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TIDAL ANALYSIS OF THE BARREN ISLAND RESTORATION AREA

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U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

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National Ocean Service
National Oceanic and Atmospheric Administration
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Tidal Analysis of The Barren Island Restoration Area

August 2022

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1. INTRODUCTION

Barren Island is one of many islands in the Chesapeake Bay that have diminished in size due to sea level rise and erosion (Figure 1**)** (Kearney, M.S. and J.C. Stevenson, 1991). Over the past several hundred years, erosion and overwash episodes induced by storm surge formed several small connections from the main body of the estuary into what is now known as the Honga River (Wray, 1995). These small tributary connections slowly grew under tidal forcing and currents and created an island chain that reached longitudinally from the central Chesapeake Bay region to the south. The main geologic component of this peninsula is of clay origin and not silica sediments (sand) that are typical of coastal islands. Due to the clay composition, the island chain has eroded very quickly with the rise in local sea level **(**Blama, 2012).

The island, best described as two lobes (northern and southern) connected via a thin shrub-covered tidal flat, has a mix of coniferous and deciduous tree types. It hosts a small population of deer that migrate to the island via ice during the winter. Along with deer, a resident population of raccoons, fiddler crabs, and other small ground animal species inhabit the island. The island continues to be a stop-over location for a variety of migratory birds as well as a place for improving environmental abundance. It is located in Dorchester County, Maryland, which ranks first in the abundance of coastal wetlands areas in the mid-Atlantic region (approximately 37-45% of total county area) (Reyer and Shearer, 1990).

Although never formally inhabited, a few fish camps and waterfowl hunting lodges were built on the island in the past century. The island came under the jurisdiction of the U.S. Fish and Wildlife Service (USFWS) in 1993. The USFWS placed the newly acquired island within the Blackwater National Wildlife Refuge in an attempt to return the island to its previous condition.

The water level data collected from the Barren Island tide gauge from January, 2002 to March, 2003 showed that there were strong similarities in water level behavior with the nearby Solomons Island gauge. Accordingly, due to these similarities and its long time series record, Solomons Island serves as a proxy used for comparative analysis to Barren Island, as a way to continue approximate observations once the gauge was removed.

Figure 1. Barren Island was once part of the Delmarva Peninsula, but has eroded over time into two remaining sections connected by a tidal flat (USACE, 2009).

2. BACKGROUND

Starting in 1989, Barren Island was a U.S. Army Corps of Engineers (USACE) demonstration project for the beneficial use of dredged material. Barren Island became an opportunity for an array of federal, commercial, and community organizations to use their particular expertise together for a common benefit—tidal marsh restoration. This collaboration presented a unique set of obstacles not found at most tidal marsh restoration sites, thus allowing scientists to use a variety of new techniques such as Kinematic Global Positioning System (KGPS), inundation analysis, and Geographic Information System (GIS) modeling.

Prior to 2002, USACE had multiple placements of several large geotextile tubes (i.e., geotubes) composed of high-strength UV-resistant nylon and filled with dredged material on the northwest corner (bayside) of Barren Island's northern lobe (Davis and Landin, 1997). These geotextile tubes (Figure 2) served a dual role: 1) a sediment retention structure for dredged material pumped from a nearby shipping channel, and 2) a wave break for protection of Barren Island's quickly eroding shoreline. USACE pumped and graded several thousand cubic yards of dredged material with similar characteristics to those found naturally on Barren Island on the landside of the geotubes to create new marsh uplands (Blama, 2012.

Figure 2. Geotextile tubes were placed on the northwest side of Barren Island by USACE to retain dredge material used to create new marsh uplands while providing a wave break for the eroding island.

The National Aquarium in Baltimore (NAIB), with help from the Beaufort Laboratory of the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Coastal Ocean Science (NCCOS) and Restoration Center (RC), conducted a preliminary investigation of the biological and botanical species found on the island. To help NOAA and NAIB scientists determine baseline vegetation type and structure, the restoration site was surveyed along several transects. Biological transects extended from the upland/tidal marsh boundary to the low marsh/bay (open water) interface. The profiles created from these transects provided data on the relationship of vegetation type (species) to the gradient of the existing marsh plane and overall coverage of vegetation at the restoration site. Two species of marsh grass, *Spartina alterniflora* and *Spartina patens*, were selected as the best match for the island's natural species. These marsh grass species serve as both a habitat for small Barren Island fauna and retention of dredged material.

The Center for Operational Oceanographic Products and Services (CO-OPS) recommended that a minimum of a 1-year data series from a water level gauge would be critical in determining tidal datum elevations. It would also provide key high water information for comparison to other long-term water level stations, particularly as a reference for sea level trends. To ensure vertical and horizontal stability of the water level station and other elevations, NOAA's National Geodetic Survey (NGS) installed a series of deep rod bench marks. These tidal bench marks were connected to the geodetic datum, North American Vertical Datum of 1988 (NAVD88), via second order leveling and KGPS techniques, thereby establishing a vertical reference frame for the tidal datums. This reference frame was used to depict various tidal scenarios onto Digital Elevation Models (DEMs) described later in this case study. KGPS elevation data were also collected for the marsh surface, geotubes, and various elevations of interest at the site. These data were critical for the proper placement of marsh grass vegetation and determining the compaction and movement of dredged material.

3. METHODS

3.1 Hydrodynamic determination

To better understand and analyze the waters affecting the Barren Island marsh site, two different types of instrumentation were deployed to collect data. First, a NOAA water level station was installed on the northeast coast, designated as Barren Island, MD (8571579). The water level station collected a total of 11 months of data over a 14-month period from January, 2002 to March, 2003.

Due to Barren Island's lack of buildings and/or permanent fixtures, a small, heavily reinforced tide stand was built adjacent to a seawall. A weatherproof box mounted to the tide stand enclosed a data collection platform (DCP), nitrogen gas tank, IP modem, Paroscientific pressure gauge, and batteries for instrument operation (Figure 3). A semi-hard rubberized tube connected the Paroscientific pressure gauge inside the box to a brass tide orifice mounted to a piling in waters off the seawall. This nitrogen gas-driven digital pressure sensor converted the pressure from the amount of water above the orifice into elevation. Barren Island's remote access forced NOAA scientists to rely on two solar panels for instrument power instead of a power grid connection. This power combination (batteries and solar panels) allowed the station to continuously collect tidal and meteorological data, such as wind speed/gust, wind direction, and barometric pressure, whether in darkness or during large weather events.

Communications with the water level station via IP modem were critical in assessing and making changes to the DCP and instrument configurations because access to the water level station could only be attained by boat. A Geostationary Operational Environmental Satellites (GOES) antenna mounted to one of the platform's two masts delivered tide and meteorological data every 3 hours to NOAA headquarters in Silver Spring, Maryland where it could be processed and quality assured. Water level data were collected at 6-minute intervals and meteorological data were collected at hourly intervals. The data obtained from this station were used to determine tidal datums, relate weather events with tidal outliers, and understand long-term sea level trends at Barren Island.

Figure 3. Barren Island water level station featuring GOES antenna, solar panels, barometer, and wind sensor (anemometer).

The other tools for analyzing the hydrodynamics around Barren Island were two distinctive measurement systems for collecting waves and currents. The first, a TriAxys® wave buoy (Figure 4), was moored in two different locations near Barren Island for a total of 1.5 months (October–November 2002). The first location placed the buoy 0.4 miles northwest from the restoration site while the second location was 2.1 miles from the southern tip of the island. At each location, the buoy was moored in approximately 13 feet of water and had a scope of 25 feet. The wave buoy's ability to operate and collect data in shallow water conditions was vital to NOAA scientists' understanding of the wave regime that affected the Barren Island shoreline. The wave buoy measured significant wave heights, wave period, and wave direction by using six different motion sensors and a fluxgate compass to correlate its movement and position in relation to the earth's gravitational field. A directional radio high frequency (RHF) antenna at a base station on the Eastern Shore mainland was used in conjunction with the buoy's line of sight radio to receive wave data every 28 minutes. These data were then downloaded and sent to NOAA headquarters in Silver Spring, Maryland where they could be analyzed. This allowed NOAA scientists to access the status of the wave buoy and its data before the wave buoy recovery date.

