National Estuarine Research Reserve System 10th Anniversary Report on the System-wide Monitoring Program (SWMP) Data Applications: 1995 – 2005

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I. Introduction

The National Estuarine Research Reserve System (NERRS) has compiled a subset of examples from across the 26 reserve sites that demonstrate the application of water and weather monitoring data to local, regional, and national coastal management needs. In accordance with regulatory guidance, the reserve system delivers relevant and timely scientific information to support informed decision making and increase public understanding of the importance of protecting estuarine and coastal habitats for future generations. The stories selected here highlight reserve science, education, and outreach capabilities with the intention of encouraging scientists, educators, resource managers, and the public to interact closely with these sites to facilitate additional collaborative efforts that promote estuarine and coastal conservation.

II. Background

Estuaries are among the most productive aquatic systems. Human civilizations have historically depended on the protected habitat that estuaries provide for larval commercial fish species and shellfish populations, the important flood control and water filtration functions, and the recreational opportunities that healthy estuarine resources provide. However, impacts on estuarine habitats such as impaired water quality and loss of fragile underwater vegetation from anthropogenic or natural disturbances have only recently been recognized. Increased awareness of the ramifications of these disturbances led to the passage of the Coastal Zone Management Act (CZMA) in 1972, which resulted in the establishment of the National Estuarine Research Reserve System (NERRS). The NERRS is a network of 26 estuarine reserves covering over one million acres of protected estuarine waters, adjoining wetlands, and uplands in coastal regions across the continental United States, Alaska, and Puerto Rico. The NERRS contain every recognized climatic zone in the United States, as well as more than 15 biogeographic regions. For more information, please visit: http://www.nerrs.noaa.gov.

A key to conserving coastal waters and restoring estuarine habitats from impacts such as those listed above is information on how human activities and natural events can change estuarine ecosystems. The broad geographic range of ecosystems and estuarine habitat types represented across the NERRS 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 NERRS 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 a System-wide Monitoring Program (SWMP; pronounced "swamp"), a phased monitoring program that focuses on three different ecosystem characteristics (NOAA 2002):

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

Figure 1. Abiotic Parameters Monitored

Water parameters:

pH
Conductivity (mS/cm)
Salinity (ppt)
Temperature (°C)
Dissolved Oxygen (%)
Turbidity (NTU)
Nitrate (mg/L)
Ammonia (mg/L)
Ortho-Phosphate (mg/L)
Chlorophyll a (µg/L)

Weather parameters:

Temperature (°C)
Wind speed and direction (m/s; °)
Relative humidity (%)
Barometric pressure (mb)
Rainfall (mm)
Photosynthetic Active Radiation (mM/m^2, total flux)

SWMP Timeline: 1995 – 2005

1995 – SWMP Initiation

- Participating reserves establish 2 long-term water quality stations using Yellow Springs Instruments (YSI™) model UPS 6000 dataloggers
- Centralized Data Management Office (CDMO) established

1996 – Equipment Buildout

- Purchase of additional dataloggers and telemetry equipment
- Data collection and management protocol developed

1997 – SWMP Maintenance

- Revisions to Quality Assurance/Quality Control protocol

1998 – SWMP Data on the Web

- CDMO publishes SWMP data on the web at http://cdmo.baruch.sc.edu

1999 – Data Synthesis and Oversight

1996-1998 synthesis report funded

- SWMP Oversight Committee formed
- Draft NERRS SWMP Plan written
- Chlorophyll-a and water level sensors were evaluated for SWMP use

2000 – Equipment Upgrade and Second Synthesis

- Upgrade from YSI UPS 6000 to the YSI UPS 6600 or 6600 EDS dataloggers

1995-2000 synthesis report funded

2001 – SWMP Enhancement

- Increased spatial coverage to 4 long-term datalogger stations per reserve
- Initiation of nutrient and chlorophyll-a monitoring efforts

2002 – Initiation of Weather Monitoring

- Participating reserves establish one Campbell CR10X weather station

2004 – Biological Monitoring and Regional Data Synthesis

- Initiation of biological monitoring program
- Regional data synthesis proposals funded by CICEET

2005 – NERRS SWMP begins process of becoming IOOS backbone element

The initial phase of SWMP focuses on monitoring a suite of abiotic parameters **(Figure 1)** 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, the 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 use remote sensing imagery and ground truthing. See **Appendix A** for more information about equipment and data-gathering specifications for phase one. See **Appendix B** for more information on SWMP biomonitoring efforts (phase two) and **Appendix C** for more information on the SWMP land use and habitat change (phase three) initiative.

This year, the NERRS is celebrating SWMP's tenth anniversary. The long-term nature of the SWMP data set makes it possible to establish baseline conditions, and examine both intra-annual (seasonal) and inter-annual patterns in estuarine systems, as well as the effects of large scale (i.e., El Niño and La Niña climatic conditions, sea level rise, hurricanes, Nor'easters) and localized episodic events (i.e., floods, drought, contaminant spills). With a NOAA investment of $3.4 million in fiscal year 2005, SWMP is providing valuable short- and long-term data to researchers, natural resource program managers, coastal educators, and other coastal decision-makers. Just a few of the many applications for data collected by the SWMP include the following examples. SWMP data are used:

- To design and measure the impacts of coastal restoration projects;
- To provide continuous water quality data for biannual assessments required under the US Clean Water Act of 1972 and for other state and federal regulatory processes;
- To measure initial impacts and estuarine recovery periods from tropical storms or other natural disturbances;
- To analyze water quality conditions related to fish kills, shellfish diseases, and other coastal resource management activities; and
- To develop coastal education curricula for K-12 students, public audiences, and training workshops for coastal decision makers across the country.

The program has increased scientific understanding of how estuaries function and change naturally and in response to human impacts. SWMP has given educators, students, and coastal managers access to a wealth of up-to-date estuarine water quality and weather data for use in coastal science curricula, coastal planning, resource management programs, and regulatory activities. Through this effort, coastal regions of the United States and Territories will continue to improve understanding, prediction, and response to the ways that estuarine ecosystems change with changes in climate and human-induced perturbations.

III. Data Management

The Role of the NERRS Centralized Data Management Office

Program Contacts: Tammy Small and Dwayne Porter, NERRS Centralized Data Management Office

To ensure accurate, high quality SWMP data, the Reserve System established a Centralized Data Management Office (CDMO) in 1995, which is housed 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 programs, technical assistance, and strong quality assurance and quality control measures across the system. The CDMO makes SWMP data available for public use by assimilating individual reserves' SWMP data into a system-wide web portal where scientists, resource managers, educators, and other users can access archived data and metadata from each reserve. For more information, see **Appendix D** or visit: http://cdmo.baruch.sc.edu.

IV. Data Applications

The following accounts of applications for SWMP data across the NERRS illustrate the value of SWMP data in coastal water quality analysis, estuarine restoration, coastal storm analysis, state and federal regulatory activities, and education programs for K-12 students, the public, and coastal decision makers. Many of the accounts illustrate the cross-sector nature of the SWMP program. For example, many NERR or university-based research programs use SWMP data to understand estuarine processes, and make their findings available to local or regional

coastal resource managers, habitat restoration programs, or science educators. These accounts show the breadth of user groups for SWMP data across the nation and describe the positive outcomes SWMP data applications have achieved.

1. Water Quality Analysis

The NERRS SWMP is unique in its uniform national protocol and the wide range of water quality parameters monitored. The costly and time-consuming nature of water quality monitoring and data management has limited most large-scale, continuous monitoring efforts to urban areas, or areas with known or suspected water quality impairment. In contrast, the NERRS SWMP has established a set of baseline data for relatively unimpacted estuarine areas in addition to areas with known impairment. The examples below show how the NERRS SWMP data have been used to detect changes in baseline water quality conditions over time and space, in order to detect contaminant spills, localized impacts, seasonal patterns, and multi-year trends.

