GREAT BAY NATIONAL ESTUARINE RESEARCH RESERVE

Developing Infrastructure and Data to Assess Some of the Earliest Ecological Effects of Relative Sea Level Change.

Vertical Control Plan & Progress Report 2011

31 August 2011

by Rachel Stevens, Stewardship Coordinator, Great Bay NERR

with comments from Kathy Mills and Paul Stacey, Research Coordinators, Great Bay NERR

and Curt Crow, State Geodetic Advisor
Galen Scott, National Geodetic Survey
Allison Allen, Center for Operational Oceanographic Products and Services

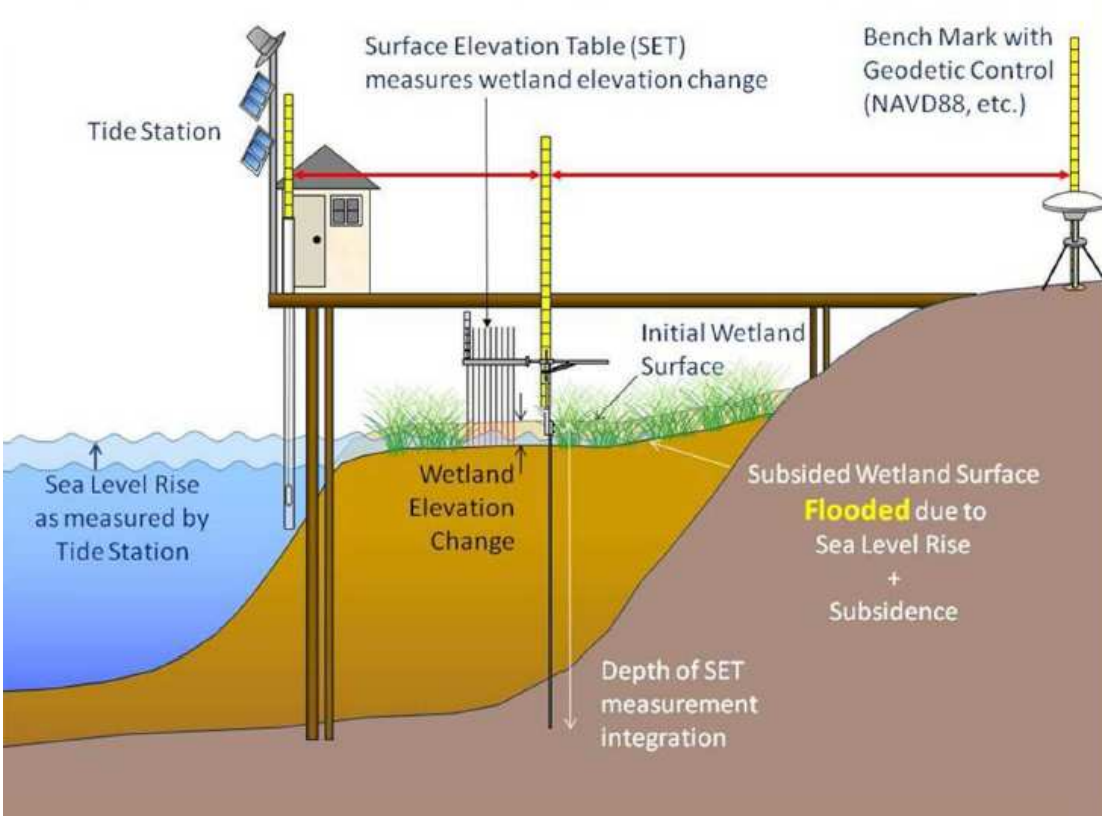
of the National Oceanic and Atmospheric Administration

Introduction

Highly accurate measurement of sea-level is crucial to assessing and modeling impacts of coastal climate change. It is also key to planning for consequences to our ecological and socioeconomic environment in these areas. Measurement of the relative relationship between changing sea and land levels requires a local network of "vertical control" infrastructure. The core elements of a local control network include;

1. Measurements of sea level change via tide stations
2. Measurements of land height referenced to bench marks with geodetic control
3. Measurement of wetland elevation change, using surface elevation tables

Together, these components form the foundation of a local sentinel site observation and monitoring system.



NOAA graphic

Figure 1. Core elements schematic of vertical control infrastructure necessary to measure sea level relative to land and wetland elevation change relationships.

This plan summarizes the current status, and future needs, of vertical control infrastructure within Great Bay National Estuarine Research Reserve (GBNERR). Vertical control adds the z spatial dimension to the x and y axis habitat characterization currently in progress at the Reserve as part of the NERRS Habitat Mapping and Change initiative (NERRS, 2007). Integrating land height and tidal data with habitat information is key to the Reserve's ability to function as a sentinel site for climate change research in accordance with NOAA's Sentinel Sites Program described in Appendix B.

1. Sea Level Change

a. Tide Stations

Historically, four tide stations have been located within the Reserve boundary (Figure 2a). However, each was established only for the short term in 1975 and has been taken offline as shown in Table 1. Tidal bench marks at each of the four historic tide stations within the Reserve boundary have been recovered and tied to the National Spatial Reference System (NSRS) by state geodetic crews and Reserve staff.

Table 1. Historic tidal bench marks and their location in Great Bay, NH.

Location	Station ID	Latitude	Longitude	Established	Removed
Bellamy River Bridge	8421737	43° 7.8' N	70° 50.8' W	Jun 24 1975	Oct 17 1975
Adams Point	8422272	43° 5.6' N	70° 51.8' W	Jun 25 1975	Sep 3 1975
Hilton Park	8421897	43° 7.3' N	70° 50' W	Jun 23 1975	Oct 3 1975
Squamscott River Bridge	8422927	43° 0' N	70° 56.4' W	Jul 1 1975	Aug 11 1975

Currently the closest active tide station is located at Fort Point, with the next closest located within Wells NERR (Figure 2b). The station at Fort Point was established in 1976, with the present installation operating since 2003. It measures primary water level only. The station at Wells NERR was established in 1999. It measures primary and backup water level, barometric pressure, conductivity and wind, air and water temperature.

Figure 2a. Location of historic tide stations in the Great Bay region. (CO-OPS map)

Figure 2b. Location of current tide stations in New Hampshire and southern Maine. (CO-OPS map)

b. National Water Level Observation Network (NWLON)

Current NWLON stations closest to Great Bay are in Portland and Boston. These have both measured a rise in sea level over an approximately 100 year period (Figures 3 and 4).

