Narragansett Bay
Research Reserve

Technical Report 2012:2

NBNERR Vertical Control Plan

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I. Introduction

Coastal and estuarine habitats are known to be very dynamic systems which are impacted by a variety of natural and anthropogenic stressors. The degree to which these habitats are influenced by changes in land use and coastal processes is a direct function of land height elevation relative to local mean sea level. Low-lying coastal areas are influenced to a greater degree than are habitats at even moderately higher elevations.

To compliment monitoring efforts designed to capture change in land cover extent (e.g. habitat mapping), vegetation composition (e.g. biomonitoring), and quality and condition (e.g. abiotic monitoring) of coastal habitat over time, it is critical to capture wetland elevations in order to evaluate the degree to which these measured changes promote, or are influenced by, changes in elevation particularly as these elevations relate to the local tidal range. In coastal salt marsh habitat for example, even in the absence of additional stressors, it is the frequency and extent of tidal inundation (a function of land height elevation relative to the local tidal datum) that clearly delineates the species composition and extent of high and low marsh habitat as well as the upland boundary.

Predicted climate change impacts for the Northeastern U.S. include an increase in air and water temperatures, an increase in winter precipitation occurring primarily as rainfall, an increase in heavy precipitation events (> 2 inches within 48 hours), an increased frequency of short-term (1 to 3 month) drought, and rising sea levels (Frumhoff et al., 2007). Sea-level rise associated with climate change is projected to increase the frequency and severity of coastal flooding and damaging storm surges, permanently inundate some low-lying coastal areas, and accelerate coastal erosion (Frumhoff et al., 2007). Habitats with high sensitivity to changes in climate such as altered precipitation patterns, sea temperature increase and sea level rise include tidal wetlands and coastal buffer habitat (e.g. beaches, dunes, riparian uplands) (NOAA OCRM, 2010).

In order to capture current elevation influences on habitat type and condition as well as evaluate habitat shifts due to a potential change in relative land height-to-sea level elevation it is necessary to develop local vertical control infrastructure tied to a known vertical reference datum. The National Spatial Reference System (NSRS), managed by the National Oceanic and Atmospheric Administration (NOAA) National Geodetic Survey (NGS), is the coordinate system that defines vertical reference datums and the North American Vertical Datum of 1988 (NAVD88) is the current accepted national datum. National spatial and tidal station infrastructure maintained by NGS and the NOAA National Ocean Service's (NOS) Center for Operational Oceanographic Products and Services (CO-OPS), respectively, which are tied to the NSRS are the basic components for developing local vertical control infrastructure.

Establishing local vertical control is generally a two-part process requiring first the identification of existing and/or the installation of new foundational components (e.g. benchmarks and water level loggers/tide gauge stations) and then the connection of these components to the NSRS to provide accurate horizontal and vertical positions. This plan provides an overview of the current status of vertical control on Narragansett Bay National Estuarine Research Reserve (NBNERR or Reserve) properties and identifies future needs to support a variety of applications.

II. Existing Infrastructure and Future Needs

The development of vertical control infrastructure on NBNERR properties was driven primarily by the need to evaluate sensitive coastal habitats with respect to sea level rise. As a result, initial components were located in or adjacent to salt marsh areas containing additional monitoring infrastructure. Subsequent vertical control infrastructure build-out has been designed to (1) allow an expansion of monitoring efforts to include other salt marsh areas at risk on NBNERR properties or (2) support targeted restoration efforts.