Figure 4. TriAxys® Wave Buoy collecting data in waters around Barren Island.

Another oceanographic measurement system, an acoustic Doppler current profiler (ADCP) (Figure 5) with Waves® software from RD Instruments was operated simultaneously with the wave buoy. This bottom-mounted ADCP w/ Waves® software was beneficial to the project area because it could be placed in deeper waters outside the near-shore zone, thereby giving NOAA scientists a variation of wave/depth data to compare with the wave buoy. The ADCP collected significant wave height, wave direction, and wave speed data based on three different measurement parameters. A pressure sensor measured long wave components, while orbital velocity and surface track were measured with the ADCP echo-ranging beam produced from the transducer head. The ADCP deployment window of October 2002 to January 2003 allowed for a 3-month collection of both current and wave data. This cross-comparison of data allowed NOAA scientists to quality-assure data while testing a new instrument (the TriAxys® wave buoy). The location of both the wave buoy and ADCP in relation to Barren Island can be found in Figure 6.

Figure 5. The bottom-mounted ADCP transducer head (in blue) can be seen as it is lowered to the Chesapeake Bay floor for waves and current data collection.

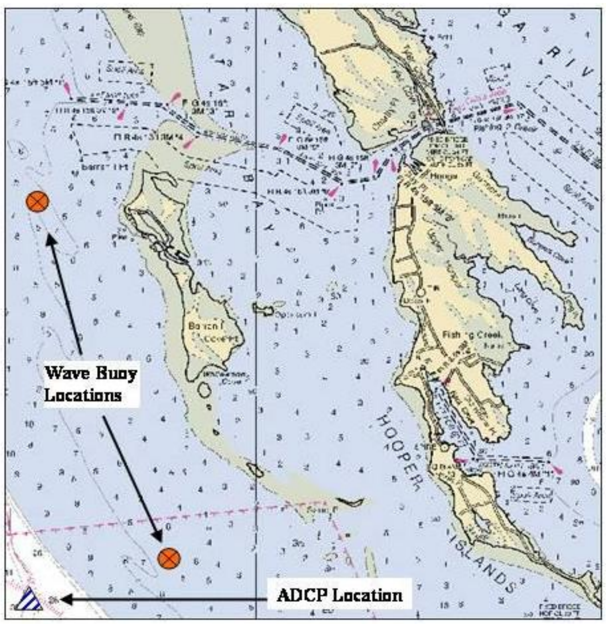

Figure 6. Locations of TriAxys® wave buoy and RD Instruments ADCP with Waves® software relative to Barren Island.

3.2 Geodetic investigation

In order to maintain long-term horizontal and vertical positioning on Barren Island, five deep rod tidal bench marks were installed to an average depth of 32.7 meters, the deepest being set to 53.6 meters. The upper portions of these rods were encased in a special greased sleeve to prevent upheaval by frost heaves that the island might incur during cold Bay winters. A steel-capped PVC pipe flange protected the rod tip bench mark from any overwashing episodes and allowed for easy recovery in the event that a future geodetic data collection was needed (Figure 7). These bench marks provided a framework for two separate styles of geodetic data collection that related tidal characteristics to the marsh surface, second-order leveling and kinematic/static GPS. This fundamental relationship was the basis for GIS data manipulation seen later in this case study.

Figure 7. Tidal bench mark with capped PVC flangedenoted as 8571579 A TIDAL.

Barren Island's remote location was a perfect situation for the utilization of GPS. Normally, several long and arduous 'over water' standard level runs would have been required to bring geodetic datums to the island. Simultaneous static GPS measurements made over a 2-day period tied Barren Island's network of tidal bench marks into NAVD88 through a high accuracy geodetic mark on a Hoopers Island bridge abutment. Using cross-comparison with an NGS Continuously Operating Reference Station (CORS) at Solomons Island, this static GPS setup attained accuracy levels of approximately 1–2 centimeters (cm) at the tidal bench marks on Barren Island. Tying into the mainland geodetic datums facilitated traditional second-order leveling. The tidal sensor and all tidal bench marks were referenced to each other using high precision digital barcode leveling instruments with matching and calibrated one-piece digital barcode invar rods. This method of leveling allowed for millimeter accuracy standards, and would be key in understanding any movement at the tidal sensor or long-term movement of the island itself.

Figure 8 shows KGPS being collected at different locations on Barren Island. KGPS, the use of a fixed GPS receiver base station located on a bench mark and a second 'roving' GPS receiver, was decisive in relating key marsh features to the geodetic framework. Two separate periods of KGPS data were collected for the Barren Island marsh site. These data sets were timed around the predicted low water events for Barren Island in order to reach as much of the marsh surface as possible. KGPS captured several unique marsh features, including several sand berms, distinct plant gradation, and the geotubes.

Figure 8. Kinematic GPS shows the roving receiver collecting data at various points of interest such as land/water interface, abrupt vegetation change, and geologic features.

Post-processed data points from the kinematic and static GPS collection methods were brought into GIS spatial software by NOAA scientists and used to create a Digital Elevation Model (DEM). An advanced Natural Neighbor interpolation me`thod (Sibson, 1981) allowed scientists to best describe the Barren Island terrain through statistical regression by modeling areas where GPS observations were not directly collected. Figure 9 shows KGPS data geo-located onto an aerial photograph of the restoration site, and Figure 10 shows the DEM developed from these data. On the DEM, the blue colors are below NAVD88 are the red colors are above NAVD88.

Figure 9. Kinematic GPS data overlaid on aerial photography of Barren Island.

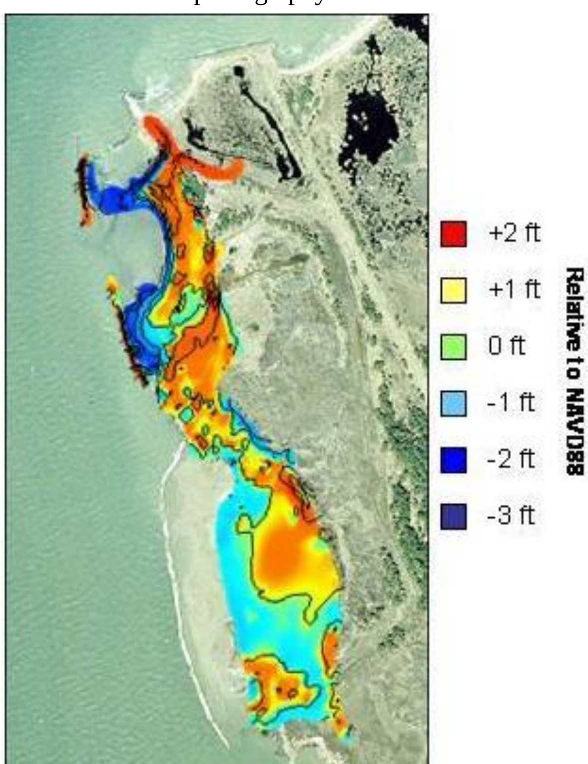

Figure 10. Digital Elevation Model (DEM) created from GPS data from Barren Island.

4. DATA ANALYSIS

4.1 Tidal datum computation

Tidal datums were computed for Barren Island using 11 months of data collected over a 14-month period (CO-OPS, 2003). A data set of this length was needed to factor seasonal, lunar, and solar variations of tidal components to produce a precise snapshot of water levels affecting the restoration site. The data collected indicated that the tidal characteristics of Barren Island were semidiurnal (two low tides and two high tides per day), similar to other locations in the Chesapeake Bay. Tidal datums were computed relative to the 1983–2001 National Tidal Datum Epoch using a comparison of simultaneous observations with the National Water Level Observation Network (NWLON) station at Solomons Island, MD[1] (CO-OPS, 2011). Figure 11 shows the accepted tidal datums relative to NAVD88 for Barren Island[2] (CO-OPS, 2005). Mean Lower Low Water (MLLW) was shown to be -0.370 meters (-1.21 feet) referenced to NAVD88 and Mean Higher High Water (MHHW) was shown to be 0.102 meters (0.335 feet) referenced to NAVD88. This results in a tidal range (GT) of 0.472 meters. Note that MLLW is below NAVD88 at this location.