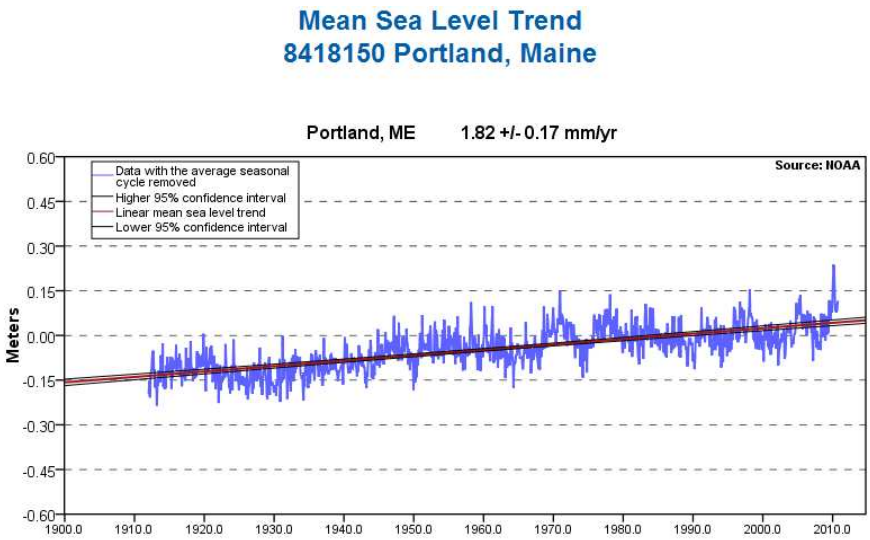


Figure 3. Mean sea level trend is 1.82 millimeters/year with a 95% confidence interval of +/- 0.17 mm/yr based on monthly mean sea level data from 1912 to 2006 which is equivalent to a change of 0.60 feet in 100 years.

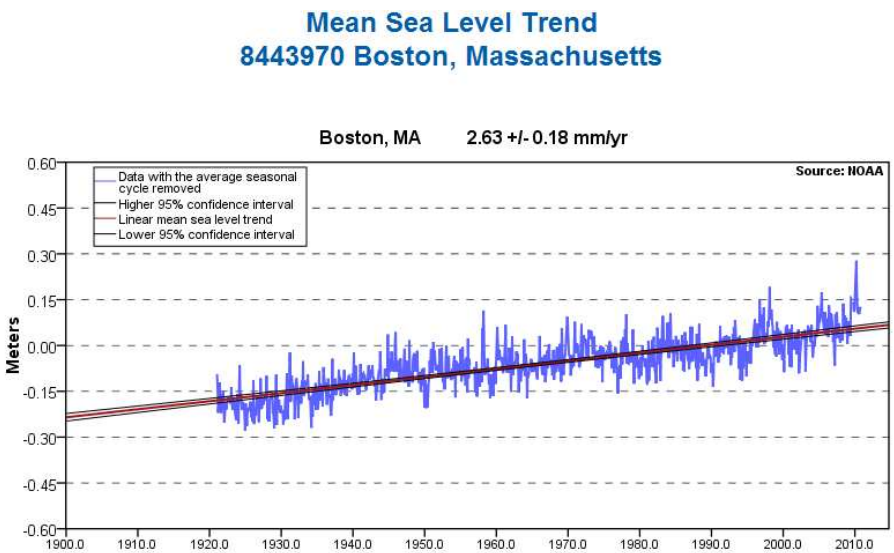


Figure 4. Mean sea level trend is 2.63 millimeters/year with a 95% confidence interval of +/- 0.18 mm/yr based on monthly mean sea level data from 1921 to 2006 which is equivalent to a change of 0.86 feet in 100 years.

Great Bay NERR is a NWLON gap. In order to establish local tidal datums, or measure any relative change in sea level, an operational tide station must be connected as part of the vertical control network. Establishment of a tide station would not only fill an existing NWLON gap but also address the data goals of other agencies such as the National Ocean Service. Developing a cross-referencing protocol to data collected at Fort Point would allow the primary water level time series to be extended back to 1976. Currently stable infrastructure exists centrally within the Reserve boundary to establish a long term tide station, but no funding is available.

A geodetic connection has been made from Fort Point to geodetic control within the Reserve boundary. If a more permanent solution for local measurement of tide heights is not available, short-term deployment of temporary tide stations may allow local tide data to be related to the tidal datum at Fort Point. However, the Great Bay estuary is recessed up to 15 miles in land and is extremely tidally restricted along the Piscataqua River. The geography of this estuary may mean a direct relationship between local tide heights and those at Fort Point does not exist, emphasizing the importance of establishing local data collection. The configuration of Great Bay, and the consequent effect that wind patterns have on tidal elevations, further complicate the ability to measure trends in tidal elevations accurately. Methodologies for accurate tidal elevation measurement are being investigated by the Joint Hydrographic Center at the Center for Coastal

and Ocean Mapping (CCOM-JHC) at the University of New Hampshire. The CCOM-JHC has also been remapping bathymetry for Great Bay.

c. Water Quality Monitoring Stations

Four System Wide Monitoring Program (SWMP) water quality monitoring sondes are currently deployed within Great Bay NERR during the ice-free months. They are located in central Great Bay and the Squamscott, Lamprey, and Oyster Rivers (Figure 5). These stations were originally installed in 1995, 1997, 1998, and 2002 respectively, for the purpose of collecting water quality data only and, therefore, did not consider vertical control needs. One station is deployed on a buoy that raises and lowers with the tide and one is on an anchor. The current housing on all stations is not constructed to remain fixed in the vertical plane. Alteration of the established method of deployment would interrupt an 8 -14 year time series of water quality data. For this reason, it is proposed that alternative options are explored such as establishing a network of water level data loggers in the vicinity of current SWMP sondes.