A. Land Height

Throughout the United States there are literally thousands of permanent reference marks or survey monuments whose positions (horizontal and vertical) relative to each other have been acquired through geodetic surveying techniques. These survey monuments or "benchmarks" are tied to the NSRS and may or may not include elevation. To expand this network of geodetic control benchmarks locally into areas of interest requires the placement of additional monuments and geodetic surveying by one of two methods: leveling or Global Positioning System (GPS) survey. Once new benchmarks are established and periodic surveys confirm stability they may be used to develop additional elevation data products and to relate land height to local tidal datums.

i. Continuously Operating GPS Reference Stations (CORS)

Although leveling to new benchmarks provides greater (sub-mm) mark accuracies, it was necessary to use the alternate Global Positioning Systems (GPS) survey method providing 2-5 cm mark accuracy to determine elevations at all local benchmarks whether historic or newly installed. NBNERR properties, which are located exclusively on islands in Narragansett Bay, had no historic benchmarks with known elevations which would provide a leveling survey start/end point. CORS provide continuous correctors for all atmospheric influences on GPS receivers, allowing high accuracy positions to be obtained through post-processing of GPS data taken within the vicinity of the CORS. Using this technology it was possible to determine accurate elevations at one historic benchmark on the island while simultaneously occupying benchmarks of known elevations off-island. The same methodology was then applied using the new on-island 'base' to determine elevations at newly established benchmarks.

Although a number of permanent CORS exist within 60 km of Reserve properties (Table 1), some effort should be made to establish a CORS within closer proximity. This would ensure that the satellite configurations and atmospheric influences provided for post-processing GPS data are comparable to those acquired by local GPS receivers during static GPS operations used to connect benchmarks to the NSRS.

Table 1: CORS Stations located closest to NBNERR properties. Source: NGS website (http://geodesy.noaa.gov/CORS/) last modified Mar 27, 2012.

Station Name	Station ID	Approximate Distance (km)	Sampling Rate (sec)	Operational Status
Newport, RI	NPRI	12.67	5	Non-operational
U of RI COOP, RI	URIL	22.69	5	Operational
Acushnet 5, MA	ACU5	38.65	5	Operational
Acushnet 6, MA	ACU6	38.67	5	Operational
MTS Fox COOP, MA	XMTS	49.38	5	Operational
Putnam, CT	CTPU	56.15	5	Operational

ii. Geodetic Benchmarks

A number of geodetic control points exist within the State of Rhode Island and of those inventoried and evaluated for use in building local vertical control infrastructure, only one benchmark on Prudence Island and three at off-island sites were identified as having the appropriate characteristics (i.e. monument found undisturbed, unobstructed view of the sky, suitable stability) to make incorporation into the local vertical control network possible.

None of the benchmarks found in or near Reserve properties were tied to NAVD88 and all except one were not located proximate to areas of interest. Individual benchmarks were initially installed in areas having additional monitoring infrastructure in 2008 and a second benchmark was installed at two of these same sites in 2010 to improve accessibility (Fig. 1). Details for benchmark site selection and monitoring infrastructure design, location, and protocols are available in Raposa and Weber (2011). Locations and elevations of current benchmarks are provided in Table 2.