Although this may not seem like a large difference, Barren Island has a maximum elevation of 1.829 meters (6 feet) above Mean High Tide (MHT) (Blama, 2012), and abnormally large tidal fluctuations and severe weather events allow water levels to inundate a large portion of Barren Island's flat terrain. NOAA scientists used a "Marsh Surface Control Point"—a previously established R-bar bench mark centralized to the restoration effort—to quality-assure geodetic/tidal data conformity prior to accepted datum configuration.

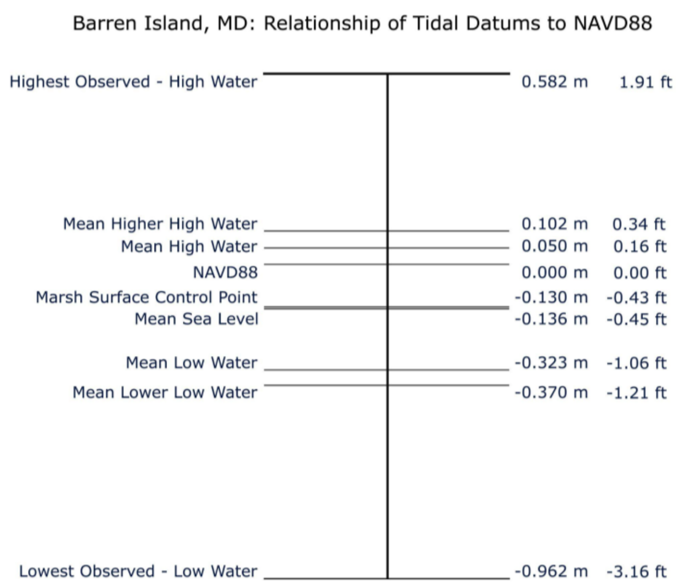

Figure 11. Accepted tidal datums are relative to NAVD88 for Barren Island over the 11-month gauge installation period.

However, since the data at Barren Island is very similar to Solomons Island, long-term station information from Solomons Island can be used as a proxy to show a progression of sea level trends for the life of the marsh surface at Barren Island. The daily and seasonal tidal signature at Solomons

[1] https://tidesandcurrents.noaa.gov/datums.html?id=8577330
[2] https://tidesandcurrents.noaa.gov/datums.html?id=8571579

Island was extremely consistent with that of Barren Island and revealed similar tide stages and patterns. The difference between Solomons and Barren's computed datums are plotted in Figure 12. A one month time series for January 2003 is shown below (Figure 13) with the overlapping residual between the two locations. The data shows Solomons Island captures the tidal variability over the course of the month, while the residual indicates some differences in amplitude with an average difference of 0.0232 m.

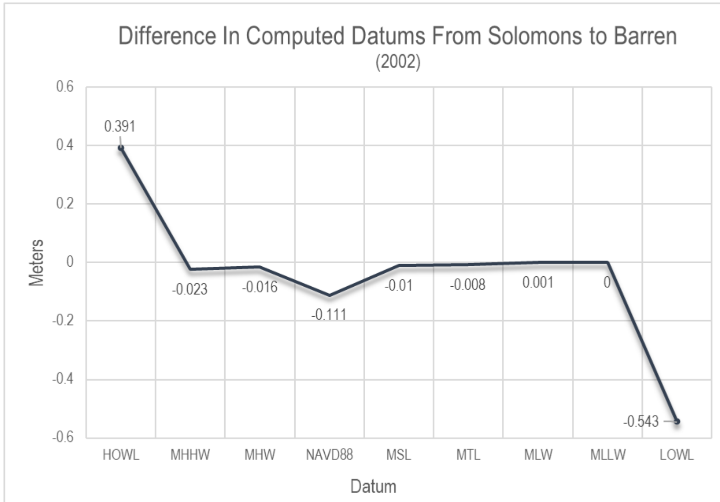

Figure 12. Differences in computed datums between Solomons Island and Barren Island.

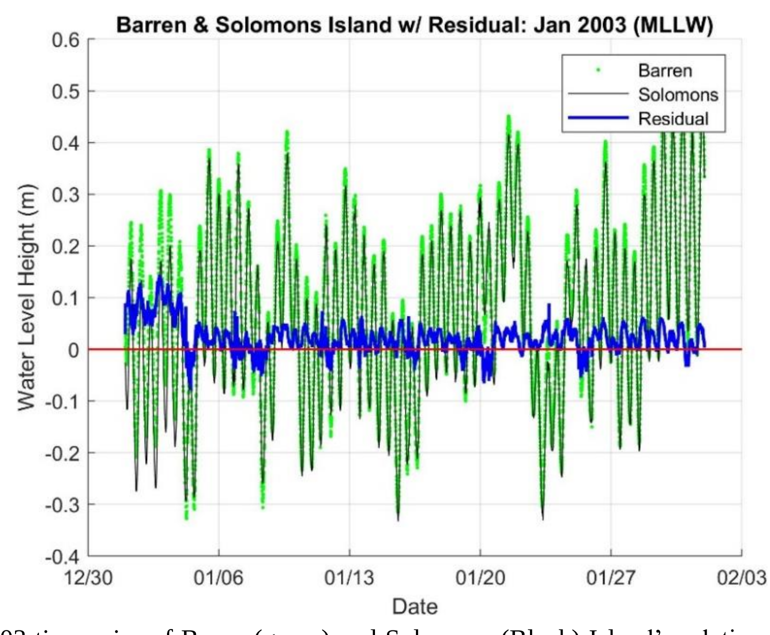

Figure 13. January 2003 timeseries of Barren(green) and Solomons (Black) Island's relative to MLLW. The residual (blue) between the two timeseries is plotted as well, with a mean difference of 0.0232 m.

An updated, long-term sea level trend for Solomons Island was calculated for the period of 1937 to 2020 (Figure 14). The updated relative sea level trend is 3.93 mm/year with a 95% confidence interval of +/- 0.230 millimeters per year (mm/yr) which is equivalent to a change of 1.29 feet in 100 years (Zervas, 2009). Barren Island, and the marsh restoration site, is expected to experience this same upward trend. The similarity between Barren Island and Solomons Island will allow for future tide level–marsh surface correlations without the need for an installation of a water level station on Barren Island itself.

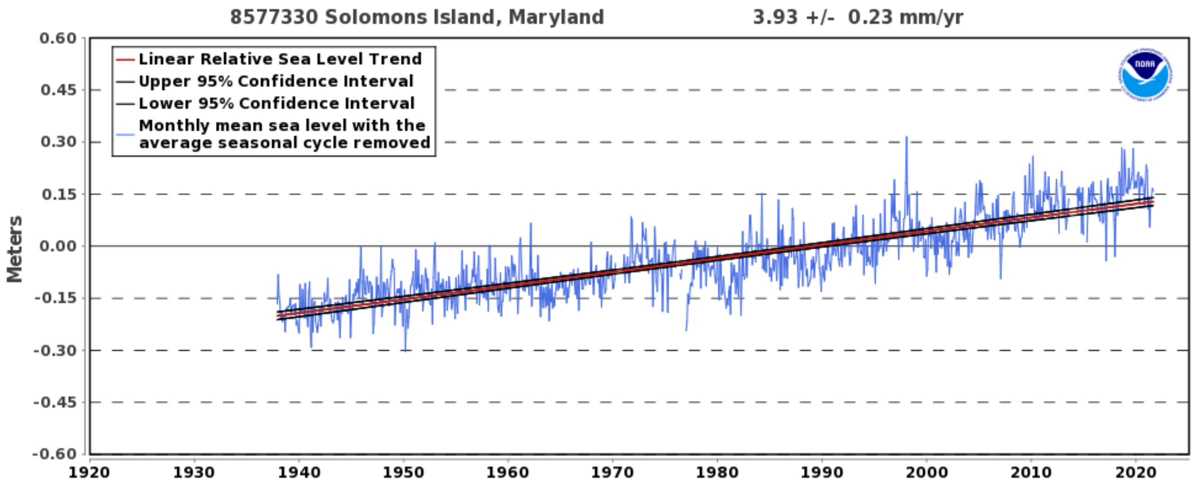

Figure 14. Solomons Island sea level trend based on data from 1937 to 2020.