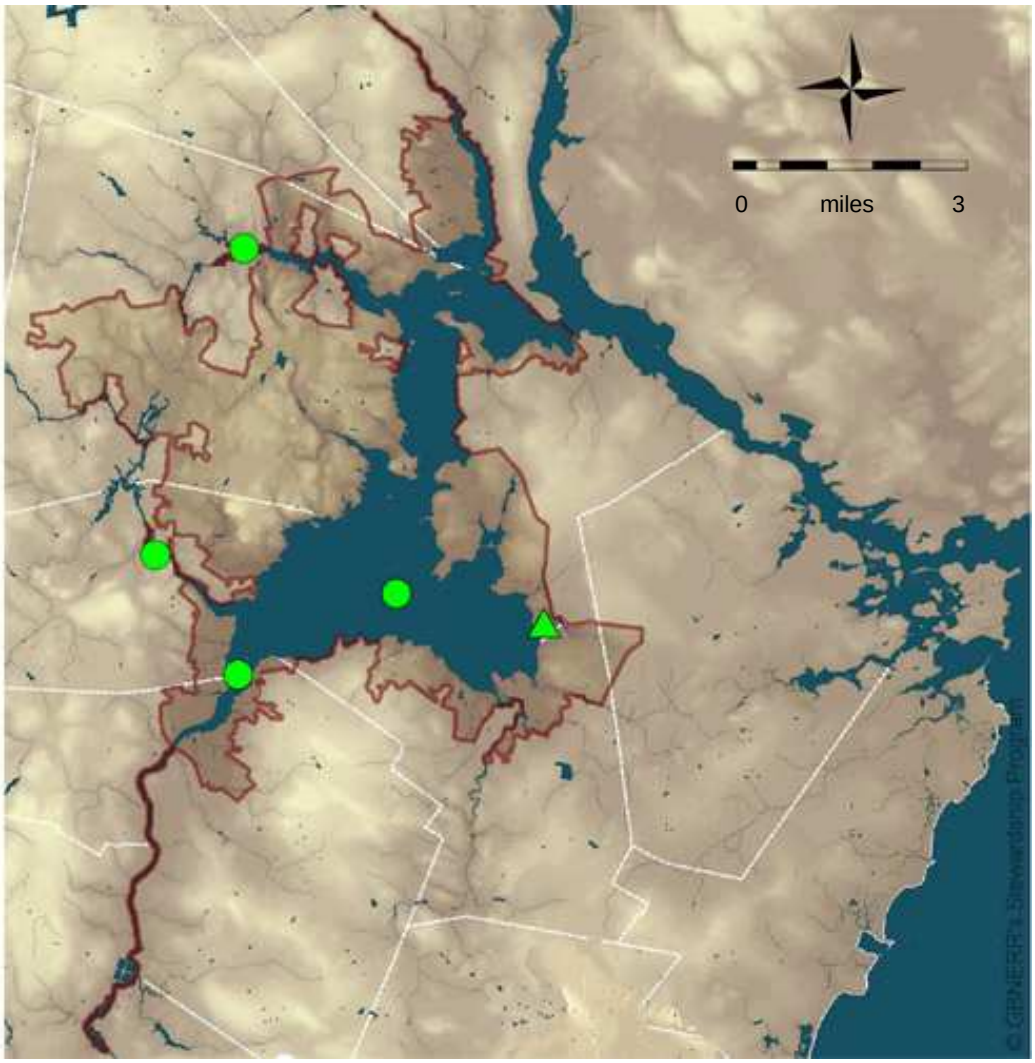


Figure 5. Location of Great Bay NERR SWMP stations. Circles mark water quality stations and the triangle marks a weather station.

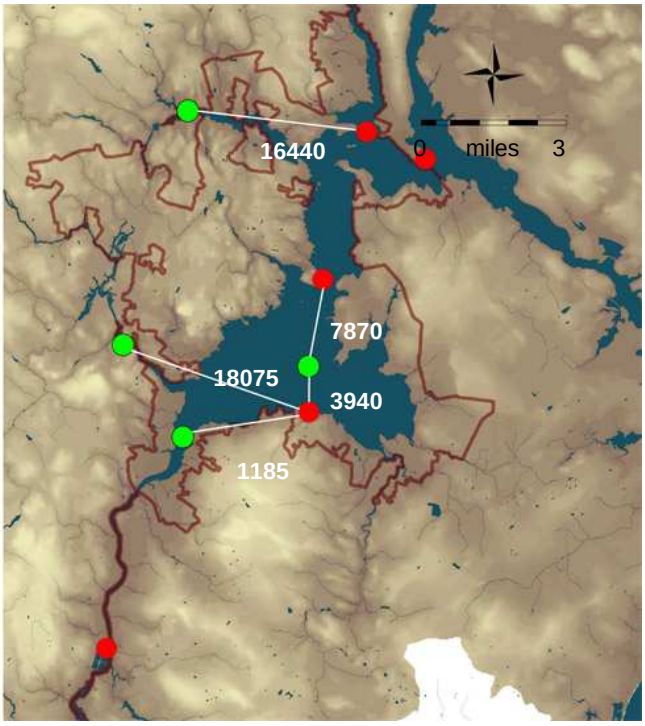


Figure 6. Nearest distances from tidal control points (shown in red) to SWMP stations (shown in green). All distances are in feet.

2. Land Height

a. Continuously Operating Reference Stations (CORS)

The National Geodetic Survey (NGS) of NOAA's National Ocean Service (NOS) manages the CORS system, which provides data to support three-dimensional positioning for the Global Navigation Satellite System (GNSS). CORS are the backbone of a geodetic control network. The deployment of CORS within functional distance of the Reserve is relatively robust. Four were located in the southern portion of New Hampshire. However, the station operated by the United States Coast Guard in Portsmouth was placed offline in 2004. This leaves an operational CORS located at the University of New Hampshire approximately 0.5 miles away from the Reserve's boundary, a CORS maintained by the NH Department of Transportation approximately 32 miles from GBNERR's boundary, and a station at the Federal Aviation Administration New England site in Nashua 36 miles from the Reserve's boundary (http://www.ngs.noaa.gov/CORS/).

b. Bench Marks and Geodetic Connection

i. Land Height Relationship to Water Level

Existing control points have been recovered, evaluated for stability, and tied to the NSRS by state geodetic crews and Reserve staff. Proximity of control points to SWMP stations is illustrated in Figure 6. Establishment of new vertical control in the vicinity of SWMP stations, or future established tide gauges, is a priority. It is also proposed that an additional water level data logger and associated SWMP station be located in the Winnicut River, the most south easterly tributary of the bay, in order to collect water depth data in close proximity to all primary reference sites (see below). Currently no leveling data has been collected by Reserve staff.

ii. GBNERR Habitat Focus Sites

Eight regions have been designated as focus sites representing broad habitats found throughout the Reserve (Figure 7). These include rocky shore, freshwater wetland, island habitat, grassland, early successional habitat and Appalachian oak pine forest. These classifications were chosen to be synonymous with those used in New Hampshire's Wildlife Action Plan. GBNERR habitat focus sites do not have a direct correspondence with regions of the Reserve designated as "core" in our 2006 management plan.