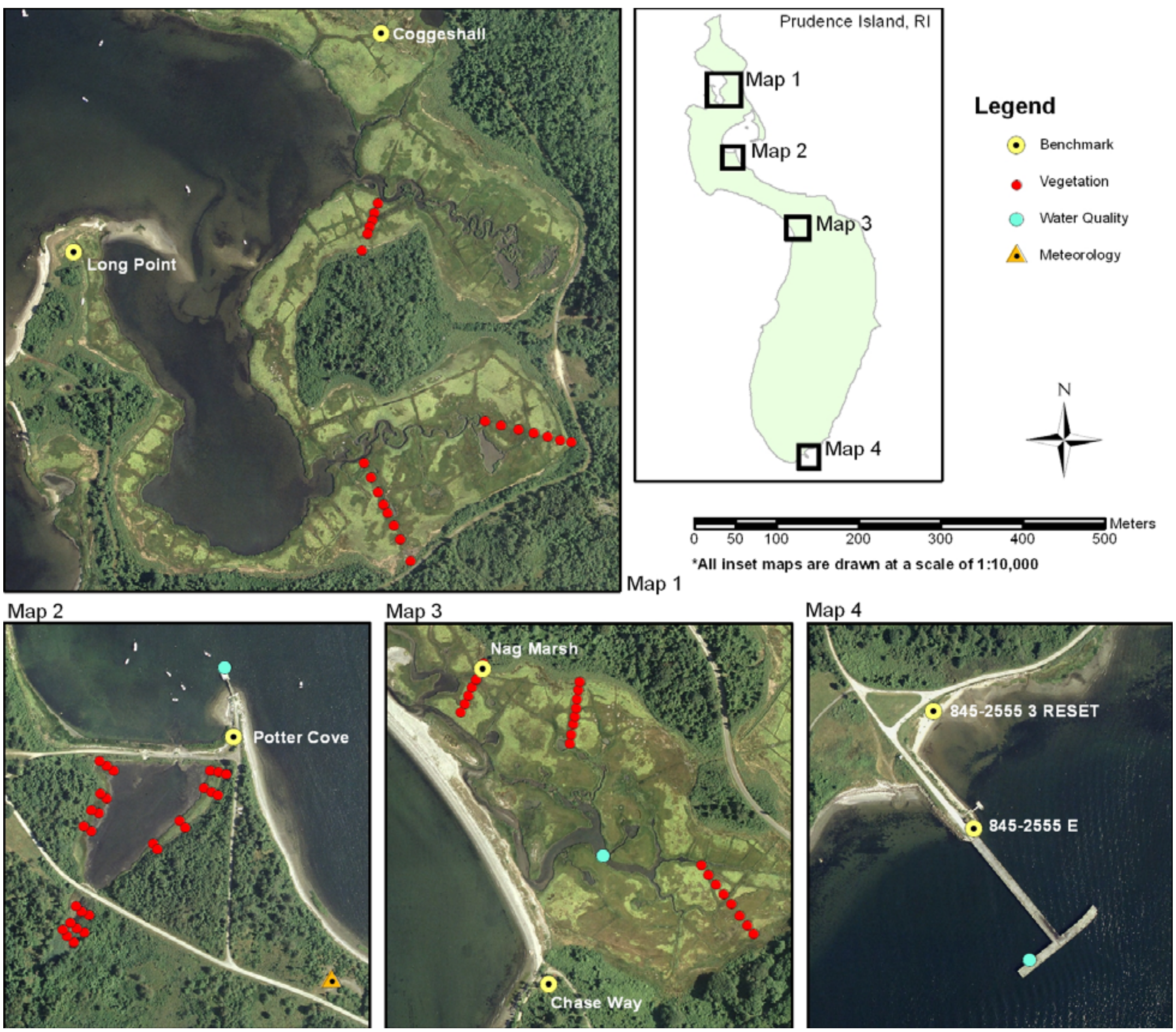

Figure 1: Location of geodetic benchmarks and associated vegetation, water quality, and meteorological monitoring infrastructure. Maps 1 through 4 depict Coggeshall Marsh, Potter Pond, Nag Marsh West, and T-Wharf study sites, respectively.

Table 2: Locations and elevations of current benchmarks included as foundational vertical control infrastructure.

Benchmark Name	Latitude	Longitude	Geoid Height (m)	Northing (m)	Easting (m)	NAVD88 Elevation
Coggeshall	41˚39'18.47120"N	71˚20'33.88145"W	-28.710	63515.989	113098.740	1.079
Long Point	41˚39'09.83501"N	71˚20'50.09921"W	-28.406	63248.874	112723.969	1.393
Potter Cove	41˚38'23.38253"N	71˚20'26.73896"W	-28.245	61816.718	113267.141	1.559
Nag Marsh	41˚37'36.11397"N	71˚19'33.44041"W	-29.073	60360.794	114503.588	0.724
Chase Way	41˚37'23.63388"N	71˚19'29.99847"W	-27.513	59975.926	114584.043	2.288
845-2555 3 RESET	41˚34'52.01715"N	71˚19'21.56397"W	-27.009	55298.741	114788.908	2.838
845-2555 E	41˚34'46.98874"N	71˚19'19.13095"W	-27.640	55143.724	114845.587	2.205

