NSF-LTER data, NERRS non-SWMP monitoring) will support more comprehensive understanding of local and regional coastal and watershed environmental conditions over time.

Chlorophyll Fluorescence (High Priority)

Long-term trends in phytoplankton biomass are an accurate indicator of eutrophication. As a result, the monitoring of chlorophyll *a* levels, a simple indicator of algal biomass, was incorporated into the monthly grab sampling of SWMP from its inception. This effort, however, requires the extraction of chlorophyll samples prior to fluorometric or spectrophotometric quantification limiting the temporal and spatial scale for data collection. A number of highly accurate fluorescence-based sensors are now available, which can detect chlorophyll fluorescence *in situ*. With such data collected at the 15 min intervals of SWMP, the ability of NERRS to quantify short-term variability and long-term change in phytoplankton biomass would be greatly enhanced.

Contaminant Monitoring (medium priority)

Sediments are long-term contaminant integrators so sampling and analysis of sediments once every five years should provide both status and trends perspectives of contamination loadings at the NERR sites sampled. Sediment contaminant data is valuable for assessing trends and health within the ecosystem, often reflecting changes in loadings due to new sources as well as decreases which correlate with regulatory efforts in more urbanized estuaries.

The selection of sample sites will have a significant impact on the interpretability and characterization value of the analytical data results. Sediment sampling sites must be depositional and collected sediments must be recently settled for the site to be effective in demonstrating temporal trends. It is recommended that a minimum of two sites be selected for each NERR sampled, and if feasible, up to four sites should be selected. Where a NOAA Mussel-Watch sediment chemistry site coincides with a deposition area proximate to the NERR, it should be considered as a potential sampling station due to the historical data already available for the site. Data can be compared with available national sediment guideline values, providing a perspective on what levels are considered "high" relative to national sediment databases and/or having greater potential to show biological impacts.

Pore Water Chemistry

As an indicator of condition, sediment chemistry is far less variable spatially or temporally than surface water chemistry and is an excellent integrator of watershed processes. Ongoing research has found that within-site spatial and temporal variations in pore water nutrients are relatively small compared to surface water collections (Nietch

and Morris submitted, Sundareshwar and Morris 1999, Paludan and Morris 1999), and that pore water nutrient chemistry is a diagnostic of fertility in habitats of varying nutrient limitation. Due to lower uncertainty in pore water measurements relative to surface water, long-term monitoring of pore water may offer a cost-effective means of quantifying change in estuarine biogeochemical conditions at the NERRS. This is a promising technique that should be considered for the system wide application once methodology of sampling has been sufficiently developed and tested.

Atmospheric Deposition Monitoring

The NERRS' estuarine location can contribute substantial monitoring data on atmospheric deposition in coastal environments to existing long-term monitoring programs such as the National Atmospheric Depositional Program (NADP) National Trends Network (NTN), Mercury Depositional Network (MDN), and the USGS (See Appendix F for existing sites). Both natural and man-made processes can lead to air pollution. As human activities increase, the amount of air pollution also increases. Pollutants may be deposited with rain fall or fog (wet deposition) or attached to particles during dry deposition or via vapor exchange. Depending on the type of compound under consideration wet or dry deposition will predominate. According to the World Meteorological Organization (1989), flux calculations for trace metals indicate that on the whole wet deposition from the atmosphere is more important than dry deposition (i.e., 80% from wet). This generalization may not hold true everywhere (e.g., arid areas) and dry deposition in coastal areas is not well understood and difficult to study. Nitrogen, ammonia/ammonium, mercury (including methyl-mercury), and sulfate can impact coastal environments productivity and condition. The long-term monitoring of atmospheric deposition allows for national, regional and local trend analysis as well as an improved ability to assess critical loadings and consequences in estuarine water quality and ecosystem responses. This in turn will improve baseline data useful for estimating future impacts to the system and formulating current and future policy and modeling efforts.

The NERRS will continue to seek funding to support additional depositional monitoring stations located in or near reserve boundaries in an effort to both fill NADP gaps in coverage as well as address local management issues. A current partnership with NOAA's Office of Atmospheric Research-Air Resources Laboratory and the Grand Bay NERR in Mississippi has lead to the installation of a precise mercury deposition monitoring station that will result in an increased understanding of the loading and sources of mercury in the Gulf of Mexico region.

Groundwater Monitoring

Additional focus on groundwater monitoring within the NERRS would be an important addition to the SWMP abiotic monitoring plan as recent research points to the importance of submarine groundwater discharge (SGD) as a source of nutrient loading to coastal areas that rival surface inputs (including riverine and atmospheric inputs) (Valiela, et al. 1992, Moore, 1996; Bugna et al., 1996; Kim et al., 2003). SGD often represents a major source of nutrients in estuaries and embayments (Krest et al., 2000; Charette et al., 2001). These nutrients may lead to, or compound, critical loading issues within estuarine

environments leading to eutrophication and additional negative environmental conditions. One recent study conducted within the Waquoit Bay NERR in Cape Cod, Massachusetts, found that total dissolved mercury introduced to the bay through SGD had a greater than through atmospheric deposition and riverine inputs (Bone et al. 2006). These types of studies will improve our understanding of nutrient loading, nutrient sources, and management options.

Studying groundwater discharge is complicated by its spatial and temporal variability of flow and by attaining reliable estimates of solute loads. There is a growing suite of tools that have been developed for sampling and measuring SGD which the NERRS could implement to better understand this source of nutrients to estuarine environments and address the question of groundwater impacts to coastal systems at national, regional and local scales (see Mulligan and Charette 2006). Additional important information on groundwater aquifer status (i.e., water level, saltwater intrusion, and other contamination) are also critical pieces of information to know about the NERRS watershed, both above and belowground, aquatic resources.

IV. SWMP Phase II: Biological Monitoring Overview

The biological monitoring phase (Phase II) of SWMP began in 2004. The central objective of Phase II is to characterize biotic diversity in NERRS estuarine ecosystems by assessing community composition and species abundance and distributions. SWMP Phase II builds on Phase I monitoring capabilities by exploring patterns of variability and spatial distribution of estuarine communities, including emergent and submerged vegetation, invasive species, benthic communities, and nekton/plankton communities. The NERRS research community has begun to develop and test a series of rigorous protocols to establish a national strategy for implementing this Biomonitoring Initiative, while retaining local flexibility as appropriate for individual reserves (e.g. Moore and Bulthuis 2003). A key component of this second phase is the production of biological monitoring data for scientists and coastal managers' use in short-term research planning or management decisions, in addition to the long-term goal of tracking biological changes over time. These monitoring efforts will be repeated over time within each reserve, and comparisons among reserves will be made as appropriate.