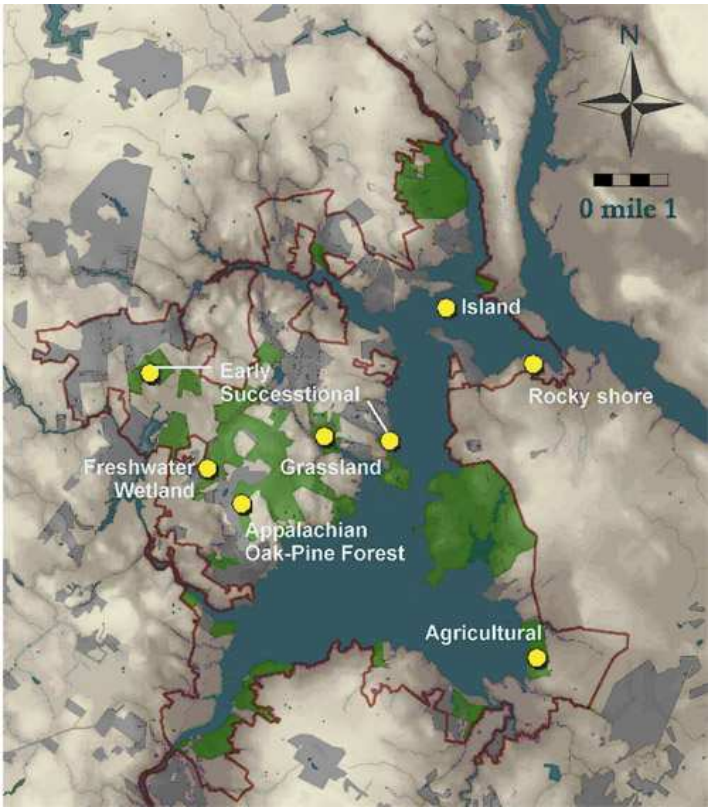


Figure 7. Location of GBNERR's upland focus habitat sites shown in yellow. Lands which GBNERR owns, holds a conservation easement on, or has a management agreement with are shown in green. Conservation land held by other entities is shown in grey.

iii. Assessing and Establishing Geodetic Control

A thorough evaluation of geodetic control within Great Bay NERR was conducted by the State Geodetic Advisor and GBNERR staff. When possible, existing control was recovered and used to tie the 16 GBNERR reference sites (Figures 7 and 9) to the NSRS. However, existing monumentation is primarily associated with human infrastructure, so nine new geodetic control stations needed to be established in order to connect rural Reserve reference sites to the NSRS (Figure 8). In 2009 and 2010, GBNERR and NHDOT staff began establishing these new stations and connecting them to the NSRS via OPUS-DB (Online Positioning Users Service database).

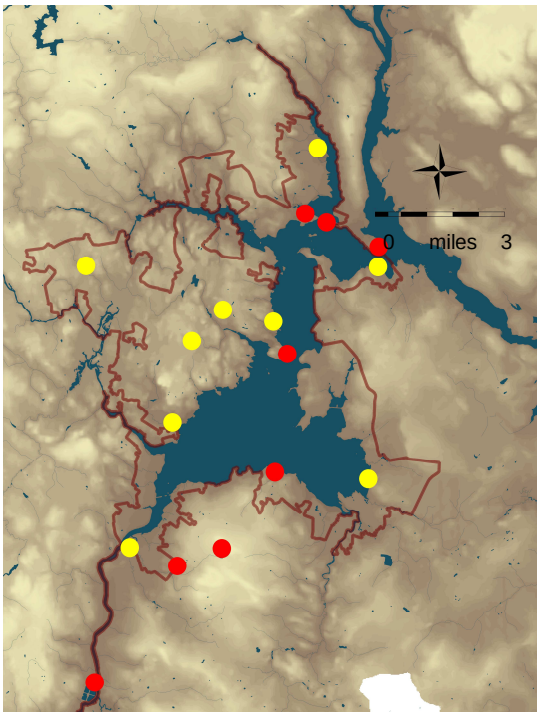


Figure 8. The spatial relationship of newly established control points, shown in yellow, and recovered control points, shown in red.

3. Assessing Changes in Wetland Elevation, Extent, and Vegetative Composition

Salt marshes are likely to show one of the earliest vegetative indicators of sea level alteration associated with climate change. The interface of the high and low salt marsh, regions dominated by *Spartina patens* and *S. alterniflora* respectively, reflects the local mean high tide line due to differential salt tolerance between the two plant species. This boundary is likely to shift as tide levels alter relative to local land uplift or depression. Saltmarsh accretion or erosion, due to sediment loading or scouring in an area, can be measured using surface elevation tables tied into a local control network (Figure 1). These alterations in saltmarsh extent and composition have direct habitat impacts for species such as the saltmarsh sparrow (*Ammodramus caudacutus*), mummichogs (*Fundulus heteroclitus*), and saltmarsh planthopper (Homoptera: Delphacidae). An established local control network facilitates better assessment of these impacts. In the human dimension, vertical control assessment allows more accurate development of tidal inundation models, improved wetland restoration design, and better land acquisition decisions in coastal environments that are essential to effective adaptation approaches that mitigate the impacts of climate change and build more resilient ecosystems.

Salt marsh is a key habitat of interest within the Reserve. All salt marsh areas currently owned by GBNERR that are logistically easy to access have been designated as “focus sites”. Of these, three of the eight areas have been designated “primary focus sites”, with each representing a different salt marsh restoration type (Figure 8).