The three off-island geodetic control benchmarks were incorporated exclusively for the purpose of using static GPS to determine elevation at our primary on-island benchmark [845-2555 3 RESET] located near the southern end of Prudence Island (Figure 1: Map 4). Benchmarks for this purpose were selected after significant reconnaissance effort to identify monument locations configured approximately equal distance from our primary benchmark. General reference information is provided in Table 3 and detailed information regarding monument characteristics is listed on benchmark datasheets available from NGS (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl).

Table 3: General reference information for off-island geodetic control benchmarks used to establish vertical control.

Designation	Permanent Identifier (PID)	Latitude (approximate)	Longitude (approximate)
MC Sparran 4	LW0673	41˚ 29' 49" N	71˚ 27' 25" W
E 28	LW0235	41˚ 35' 47" N	71˚ 15' 47" W
H 28	LW0252	41˚ 33' 49" N	71˚ 17' 07" W

The current benchmarks provide a sufficient framework to tie existing and planned vertical control infrastructure to the NSRS for many applications. Elevations for current vertical control benchmarks have been acquired by using static GPS technology (also described as height modernization), however additional effort to ensure the accuracy of these values may be necessary to ensure that protocols described in a new guidance document under development (NGS/NERRS/CO-OPS, 2012) have been adhered to (specifically the requirement for static GPS data collection over multiple days). To support additional applications; specifically, expanded monitoring efforts in other salt marsh areas at risk on NBNERR properties such as at the extreme north end of the island at Providence Point or in support of targeted restoration efforts at Mill Creek, additional benchmarks will need to be established (Figure 2).

iii. Surface Elevation Tables (SETs)

SETs are portable measuring devices that are deployed on vertical rod benchmarks installed in the coastal wetland to determine millimeter-level change in surface elevations over time. They are designed to capture all processes affecting elevation change such as deposition/accretion and subsidence/erosion. If properly installed using deep-rod foundations they may also serve as components of the vertical control infrastructure.

Six legacy SETs are located on Reserve properties. They were installed by Dr. Fred Burdick of the University of New Hampshire's Jackson Estuarine Laboratory in the 1990's using a pile-driver and are assumed to be of sufficient depth and stability to be used for the purpose of vertical control.

Figure 2: Priority areas for additional benchmark installation.

However, as no effort was made at the time of installation to determine elevation of these legacy SETs relative to NSRS, stability will require confirmation over a period of years.

An additional twelve SETs were installed in July/August 2012 to evaluate fine-scale elevation changes on the marsh surface as a required monitoring component of the NERRS Sentinel Site Program effort (NERRS, 2012). SETs were installed in representative low and high marsh within 2.5 meters of the three vegetation monitoring transects at the two primary study sites [Coggeshall Marsh and Nag Marsh]. All recovered legacy SETs and newly installed SETs will be tied to the NSRS using geodetic surveying techniques in accordance with methods described in Geoghegan, et. al. (2009).

iv. Elevation Models

Surface elevation models, while not actual components of vertical control infrastructure, are worth mention since they are validated by or derived through the use of established infrastructure and can provide a more broad scale visualization of coastal features and the processes that may influence them.

NBNERR collected data using Real Time Kinematic GPS (RTK) at approximately one meter intervals to generate a digital elevation model (DEM) for a subset of the Nag Marsh study site. Repeated efforts to generate a similar product in future years may indicate surface elevation change related to broad scale effects of natural and anthropogenic stressors such as extreme storm events or sea level rise which are not captured through evaluating local fine scale change in surface elevation using SETs.