Elkhorn Slough NERR, CA – Seasonal Reversals in Nitrate Sources

Program Contacts: John Haskins and Kerstin Wasson, Elkhorn Slough NERR

Elkhorn Slough, the largest estuary in central California, is surrounded by productive farmlands. Detecting potential agricultural pollution and its ecological impacts is a central focus of research at the Elkhorn Slough NERR. The frequency of SWMP sampling over tidal cycles at Elkhorn Slough has helped scientists understand the complex sources and fates of nutrients in the Elkhorn Slough estuarine ecosystem. In summer months, nitrate concentrations at the Reserve's South Marsh nutrient sampling station are generally quite low, with the lowest levels occurring at low tide. In winter, heavy rains lead to agricultural runoff with nitrate concentrations that are an order of magnitude higher than those in summer runoff, and highest nitrate concentrations occur at low tide. This seasonal difference in peak nitrate concentrations over a tidal cycle indicates that upwelling of cold, nutrient-rich water from the ocean depths could be responsible for making Elkhorn Slough a sink, not a source, of nitrates in summer months; while in winter, this study indicates that local sources of polluted runoff and groundwater may contribute nitrate to South Marsh, rather than ocean waters. This seasonal reversal in nitrate sources has important implications for managing agricultural runoff in the Elkhorn Slough watershed. Elkhorn Slough NERR staff and their regional partners are working to make this information available to local watershed managers and coastal decision makers.

Elkhorn Slough NERR researcher working with a SWMP datalogger in the field.

ACE Basin NERR, SC – Using Weather Data to Analyze the Impacts of Monkeys on Estuarine Water Quality

Program Contact: Elizabeth Wenner, ACE Basin NERR

A parcel of land called Morgan Island was acquired by the ACE Basin NERR in 2002. The upland area of the island is home to the only free-ranging colony of rehesus macaque monkeys in the United States. The US Food and Drug Administration (USFDA) owns the 3,200 monkeys and has a longstanding contract to maintain the population for biomedical research and testing. In addition to the monkeys' value to the USFDA, they present possible legal, financial, and environmental liabilities, including the potential to transmit disease to humans, escape to mainland habitats, and unknown environmental impacts to Morgan Island and the surrounding estuarine area. ACE Basin NERR researchers are involved in an ongoing study to determine the environmental impacts of the monkey colony. To determine the impacts of the monkeys' fecal matter in stormwater runoff to adjacent island creeks, SWMP weather and water quality data were used to identify rain fall events and examine coincidence with fecal coliform concentrations. The study found that the rhesus colony has a localized impact on the adjacent Morgan Creek.

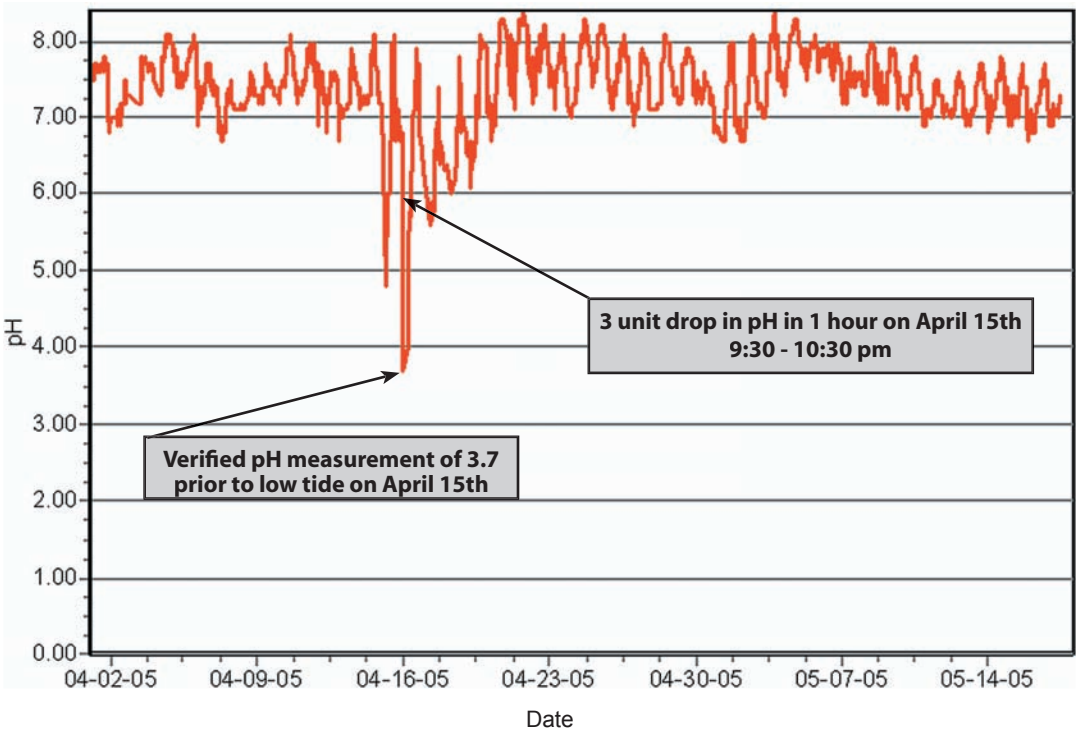
Grand Bay NERR, MS – SWMP Data Used to Track Impacts of a Phosphate Spill

Program Contacts: Christine Walters and Mark Woodrey, Grand Bay NERR

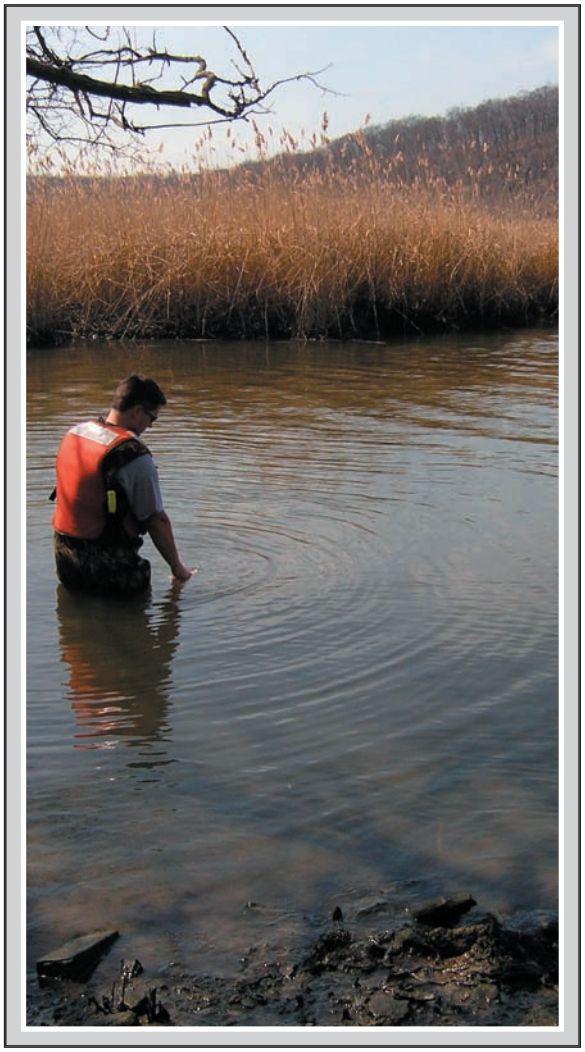
The western border of the Grand Bay NERR in southeastern Mississippi is lined with heavy industry. Grand Bay NERR staff rely on SWMP data to monitor baseline water quality conditions and identify abnormalities in the data resulting from contaminant spills or other water quality incidents. One such incident occurred on April 14, 2005, when levees surrounding containment ponds at a nearby phosphate fertilizer manufacturing company gave way after two weeks of record breaking rain. A large volume of discharge water from the ponds entered an adjacent tidal lake within the Reserve boundaries, resulting in an abrupt drop in pH levels. At the SWMP datalogger in the center of the lake, the water reached a low of 3.7 pH units. Eleven days later, phosphorus levels in the lake were ~5000 times greater than prior to the spill, and chlorophyll-a (a measure of primary productivity) was nonexistent in the lake water. Continual SWMP monitoring at Grand Bay NERR, has begun to capture the long term effects of this spill, and in conjunction with other research and monitoring efforts, document the full recovery of this vital eco-system. Following this incident, NERR staff used SWMP data to brief the Mississippi Commission of Marine Resources on the spill, and they are working with Mississippi Department of Environmental Quality staff to recommend retributions and restoration measures for the spill site.