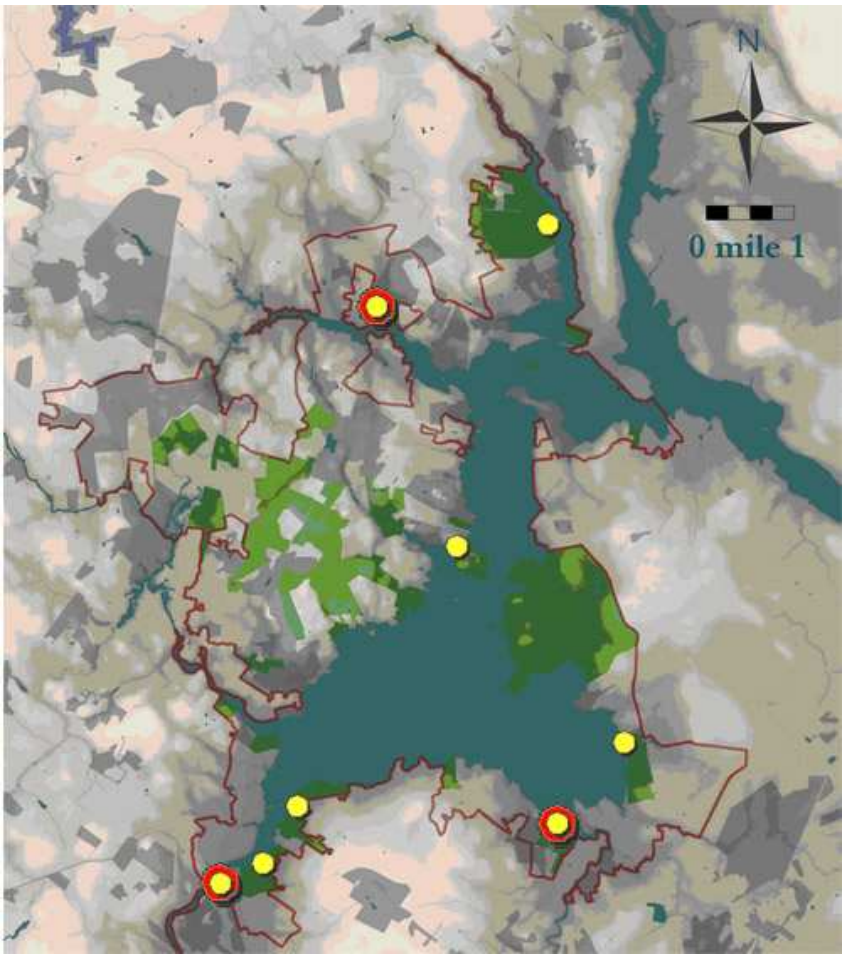


Figure 9. Location of GBNERR’s salt marsh focus sites shown in yellow. Primary focus sites are ringed in red. Lands which GBNERR owns, holds a conservation easement on, or has a management agreement with are shown in green. Conservation land held by other entities is shown in grey.

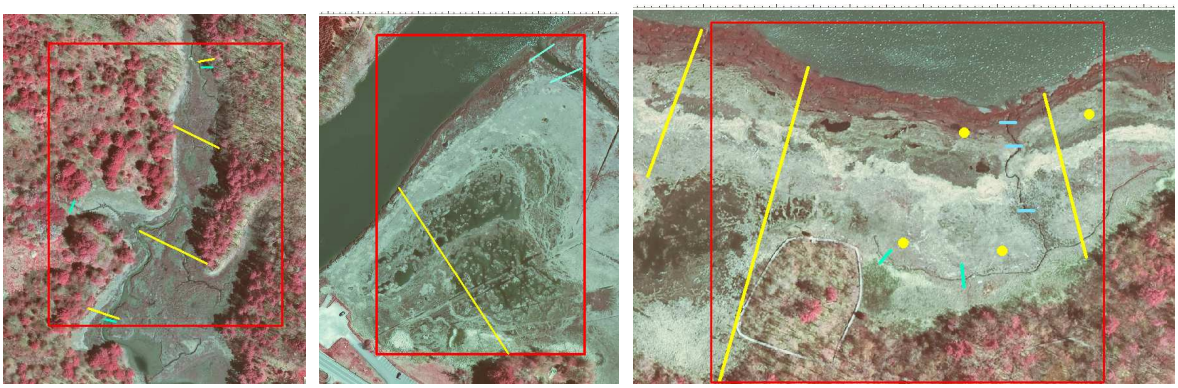
a. Wetland Elevation

i. Surface Elevation Tables (SETs)

Establishment of SETs is essential to monitoring coastal land elevation changes relative to local sea level in salt marsh environments. Currently at least nine SETs are deployed within GBNERR's boundary. Three had sediment elevation measured annually from 1996 to 2008 and one has annual measurements from 1996 to 2005 under the supervision of Dr Fred Short from the UNH Jackson Estuarine Laboratory (JEL). Four were established by Dr David Burdick from JEL and are located in one marsh at the site of GBNERR's Great Bay Discovery Center. Working with the University of New Hampshire, GBNERR has plans to deploy SETs at the three primary salt marsh focus sites (Bunker Creek in Durham, Chapman's Landing in Stratham, and Great Bay WMA in Greenland) within the Reserve (Figure 9) as part of our biomonitoring work. Each of these sites represents a different salt marsh ditching or restoration type. When funding and logistical needs are in place, SETs will be deployed at other salt marsh focus sites. Standardized protocols for connecting SET benchmarks to the NSRS have been developed by the NGS.

ii. Salt Marsh Digital Elevation Models (DEMs)

GBNERR has collected data using Real Time Kinematic Geographic Positioning System (RTK-GPS) protocols to develop 5m grid DEMs of the two most westerly primary salt marsh focus sites within the Reserve. The same protocol was used to collect data to develop a DEM of the marsh at Great Bay Discovery Center. All data collection took place between 07 September and 14 October 2010. At each site, several marsh profiles were collected at 1m spacing and tidal creek profiles were collected at 10cm spacing (Figure 10).



Bunker Creek **Chapman's Landing** **Great Bay Discovery Center**

Figure 10. Sampling protocol for RTK GPS elevation sites. Data to create digital elevation models were collected throughout the areas within each red box. Marsh profiles were collected along lines shown in yellow and located along biomonitoring transects where possible. Tidal creek cross-sections were collected at points shown in turquoise.

Data have been processed and digital elevation model and contour maps developed for these areas (Figures 11-13). Metadata remains to be authored. The Discovery Center and Bunker Creek are also being used as NERRS Tier 2 emergent vegetation biomonitoring sites as part of the SWMP.