At the broadest level, the biological monitoring program addresses the same temporal question as the existing water quality monitoring: what are the patterns of short-term variability and long-term change? As with Phase I, general questions about spatial differences in these patterns within estuaries, among estuaries, and among geographic regions are addressed. However, the biological monitoring program may also answer more focused questions or issues such as:

- What is the relationship between water quality and biological community composition and species abundance and distributions?
- What changes in habitat and species distributions are associated with climate change? With specific and cumulative anthropogenic disturbances?

- How variable is recruitment in space and time among major groups of planktonic larvae?
- What invasive species have recently invaded specific estuaries or reserves (early detection)?
- What influence does habitat degradation or restoration have on associated biological communities?

The reserve system represents different biogeographical zones with diverse habitat types, biotic resources, and management concerns. Rather than requiring all reserves to address a single focus area that may be of little importance to some reserves or regions, an approach that maximizes flexibility for a reserve while ensuring scientific rigor and consistency is being implemented. The biological monitoring program includes a set of monitoring protocols for several biological communities (Appendix G: include available protocols). Each reserve can implement one protocol each year. The same protocol can then be repeated annually, or different protocols can be carried out in alternation. Eventually, if funding permits, multiple protocols per year might be carried out by the reserves. As of 2006, only submerged and emergent monitoring protocols have been funded, and these have been implemented only once during 2004 to 2006 at a majority of the reserves (see Appendix H for further details).

Submerged Aquatic and Emergent Vegetation Monitoring

Macrophyte communities including emergent tidal wetlands and submersed aquatic vegetation (SAV) beds are important components of estuarine ecosystems. They form buffers between upland systems and the sea and provide complex habitats with irreplaceable value to both coastal systems and their adjacent watersheds. They also serve as important sites for education as well as recreation and are critical components of the NERRS. The presence, growth, and spatial distribution of emergent and submerged vegetation fluctuate over seasonal, annual, and longer time scales in response to natural forces and anthropogenic causes (Short and Wyllie-Echeverria 1996, Roman et al. 1997, Orth and Moore 1983, Dahl 1990). Changes in the aerial extent of SAV or emergent marshes provide a broad evaluation of the health of the community and usually require airborne or other remote sensing methods. Changes in the vegetative characteristics (community composition, biomass, density, etc.) of selected stands provide a more detailed evaluation of the health of those selected stands and usually requires on the ground sampling. Thus, monitoring the aerial extent and vegetative characteristics of these communities was one of the first elements of biological monitoring to be implemented as part of the NERRS SWMP Phase II.

Examples of questions addressed within this biomonitoring framework are: What are the patterns of inter-annual variability in the area and spatial distribution of emergent and submerged vegetation, and what are the patterns of long-term change? What are the seasonal and interannual patterns of vegetative characteristics of selected vegetative stands and what are the patterns of long-term change? What are the relationships between these vegetative patterns and physio-chemical habitat conditions?

The current SAV/Emergent Monitoring program uses two approaches, known as Tier 1 and Tier 2 (see Appendix G for specific protocol). Tier 1 monitoring addresses the overall spatial distribution of either emergent vegetation or SAV communities within the boundaries of the reserves at annual and multi-annual time scales. Tier 2 monitoring addresses the vegetative characteristics of selected stands of these communities within reserve boundaries.

Tier 1 monitoring of spatial distribution of emergent and submerged vegetation uses a combination of surveys, remote sensing, ground truth with global positioning system (GPS), georectification and mapping with geographic information system (GIS), and GPS mapping. In general, the protocols adopted for C-CAP (NOAA Coastal Change Analysis Program) and the Chesapeake Bay Program are used by the reserves (Dobson et al. 1995, NOAA CSC 2001). Tier 2 monitoring of selected stands of vegetation consists of fixed transects with permanent sampling stations located along transects that can be stratified, if necessary, within vegetation zones or segments of the marsh or submersed vegetation beds. This approach has been used in a variety of studies for assessments of vegetative communities (Doumlele 1981; Moore et al. 1995; Perry and Atkinson 1997; Perry and Hershner 1999) and has been recently adopted as a monitoring protocol by the National Park Service and others to assess and compare both reference and restoration wetland sites on local and regional scales (Neckles and Dionne 2001; Roman et al. 2001; Neckles et al. 2002). Additionally, similar protocols have been established for quantification of seagrass dynamics in a global seagrass monitoring program (http://www.SeagrassNet.org; Short et al. 2002).

As of 2006, 16 NERRs have participated in these biomonitoring efforts, and it is anticipated that some portion of the remaining 10 sites will be funded to start biomonitoring work in the near future. Ongoing biomonitoring projects have focused on developing baseline vegetation distribution maps for use in future land use change research, determining changes in health and distribution of communities with long-term changes in water quality and quantity, and quantifying changes in marsh land cover types. All biomonitoring efforts are linked, where appropriate, with reserve education and outreach initiatives in order to utilize biomonitoring data as an educational tool for improving coastal management. For further details on the status of the 16 SAV/Emergent pilot projects, see Appendix H.

Next Steps in Biological Monitoring

In the development of a biological monitoring component for the NERRS SWMP program it was recognized that there were a series of focus areas that could be focus areas for NERRS involvement. The following focus areas (i.e., nekton, plankton, benthic, invasive species) merit further discussion as possible additions to the NERR monitoring program at some point in the future. Workgroups were developed for each of the additional focus areas listed below and these groups, with input from outside experts, have begun to develop monitoring protocols. As the SAV/Emergent monitoring protocol took some time to prepare, it is anticipated that these additional protocols will also take time to develop. In developing the monitoring protocol, each workgroup will carefully

assess relevant existing large-scale coastal monitoring activities (funded by EPA, USGS, National Park Service, etc.). In some cases, it may be possible to collect data with the same protocols so comparisons can be made across the reserve system and non-NERR sites. National implementation requires additional funding and therefore the development of these additional monitoring protocols are not linked to a specific timeline for establishment, rather, the workgroups are encouraged to build out the protocols as possible in order to continue to move forward with external funding opportunities as appropriate. The result of these planning processes will be a summary document that includes 1) the key questions that will be addressed; 2) the best methods for answering the questions; 3) the products that should result from the monitoring; 4) a data management strategy for archiving and accessing data collected at NERRS; and 5) a system wide implementation strategy. A cost estimate for each monitoring program (per reserve and for national coordination of the program) will be included.

Personnel Needs

Similar to the need for consistent, competent, and trained research staff to support the abiotic component of the SWMP there is a concurrent need for additional technical and data management personnel to support biological monitoring programming. Thus, it is highly desirable to support an additional full time technician at each Reserve to support biological monitoring program expansion as possible.