Similarly, bare earth elevation models derived from Light Detection and Radar (LiDAR) data can be applied for the same purpose and has the advantage of greater geographic coverage. LiDAR data for the State of Rhode Island was acquired in 2011 as part of the Northeastern Coastal LiDAR Acquisition Project coordinated by NGS with funding from the American Recovery and Reinvestment Act. Provisional data products are currently available and final products are scheduled for delivery in 2012. Topographic LiDAR products are not as accurate in coastal marshes as they have proven to be in upland habitats (Schmid, et al., 2011) so additional accuracy evaluation and, if warranted, post-processing of this data may be required prior to its use in NBNERR research and monitoring efforts.

B. Sea Level

Coastal processes at the land-sea interface are influenced by tidal stage as well as local land heights. It is therefore necessary to tie vertical control infrastructure to local tidal datums, which describe mean water levels, in addition to the NSRS. Tidal datums are preferentially computed from 19 years of observed water levels (primary control tide stations) or, if shorter time series data are available, through comparison with simultaneous observations at a nearby primary control tide station with similar hydrographic characteristics. Sea level trends computed from observations at two primary control tide stations in Narragansett Bay suggest an increase of 1.95 ± 0.28 mm/yr at Providence, RI and 2.58 ± 0.19 mm/yr at Newport, RI for the period from 1938 to 2006 and 1930 to 2006, respectively (Zervas, 2009). Updated trends for the same start year through subsequent years provide more precise measurements of sea level trends at these locations (Figure 3). Relative sea level rise reflects the combined influences of global sea level changes and localized vertical land movement. Douglas (1991) suggests that 1.6 mm/yr of the sea level trend computed for the time period 1930-1980 at Newport, RI can be attributed to postglacial rebound. Regardless of cause, monitoring coastal habitats with respect to tidal datums will provide greater insight into all potential processes and stressors influencing change.

i. National Water Level Operation Network (NWLON) Tide Stations

A national network of tide stations maintained by CO-OPS provides controls in determining tidal datums for water level stations of short duration and NBNERR is not located within an NWLON gap. One historic tide station located on Prudence Island, two primary (NWLON) tide stations, and three secondary tide stations are found within Narragansett Bay and Mt. Hope Bay and capture the range of tide from the mouth of Narragansett Bay and the Sakonnet River at Rhode Island Sound through the lower reaches of the Blackstone and Taunton Rivers at Providence, RI and Fall River, MA respectively (Figure 4).