Large areas of marsh vegetation at Grand Bay NERR died as a result of the April 14, 2005 phosphate spill.

SWMP Measurements Showing Impact of April 14, 2005 Phosphate Spill on pH Levels in Bangs Lake



Hudson River NERR, NY – Using SWMP Data to Track Chloride Concentration Trends in Hudson River Tributaries

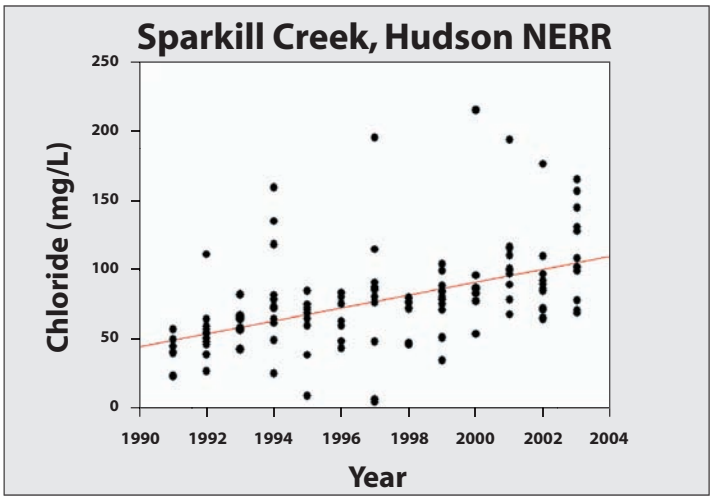


Hudson River NERR researcher monitoring chloride concentrations in Sparkill Creek.

Program Contacts: Chuck Nieder and Emilie Hauser, Hudson River NERR

Reference: Hauser, Emilie (Ed.) (2004) Rising Salt Concentrations in Tributaries of the Hudson River Estuary Proceedings. Altamont, NY. Hudson River Environmental Society.

The Hudson River NERR began monitoring chloride levels to track changes in salinity in tributaries running through the four component sites of the Reserve in 1991. Chloride monitoring has remained a central focus of the Reserve's SWMP program since SWMP was established in 1995. The study has revealed striking upward trends in chloride concentrations in all monitored tributaries in the Reserve over the past 14 years, with concentrations increasing by more than 100 percent (from 40 mg/L to 110 mg/L) in the Reserve's most urban sampling location. Data analysis indicates three anthropogenic sources of chlorides to these tributaries: road deicers, on-site wastewater treatment systems (septic systems), and municipal wastewater treatment. To discuss the trends these SWMP data illustrate, Hudson River NERR co-hosted a workshop for interested members of the public; municipal, state, and federal resource managers; and state officials to learn about sources of chlorides, best management practices for use of chloride-containing products, and acute and long term biological effects of chloride pollution. By helping to increase public and resource managers' awareness of chloride pollution, the Hudson River NERR is providing communities in the Hudson River Valley with information necessary to begin the process of reversing these trends.



2. Estuarine Restoration

Many estuarine areas have been severely degraded through natural events such as storms or through human impacts such as dredging and filling, coastal development, nonpoint source pollution, and exotic species invasions. As a result, habitat restoration activities are central to the NERRS mission. The following accounts demonstrate the value of using SWMP data to understand local site conditions and set water quality performance targets and restoration design parameters for three NERRS restoration projects.

Rookery Bay NERR, FL – Setting Water Quality Performance Targets for Estuarine Restoration Projects

Program Contact: Michael A. Shirley, Rookery Bay NERR

The timing and quantity of fresh water flowing into the Rookery Bay National Estuarine Research Reserve (RBNERR) in southwest Florida has been altered by channelization of natural watershed sheetflow and increases in freshwater storage for aquifer recharge and irrigation. As part of the ongoing Everglades Restoration Initiative, the Picayune Strand Restoration and Henderson Creek Restoration Projects are opportunities to redistribute watershed sheetflow and restore the natural timing and quantity of fresh water flowing into the Reserve's estuaries. For five years (December 2001- present), SWMP dataloggers have been used to record water quality at continuous thirty-minute intervals within five estuaries managed by the Reserve. These five estuaries differ in their seasonal and annual salinity patterns as influenced by varying degrees of anthropogenically altered freshwater inflow. Recent publications document differences in estuarine species composition correlated to altered freshwater inflow. These data sets have been used to set hydrologic and ecological targets to assess watershed restoration activities.

South Slough NERR, OR – Use of NERR SWMP Datasets for Restoration Planning and Increased Understanding of Nutrient Dynamics within the South Slough Estuary, Oregon

Program Contacts: Steve Rumrill and Sue Powell, South Slough NERR

References: Powell, S.L. and S.S. Rumrill. 2001. South Slough National Estuarine Research Reserve: Monitoring Short-term Variability and Change in the Estuary's Water Quality. Earth System Monitor. 11(3); p 5-11.

Cornu, C.E. and S. Sardo. 2002. Physical and Functional Responses to Experimental Marsh Surface Elevation Manipulation in Coos Bay's South Slough. Restoration Ecology (10)3; p 474-486.

SWMP data sets have been applied to two distinct coastal resource problems within the South Slough NERR in Oregon. First, SWMP data were used to evaluate plans for a 1995-1997 experimental salt marsh restoration project called the Winchester Tidelands Restoration Project (WTRP). The WTRP was designed to remove earthen dikes and restore tidal inundation to a former salt marsh that was drained to create pasture land at the turn of the 20th Century. Scientists were concerned that restoring tidal inundation to an area that had been colonized by terrestrial plants would cause these salt intolerant species to die and decay, using up available dissolved oxygen and impairing water quality in adjacent estuarine waters. In response, South Slough NERR staff analyzed SWMP data records from the Winchester Creek datalogger, which showed that dissolved oxygen levels measured downstream from the WTRP were not substantially different from an unmanaged control site. A second ongoing application of South Slough SWMP data addresses the extent to which nutrient concentrations within the estuary are driven by oceanic upwelling and tidal forcing versus freshwater runoff and watershed inputs. This project is designed to help coastal resource managers improve their understanding of natural variability within the estuarine tidal channels, and to assist them with the early identification of anthropogenic changes in critical indicators (i.e., nitrogen loading and eutrophication) in a representative Pacific Northwest drowned-river mouth estuary.

Wells NERR, ME – SWMP Data Provides the Basis for Successful Restoration Design

Program Contacts: Ray Konisky and Michelle Dionne, Wells NERR

New box culvert and self-regulating tide gate at Drakes Island Marsh, near the Wells NERR.

References: Burdick, D.M., M. Dionne, R.M. Boumans, and F.T. Short. 1997. Ecological Responses to Tidal Restorations of Two Northern New England Salt Marshes. Special Issue: Hydrologic Restoration of Coastal Wetlands. Wetlands Ecology and Management. 4(2): 129-144.

Boumans, R.M.J., D.M. Burdick, and M. Dionne. 2002. Modeling Habitat Change in Salt Marshes After Tidal Restoration. Restoration Ecology. 10(3): 543-555.