Nekton Monitoring

If the NERRS is to comprehensively monitor changes in abiotic and biological parameters and understand the meaning of these changes at the ecosystem level, it is critical that nekton be included as one of the biological components of the NERR SWMP program. Nekton (fishes and decapod crustaceans) is a highly abundant and integral component of estuarine food webs, thus providing linkages among adjacent trophic levels and among various estuarine habitats (e.g., marsh and open water) (Cicchetti 1998). Many small, nektonic species in estuaries are juveniles of commercially and recreationally important species. Some species of nekton provide forage for larger economically important fisheries species as well as for wading and other piscivorous estuarine birds (e.g., Friedland et al. 1988; Smith 1997). As a higher trophic level, nekton essentially serves as an integrator of various estuarine processes and thus can serve as an excellent indicator of estuarine condition (Hughes et al. 2002). Additionaly, many estuarine nekton are also highly recognizable and of great interest among non-scientists, which facilitates the transfer of knowledge gained from any nekton monitoring program to other education, stewardship, and management programs.

The ecological, educational, and economic value of estuarine nekton provides a strong impetus for development of a system-wide program for nekton monitoring within the NERRS. Such a program is crucial to obtaining a better understanding of the ecosystem-level implications of other biotic and abiotic data that are being collected throughout the system (i.e., to put these data into context). Additionally, the NERRS is in a unique position to collect and synthesize nekton data at a national scale to enhance understanding of national and regional trends.

The NERRS is currently exploring how best to implement a national nekton-monitoring program within the system. One strategy is to develop semi-standardized protocols for monitoring with a small number of sampling gear types. A second strategy is to take advantage of nekton monitoring that is already occurring within NERR sites or in the surrounding estuaries. Whichever strategy is employed, the eventual development of a system-wide nekton monitoring program will allow the NERRS to track changes in estuarine nekton assemblages over time and relate these data to other abiotic and biological components that are also being monitored as part of a comprehensive ecosystem-level NERR SWMP program.

Phytoplankton Monitoring

As anthropogenic nutrient loading to estuaries increases, the phytoplankton community changes as a response. In addition to simply increasing total phytoplankton biomass, the nutrient type and their availability greatly alter phytoplankton community composition and activity, including the occurrence of Harmful Algal Blooms (HAB) (*refs*). Such alterations can, in turn, impact the structure and function of the estuarine food web (*refs*). The first priority of NERR plankton monitoring efforts is thus to extend phytoplankton monitoring to include taxonomic composition and measures of phytoplankton photosynthetic capacity and physiological status.

Phytoplankton photopigment analysis is an extremely useful tool for assessing the relative abundance of characteristic algal groups. High performance liquid chromatography (HPLC), provides rapid and highly quantitative separation of algal chlorophylls and carotenoids, for photopigment-based characterization of phytoplankton taxonomic composition of discrete grab samples, however, this technique can be time and labor intensive Recent advances in sensor technology have made possible the potential for fluorometric separation of phytoplankton photopigments *in situ*, with sufficient resolution to allow for taxonomic discrimination at the class level. Indeed, NERRS has already hosted a number of CICEET-funded studies piloting such technology. In addition, several commercially available fluorometers allow for the *in situ* characterization of phytoplankton photosynthic performance and physiological status through the analysis of fluorescence excitation and emission (e.g., Chelsea instruments, Turner Designs). The availability of such technologies raises the possibility of near real-time monitoring of phytoplankton community composition, including the formation of HABs, as well as phytoplankton physiological status as influenced by nutrient availability. These various technologies are all expensive, especially to implement System-wide, but the SWMP platform is particularly well positioned to incorporate such technology. Its addition would also greatly extend the contribution of NERRS towards incorporating biological monitoring efforts into IOOS.

Benthic Monitoring

This monitoring program will address the abundance, diversity, and composition of benthic communities, focusing on detecting changes in these assemblages due to natural and anthropogenic stressors. This bio-monitoring program will be designed to contribute to our understanding of basic ecological principles but will also have a variety of important management implications. Many benthic species are commercially important

(e.g., shellfish and crabs), or serve as food resources for other species of conservation interest (e.g., fish and birds). Benthic communities also have been heavily impacted by deleterious exotic species, and are often used as indicators of ecosystem health. Examining patterns and processes of benthic community development also has direct implications for the science and management of Marine Protected Areas by addressing such topics as the benthic / pelagic coupling, linkages between populations, and source / sink dynamics in geographically discrete areas.

Our approach will be to first create a broad conceptual framework within which benthic communities can be considered. Given the needs and constraints of a system-wide monitoring effort, we will then identify a sampling program that will address discrete elements of this framework. Remaining elements can be incorporated into reserve-specific programs (if funding is available), and are designed to stimulate additional research within reserves. For example, by virtue of our long-term water monitoring, our national program will tend to have a "bottom-up" focus (addressing abiotic forcing factors). However, the results of our monitoring should also facilitate future reserve-based "top-down" research (such as examining the role of predation in structuring benthic communities). Our sampling will focus on three major benthic habitat types: soft sediments, such as mud and sand; unconsolidated hard substrates, such as shells, cobbles, and reefs; consolidated hard substrates, such as rock faces and pier pilings.

The proposed bio-monitoring will take advantage of the many strengths of the NERR system, including geographic coverage, permanent on-site staff, and ongoing water and weather monitoring. The benthic bio-monitoring is designed to meet several criteria:

- There must be a degree of uniformity in sampling across reserves, suggesting that the proposed protocols must be relatively simple (given that sampling methods must be implemented across a wide range of environmental settings).
- We also wish to allow for some flexibility in order to address reserve-specific goals. For this, we will utilize a "toolbox" approach, where we develop criteria for a number of different sampling protocols.
- Although this monitoring is designed to only address portions of a larger framework, the results of our sampling must serve as a stand-alone products to advance the science and management of estuarine ecosystems.
- The monitoring will be linked as closely as possible to the other SWMP, allowing us to couple abiotic and biotic processes.
- The monitoring is also designed to link as much as possible to other large-scale studies of coastal waters (e.g. EPA EMAP, PISCO, SERC).

Invasive Species Monitoring

Biological invasions are a significant conservation and management concern for the NERRS. However, the consensus among invasion experts and NERRS scientists is that no monitoring program should be developed that only focuses on alien species; rather, all monitoring should jointly investigate both natives and aliens (Wasson et al. 2002). Biological monitoring programs developed and implemented as a part of SWMP will include determination of status of the species detected: native, alien, or cryptogenic (origin uncertain). Consistent biological monitoring protocols across Reserves will allow

for comparisons of the extent of invasions (percentage of species that are aliens and percentage of abundance accounted for by aliens) across estuaries, as well as mapping of national distribution and spread of key species.