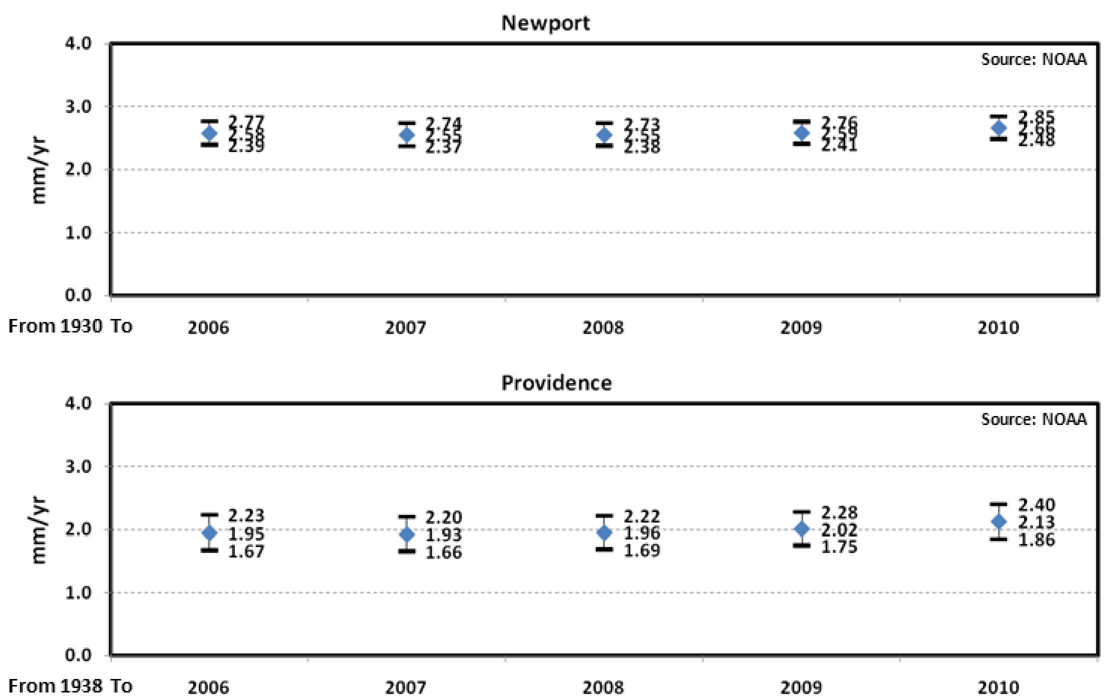

Figure 3: Mean sea level trends and 95% confidence intervals computed for Newport and Providence tide stations updated annually for the data period beginning with the common listed year through 2010. Source: NOAA CO-OPS Sea Levels Online. Available: http://tidesandcurrents.noaa.gov/sltrends/sltrends.shtml.

The Prudence Island historic tide station was located at approximately the same latitude as the Quonset Point tide station and reflects comparable tidal means (Table 4). Unfortunately, the time series for datum computation was very short (2 months) and the time period in which this historic station was active (September to October 1977) pre-dates the establishment of the Quonset Point tide station so no direct comparison with the data record for that site is possible. However, the presence of two primary control (NWLON) tide stations and current continuous operation of secondary stations in the Bay are sufficient for simultaneous observations of local water level for computing tidal datums relevant to the hydrographic characteristics of NBNERR study sites. As tidal benchmarks associated with the historic tide station were recoverable, and have been tied to the NSRS, no further action related to NWLON stations is required for vertical control.

Figure 4: Tide stations located in Narragansett Bay (RI) and Mount Hope Bay (MA).

Table 4: Local tidal datums computed for tide stations in proximity to NBNERR (relative to the 1983-2001 Epoch).

Station Name	Newport	Prudence Island	Quonset Point	Conimicut Light	Providence	Fall River
Station ID	8452660	8452555	8454049	8452944	8454000	8447386
Length of Series	19 years	2 months	10 years	9 years	19 years	10 years
Highest Observed Water Level	4.056 (9/21/38)	---	2.224 (4/16/07)	2.516 (4/16/07)	5.337 (9/21/38)	2.446 (4/16/07)
Mean Higher High Water (MHHW)	1.174	1.259	1.249	1.398	1.476	1.456
Mean High Water (MHW)	1.099	1.186	1.174	1.322	1.401	1.383
Mean Tide Level (MTL)	0.571	0.617	0.611	0.687	0.728	0.717
Mean Sea Level (MSL)	0.529	0.569	0.566	0.642	0.686	0.672
Mean Low Water (MLW)	0.042	0.047	0.047	0.052	0.055	0.052
Mean Lower Low Water (MLLW)	0	0	0	0	0	0
Lowest Observed Water Level	-0.943 (1/25/36)	---	-0.839 (2/11/01)	-0.850 (2/11/01)	-1.094 (1/5/59)	-0.774 (2/11/01)

ii. System Wide Monitoring Program (SWMP) Stations

Four water quality SWMP stations are maintained by NBNERR and the deployed data loggers capture changing water levels (amongst other parameters) at fifteen minute intervals throughout the year as conditions (i.e. ice- and storm-free) and resources permit. At the time of their installation, no effort was made to ensure that vertical control could be established with the SWMP station deployment infrastructure and data loggers since that need was not anticipated. Retrofitting for this purpose presents an overwhelming challenge and would potentially disrupt long-term monitoring datasets so no action will be undertaken to tie existing SWMP monitoring stations to the NSRS.