Restrictions to salt marsh tidal exchange threaten the health and function of salt marsh ecosystems in the United States (Boumans et al. 2002). Restrictions such as roads, dikes, and causeways with undersized culverts that do not allow salt water to flow into historically inundated areas often cause freshwater flooding after storms and persistent dominance of brackish marsh plant species. To address these problems, staff from the Wells NERR in southern Maine spearheaded a local community effort to expand an undersized culvert restricting tidal saltwater exchange in Drakes Island Marsh, a 77-acre coastal marsh located near the Wells NERR. Wells SWMP data provided detailed hydrologic records, including nearly ten years of water level monitoring data, which allowed NERR staff to determine long-term average conditions for tidal flooding and extreme conditions associated with storm surges, heavy rainfall, and drought. These data were used to calibrate a hydraulic model of marsh flooding, which was used to determine the appropriate type and size for a replacement culvert. With funding assistance from the NOAA Fisheries Community Restoration Program, NERR staff installed a 5'x 4' box culvert with a self-regulating tidegate in May 2005. Already, the marsh is experiencing better drainage of rainwater and greater influx of seawater on the high tides.

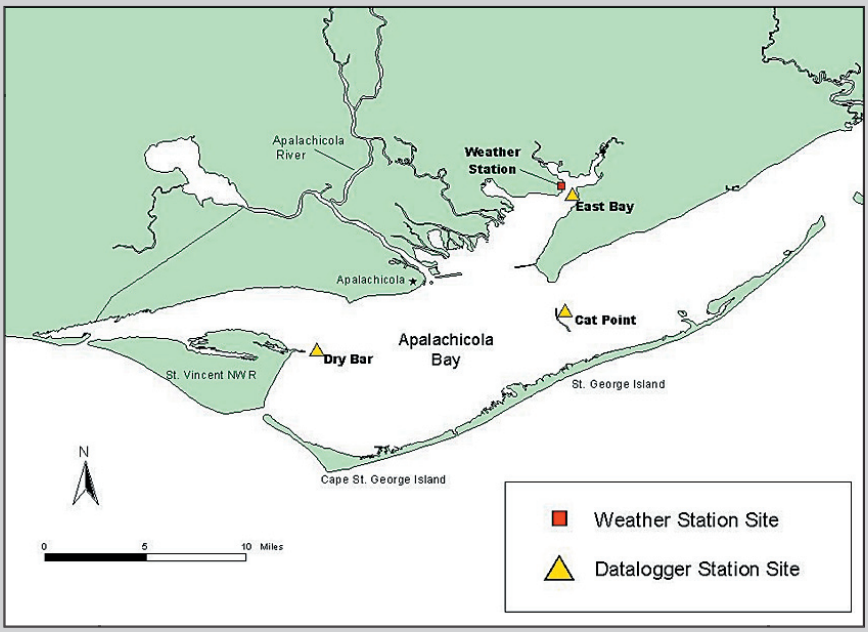
3. Storm Analysis

During the past decade, the NERR SWMP has become an important source of data used by NERR researchers and other scientists to track tropical storm impacts in estuarine systems in the Eastern, Southeastern, and Gulf of Mexico regions of the United States. The examples below describe analyses of the impacts of 1994 Tropical Storms Alberto and Beryl on the Apalachicola Bay NERR, in Florida, and 2003 Tropical Cyclone Isabel on the Chesapeake Bay NERR in Virginia. The Weeks Bay and Grand Bay NERRs in Alabama and Mississippi, respectively, will begin analyzing SWMP data collected during 2005 Hurricanes Katrina and Rita during the coming months.

Apalachicola NERR, FL – Using SWMP Data to Determine the Effects of Storm Events on Oyster Reefs in the Apalachicola Bay

Program Contact: Lee Edmiston, Apalachicola NERR

Ninety percent of Florida's commercially harvested oysters and 10% of the nation's oysters are produced in Apalachicola Bay, making the industry a cornerstone of the local economy. To better understand how freshwater inflows to the Bay affect salinity patterns and the health of the Bay's oyster populations (oysters do not open to feed at low salinity),



Location of datalogger deployment sites and weather station site in the Apalachicola NERR.

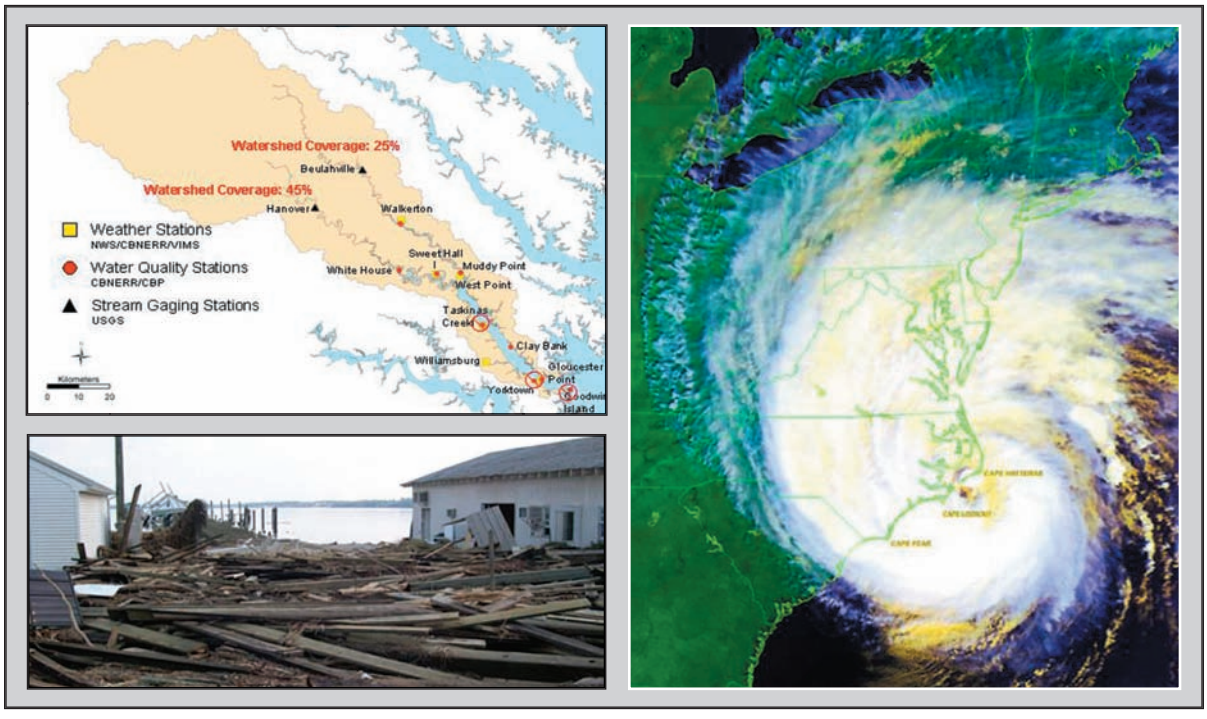
Apalachicola NERR researchers used SWMP data to analyze salinity patterns in the Bay following July and August 1994 Tropical Storms Alberto and Beryl. The combined impact of freshwater runoff from these two storm events killed 80-90% of harvestable oysters at the Dry Bar harvesting location, but did not significantly affect oysters at Cat Point. The data indicate that this site-specific die-off was caused by the east-to-west movement of currents in the Bay, which carry freshwater runoff into the western half of the Bay, drawing saltier water from the Gulf of Mexico into the eastern half of the Bay. In addition, the western portion of the Bay normally receives a higher volume of freshwater runoff from the 20,000 square mile Apalachicola River Basin, while the eastern portion of the Bay receives smaller quantities of stormwater runoff from a 500 square mile subwatershed to the east of the Apalachicola Basin. As a result of this study, Florida commercial oyster reef managers recognize that it is possible to safely limit shellfish closures to specific parts of Apalachicola Bay, depending on the size and location of storm events, rather than simply closing the whole Bay to shellfishing after large storm events.

Chesapeake Bay NERR, VA – Impacts of Tropical Cyclone Isabel on Shallow Water Quality of the York River Estuary

Program Contacts: William Reay and Ken Moore, Chesapeake Bay VA NERR

Reference: Reay, W. and K. Moore. 2005. Impacts of Tropical Cyclone Isabel on Shallow Water Quality of the York River Estuary. Hurricane Isabel in Perspective. Conference Proceedings. November 2004. Linthicum Heights, MD. (In press).