Two examples of programs that have been developed to specifically look for invasive as well as native species include:

Decapod crustaceans, and especially crabs, are important ecologically and economically in many of the NERRs. They are also easy to catch and identify, and thus are well-suited to an inexpensive, standard national monitoring effort. Nine reserves piloted a crab monitoring protocol in 2003-4. From this effort, a SWMP crab monitoring proposal was developed. The goals of the crab monitoring program are 1) to characterize estuarine crab communities, 2) to analyze geographic patterns of crab invasions, with an emphasis on early detection, 3) to track changes in crab communities over time, especially impacts of non-native invaders on native populations. The crab monitoring program requires all participating Reserves to follow a detailed standard protocol involving deployment of three habitat trays and three minnow traps at five sites along an estuarine gradient, ideally using locations at/near the SWMP sites. To complement this standardized sampling, each Reserve would deploy further traps and trays to test locally relevant hypotheses. This monitoring program would entail only very modest costs, equivalent to the cost of a summer intern at each Reserve and some support for a central coordination.

Sessile invertebrate communities on hard substrates in bays and estuaries are biologically rich assemblages that are of both general and applied interest. These communities include key components of ecological and economic values, such as oysters and mussels, but they are often heavily invaded by exotic species. Hard substrate communities also can represent substantial nuisances when they occur as fouling on maritime structures, vessels, or scientific equipment. In order to assess these communities within coastal waters, five reserves and three national marine sanctuaries piloted a monitoring program in 2004-5, in partnership with the Smithsonian Environmental Research Center (SERC). From this effort, a SWMP monitoring proposal focusing on hard substrate communities was developed. The goals of this monitoring program are 1) to measure spatial, temporal, and taxonomic patterns of invasion, 2) to test hypotheses about the relative importance of vector activity, disturbance, and salinity or other gradients in invasion processes, 3) to track the arrival and spread of non-native species, and the efficacy of various management strategies to reduce rates of invasion, and 4) to characterize the structure and species composition of sessile invertebrate communities at various spatial scales, including both native and non-native components, and how these vary in space and time due to a broad range of forcing functions (e.g., climate change, nutrient dynamics, invasions, etc.). The proposal involves a team from SERC conducting fieldwork and laboratory identifications and analyses at 5 Reserves each year, with rotation across regions such that each Reserve is assessed approximately every 5 years. Standard protocols involving consistently deployed and assessed settlement plates ensure that rigorous spatial and temporal analyses can be conducted. The cost of this program would mostly consist of funding two full-time researchers at SERC, with some very modest additional support for the participating reserves and coordination.

Marsh Bird Monitoring

Populations of many emergent wetland-dependent bird species appear to be declining (Tate 1986, Eddleman et al. 1988, Conway et al. 1994), but we currently lack adequate monitoring programs to determine status and estimate population trends. To monitor short-term variation and long-term trends in marsh bird populations throughout the NERRS, it is recommended that the system use the protocol outlined in the Standardized North American Marsh Bird Monitoring Program (Conway 2005). The primary bird groups addressed through this monitoring effort include rails, bitterns, grebes, gallinules, moorhens, wrens, and sparrows.

This standardized monitoring protocol, which uses broadcast calls to elicit vocalizations, is designed to address a series of issues relating to the monitoring and conservation of marsh birds. Specifically, the goals of this program are:

1. Determine the population status and breeding distribution of marsh birds;
2. Determine species-habitat associations of marsh birds;
3. Determine population trends of marsh birds at local (e.g., NERR Site), regional (e.g., Gulf Coast), and national geographic scales as well as various temporal scales;
4. Determine the environmental factors that influence distribution of marsh birds;
5. Increase local volunteer (birders or bird-watchers) participation in research and monitoring programs.

Understanding marsh bird populations within NERRS is important because they (1) may be affected by accumulation of environmental contaminants in wetland substrates, (2) are vulnerable to invasive plants, (3) potentially serve as "indicator species" for assessing wetland ecosystem quality, (4) can be used to evaluate the success of wetland restoration efforts, (5) have high recreational value; many species are highly sought-after by recreational birders, and (6) several rails are game species in many states.

Analytical Component

As outlined in the abiotic monitoring section, the NERRS strongly supports the regular synthesis of SWMP data to support improved understanding of national, regional, and local coastal and watershed conditions. With the commencement of the biological phase of the SWMP program the NERRS proposes that funds be allocated every 3-5 years to analyze and synthesize the biological community monitoring information that is generated through the current community monitoring efforts. Similar to the abiotic syntheses, regular syntheses will determine the similarities/dissimilarities among reserves, provide status and trends associated with the NERRS habitats, and have the ability to address priority management concerns in coastal environments. Additionally, incorporating ancillary data sources within an analysis of SWMP biological data (i.e., USGS, NSF-LTER, and SERC data) will support more comprehensive understanding of local and regional coastal and watershed environmental conditions over time.

V. SWMP Phase III: Land Use and Habitat Change Overview

The SWMP land use and habitat change phase (phase three) focuses on tracking and evaluating changes over time in coastal and estuarine habitat as they relate to changes in watershed land use practices. Phase three is well-aligned with phase two, as both of these efforts combine remote sensing imagery analysis with ground truthing efforts. The main objective of this element will be to examine the link between coastal habitat quality and adjacent land use activities. The basic question to be addressed is "What is the magnitude and extent of habitat change in estuarine systems and how are these changes linked to watershed land use practices?" (NOAA 1998).

The reserves provide a framework for understanding processes that occur at local scales and for assessing short and long term variability. The fact that the NERRs are currently intensively monitored in a coordinated and consistent manner makes these sites valuable in developing a more complete understanding of current conditions and future changes and offers the prospect of using the NERRS as a network of index sites for future ecosystem models. It is anticipated that the use of remote sensing coupled with *in situ* sampling will be necessary to provide a broad understanding of spatial and temporal variability in the ecosystem and the characteristics of concern.

In order to develop this SWMP element, a set of habitat and scale dependent standard monitoring procedures will be developed and adopted that specify the acceptable level of measurement accuracy and the spatial and temporal monitoring frequency. The use of consistent methods will allow the "status and trends" of habitat change to be assessed at local, regional and national scales, and provide data to asses changes in habitat condition and to identify those coastal land use practices best able to ameliorate habitat degradation. By applying system-wide standardized protocols for this process, the Reserve System is uniquely suited to accomplish this task at a scale useful for making local and regional recommendations while considering national implications.