Tidal analyses demonstrated that the number of tides per day and the equality of the two daily high tides allowed for the development of limits for specific marsh plants to thrive and grow (Zedler and Callaway, 2001). Specifically, for *Spartina alterniflora*, the elevational range was positively correlated with tidal range and that tidal range accounted for 70% and 68% of the variation in upper and lower limits of its distribution, respectively (McKee and Patrick, 1988; Zedler and Callaway, 2001). Also, the tidal datum of Mean High Water (MHW) typically delineates the boundary between *Spartina patens* and *Spartina alterniflora*, with *S. patens* inhabiting higher, less flooded areas lying above the MHW line and *S. alterniflora* requiring more drenched conditions below MHW (Gleason and Zieman, 1981).

4.2 Frequency and duration of inundation analysis

Information about the frequency and duration of water inundation is critical to the health and responsiveness of a working marsh. For this reason, the 6-minute high-water data from January 2002 through March 2003 at Barren Island were analyzed in order to place the two aforementioned species of marsh grass. A histogram of frequency versus elevations relative to MLLW for the observed high waters is depicted in Figure 15. The graph is partitioned off to highlight how many cumulative high waters affected each specific growing zone of marsh grass. Below MHW (or to the left) of the green dashed line shows the frequency at which high waters submerged the *S. alterniflora* zone while the right section delineates areas above MHW in which *S. patens* were inundated by high waters. Anything below MLLW likely would not have enough dry time to support effective growth of either species and was not included in these analyses.

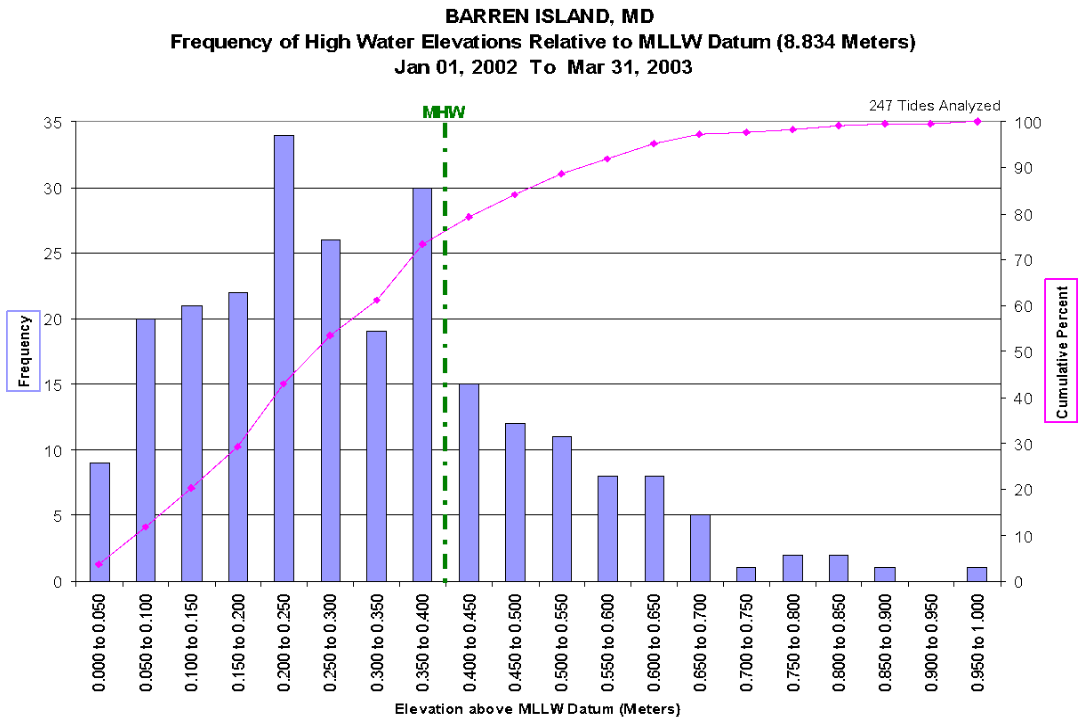

Figure 15. Frequency of high water elevations for Barren Island relative to the MLLW tidal datum.

Based on the cumulative percent in Figure 15, 74% of water levels fell between the published MLLW and MHW tidal datums. Once scientists had tidal datums and knew the positioning of the MLLW and MHW lines, special attention was given to the more pronounced inundation events. These outliers would be the critical survival point for the plant species, especially the *S. patens*, which needs fairly dry conditions (Gleason ML and Zieman JC., 1981).

Figure 16 shows the duration of inundation versus the elevation of high water above MHW. The figure portrays a relatively linear relationship between frequency and duration with the majority of inundation events lasting 7 hours or fewer. A few events, however, lasted more than 20 hours and overtopped MHW by over a half meter. Due to its flat terrain and narrow tidal range, Barren Island is highly susceptible to inundation caused by storm surge from extreme weather events.

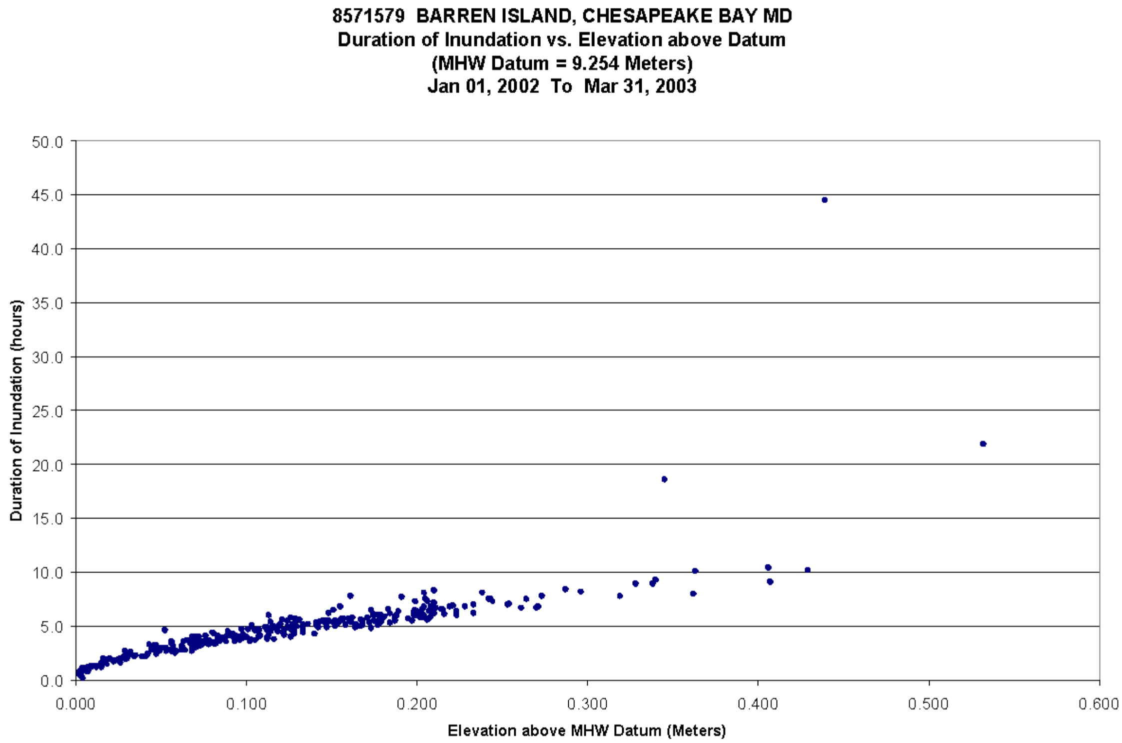

Figure 16. An inundation analysis for the 11-month period of water level data collected on Barren Island, MD from January 1, 2002, through March 21, 2003 relative to MHW.