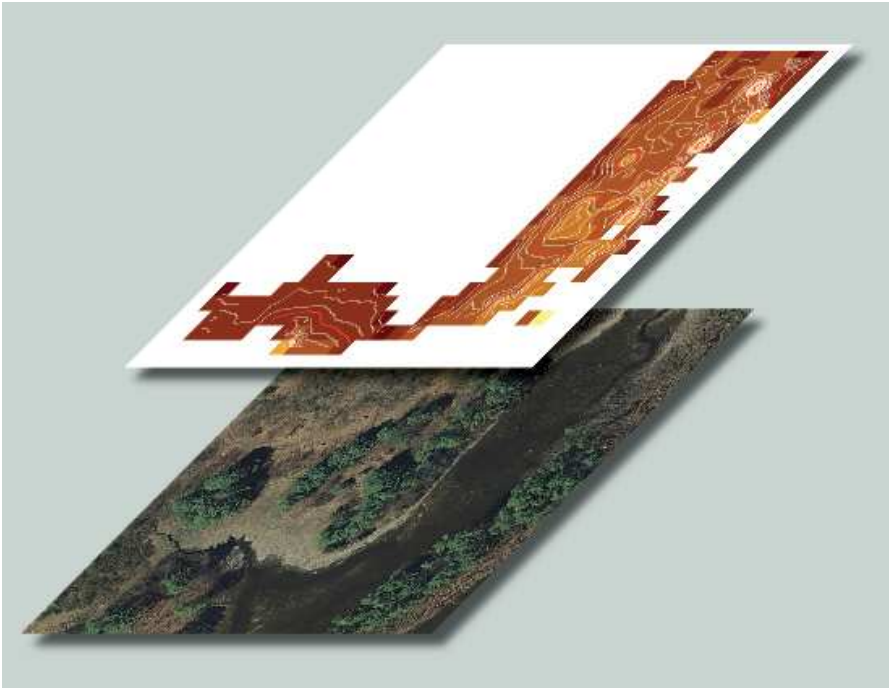


Figure 11. Elevation data for a 1.81 acre portion of salt marsh at Bunker Creek, Durham, NH.

Figure 12. Elevation data for a 11.47 acre portion of salt marsh at Chapman's Landing, Stratham, NH. White areas in the center of the DEM indicate regions of pools and panes with unconsolidated bottom so no accurate elevation data could be obtained.

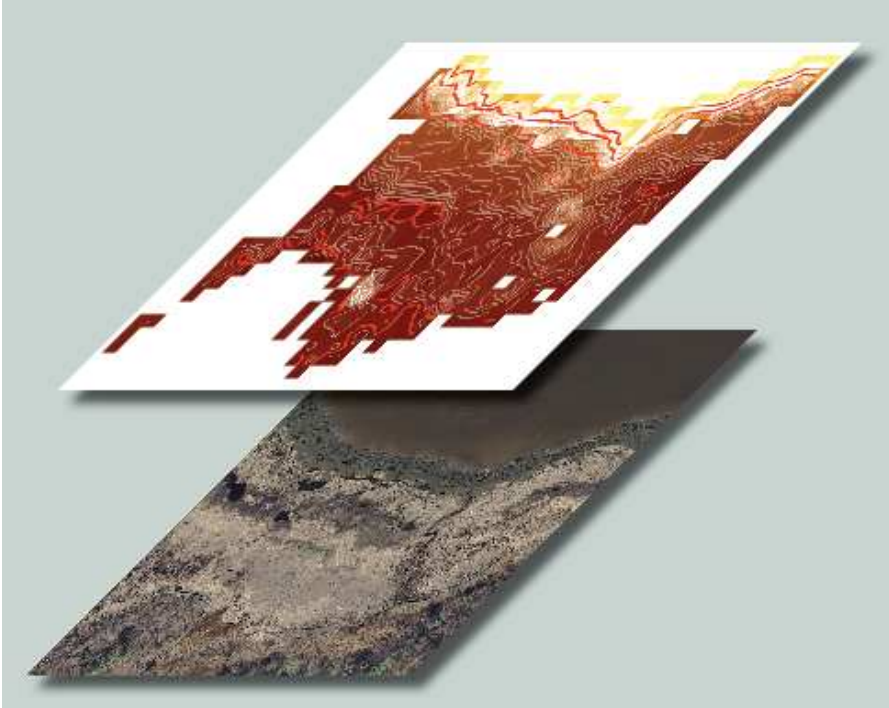


Figure 13. Elevation data for a 4.52 acre portion of salt marsh at Great Bay Discovery Center, Greenland, NH.

Elevation data for the three salt marshes has also been converted into KML format. This enables them to be visualized in Google Earth and navigated in three dimensions in a web browser environment. In Figure 14, areas of *Spartina alterniflora* are depicted by red pins and *Spartina patens* by light yellow pins. The Reserve's boundary is shown in the background in bright yellow.