Reserve Habitat and Watershed Land Use Mapping

In a first step toward system-wide phase-three monitoring implementation, NERRS staff are working to define a common classification protocol to assist the Reserves in consistent, and thus nationally comparable, habitat and watershed mapping and inventorying efforts (Kutcher et al. 2005). Two scale-specific common classification systems have been identified to enable the NERRS to assess trends in habitat and land cover change at local, regional, and national scales and identify the status of coastal habitats (i.e. degrading, improving, or maintaining). First, in an effort to encompass the variety of habitats that exist within the NERRS boundaries a classification scheme was developed, which incorporates aspects of other national systems (i.e. Corwardin, Anderson, and NRCS Curve Numbers) to characterize habitats of reserve properties at a high resolution (NERRS Classification Scheme, Kutcher et al. 2005). Currently, 26 NERRs are implementing this scheme to inventory reserve habitats in a nationally systematic manner. It is anticipated that this will further inform the NERRS on existing mapping methodologies utilized across the system as well as provide an initial system-

wide dataset of habitat types and quantity. Second, in partnership with the Coastal Services Center, the NERRS is currently implementing a System-wide mapping effort to characterize land use and cover in each reserve's watershed at moderate resolution (30-m.) using CCAP data and protocols. This partnership will provide standardized background data, change analyses, percent impervious data, and predictive modeling capabilities to the entire Reserve System on five-year intervals in perpetuity.

By comparing regional differences in watershed land use patterns and their influence on estuarine habitat quality, the activities patterns most detrimental or beneficial to estuarine habitat quality will be identified. In addition, differences, if any, in this relationship at each Reserve will allow an examination of regional differences in the sensitivities of estuarine habitats. Products derived from these protocols will provide the basis for regional recommendations regarding coastal land use planning, including habitat restoration, to benefit estuarine habitat quality. The results of this component will be linked to the biomonitoring component by identifying coastal habitats at risk from sea level rise and other anthropogenic impacts. Recommendations can then be formulated to guide coastal land use planning and habitat restoration goals to accommodate projected future changes in the distribution of these important estuarine habitats.

SWMP Phase III Next Steps

Personnel Needs (High Priority)

The habitat change focus of the SWMP will require a full time technician who is proficient in the use of GIS. This is especially critical since the Protected Area GIS (PAGIS) program that has provided GIS expertise to the NERRS is being phased into an operational program using base NERRS funding.

Benthic Intertidal and Subtidal Habitat Mapping (High Priority)

Because of the relatively shallow nature of most estuarine environments, the biogeochemsitry of the estuarine benthos is critical to the functioning of the entire ecosystem. The first step in understanding such linkages is to obtain an accurate picture of the benthic environment both in terms of its physical and biological structure. Habitat mapping techniques can be broken into two broad categories, aerial imagery and *in-situ* sampling, of which only the latter is generally useful for mapping benthic estuarine habitats. *In-situ* sampling of benthic habitat involves data collection through acoustic, visual, grab, or coring programs (Bell et al., 2006, Nitsche et al. 2005 and 2004). Sediment Profiling Imagery (SPI), when used with traditional grab or core sampling can also be used to define benthic habitat characteristics (Rosenberg et al. 2003, Smith et al. 2003). These methods are costly, time-consuming and/or labor intensive and the methods selected depend on available resources and the characteristics (i.e., mean depth, total area) of the location to be studied. Besides mapping the geophysical environment, other information is necessary to effectively link the geophysical and chemical measurements to the biota. This typically involves measurements of sediment texture, nutrient distribution and biological characterizations along with bathymetric measurements.

The most efficient, cost effective plan for the NERRS would be to characterize benthic habitat only near water quality monitoring sites (e.g., within a 500 foot radius in open water areas or specified linear distance upstream and downstream in tidal channels). This tactic would, however, result in spatially limited data and information making it difficult to interpolate the results and make comparisons across the NERRS sites. To produce a more robust product, benthic characterizations could be completed for the entire submerged area of each reserve. This would be more costly and time consuming but would yield a product of greater value for understanding and managing our estuarine resources. The number of stations sampled would depend on the reserve and amount of spatial detail required. Due to the costs and complexity associated with benthic habitat characterizations, much of the work would be contracted and would probably be done on a rotating basis, three to five reserves per year.

Climate Change Impact Assessment and Analysis

Climate change is predicted to strongly affect coastal areas due to sea level rise, increase in storm frequency, and changes in weather patterns. Since human populations are increasingly drawn to coastal areas, the continued interactions of human activities with the natural environment need to be understood, especially in light of a changing climate, which may alter these interactions.

NERRS is well placed to play an important role in climate change monitoring and research. Current monitoring efforts associated with the three phases of SWMP provide valuable baseline data to quantify and better understand the impacts and resiliency of coastal ecosystems to climate change. Regional or local efforts to estimate the impacts of climate change may include determining relationships between predicted increased storm frequency, sea level rise and salt water intrusion and overall coastal ecosystem health. In addition, SWMP could be expanded to include assessments of habitat loss and changes in biodiversity, population structure, and productivity in coastal communities as a result of climate change impacts.

Sea levels are rising worldwide and along much of the U.S. coast. Current estimates indicate global mean sea level has risen 1-2 mm yr^{-1} for the past 100 years. The rate of global mean sea level is projected to rise by 0.09 to 0.88 m between 1990 and 2100 (0.8 to 9 mm yr^{-1}, although this increase is not uniform from region to region (IPCC, 2001). For example, sea level has been rising 2.0-3.0 mm yr^{-1} along most of the U.S. Atlantic and Gulf coasts and about 10 mm yr^{-1} along the Louisiana coast, due to local land subsidence (IPCC, 2001). While natural ecosystems may be capable of adapting to some amount of change, the pressure of accelerated sea level rise plus the impact of human activities in the coastal zone may compromise coastal wetland abilities to maintain themselves, making them vulnerable to habitat degradation and loss.

The main objective of this component will be to establish a surface elevation table (SET) network within wetland habitats (e.g. marsh, mangroves, etc.) of the Reserves to support long-term monitoring and research of factors affecting the elevation of coastal wetlands with respect to sea level. SET data will be analyzed to develop surface elevation trajectories which will allow the evaluation of whether the wetland surfaces are keeping

pace with sea level. Coupled with other components of SWMP, this information could be used to investigate processes resulting in elevation change, and community responses to this change.

In an effort to enhance the SET data the NOAA National Geodetic Service (NGS), the Center for Operational Oceanographic Products and Services (CO-OPS)/National Water Level Observing Network (NWLON), the U.S. Geological Survey (USGS), and the NERRS are working together on a plan to establish a geospatial infrastructure at NERR sites to provide high accuracy land elevations and water levels. In addition to SET installation, this plan includes the deployment of tide gauges in identified CO-OPS gaps within the NERRS and tying the SETs to the NGS North American Vertical Datum of 1988 (NAVD88) as well as local tidal datums. All products derived from this effort will not only support the important climate change research within NERRS, but will also provide useful information for the wider range of research and monitoring activities (see Appendix I for the proposed agreement)

VI. SWMP Data Management

To ensure accurate, high-quality SWMP data, the Reserve System established the Centralized Data Management Office (CDMO) in 1995 at the North Inlet-Winyah Bay NERR in South Carolina. CDMO staff develop, implement, and manage the basic infrastructure and data protocol of the NERR SWMP and provide training, technical assistance, and strong quality assurance and quality control measures across the System. Quality assurance/quality control protocols have been established for the collection of all NERRS SWMP parameters and for the Federal Geographical Data Committee (FGDC) compliant metadata associated with the time-series datasets. Standardized protocols developed by the Reserves ensure that sampling, processing, data management techniques, documentation and dissemination techniques are comparable among sites. The CDMO makes SWMP Phase I data available for public use by assimilating it into a system-wide data portal where scientists, resource managers, educators, and other users can access near-real-time and archived data and metadata from each Reserve (http://cdmo.baruch.sc.edu).