4.3 Wave data

Early in the characterization of the Barren Island restoration site, scientists realized the critical role waves in shaping the coastline. The data produced by the two unique wave instruments, the TriAxys® wave buoy and the RD Instruments ADCP, reinforce this initial hypothesis. Barren Island, like other islands of the mid-Chesapeake Bay, is subjected to small (0.1 ft–2.8 ft), high frequency (3-8 seconds) waves that are induced by localized winds. Figures 17 and 18 show that these wind-induced waves are characteristic of the restoration site, as exemplified by the 4-day period of data from November 9–12, 2002 collected by the TriAxys® wave buoy. Figure 17 shows the relationship of wave period and direction from which the waves were transiting. NOAA scientists found that when the winds abated and changed directions, longshore Kelvin waves developed, as seen in Figure 17 on November 11, 2002 when the period jumped to around 26 seconds.

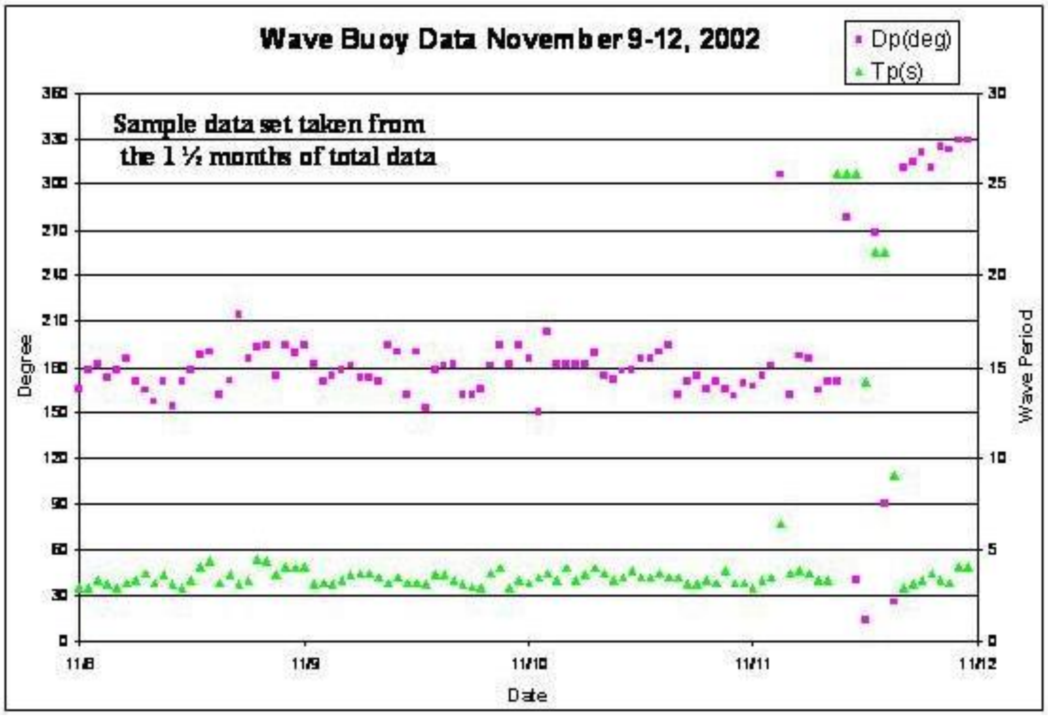

Figure 17. TriAxys® wave buoy data for Nov. 9-12, 2002 showing period (green dots) and direction (purple dots).

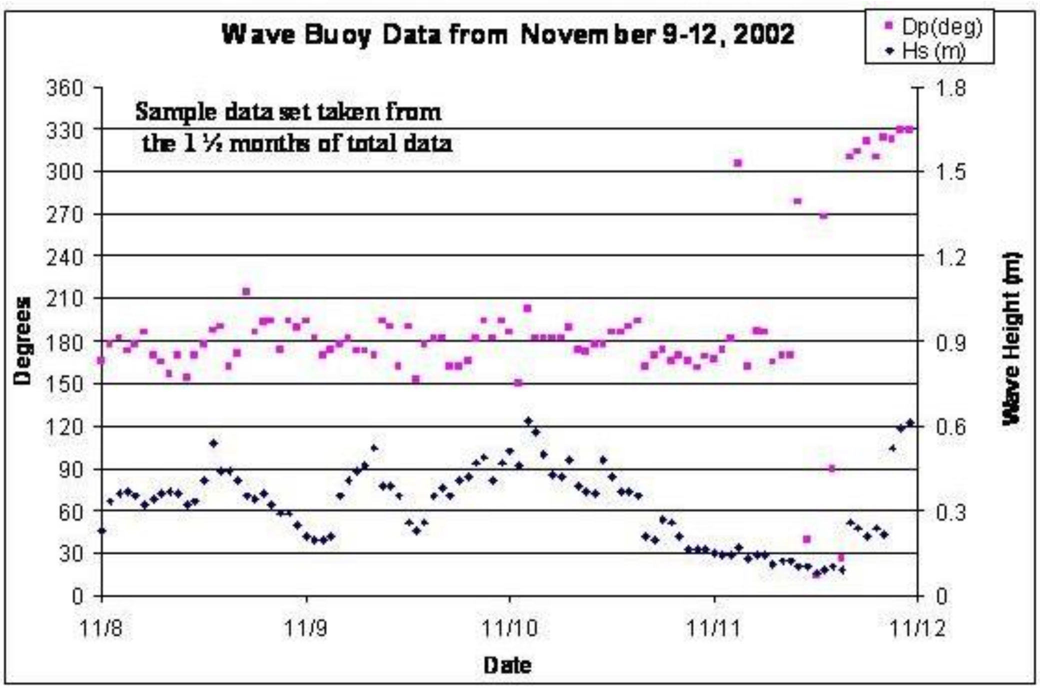

Figure 18. TriAxys® wave buoy data, typical of the entire data set describing wave height (black dots) and direction (purple dots).

Typically, this would not affect a normal coastline. Since Barren Island's shoreline mimics a clay shelf with no slope, this high period wave tends to erode the fine grain material very quickly. Also, the shape of the Chesapeake Bay's bathymetry near Barren Island demonstrates a gradual slope from the shoreline to a sudden, deep natural channel near the center, inducing what is known as a wave caustic or wave reflecting boundary. Thus, large waves created by vessel travel, specifically large displacement boats (tankers, cargo, etc.), are reflected between the shoreline and the caustic, giving more opportunities for the same energy to be potentially more destructive.

Data from the ADCP further supported the findings of high-frequency waves induced by local winds. Scientists used the ADCP to verify the newer TriAxys® buoy technology. Both instruments found that waves evolved from the northwest and south directions. This correlated well with the long fetches of open water in each of these directions relative to the Barren Island deployment site and restoration area. Almost 52% of waves affecting the Barren Island shoreline were from the northwest, which followed typical meteorological patterns for the area. Anemometers measuring wind direction co-located with the water level station operating during the time of ADCP data collection also measured a majority of winds from the northwest (i.e., strong correlation). , Another 21% of waves propagated from the south and most likely from the mouth of the Chesapeake Bay. The ADCP sensor in conjunction with the water level station meteorological sensors demonstrated a correlation between strong currents and high wind speeds to produce larger than typical wave fields affecting the island. Figure 19 shows a snapshot of the currents and waves. The currents for this area are produced by the filling and draining of the Chesapeake basin via tidal influence near its mouth at the Atlantic Ocean. The data collected from these instruments will not only help baseline environmental statistics for this area, but will be used in the construction of a new retention system for further restoration efforts.