This study utilized SWMP data to investigate the impact of Tropical Cyclone Isabel on shallow water quality in the York River Estuary, which includes the York River proper and two of its tidal tributaries, the Mattaponi and the Pamunkey Rivers. Regional rainfall resulting from the passing of Isabel was 5.8-11.7 cm and peak mean daily streamflow increased by 20-30 times over pre-storm conditions. The resulting storm surge was 1.7 m near the mouth of the estuary and 2.0 m in the upper tidal freshwater regions. Maximum wave heights were up to 2.0 meters. NERR researchers found that the storm surge resulted in a relatively short-term pulse of high salinity water, ~10 parts per thousand (ppt) above pre-storm conditions,



Clockwise from top left: Map of the York River watershed showing the locations of Chesapeake Bay VA NERR SWMP stations and US Geological Survey stream gaging stations; NOAA satellite image of Tropical Cyclone Isabel; Damage to the Chesapeake Bay VA NERR pier and offices at the Virginia Institute of Marine Sciences, Gloucester Point, VA.

in the central oligohaline portion of the estuary. In comparison, salinity levels within the upper tidal freshwater and down river poly- and mesohaline regions remained relatively unchanged. Following the storm surge, freshwater runoff resulted in depressed salinities of 1.5 to 4.5 ppt in the lower portions of the estuary. Elevated turbidity, in some cases extreme, was in direct response to the storm surge and waves associated with Isabel. With the exception of a single station, maximum storm-associated turbidity levels varied between 192 and >1000 NTUs. Turbidity levels returned to pre-storm conditions within a 24-30 hour period at most stations. Perhaps the most significant environmental impact associated with the passage of Isabel was the persistent low dissolved oxygen levels, 3-4 mg L^{-1}, which occurred at the tidal freshwater stations. Low dissolved oxygen at these stations coincided with increased freshwater inflow to the Mattaponi and Pamunkey Rivers suggesting augmented loadings of readily degradable organic material from the watershed. It took approximately two weeks for mean daily dissolved oxygen levels to return to pre-storm levels at these sites. Dissolved oxygen levels at the poly and mesohaline stations within York River proper remained at or above 5 mg L^{-1} prior to, during, and after the storm's passage.

4. State and Federal Regulatory Activities

SWMP water quality and weather data are used in many local, state, and federal monitoring and regulatory programs across the United States. The examples below describe two applications of SWMP data that have helped states meet requirements under sections 305(b) and 303(d) of the federal Clean Water Act. SWMP data have also been included as a vital component of the United States' plans for a national Integrated Ocean Observing System (IOOS), which is discussed in the "New Developments" section of this report.

Great Bay NERR, NH – Using SWMP Data to Complete Biannual Water Quality Assessments under Section 305b of the Clean Water Act

Program Contact: Brian Smith, Great Bay NERR

The New Hampshire Department of Environmental Services (NHDES) uses the Great Bay NERR SWMP data extensively for water quality assessment. Every two years, states are required to report the status of their waters to Congress under section 305(b) of the Clean Water Act of 1972. There are two dissolved oxygen standards used by NHDES in which SWMP data are critical. To meet NHDES standards, dissolved oxygen in a water body must not fall below 5 mg L^{-1} at any time and must have a daily mean percent saturation of at least 75%. A water body failing to meet these standards is listed as impaired in the NHDES database and becomes eligible for funding for additional studies. The Great Bay NERR SWMP data set is unique in that it provides continuous standardized data from set locations. The continuous nature of SWMP data allows NHDES to evaluate a water body based on data collected every thirty minutes, every day, and under changing weather conditions and seasons. The NERR SWMP is currently the only source of information of its kind available to an agency like NHDES for use in the 305(b) process.

Delaware NERR – Using SWMP Data to Inform the Delaware TMDL Allocation Process

Program Contact: Bob Scarborough, Delaware NERR

Nearly all of Delaware's 2,509 miles of rivers and State waters are listed as "impaired" under Section 303(d) of the Clean Water Act. Under this listing, approximately ninety-four percent of these waters do not fully support swimming water quality standards, and sixty-five percent do not fully support water quality standards for fish and wildlife activities (State of Delaware 2002). States are required by the Clean Water Act to develop Total Maximum Daily Loads (TMDLs) for each impaired water body. TMDLs set limits for the amount of any given pollutant that can be discharged into a water body without exceeding water quality standards. TMDLs are determined by computer models that are calibrated and verified with existing water quality data. Sources of water quality data in Delaware and many other states are limited in terms of temporal and geographic coverage and the parameters that are measured. The Delaware NERR SWMP program has helped state water quality managers by providing large quantities of high quality data for the areas adjacent to Delaware NERR's SWMP dataloggers. This data helps managers calibrate models that extrapolate across the gaps in other data sets.

5. K-12 Education, Public Education, and Training Programs

Applications of SWMP data in education programs throughout the NERRS have increased markedly during the past five years, and have become a central effort within the NERRS education community. Many reserve's interpretive areas contain displays that translate SWMP data into charts and graphs for public education. In addition, SWMP K-12 education programs provide tools and training to help teachers bring inquiry-based research concepts into increasingly standards-driven science curricula. Professional training programs help coastal managers learn how to use baseline monitoring data and trend analysis to inform resource management decisions. The examples below describe how the NERRS K-12 programs are using SWMP data to support educational estuarine restoration programs, develop internet-based resources to help students and teachers use monitoring data in classrooms, and help students prepare for state and national science competitions.

Weeks Bay NERR, AL – Using SWMP Data to Set Parameters for a Local High School Submerged Aquatic Vegetation (SAV) Restoration Project

Program Contacts: Margaret Sedlecky and Scott Phipps, Weeks Bay NERR

Weeks Bay is a shallow estuarine embayment off of Mobile Bay near Fairhope, Alabama. Because much of Weeks Bay is shallow enough for sunlight to reach the Bay floor, submerged aquatic vegetation (SAV) has historically been an important habitat type in the Reserve. Over the past several years, SAV growth in the reserve has declined significantly due in part to nonpoint source pollutants (i.e. sediments and excess nutrients) and exotic species invasions. In response to the SAV loss, Weeks Bay NERR staff developed a collaborative education and stewardship partnership with a local high school in 2004. A science teacher from the school has grown tape grass *(Vallisneria americana)* with her students for the past two years in order to plant it in a part of the Reserve that has experienced a dramatic decline in SAV. To help the teacher match temperature and salinity in her classroom SAV tanks to the natural conditions of the area, Weeks Bay NERR staff provided water salinity and temperature data from the

Weeks Bay NERR staff and Gulf Shores High School students and teachers planting tape grass (*Vallisneria americana*).

SWMP datalogger located adjacent to the project location. Using SWMP data to set these parameters ensured greater tape grass survival and growth when planted at the site, and provided a valuable opportunity for this teacher to educate her students about the specificity of different estuarine species' environmental habitat conditions.

Hudson River NERR, NY – "Swamping the Classroom" a Pilot Program Designed to Help Educators use SWMP Monitoring Data in Science Curricula

Program Contact: Jean Valla McAvoy, Hudson River NERR

In the spring of 2005, the Hudson River NERR developed a pilot program called "Swamping the Classroom," which is a web-based educational program designed to use SWMP data to teach students about the Hudson River Estuary and its watershed. The pilot project is intended to link middle-school science classes in the mid-Hudson Valley with 12 years of water quality monitoring data from five tributaries of the Hudson River spanning the middle hundred miles of the 153 mile-long Hudson River Estuary. "Swamp-

ing the Classroom" includes learning modules, preselected data sets, watershed maps, aerial photos and links to related websites and videos. When it is ready to be launched for a wider audience on the Internet, it will be housed on Blackboard, a web-based education platform, and accessed through Ulster County BOCES (Board of Cooperative Educational Services), a county-level network in New York State. If the pilot proves successful, "Swamping the Classroom" will consider expanding its scope in the following dimensions: wider geographical and curricular audiences, links to related Hudson River educational programs, and expanded links to the NERRS' website (www.nerrs.noaa.gov).