The NERRS SWMP is a backbone component of the NOAA IOOS effort (Ocean.US Pub.# 9 2006) and the Reserves are successfully delivering near-real-time, data from at least one water quality and one meteorological station in each Reserve. Appropriate and timely environmental data are often not readily available to researchers, managers, educators, or the general public and such data are critical to many research efforts where data collection must be tied to stochastic events. Likewise, projects that use data for modeling environmental health could assess the status of habitats more rapidly if the data input to models was more readily available. The ability to see cause and effect changes rapidly has stimulated a variety of research questions about how estuarine systems respond to weather events. Educators have access to these data and incorporate them into relevant curricula concerning environmental processes. Despite this utility, a major challenge of delivering near- real-time data is that the data delivered are raw data often without sufficient QA/QC and metadata information. Currently, advanced automated

QA/QC filters are being utilized by the CDMO to filter these near-real-time data quickly for better delivery and dissemination. The CDMO and the Reserves will be able to refine this improved data management system as required, allowing for a projected overall savings in SWMP personnel time. The NERRS data is compliant with the IOOS Data Management and Communications (DMAC) guidance as it currently is defined (Ocean.US Pub. #6 2005).

The CDMO staff also provide technical support services for NERRS staff, and outside individuals, via telephone, email, and individual and group training workshops. CDMO staff developed a NERR SWMP Data Management Manual to outline data acquisition, pre-processing, validation, archival, editing, metadata and submission methods for NERRS staff, and they work with the NERRS Data Management Committee to review case-by-case questions as they arise.

Conservative estimates for the volume of data the CDMO handles each year are:

- 13.5 million data points for the water quality monitoring program (4 stations collecting 8 parameters every half hour at each of 26 reserves),
- 34.4 million data points per year for the meteorological monitoring program (1 station collecting 25 parameters at quarterly, hourly, and daily intervals at each of 26 reserves), and,
- 31,104 data points per year for the nutrient monitoring program (4 stations collecting monthly grab samples and 1 station collecting monthly diel (24-hour sample period) of 6 parameters at each reserve).

Future challenges to the current data management system include the need to: 1) plan for the expansion of the number and type of abiotic monitoring stations; 2) plan for the inclusion of new types of data (i.e. biological and land use); and 3) expand the web interface to better meet the needs of various user groups.

VII. SWMP Information Translation and Dissemination

Collecting and analyzing monitoring data are important activities, but translation and dissemination of monitoring results to coastal decision makers are equally important and a cornerstone of the NERRS. The majority of K-12 and adult educational programming at reserves are led by reserve education and coastal training program (CTP) coordinators respectively. Reserves have growing experience providing scientific information to non-scientist audiences through reserve-sponsored coastal decision maker workshops. Currently, the NERRS SWMP data (both historical datasets and near real-time data) are integrated into specific training workshops as well as integrated into educational curricula (see Appendix J for examples).

Public access to the NERRS SWMP abiotic data (i.e., SWMP phase I water and meteorological data) is through the CDMO and it is anticipated that data resulting from the second (biological monitoring) and third (watershed and land use mapping) phases of SWMP will also be accessible from CDMO. This federally-mandated service is important to numerous user-groups within local, state, and federal government, academic,

and private sectors, particularly since environmental data collection efforts are expensive to implement and maintain. The CDMO staff assimilate individual reserves' SWMP data into a system-wide web portal where data and metadata from each reserve's archive can be accessed and exchanged. Recent additions to the CDMO website include various web visualizations that allow users to easily access near real-time data collected (i.e., water temperature, wind direction, etc). The CDMO has thus far reviewed, archived, documented and made available: nine years of historical water quality data, three years of historical meteorological data, and two years of historical nutrient data. The SWMP data are sent by CDMO to NOAA's National Ocean Data Center for annual archiving and are also available through the National Weather Service's Hydrometeorological Automated Data System (HADS) and the National Data Buoy Center.

Recent findings of the U.S. Commission on Ocean Policy and the Pew Oceans Commission outlined the need to increase general ocean literacy through collaborative formal and informal education (USCOP Final Report 2005, Pew Oceans Commission report, 2003). With a suite of diverse educational programs focused on the coastal environment, the NERRS offers an established framework that can contribute to, and further, the educational goals outlined for the nation. The NERRS education programs provide several benefits to the emerging outreach and education needs of the nation including: a national network of experienced coastal educators, an extended network of partnerships with other education organizations at regional and local levels (environmental organizations, school districts, etc.), access to a broad diversity of established educational programs, access to a broad diversity of established user groups for monitoring data, including K-12 educators and students, recreational enthusiasts, economic interests, tourists, etc. The NERRS education community has recently identified the development of a system-wide K-12 and teacher professional development program focused on field-based estuarine research as a high priority. Such a formal education program could not only increase the usability and relevance of SWMP data from all phases of the program, but could also include other data sources from coastal observatories to enhance the public's understanding of an ecosystem approach to management. SWMP data is currently being incorporated in two separate curriculum development projects for grammar and secondary school students. These projects, Estuaries 101 and the NOAA Ocean Data Education Project (NODE), are being specifically designed to incorporate real data and data products into the learning experience.

In addition to formal education, the NERRS conducts informal education and training experiences including workshops, field trips, lectures, public exhibits and student programs. Additional programs could be developed that would highlight regional coastal observatories, including the role that NERRS research and monitoring play in promoting an understanding of the function and management of our coastal environments.

One of the NERRS' missions is to help resolve societal issues affecting coastal and ocean systems, thus, it is critical that data being generated by SWMP are as useful and accessible as possible. This means that potential data users need to be involved in the planning process to help define information needs, data products, and formats for

delivering the information and products. More often than not, the raw data alone will have little utility to a coastal resource manager, ship captain or fish harvester, and will need to be transformed into useful products. The NERRs have experience in creating productive forums for information exchange between scientists and a range of coastal decision-makers, from commercial and recreational fishers to state agency staff and local planning commission members. Reserves also have experience in many types of audience needs assessments that have been and should continue to be utilized to ascertain the kinds of information, data products and delivery systems preferred by user groups. Through its partnerships with groups like Sea Grant, coastal zone management programs, and colleges and universities, the NERRS Coastal Training Program is ideally suited to deliver information and data products generated by coastal ocean observatories to user audiences.