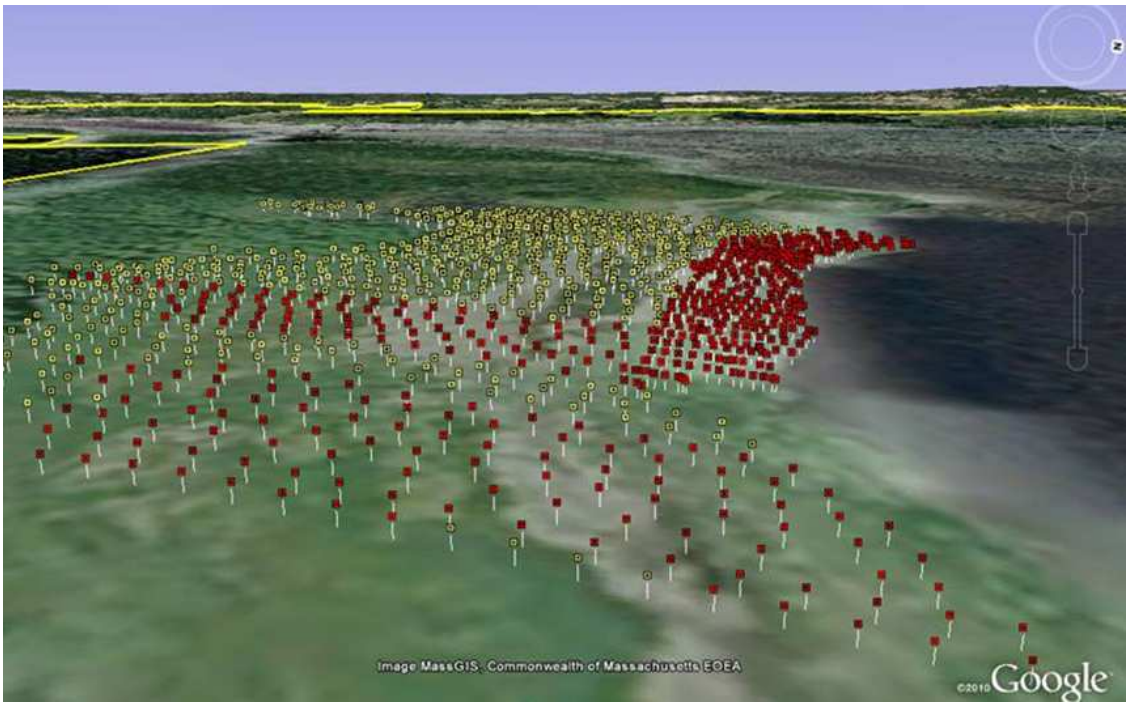


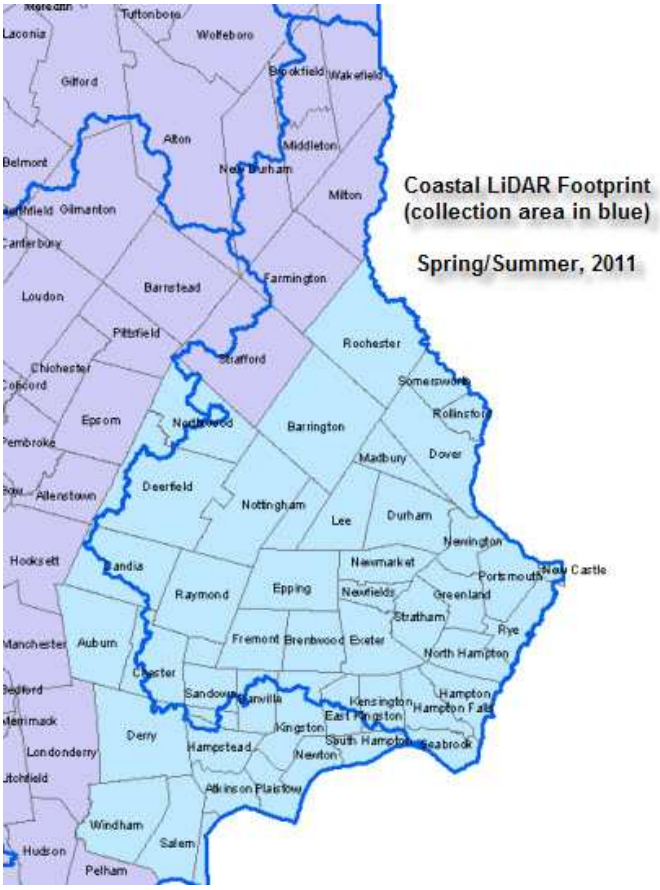
Figure 14. A "Google Earth" view of elevation data for saltmarsh in the grounds of Great Bay Discovery Center.

iii. LiDAR data

Updated seamless LiDAR data have recently been acquired through the Northeastern Coastal LiDAR Acquisition Project. Data collection had to comply with minimum requirements of The National Map being created by the US Geological Service's National Geospatial Program with funding from the American Recovery and Reinvestment Act.

As of June 2011, collection of the raw LiDAR data for coastal NH was completed. These data are currently being processed, and are scheduled for delivery to the state in the fall of 2011. The collection area covered the majority of Great Bay's watershed, with the exception of approximately eight towns in the northern portion (Figure 15).

The saltmarsh DEMs may provide a fine scale ground-truthing accuracy assessment of LiDAR data collected at a relatively contemporary period.



UNH graphic

Figure 15. Coastal New Hampshire LiDAR collection area.

b. Saltmarsh Extent

In 2009 and 2010, GBNERR partnered with UNH Complex Systems Research Center to complete a detailed saltmarsh mapping project. Saltmarsh extent throughout the Reserve was hand digitized from 1foot aerial photography flown in 2005. Figure 16 illustrates the detail of this saltmarsh mapping to pre-existing data. Even at the fairly gross scale of approximately 1: 2,000, a network of tidal creeks can clearly be seen in the new data. Metadata for this new saltmarsh layer is in development.

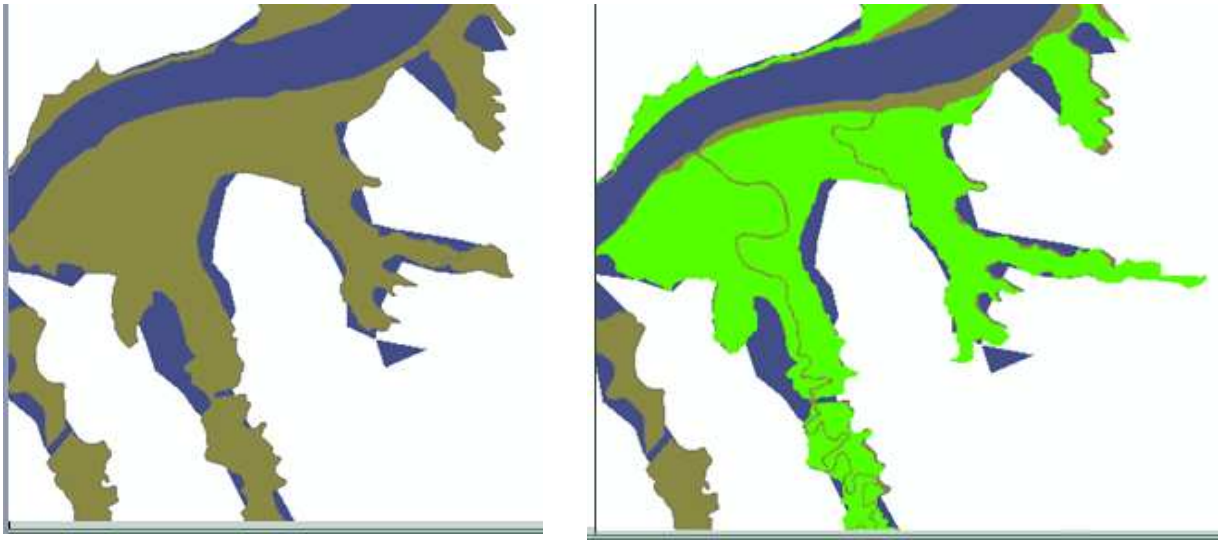


Figure 16. High resolution saltmarsh data. Water shown in blue, current data in brown and new saltmarsh extent in green.

c. Salt Marsh Composition: Establishing the Extent of High and Low Salt Marsh

The interface of high and low saltmarsh is a vegetative indication of local mean high water level. This boundary was mapped throughout the Reserve using a hand carried sub-meter accuracy GPS unit. The fieldwork for this mapping effort took place in 2009 and 2010. Data are in the process of being assessed for quality and integrated into a larger habitat mapping and change effort throughout GBNERR.

Future Modeling

The detailed salt marsh mapping and elevation data summarized in this document are planned to be utilized to help develop predictive models of how saltmarsh extent may change under varying sea level change scenarios. We plan to apply the US Fish and Wildlife Service's Sea Level Rise Affecting Marshes Model (SLAMM) within Great Bay NERR. SLAMM simulates the dominant processes involved in wetland conversions and shoreline modifications during long-term sea level change. These models of tidal inundation and marsh migration will be used to help with restoration efforts and land acquisition planning.

Thanks to ...