iii. Water Level Loggers

In an effort to corroborate the historic local tidal datum associated with tidal benchmarks (845-2555 3 and 845-2555 E) at the south end of Prudence Island, a dedicated vented water level logger will be installed in close proximity to the previous tide station location at the base of the T-Wharf. The logger will be affixed to a stable platform in a manner that will allow the logger position to be tied to the NSRS using geodetic surveying techniques. Observations collected at six minute intervals will be used to tabulate tides and compute mean values. The computed means will then be statistically compared to nearby primary and secondary long term control stations to derive a local tidal datum and associated error estimations at this location following a process described in *Guidelines for Determining Tidal Datums for National Estuarine Research Reserves* (COASTAL/CO-OPS, 2007).

It is anticipated that the derived local tidal datum at the historic tide station will not universally apply to priority NBNERR study sites. While the distance to the farthest area of interest is not extreme (< 10 km) the differences in site hydrographic and bathymetric characteristics, particularly in tidal salt marsh, will influence tidal datum elevations. A second dedicated vented water level logger will be deployed at each of the priority study sites for a minimum of three months so that simultaneous observations with the T-Wharf logger are available for comparison. Short duration water level logger deployments at priority study sites will require a stable platform so that geodetic surveying can be used to tie logger position and observations to the NSRS. Water level observations obtained by dedicated water level loggers will provide the basis for deriving a series of local, site specific, tidal datums.

II. Vertical Control Applications within the NBNERR

A. Sentinel Sites

NBNERR will contribute to a national multi-agency monitoring program of sentinel sites designed to evaluate the impact of changing sea level and inundation patterns on coastal habitats. Sentinel sites combine protocols for vegetation monitoring to capture horizontal rates of marsh migration and upland transgression, sediment elevation tables (SETs) to determine rates of accretion and subsidence, as well as water level, elevation survey, water quality and meteorological data to evaluate changing conditions and answer questions related to the relative influence of stressors on habitat quality and distribution.

B. Research and Restoration

In addition to monitoring change within tidally influenced coastal habitats such as established salt marsh, NBNERR has identified two potential restoration sites on its properties which may, as the result of rising sea level, transition from upland / freshwater wetland to brackish / salt marsh over time. These sites provide an opportunity to evaluate climate driven rates of change in vegetation composition within low-lying areas proximate to the coast and will provide guidance for future proposed restoration efforts throughout the state.

C. Adaptation Planning

NBNERR managed and adjacent properties share infrastructure (e.g. roads, water distribution lines, utility lines) that are subject to damage from extreme storm events such as hurricanes and ice storms. Past storm events have caused significant damage including road wash-outs, loss of power, and destruction of homes and businesses. The anticipated climate change impacts, particularly an increase in heavy precipitation events and rising sea levels, will place shared infrastructure at increasingly greater risk. Identifying areas that will be most sensitive to damage and anticipating long-term needs for infrastructure redesign or relocation will be of benefit to all local stakeholders.

D. Land Acquisition

Properties currently incorporated within the Reserve and those targeted for inclusion generally share the characteristic that they are relatively pristine and contain unique or unusual habitat. The anticipated loss of coastal salt marsh due to climate change impacts such as permanent or extended periods of tidal inundation and greater coastal erosion may be mitigated to some extent by marsh migration and upland transgression. Lands adjacent to current salt marsh habitat which are of suitable elevation to allow for migration/transgression or which contain streams that provide sediment for marsh accretion will be identified as priority targets for future acquisition.

E. Predictive Modeling

As more comprehensive land surface elevation and bathymetric data are developed and the influence of sea level rise on coastal habitats is better understood it should be possible to develop more accurate predictive models to demonstrate broad-scale climate effects. Projected shifts in habitat in response to climate change and/or other stressors may be used to inform coastal management decisions throughout the region.

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