VIII. NERRS, NOAA, and Other National Monitoring Programs

Estuarine ecosystems are naturally highly variable and complex systems with variations occurring over many spatial and temporal scales, thus distinguishing variability due to natural events from those due to anthropogenic factors is challenging. Long-term coastal monitoring programs are highly valuable for tracking changes in estuarine systems and contributing data to assess cause and effect relationships. A number of long-term monitoring programs exist nationwide and quite a few of these complement the efforts of the NERRS and should be used concurrently to more fully understand short term variability and long-term changes in estuarine ecosystems.

NOAA's National Status and Trends (NS&T) program of the National Centers for Coastal Ocean Science (NCCOS) and the National Water Level Observation Network (NWLON) program of the Center for Operational Oceanographic Products and Services (CO-OPS) both have co-located long-term monitoring sites within and near the NERRS (Appendix K: map of NERRS with overlapping locations of Mussel Watch and NWLON stations). The NS&T program, the nation's longest running coastal contaminant monitoring program, was established in 1984 to determine the status of environmental quality in U.S. coastal and estuarine waters by monitoring contaminants in bivalve tissues, benthic fish and sediments. The three main components of the program are the Mussel Watch program, the Benthic Surveillance and the Bioeffects Assessment Projects. Currently NS&T monitors stations located in or near 23 of the 27 reserves across the nation on an annual or bi-annual basis. The NWLON program is a backbone component of the National Water Level Program with 175 long-term water level stations throughout the nation. NWLON's data continuity, vertical stability and careful referencing of stations produce data that can be used to estimate relative sea-level trends. Currently, 24 of 27 reserves nationwide have local NWLON stations that provide coverage for these areas and there are at least 3 reserves that have NWLON stations established within their reserve (see Appendix K).

Nationwide monitoring programs that have a focus on tracking estuarine conditions include the Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program (EMAP) as a component of EPA's National Coastal Assessment

and the National Science Foundation's Long-term Ecological Research (LTER) and the former Land Margin Ecosystem Research (LMER) programs. The EMAP program examines estuarine conditions in several biogeographic regions by using a combination of indices to evaluate broad-scale questions on ecosystem quality, biotic integrity, and societal value (EPA 2001, 2005). The LTER program seeks to understand ecological phenomena over different temporal and spatial scales and provides a long-term data set at each site. The LMER projects focused on linkages between land and sea ecosystems and the impacts that natural environmental phenomena such as tides and sea level rise have on these systems. These two programs have provided data on ecological conditions at various sites around the country; however, the frequency of measurements on a temporal scale is limited within the EMAP project unlike designated LTER sites.

In the past decade, interest in understanding trends and impacts associated with atmospheric deposition has produced a series of inter-agency national network monitoring efforts. The primary wet deposition monitoring effort is the National Atmospheric Deposition Program (NADP), through its subnetworks of the National Trends Network (NADP/NTN), the Atmospheric Integrated Research Monitoring Network (NADP/AIRMoN), and the Mercury Deposition Network (NADP/MDN). The primary network estimating dry deposition loadings is the EPA's Clean Air Status and Trends Network (CASTNET) program. An additional network, the Integrated Atmospheric Deposition Network (IADN), a program jointly run by Environment Canada and the U.S. EPA, focuses on the deposition of toxic chemicals in the Great Lakes Region. Primary concerns which are being addressed initially are acid, nutrient, and mercury deposition. The NERRS contribute to the NADP program on a site-by-site basis as defined by the priority research questions at the reserve.

Coordination among Monitoring Programs:

The Marine Board of the National Research Council (NRC 1990) identified the need for interagency and intergovernmental coordination for coastal monitoring and suggested a union of national and regional monitoring programs as a basis for coastal monitoring. More recently, the USCOP Final Report called for the formation of a national coordinated monitoring effort that would be linked to the Integrated Ocean Observing System. NOAA has recently been designated the lead IOOS agency and an IOOS program office has been established within the National Ocean Service. The coastal component of IOOS was envisioned as a national network of data acquisition and dissemination sites that will provide comprehensive and timely information about the status, condition, and future of the nation's estuaries and coastal ocean waters (Nowlin, 2001; Ocean.US, 2002ab). The NERRS has been identified as a backbone component of this network (Ocean.US 2006) and, specifically, as a key design element of the IOOS Coastal Observing Subsystem (CORE, 1999; Frosch, 2000). The current IOOS effort is focused on getting all subsystem elements to conform to a common suite of data interoperability standard for five core variables including: 1) sea surface temperature; 2) salinity; 3) sea level; 4) surface currents; and 5) ocean color. Of these five parameters, SWMP is currently monitoring the first two and is consulting with the NOAA IOOS Program Office to ensure continued compliance with IOOS data format and availability

requirements. The NERRS Centralized Data Management Office (CDMO) maintains and serves both the near real-time and archived SWMP data and both its data archive and dissemination protocols are in compliance with Federal Geographic Data Committee (FGDC) and IOOS Data Management and Communications Committee guidelines. The CDMO will be participating in IOOS Program Office interoperability experiments during the summer of 2007. Other interagency efforts to coordinate estuarine and coastal monitoring programs include the National Coastal Monitoring Network (NCMN). The NCMN design is predicated on the formation of a national monitoring network that enables the integration of regional monitoring programs, e.g. Chesapeake Bay, National Estuary Programs, and state coastal programs. That is, the NCMN is a network of networks. The design focuses on regional- and national-scale objectives, not site-specific scale objectives. IOOS regions are the principal regional scale used in the network design. As with IOOS, the NERRS SWMP program also contributes to the NCMN as a source of coastal monitoring data in developing regional pilot projects that integrate multiple data streams.

The integration of coastal datasets from numerous sources must also be matched with a strengthening of ties between coastal monitoring programs and their inland, watershed, monitoring program counterparts to support improved management decisions inland that impact downstream ecosystems. Currently, the National Science Foundation is supporting the establishment of a number of related watershed level programs including the National Ecological Observatory Network (NEON), a continental scale research program consisting of a geographically distributed infrastructure, networked via state-of-the-art communications; the Hydrological Observatory (HO) program is being promoted by the Consortium of Universities for Advancement of Hydrologic Science, Incorporated (CUAHSI), and the Collaborative Large-scale Engineering Analysis Network for Environmental Research (CLEANER) program whose goal is to advance the scientific and engineering knowledge base to address the challenges of large-scale human-dominated complex environmental systems. Initial pilot research programs focused on coastal and upland linkages are under development with NEON and a sub-set of NERRS have been identified as significant contributors of necessary monitoring data.