Waquoit Bay NERR, MA – Using SWMP Data to Support Internet-Based Coastal Education Programs

Program Contact: Pat Harcourt, Waquoit Bay NERR

The Waquoit Bay NERR on Cape Cod, MA has developed a series of lesson plans that introduce students to the SWMP data sets. The lessons use SWMP data to integrate math skills with science concepts and help students find answers to their own scientific questions by teaching them how to create graphs from the data and interpret the patterns and trends they reveal. Students can look for temporal patterns in temperature, salinity, dissolved oxygen, or turbidity. These exercises give students an opportunity to work with real data from many coastal areas of the United States. The lessons are intended to enable teachers from a wide range of ecological and marine science disciplines to teach students about the applications of coastal monitoring data and the lessons to be learned from short-term variability and long-term trend analysis. Waquoit Bay NERR staff developed step-by-step instructions to help students and teachers download the SWMP data and translate it into Mircosoft Excel files. These instructions can be found on the web at: http://www.waquoitbayreserve.org/pdf/access_data.pdf.

Delaware NERR, DE – Using SWMP Data to Teach High School Students how to Identify Connections between Physical Parameters, Water Chemistry, and Biotic Communities

Program Contact: Katy O'Connell, Delaware NERR

Each year, Delaware NERR staff help local high school students prepare for a state-wide ENVIROTHON competition by using SWMP data from several different locations to give them practice identifying physical and chemical water parameters, and the types of biota that are found in different natural systems. The Delaware NERR staff also help students identify episodic events or trends in the SWMP data that may suggest human influences or perturbations of natural conditions. For example, the students learn that low dissolved oxygen levels or high nutrient levels can be indicative of waters that receive large amounts of urban or agricultural stormwater runoff that contains fertilizers, animal waste, or effluent from combined sewage overflows.

High school students prepare for their state-wide ENVIROTHON by using SWMP data to learn about relationships between abiotic parameters and biotic communities at the Delaware NERR.

V. Data Synthesis

Since SWMP data collection began in 1995, NERRS staff have made large-scale efforts to synthesize the CDMO SWMP data archives and analyze trends across the system every two to four years. The first SWMP data synthesis report (A Synthesis of Water Quality Data from the National Estuarine Research Reserve's System-wide Monitoring Program) is a summary of SWMP water quality data collected by 22 of the 25 National Estuarine Research Reserves between 1996 and 1998 (Wenner et al. 2001). This first report was produced under

the direction of the ACE Basin, SC NERR, in collaboration with South Carolina Marine Resources Division and the University of South Carolina, and released in 2001. The second synthesis (A Synthesis of Water Quality Data: National Estuarine Research Reserve System-Wide Monitoring Program 1995-2000) was also completed by staff at the ACE Basin NERR in SC, and was released in 2002 (Sanger et al. 2002). Both synthesis efforts were funded by the Cooperative Center for Coastal and Estuarine Environmental Technology (CICEET), an environmental technology research center that is supported through a partnership between NOAA and the University of New Hampshire. Datalogger deployments increased from a total of 44 to 55 across the System between the first and second synthesis reports, a number that has continued to rise in the last five years as the reserves increased their monitoring capabilities. Currently, there are over 130 dataloggers deployed across the reserve system. To read a summary of the first and second synthesis report findings, see **Appendix E**. To access the reports visit: http://www.nerrs.noaa.gov/Monitoring/Synthesis.html.

In the three years since the 1995-2000 synthesis report was released, the SWMP data synthesis effort has developed into a regional approach. In 2005, CICEET funded four synthesis projects that will integrate SWMP data and relevant ancillary research and monitoring data sets in an effort to address important coastal management issues at the reserve level as well as at the scale of the entire bioregion. These projects also include strategies for making SWMP data available to a wider public audience. The bioregions included in these research efforts are the Pacific, Mid-Atlantic, South Atlantic, and New England. Specific coastal management issues addressed through these newest synthesis efforts include:

1. Assessing the status of estuarine eutrophication and nutrient management measures;
2. Investigating the effects of human activities on estuarine water quality conditions and living resources (e.g. submerged aquatic vegetation);
3. Increasing understanding of the impacts of short-term climatic events (i.e. tropical storms and hurricanes), and large-scale events (i.e. El Nino, North Atlantic Oscillation) on estuarine water quality parameters; and
4. Assessing how watershed inputs and oceanic forcing drive changes in estuarine nutrient concentrations.

An additional SWMP synthesis effort took place in 2004, when NERRS staff prepared papers for a special issue of the Coastal Education and Research Foundation's *Journal of Coastal Research*. The peer-reviewed issue, Special Issue No. 45, was titled 'NERRS Research and Monitoring: A Nationally Integrated Program, and it included papers on SWMP-related research and other NERRS research efforts (Kennish and Finkl 2004). The 15 studies were conducted at the NERRS by individuals from academic institutions, state and federal government agencies, and independent research institutions. The issue represents an additional venue through which the NERRS makes its research and SWMP findings accessible for a broad range of users.

SWMP data synthesis reports and published data provide baseline information for future assessments and valuable information about how estuaries function in different tidal regimes, climate conditions, and geographic locations across the System. These efforts also assist coastal managers in developing appropriate strategies to better manage coastal resources (i.e. non-point source pollution programs), and will help develop predictive capabilities (i.e. forecasting and warnings) for estuarine and coastal environments.

In addition, the process of reviewing SWMP data trends every several years creates opportunities to share information and lessons learned across all reserves and evaluate the progress of system-wide research initiatives. This broad review of water quality data from the NERRS SWMP allows for systematic evaluation of anthropogenic influences on estuarine systems, and provides necessary background data from which specific, experimental hypotheses are formulated. NERRS staff then incorporate these hypotheses into the NERRS research and stewardship program planning processes.

VI. New Developments and Future Outlook

During the past decade, the first phase of the NERRS SWMP (abiotic estuarine water quality and atmospheric monitoring) has matured and continually

expanded its data utility among highly diverse user groups. In addition, NERRS staff laid the technical groundwork necessary for the phase one SWMP data collection network to be integrated into the backbone of the United States' Integrated Ocean Observing System (IOOS), with a near-real-time telemetry system for timely dissemination. Concurrently, NERRS staff significantly expanded the scope of the SWMP by developing and starting to implement the second and third phases of the program. Phase two and phase three of the SWMP include implementation of standard protocols for biomonitoring (phase two), and monitoring of land use and habitat change (phase three). Several Reserves have also begun to participate in pilot programs linking SWMP data with other national data sets, such as the NOAA National Water Level Observation Network (NWLON).

1. Integrated Ocean Observing System (IOOS)

The IOOS initiative is developing an integrated national observation system for the United States' coastal zone built upon federal monitoring efforts and regional coastal and ocean observing systems that monitor the state and characteristics of the United States' coasts, oceans, Great Lakes, and estuaries. The system will be a coordinated network of observation platforms and data management, analysis, and modeling systems that acquire and disseminate data on past, present, and future states of the United States' ocean and coastal areas (Ocean. US 2002a, 2002b).

The NERRS SWMP has been identified as a national backbone component for IOOS due to the Reserve System's broad coverage of estuarine and coastal habitats. The NERRS data is a particularly valuable component of the IOOS network as it is one of few contributing members that will deliver important estuarine data (NOAA 2004). The estuarine water and weather data generated by the NERRS can be used to provide information to support a number of IOOS goals including: sustaining living marine and estuarine resources, protecting and restoring healthy coastal marine and estuarine ecosystems, improving modeling and predictions about the consequences of coastal climate change, and mitigating the effects of coastal storms and other natural hazards. Users will include coastal resource managers, scientists, educators, mariners, and emergency responders. For more information, see **Appendix F**.