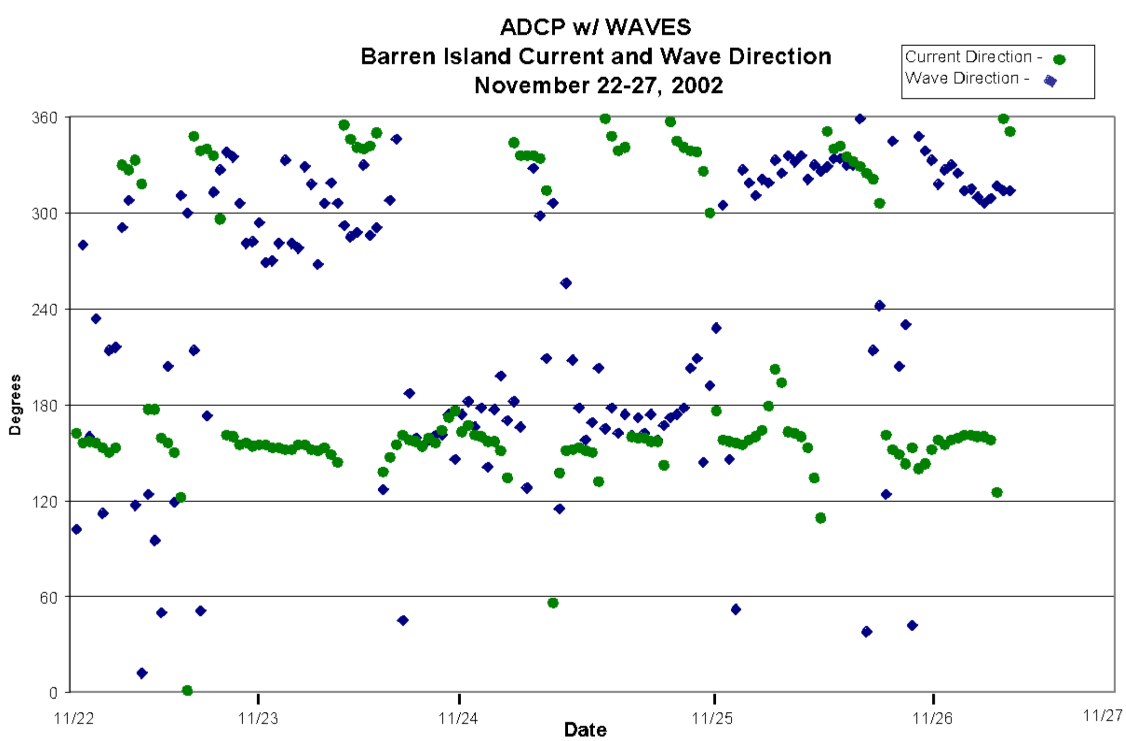

Figure 19. Wave direction (blue dots) and current direction (green dots) for a 5-day period in November 2002.

4.4 Water-marsh surface intersection determination

After data collection and analysis, NOAA scientists used a GIS platform to geo-locate and digitally integrate the various tidal, geodetic, and biological information. It is important to note that this piece of analysis was done after restoration efforts had taken place, but will be used in the future as a planning tool. This assimilation of unique data allowed scientists to visualize basic planning routines, such as specifying zones of optimal growth for each of the plant species, understanding the layout of the restoration area vertically, and making estimates on future personnel/cost needs.

As previously mentioned, MHW and MLLW values were used to delineate areas in which both *S. alterniflora* and *S. patens* would tend to thrive and take hold. Based on the digital integration of tidal and geodetic data, Figure 20 illuminates which areas, color-coded by species, would be optimal for planting marsh grass. Red zones (below MHW to the MLLW line) were the most beneficial for *S. alterniflora* and the blue zones (above MHW but below the MHHW) have the proper amount of water for *S. Patens.* Note the black zones—these are areas that received less than 2% of high-water inundation over the 11-month data series collected on Barren Island, and would likely be re-graded to match surrounding marsh heights or considered 'no plant' zones. These areas are likely to be much too dry for anything other than high marsh plants. Figure 21 shows the vertical relief of the restoration area and how digital interpolations can benefit a wetland biologist or restoration specialist. The severe slope from flat 'beach zone' to deep erosional pond portion was a consequence of a geotube failure. This same feature was reproduced in the grass optimization figure (Figure 20) with tight bands where each grass would thrive. Also, a long natural berm running from north to south just behind the restoration site was evident in the 3-D rendering of the aerial photograph.

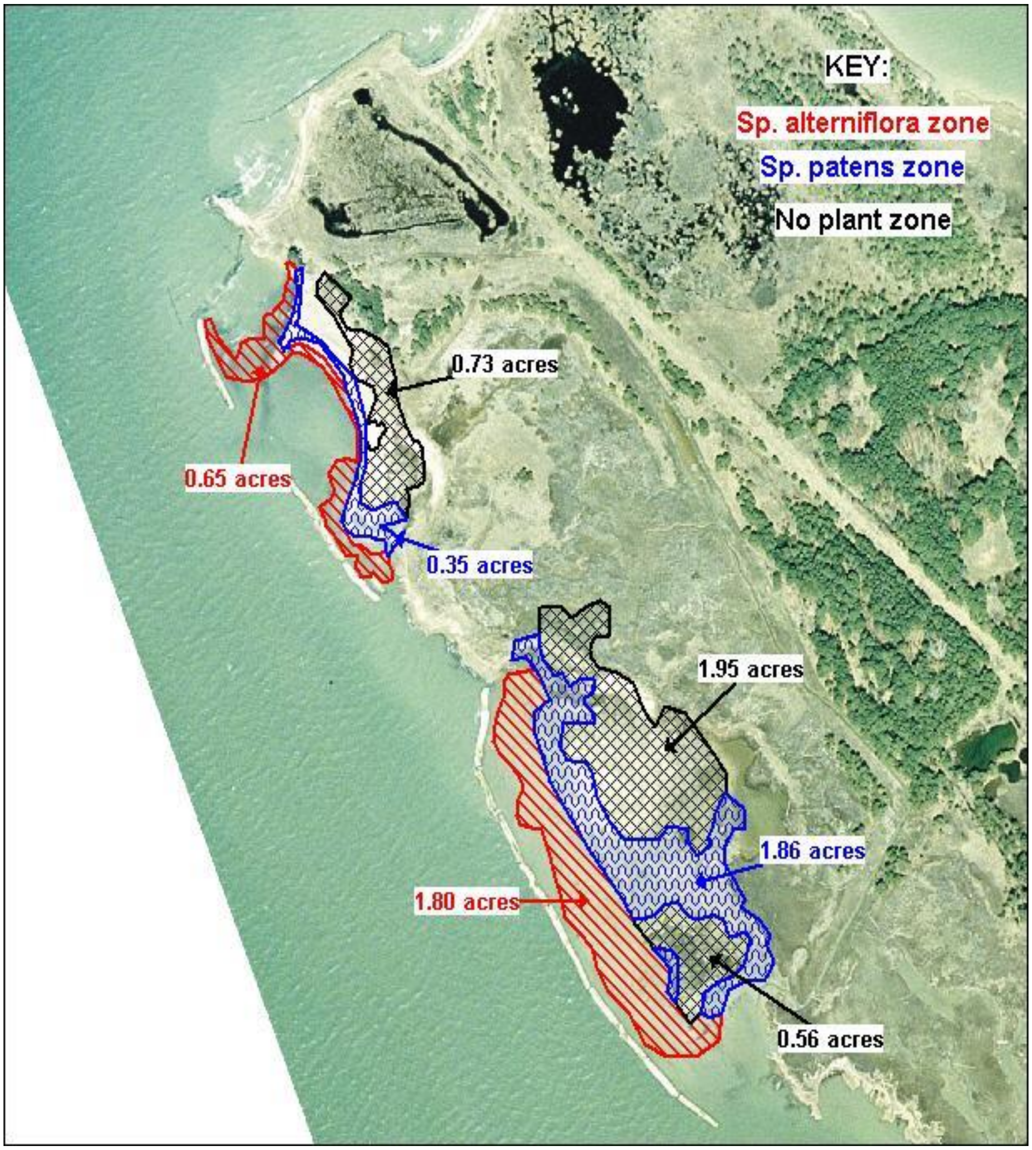

Figure 20. Optimal marsh grass tidal parameters overlaid onto an aerial photograph using KGPS.