Challenges for the Establishment and Maintenance of Monitoring Programs:

There are a number of major challenges in establishing and maintaining long-term nationally comprehensive monitoring programs. The need for long-term financial support to define variability and trends, the absence of communication and coordination among the entities conducting monitoring, and the difficulty in designing programs that not only track natural variability but detect change and separate human impacts are just a few examples of these implementation and sustaining obstacles. Additionally, there have been only limited efforts to inform and actively involve the public and elected officials in monitoring goals and decisions. If support for monitoring is to be gained and maintained, then the public must be involved in a meaningful way. The NERRS has developed the infrastructure and public support needed to conduct long-term monitoring projects and establish its national System-wide Monitoring Program (SWMP). It is anticipated that the close ties of the reserve system with local and regional coastal zone management

agencies will facilitate integration of results based on SWMP data into decision-making and planning efforts by coastal zone managers.

IX. The Future of the NERRS System-Wide Monitoring Program

The key to a successful monitoring program is consistency in sampling methods while incorporating flexibility to accommodate changes in objectives over time. The NERR SWMP should have a process built into the program in which periodic reviews of data and objectives are done to evaluate the existing program. The success of the monitoring program, however, will ultimately depend on the necessary funding to adequately implement the SWMP. This funding must include not only needed instrumentation and funds for sample processing but skilled technicians to conduct field sampling and to operate and maintain equipment.

The NERR SWMP provides a unique opportunity to increase our understanding of how various environmental factors influence estuarine processes. Only by understanding how estuaries function and change naturally over time, we will be able to predict how these systems respond to changes in climate and human-induced perturbations. However, monitoring alone, no matter how comprehensive the program, is not sufficient. Research is critical to the interpretation of monitoring results and for testing hypotheses generated by monitoring. Research is needed for the evolution of an effective monitoring program in which variables and the scale at which they are measured are identified. Whereas monitoring determines whether and how much the environment has changed from its reference state, research provides an understanding of ecological complexities and helps establish causal relationships. The NERR monitoring program, coupled with ongoing NERR supported research programs that examine ecosystem function, habitat change, transport and fate of contaminants, and their biological effects provides a mechanism for gathering information essential to better environmental protection and sound management decisions.

Clearly there is a need to have protected sites in order to conduct sustained long-term observations. Currently, the NERRS provides a framework for making systematic and continuous observations of ecosystem variables. The advantages to a NERR-based monitoring program are that it:

- Provides an ecosystem-based network for understanding the temporal and spatial variability of ecosystem components and their interactions.
- Provides a long-term database for the estuarine reserves' protected area network.
- Establishes a baseline for measuring changes in environmental conditions and ecological processes.
- Provides a research framework for evaluating ecosystem conditions and interpreting and predicting responses to change.
- Provides the basis for an ecosystem-based approach to managing coastal resources.

Although limited, the NERR sites have a baseline funding framework and institutional support linked with coastal zone management. They have demonstrated an ability to develop a national framework for integration and coordination of environmental monitoring and related research. They have established programs for education of the public, students and resource managers regarding monitoring results. The operational status of the first phase of SWMP (abiotic monitoring) and successful initiation of the second (biological monitoring) and third (watershed and land use mapping) phases of SWMP, coupled with a sophisticated data management and dissemination element, reflects the commitment of the NERRS and NOAA to supporting ongoing ecosystem monitoring for the purposes of improving the state of the knowledge regarding coastal environments and supporting improved coastal management decisions. The NERRS is now looking forward to expanding its research and monitoring capabilities and the application of this information through directed partnerships with a variety of local, regional, and national science and management programs (see appendix L for examples).

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Program Elements and Their Estimated Costs

	Parameter	**Periodicity**	**Implementation**	**Estimated System Cost/yr.****
I. Water Quality (in addition to existing program)				**$2.75 million** **$30,000-$60,000**
Existing Program *Personnel*	-Suite of water quality variables -Suite of Weather variables	30 min. 1 hr.	-min. 4 YSI meters and probes per reserve -1 Weather station per Reserve -1 full time RC and 1 full time Technician	1.00 million $250,000
Build out *Personnel* *Data analysis*	-Suite of water quality variables -Suite of Weather variables	30 min 1 hr.	-8 YSI 6600 per site -1 additional weather station -1 full time Technician -Analysis and synthesis	1.35 million $250,000 1 million $150,000
Contaminants	-Normal suite of contaminants -Additional suite (dioxins and furans)	Every 5 years (5 reserves /yr) Every 5 years (selected sites only)	At minimum of 2 and maximum of 4 depositional sites within each Reserve	$ ~30,000 (2 sta. x 5 NERR) $ ~60,000 (4 sta. x 5 NERR) $ 6,000

II. Eutrophication				**$ 750,000** **$ 360,000**
Nutrients (starting in 2001)	Total inorganic, and organic suspended solids; chlorophyll a; dissolved organic carbon; total N, total P, dissolved organic N, dissolved organic P, orthophosphate, nitrate/nitrite, ammonia, and silica.	Once a month at 4 sites and over a tidal cycle once a month at one site.	-Sampling at 4 locations in each Reserve	$500,000
Chlorophyll (starting in 2001)	estimates of chlorophyll concentration	Once a month at 4 sites and a over a tidal cycle once a month	-Sampling at 4 locations in each Reserve	$250,000
Photopigment Analysis	quantification of chlorophylls and carotenoids, for photopigment-based characterization of microalgae	Monthly	-Sampling at 4 locations in each Reserve	$360,000

III. Land Use and Habitat Change				**$1.47-3.68 million** **$100,000**
Subwatershed	% Land Cover Categorized by Activity	Every 5 Years Starting 2000	USGS DOQQ's 16 Quads per Reserve	$120,000 for imagery
		Annual	850 mile^2 of watershed, IKONOS (4 m color) Satellite Imagery	$1.68 million for imagery
Personnel			Landscape Ecologist/GIS Technician	$1.25 million
Benthic habitat mapping	Habitat type, sediment type, infauna, epifauna, voids, the depth of the redox potential discontinuit, successional stage, and any physical features on the sediment surface.	Winter & summer every 2-3 years	At water quality monitoring sites	$ 100,000
		One time only (summer/fall)	Entire bottom of each Reserve	$750,000 (5 sites per year)
SET Tables	Elevation	Every six months	At two sites within each Reserve	$100,000
IV. Biological Monitoring				?
V. Real time data delivery and management	Broadband data delivery system that allows a variety of programmable data management options, including many levels of filtering		All reserves	$428,000

Total				**$5.3-7.18 million**
				$490,000-520,000

* H--high priority item to be accomplished as soon as funds are available
**M--medium priority that is important to the monitoring program but may require further evaluation or will be implemented later based on 27 sites