2. Data Telemetry

A portion of the NERRS IOOS funding is currently financing development of a telemetry system that will stream SWMP data in a common format that is compatible with IOOS. The data will be transmitted to the NERRS Central Data Management Office in South Carolina using NOAA's system of Geostationary Operational Environmental Satellites (GOES) for near-real-time access via the Internet. This approach will provide uniformity across the system and 24-hour, 7 days per week support for all NERRS data served in support of IOOS activities. For more information, see **Appendix G**.

3. Biological Monitoring – SWMP Phase Two

In 2004, the 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. SWMP 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, including emergent and submerged vegetation, invasive species, benthic communities, and nekton/plankton communities. 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. Currently, 16 NERRs are piloting protocols for monitoring submerged aquatic vegetation (SAV) and emergent vegetation. For more information, see **Appendix B**.

4. Land Use and Habitat Change – SWMP Phase Three

The SWMP land use and habitat change initiative (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 utilize remote sensing imagery and ground truthing. In a first step toward system-wide phase-three monitoring, NERRS staff are working to define a common classification system to assist the Reserves in consistent, and thus nationally comparable, habitat and watershed mapping and inventorying efforts. Currently, five NERRs are piloting the newly designed "NERRS Classification Scheme" to assess its applicability to Reserve System. For more information, see **Appendix C**.

5. Linking SWMP with Other National Data Sets

Example Program Contacts: Michelle Dionne and Ray Konisky, Wells NERR, and Kristen Tronvig, NOAA Center for Operational Products and Services

One example of a partnership linking SWMP with other national data sets is a recent collaboration between the Wells NERR in Wells, Maine, and NOAA's Center for Operational Oceanographic Products and Services (CO-OPS). This partnership was developed to demonstrate the benefits of collaborating to produce improved data products for coastal managers and other user groups. In August, 2005, CO-OPS installed a new tide station within the Wells Reserve. The station is a component of NOAA's National Water Level Observation Network (NWLON), and produces detailed tide, water level, and weather information within the Reserve. This NWLON station was co-located with one of the Wells NERR SWMP stations, resulting in better data characterization of the site, and more detailed information for supporting coastal management decisions, research programs, restoration projects, and education programming. The data from these instruments are sent via telemetry over the NOAA GOES satellite, providing additional support for the growing national Integrated Ocean Observing System (IOOS). This is the first station of its kind established in the NERRS, and further collaborations between CO-OPS and the NERRS are anticipated.

VII. Conclusion

The National Estuarine Research Reserve System is proud to be a source of high quality estuarine water quality, meteorological, and soon habitat and biological monitoring data for a diverse set of applications in research, coastal resource management and regulation, and education. This report marks a decade of NERRS efforts to make these data available to a wide range of users, with continually expanding numbers of sampling parameters and geographic locations, and continually advancing technological sophistication.

The NERRS strives through its SWMP, research, education, and stewardship programs and numerous local, state, and federal partnerships to translate its research and monitoring data into timely and relevant information for its many user groups. As the program accounts above demonstrate, the NERRS' multifaceted, collaborative programs have worked with scientists, coastal managers, regulatory agencies, teachers, students and members of the public, to turn a decade of estuarine monitoring data into management and policy decisions and educational programs that protect and enhance coastal ecosystems.

The NERRS looks forward to celebrating many more SWMP anniversaries in the future, as it continues to support coastal research and management, regulatory processes, restoration efforts, and education programs that protect public health, enhance the economic value of coastal resources, and improve the ecological health of estuarine ecosystems across the United States.

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Key Websites

- National Estuarine Research Reserve System (NERRS): **http://www.nerrs.noaa.gov**
- NERRS Centralized Data Management Office (CDMO): **http://cdmo.baruch.sc.edu**
- The Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET): **http://ciceet.unh.edu/**
- Integrated Ocean Observing System (IOOS): **http://www.ocean.us/**

IX. Appendices

Appendix A – Equipment and Data-gathering Specifications

Water Quality Stations:

At program initiation, each site installed two Yellow Springs Instrument Co. (YSI™) model 6000 water quality dataloggers to begin monitoring abiotic factors (Phase I) (Ross 2003). This equipment was subsequently upgraded to YSI Model 6600's and 6600 EDS's (Extended Deployment System). Both initial water quality stations continuously monitored (every thirty minutes) conductivity, salinity, temperature, pH, dissolved oxygen, turbidity, and water level. Each reserve placed one datalogger at a control site and placed the other at a site that is impacted by human activity that exemplifies a concern of the reserve (e.g., nonpoint source pollution). In 2001, SWMP data-gathering protocol increased minimum spatial coverage to four long-term datalogger stations per reserve. The additional dataloggers were placed along known or suspected gradients in abiotic parameters (e.g. salinity, dissolved oxygen, or turbidity) to measure natural or human impacts of particular importance to the reserve.

Weather Stations:

Starting in 2002, participating sites installed one Campbell CR10X weather station. The weather stations collect data every 15 minutes, monitoring temperature, wind speed and direction, relative humidity, barometric pressure, rainfall, and Photosynthetic Active Radiation (PAR).

Appendix B – Biological Monitoring

The biological monitoring phase (phase two) of SWMP began in 2004. The central objective of phase two is to characterize biotic diversity in NERRS estuarine ecosystems by assessing community composition and species abundance and distributions. SWMP phase two builds on phase one monitoring capabili-

ties by developing inquiry-based research projects that explore patterns of inter-annual variability and spatial distribution of estuarine communities, including emergent and submerged vegetation, invasive species, benthic communities, and nekton/plankton communities. The NERRS research community developed and tested a series of rigorous protocols to establish a national strategy for implementing this biomonitoring initiative, while retaining local flexibility as appropriate for individual reserves (Moore and Bulthius 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 research efforts will be repeated over time within each reserve, and comparisons among reserves will be made as appropriate to the biological communities monitored.

Currently, the NERRS is working to implement a national biomonitoring program focused on emergent and submerged aquatic vegetation (SAV) communities. The program uses two methodologies, known as Tier 1 and Tier 2, which are detailed protocols developed by the NERRS research community. Tier 1 efforts monitor the overall spatial distribution of either emergent vegetation and SAV communities within the boundaries of the Reserves at annual and multi-annual time scales. Tier 2 efforts monitor the vegetative characteristics of selected stands of these communities within Reserve boundaries. Tier 1 monitoring uses a combination of surveys, remote sensing (i.e. aerial photography and satellite imagery), ground truthing with global positioning system (GPS), georectification and mapping with geographic information systems (GIS), and GPS mapping. Tier 2 monitoring consists of fixed ground transects with permanent sampling stations located within either of these two vegetation communities. Reference sites are located in non-impacted areas, and sites where greater impact has occurred (i.e. land development, exotic species invasion) are monitored for comparison.

At present, 16 NERRs have participated in these biomonitoring efforts, and it is anticipated that the remaining 10 sites will be funded to start biomonitoring work in 2006. 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. Future biomonitoring efforts within the NERRS will likely focus on invasive species, benthos, plankton and nekton communities in these sites.

Appendix C – Land Use and Habitat Change

The SWMP land use and habitat change initiative (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 use remote sensing imagery and ground truthing.

In a first step toward system-wide phase-three monitoring, NERRS staff are working to define a common classification system to assist the Reserves in consistent, and thus nationally comparable, habitat and watershed mapping and inventorying efforts (Kutcher et al. 2005). The use of a common classification system will enable the NERRS to assess habitat change at local, regional, and national scales and identify the status of coastal habitats (i.e. degrading, improving, or maintaining). In addition, system-wide use of this classification system will provide a baseline of information that can impact restoration or "best-use" practices and recommendations to conserve and protect these important habitats. In an effort to encompass the variety of habitats that exist within the NERRS boundaries and associated watersheds, the proposed NERR habitat classification system incorporates aspects of other national systems (i.e. Corwardin, Anderson, and Coastal Change Analysis Program (C-CAP) systems).

Currently, five NERRs are piloting the newly designed "NERRS Classification Scheme" to assess its applicability to Reserves. These Reserves will report back to the NERRS after working with the classification system and further steps will be taken to refine the classification and integrate this effort with additional remote sensing efforts.