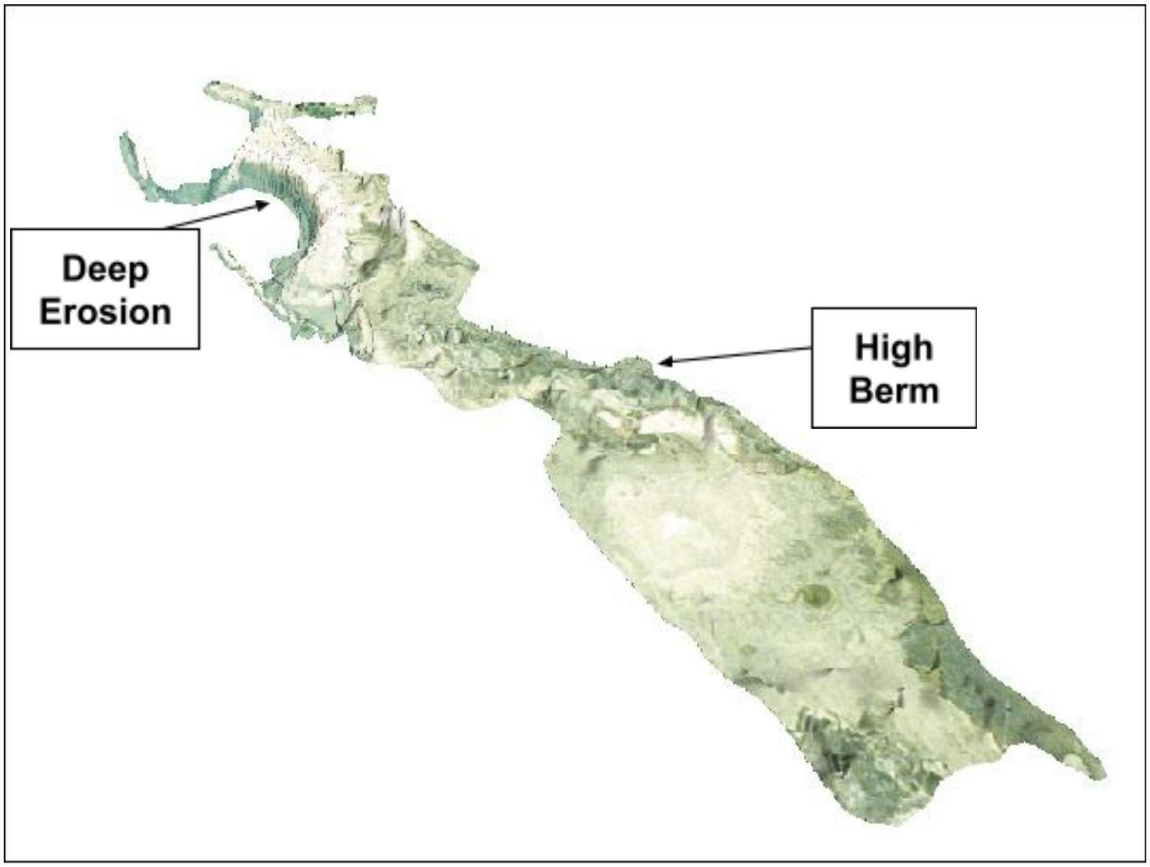

Figure 21. Aerial photograph digitized to show 3D heights of KGPS data collection.

CONCLUSIONS

NOAA worked with the National Aquarium, USACE, USFWS, NGS, and NOAA's Restoration Center on the large-scale Barren Island marsh restoration project. This project demonstrated a significant, beneficial use of dredged material. The USACE dredged from nearby navigation channels and deposited the tailings on the marsh face and land surface that had been eroded away by wave action. Geotubes were placed along the western side of the island to help protect the renewed marsh from erosion and to contain the dredged material. The island was still subjected to severe erosion, further observed when one of the original geotubes failed, resulting in scalloping. Water level information was collected and combined with the NGS-conducted KGPS surveys to determine Barren Island's marsh surface topography. Wave and current measurements were collected offshore and helped the USACE design further protective infrastructure. The results indicated that further water level data collection is not required at Barren Island as long as the Solomons Island gauge remains operational. The elevation data helped determine where to continue marsh restoration with seedling placement, placement and volume of dredged material on the subsiding marsh, and the height of the protective infrastructure. USACE built out Barren Island over the past decades and has continued building a large levee system. Elevations and high water analyses have been provided for designing and implementing future protective structures.

This project demonstrated the capabilities of integrating tidal and geodetic measurements with high water analyses, as well as analyses of wave and current data, to provide much-needed baseline information required by coastal engineers and marsh restoration scientists.

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APPENDIX A

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National Oceanic and Atmospheric Administration
National Ocean Service

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Station ID: **8577330** **PUBLICATION DATE:** **10/06/2011**
Name: **SOLOMONS ISLAND, PATUXENT RIVER MD**
NOAA Chart: **12284** **Latitude:** **38° 19.0' N (38.31667)**
USGS Quad: **SOLOMONS ISLAND** **Longitude:** **76° 27.1' W (-76.45167)**

T I D A L   D A T U M S

Tidal datums at SOLOMONS ISLAND, PATUXENT RIVER based on:

LENGTH OF SERIES:	19 YEARS
TIME PERIOD:	January 1983 - December 2001
TIDAL EPOCH:	1983-2001
CONTROL TIDE STATION:	

Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in METERS:

HIGHEST OBSERVED WATER LEVEL (09/01/2006)		= 1.343
MEAN HIGHER HIGH WATER	MHHW	= 0.449
MEAN HIGH WATER	MHW	= 0.404
North American Vertical Datum	NAVD88	= 0.259
MEAN SEA LEVEL	MSL	= 0.230
MEAN TIDE LEVEL	MTL	= 0.226
MEAN LOW WATER	MLW	= 0.048
MEAN LOWER LOW WATER	MLLW	= 0.000
LOWEST OBSERVED WATER LEVEL (01/01/1963)		= -1.135

North American Vertical Datum (NAVD88)

Bench Mark Elevation Information In METERS above:

Stamping or Designation	MLLW	MHW
7330 E 1980	3.321	2.916
NO 5 1937	4.508	4.104
10 1946	4.363	3.959
NO 11 1963	4.642	4.238
7330 C 1979	2.324	1.920
7330 D 1980	2.282	1.878
7330 F 1998	1.731	1.327
7330 G 2003	4.838	4.433
7330 H 2006	1.143	0.738
7330 J 2006	0.956	0.551

Figure A-1. Benchmark Sheet for Solomons Island, MD with respective tidal datums.