Katie Arey, Jim Dunphy, Brian Easler, Brett Forest, Nina Garfield, Andy Gould, David Justice, Errika Lewis, Jordan Mora, Jim Orr, Fay Rubin, Jay Sullivan, Brad Sylvester, A. Richard Vannozzi, and John Wallace for their assistance with this project.

Literature Cited

NERRS, 2007 Draft. SWMP Phase III: Land use and habitat change. Draft White Paper of the NERRS Habitat Mapping and Change Oversight Committee. 48 p.

NERRS, Undated. 2011-2016 National Estuarine Research Reserve System strategic plan. NOAA Estuarine Research Division, Silver Spring, MD. 12 p.

National Estuarine Reserve System. 2008. Climate change: science education and stewardship for tomorrow's estuaries. July 2008 white paper by the NERRS Climate Change Workgroup Members. 16 p.

NOAA, 2010. NOAA's next-generation strategic plan. National Oceanic and Atmospheric Administration, Silver Spring, MD. 40 p.

NOAA, 2011. Introduction to the proposed NOAA Sentinel Sites Program. 6/17/2011 Pre-Decisional Draft of the NOAA Sentinel Sites Program Working Group. NOAA, National Ocean Service (NOS), Silver Spring, MD. 12 p.

Appendix A. Summary of Great Bay status by NOAA's Center for Operational Oceanographic Products and Services.

Great Bay NERR falls within an NWLON gap. A long-term tide station (NWLON standards) is recommended.

A tide station is currently operating at Fort Point, NH (since 2003), which can be used for secondary control (for local datum computation), but should not be used as long-term control or local tidal information for the Reserve. Station will be removed (date TBD). However, tidal information from this site provides good information regarding forcing into the Great Bay system.

No tidal bench marks within the Reserve have updated tidal datums. Leveling to existing tidal bench marks is still encouraged, but will not provide immediate vertical control with updated tidal datums. Local observations are required.

NOS tide station bench marks at Fort Point and Seavey Island can be tied to from project site using GPS (of limited value- local tidal information is more important. Doing so would provide a regional comparison of tidal datums, rather than local information.).

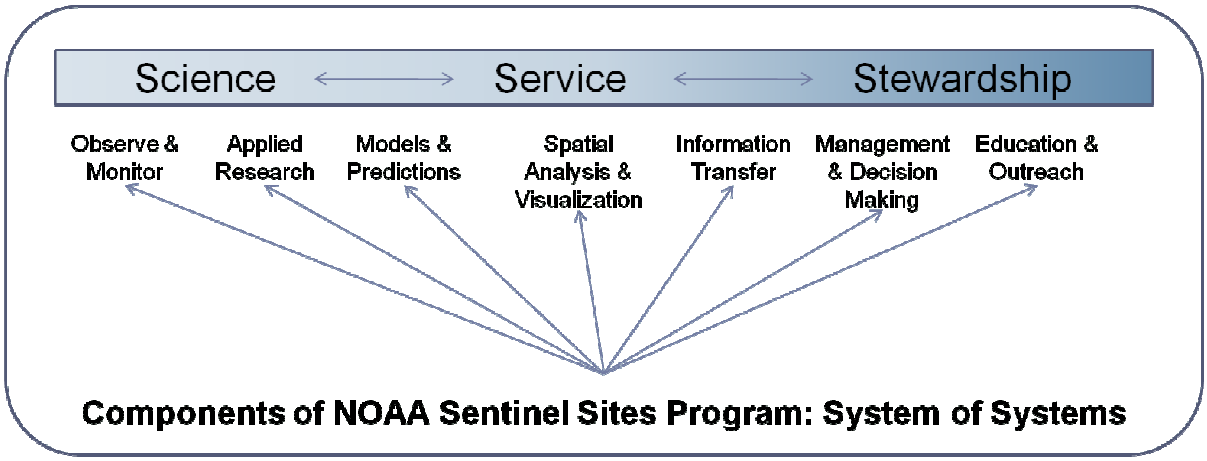
Water levels could be collected at all Great Bay SWMP sites (including Oyster River, Squamscott River, and Lamprey River, which provide important bracketing information) to compute tidal datums and bound project site (with geodetic connections made). A new long-term station would provide control for datum computation (without a control station, datums will be based only on observations at the SWMP sites, which are at multiple cm accuracy. Currently, Fort Point can also be used.).

Appendix B. Administrative Context of this Plan.

By Paul Stacey, Research Coordinator, Great Bay NERR.

In *NOAA's Next-Generation Strategic Plan* (NOAA, 2010), a long-term Climate Adaptation and Mitigation goal of "An informed society anticipating and responding to climate and its impacts" was established. The goal addresses a central theme of NOAA's "Science, Service, and Stewardship" mission, "To understand and predict changes in climate, weather, oceans, and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources." The *2011-2016 National Estuarine Research Reserve System Strategic Plan* has a consistent focus on climate change and identifies the National Estuarine Research Reserve System (NERRS) as "…well positioned to monitor and study the impacts of climate change on estuaries and to work with communities to plan and adapt to these changes." The foundation for this NERRS focus was established in a 2008 report, *Climate Change: Science, education and stewardship for tomorrow's estuaries* (National Estuarine Reserve System, 2008) and has been evolving to keep pace with the rapid growth of climate change science and adaptation options. In that paper, the NERRS established three goals relevant to this Vertical Control Plan, especially to "Contribute to scientific understanding of climate change and monitor ecosystem changes."

NOAA's Sentinel Sites Program Working Group has developed a conceptual framework for a proposed Sentinel Sites Program (NOAA, 2011). The framework emphasizes partnerships and has identified the NERRS and National Marine Sanctuaries (NMS) assets as key resources for the initial phase of the program as sentinel sites that are already operational. Their initiative "…provides a place-based approach that concentrates infrastructure and resources to track the status of key indicators of ecosystem integrity and uses these indicators to inform adaptation planning and management response to stressor impacts." Full implementation of the program would link science to service to stewardship. NERRS climate change activities, including those at the Great Bay NERR, are already structured and being implemented within resource capacity to serve virtually the same structural framework. Vertical control planning and infrastructure activation are an important component of an integrated sentinel site structure and program to measure sea level rise and interrelated indicators of physical, chemical and biological change.



The complete NOAA conceptual framework for a sentinel site program has a strong science foundation in field observation and monitoring to quantify the forcing factors and effects of climate change. A complete sentinel site system provides the essential physical, chemical and biological observation and monitoring that supports understanding of climate change. Combined with other indicators and systems research supported by a sentinel site observation and monitoring program, an ecosystem-based understanding and management framework can be developed.