Appendix D – The Role of the NERRS Centralized Data Management Office

Program Contacts: Tammy Small and Dwayne Porter, NERRS Centralized Data Management Office

To ensure accurate, high quality SWMP data, the Reserve System established a Centralized Data Management Office (CDMO) in 1995. The CDMO is housed 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 strong quality assurance and quality control measures across the system. The CDMO supports data training programs to make sure reserve staff are familiar with standard operating procedures and uniform water quality and weather data collection methodology.

The CDMO is responsible for making the NERRS SWMP data available for public use. 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. 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.

CDMO staff 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)
- 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)

Appendix E – Summary of First and Second Synthesis Report Findings

SWMP data analyses between 1995 and 2000 showed that water depth, salinity, and dissolved oxygen patterns were dominated by tidal cycles at sites that experienced moderate daily tidal heights (6-13 ft.) (Wenner et al. 2001). Water depth at most sites was shallow (< 6.5 ft); thus, these sites were often nearly dry at low tide. At several freshwater sites and a few high salinity (marine) sites, tidal cycles were minimal. At these sites, day-night cycles, local weather conditions and freshwater discharges (usually manmade disturbances) were primarily responsible for short-term variation in salinity.

A condition called hypoxia occurs when dissolved oxygen concentrations fall below 2 ppm, a level generally accepted as the minimum oxygen level required to sustain aquatic life. Many estuarine plants and animals have adapted to withstand the occasional stress hypoxia causes; however, chronic hypoxia can cause negative environmental impacts. Severe hypoxic events are frequently associated with large-scale mortality of aquatic organisms, such as "fish kills." Between 1996 and 1998, 765 hypoxic events were observed during the first 48 hours of all instrument deployments, with at least one event observed at almost all NERR sites. Most hypoxic events lasted less than eight hours. Hypoxia was most frequently observed at West Coast reserves (40%), followed by reserves in the Gulf of Mexico and Caribbean (22%). East Coast and Great Lakes reserves (Southeast, Mid-Atlantic, Great Lakes, and Northeast) had fewer hypoxic events overall (10-16%) and represented the least frequent occurrence of hypoxia geographically. Hypoxia was observed at relatively pristine reserve sites as well as at sites disturbed by manmade influences, and occurred

most frequently during the summer. These findings collectively suggest that hypoxia in the NERRS is largely determined by latitude and climate, while site-specific conditions such as land use, pollution, or other local events can also influence the frequency and duration of hypoxic events. For example, the Tijuana River NERR in Southern California has experienced chronic hypoxia associated with river pollution and extremely dense coastal development.

Conversely, excessively high levels of dissolved oxygen (i.e., supersaturation) may also be detrimental to aquatic organisms. In areas where plants and algae produce high amounts of dissolved oxygen during the day, dissolved oxygen levels can be three to five times higher than normal in shallow estuarine waters. In the NERRS, supersaturation was most prevalent in the cooler months, particularly in spring, and may have been related to increased algal production. However, the geographic and seasonal occurrence of supersaturation events was not as clear as with hypoxia.

Examination of the dissolved oxygen data collected by SWMP indicates that only a few reserves have chronic problems with hypoxia (low oxygen) or supersaturation (high oxygen). Considerable year-to-year variability exists in the frequency and severity of dissolved oxygen levels. Large annual changes in hypoxia and supersaturation appear to be related to site-specific circulation patterns, land use, climate, pollution levels, and environmental conditions.

The second synthesis (1995-2000) also produced information regarding the impacts of storms on estuarine water quality conditions (Sanger et al. 2002). Prior to storm passage through NERR sites, abrupt decreases in water temperature were consistently observed. These water cooling trends were strongly related to increasing storm activity. These observations correspond with oceanic research that relates sea surface temperature cooling with maximum hurricane winds, whereby upwelling and wind mixing occurs such that the cool waters below the thermocline are brought to the surface and replace the warmer surface waters in the wake of a storm (Sakaida et al. 1998, Shay et al. 1998). Additional short term, abrupt, changes in salinity and depth were also reported during the passage of storm systems through the NERRS. The demonstration of this type of oceanic response to storm passage in estuarine and coastal environments is minimal and thus the synthesis of the long-term SWMP data again provided more information than was previously available and improved understanding of storm impacts on estuarine water conditions.

Both syntheses can be found at the following internet address: http://www.nerrs.noaa.gov/Monitoring/Synthesis.html.

Appendix F – Integrated Ocean Observing System

The IOOS initiative is developing an integrated national observation system for the United States' coastal zone built upon federal monitoring efforts and regional coastal and ocean observing systems that monitor the state and characteristics of the United States' coasts, oceans, Great Lakes, and estuaries (Ocean.US 2002a, 2002b). The system will be a coordinated network of observation platforms and data management, analysis, and modeling systems that acquire and disseminate data on past, present, and future states of the United States' ocean and coastal areas. Users will include coastal resource managers, scientists, educators, mariners, and emergency responders.

The NERRS SWMP has been identified as a national backbone component for IOOS due to the Reserve System's broad coverage of estuarine and coastal habitats. The NERRS data is a particularly valuable component of the IOOS network as it is one of few contributing members that will deliver important estuarine data (NOAA 2004). The estuarine water and weather data generated by the NERRS can be used to provide information to support a number of IOOS goals including: sustaining living marine and estuarine resources, protecting and restoring healthy coastal marine and estuarine ecosystems, improving modeling and predictions about the consequences of coastal climate change, and mitigating the effects of coastal storms and other natural hazards. The NERRS received grants from NOAA's Coastal Services Center (CSC), National Ocean Service (NOS), and Office of Education to invest in the new technology and implementation costs necessary to coordinate its SWMP with the larger IOOS initiative.

Key objectives of the NERRS IOOS data management plan for regional and national observing system initiatives include:

- Coordination and integration of quality assurance/quality control and metadata protocols necessary for sharing data among regional partners
- Additional web portals for broader dissemination of data and information products
- Regional archives for data and information products
- Increased communication with core and cooperating programs involved with IOOS in an effort to coordinate intra- and inter-regional data management efforts

While the impetus for the IOOS originated within the scientific community, one of the goals of the program is to improve public understanding of estuarine and coastal habitats. With a suite of diverse educational programs focused on the coastal environment, the NERRS offers an established framework that will contribute to and further the educational goals of the IOOS. For example, the NERRS Coastal Training Program (CTP) and education programs are ideally suited to deliver information and data products generated by ocean observing systems to user audiences. Through its partnerships with groups like Sea Grant, coastal zone management programs, and colleges and universities, the CTP can offer IOOS Regional Associations, such as the Southeast Coastal Ocean Observing Regional Association (SECOORA), assistance with providing information to user groups in meaningful formats. Thus, the NERRS network of research sites and observing systems, when integrated with complementary programs for coastal training, education, stewardship, and coastal zone management, will be capable of providing timely scientific information to a diverse group of users among academic scientists, agency investigators, resource managers, educators, and members of the public.

Appendix G – Data Telemetry

A portion of the NERRS IOOS funding is currently financing development of a telemetry system that will stream SWMP data in a common format that is compatible with IOOS. The data will be transmitted to the NERRS Central Data Management Office in South Carolina using NOAA's system of Geostationary Operational Environmental Satellites (GOES) for near-real-time access via the Internet.

In April 2005, the NERRS telemetry committee, consisting of NERRS staff and external federal agency staff from the United States Geological Survey (USGS) and NOAA, reviewed a range of technical strategies for the NERRS SWMP data telemetry. The strategy chosen ensures that all reserves will use a common data format, data control platform (DCP), and the GOES primary transmission mechanism for streaming data to the CDMO via the Internet. This approach will provide uniformity across the system and 24-hour, 7 days per week support for all NERRS data served in support of IOOS activities. This approach also allows the reserves to continue using their existing telemetry infrastructure systems to transmit SWMP data to the CDMO as back-up systems, in case data is lost through an interruption in the primary GOES telemetry system.