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Station ID: **8571579** **PUBLICATION DATE: 01/27/2005**
Name: **BARREN ISLAND, CHESAPEAKE BAY MD**
NOAA Chart: **12261** **Latitude: 38° 20.5' N (38.34170)**
USGS Quad: **BARREN ISLAND** **Longitude: 76° 15.9' W (-76.26500)**

T I D A L   D A T U M S

Tidal datums at BARREN ISLAND, CHESAPEAKE BAY based on:

LENGTH OF SERIES:	15 MONTHS
TIME PERIOD:	January 2002 - March 2003
TIDAL EPOCH:	1983-2001
CONTROL TIDE STATION:	8577330 SOLOMONS ISLAND, PATUXENT RIVER

Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in METERS:

HIGHEST OBSERVED WATER LEVEL (03/21/2003)		= 0.952
MEAN HIGHER HIGH WATER	MHHW	= 0.472
MEAN HIGH WATER	MHW	= 0.420
North American Vertical Datum	NAVD88	= 0.370
MEAN SEA LEVEL	MSL	= 0.240
MEAN TIDE LEVEL	MTL	= 0.234
MEAN LOW WATER	MLW	= 0.047
MEAN LOWER LOW WATER	MLLW	= 0.000
LOWEST OBSERVED WATER LEVEL (01/24/2003)		= -0.592

North American Vertical Datum (NAVD88)

Bench Mark Elevation Information In METERS above:

Stamping or Designation	MLLW	MHW
1579 B 2001	1.166	0.746
1579 A 2001	1.163	0.743
1579 C 2001	0.934	0.514
1579 D 2001	1.069	0.649
1579 E 2001	1.060	0.640
BARREN 3 1993	0.933	0.513
33B1 1	0.887	0.467
33B1 2	0.874	0.454

Figure A-2. Benchmark Sheet for Barren Island, MD with respective tidal datums.

Datums for 8577330, Solomons Island MD

NOTICE: All data values are relative to the MLLW.

Elevations on Mean Lower Low Water

Station: 8577330, Solomons Island, MD
T.M.: 0
Status: Accepted (Sep 30 2011)
Epoch: 1983-2001
Units: Meters
Datum: MLLW
Control Station:

Datum	Value	Description
MHHW	0.449	Mean Higher-High Water
MHW	0.405	Mean High Water
MTL	0.226	Mean Tide Level
MSL	0.231	Mean Sea Level
DTL	0.225	Mean Diurnal Tide Level
MLW	0.048	Mean Low Water
MLLW	0.000	Mean Lower-Low Water
NAVD88	0.259	North American Vertical Datum of 1988
STND	-1.135	Station Datum
GT	0.449	Great Diurnal Range
MN	0.356	Mean Range of Tide
DHQ	0.045	Mean Diurnal High Water Inequality
DLQ	0.048	Mean Diurnal Low Water Inequality
HWI	6.900	Greenwich High Water Interval (in hours)
LWI	0.930	Greenwich Low Water Interval (in hours)
Max Tide	1.343	Highest Observed Tide
Max Tide Date & Time	09/01/2006 23:24	Highest Observed Tide Date & Time
Min Tide	-1.135	Lowest Observed Tide
Min Tide Date & Time	01/01/1963 04:00	Lowest Observed Tide Date & Time
HAT	0.567	Highest Astronomical Tide
HAT Date & Time	09/17/1993 19:42	HAT Date and Time
LAT	-0.157	Lowest Astronomical Tide
LAT Date & Time	01/21/1996 13:30	LAT Date and Time

Tidal Datum Analysis Periods

01/01/1983 - 12/31/2001

Figure A-3. Datums for Solomons Island, MD with respective tidal datums.

Datums for 8571579, Barren Island MD

NOTICE: All data values are relative to the MLLW.

Elevations on Mean Lower Low Water

Station: 8571579, Barren Island, MD
Status: Accepted (Jan 26 2005)
Units: Feet
Control Station: 8577330 Solomons Island, MD

T.M.: 75
Epoch: 1983-2001
Datum: MLLW

Datum	Value	Description
MHHW	1.55	Mean Higher-High Water
MHW	1.38	Mean High Water
MTL	0.77	Mean Tide Level
MSL	0.79	Mean Sea Level
DTL	0.78	Mean Diurnal Tide Level
MLW	0.16	Mean Low Water
MLLW	0.00	Mean Lower-Low Water
NAVD88	1.22	North American Vertical Datum of 1988
STND	-28.98	Station Datum
GT	1.55	Great Diurnal Range
MN	1.22	Mean Range of Tide
DHQ	0.17	Mean Diurnal High Water Inequality
DLQ	0.16	Mean Diurnal Low Water Inequality
HWI	6.78	Greenwich High Water Interval (in hours)
LWI	0.76	Greenwich Low Water Interval (in hours)
Max Tide	3.13	Highest Observed Tide
Max Tide Date & Time	03/21/2003 08:36	Highest Observed Tide Date & Time
Min Tide	-1.94	Lowest Observed Tide
Min Tide Date & Time	01/24/2003 17:30	Lowest Observed Tide Date & Time
HAT		Highest Astronomical Tide
HAT Date & Time		HAT Date and Time
LAT		Lowest Astronomical Tide
LAT Date & Time		LAT Date and Time

Tidal Datum Analysis Periods
01/01/2002 - 01/31/2002
03/01/2002 - 09/30/2002
01/01/2003 - 03/31/2003

Figure A-4. Datums for Barren Island, MD with respective tidal datums.

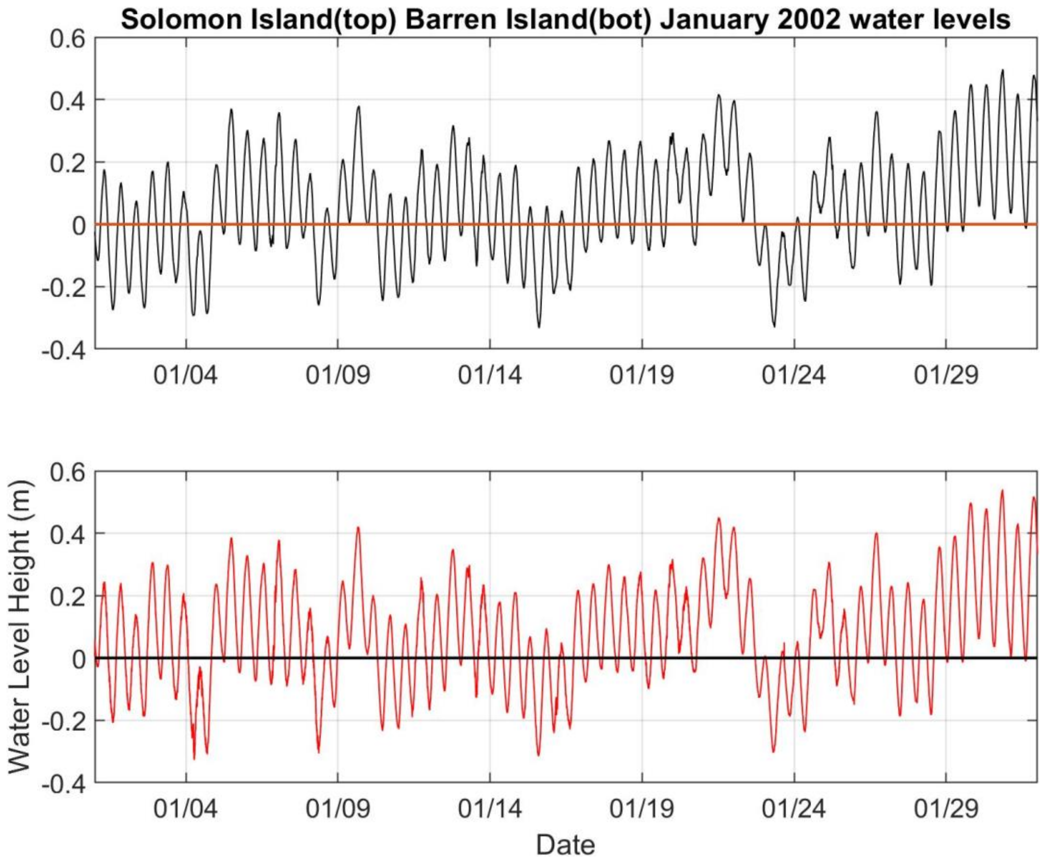

Figure A-5. Solomons Island and Barren Island water levels for January 2002.

ACRONYMS

Acronym	Term
ADCP	Acoustic Doppler Current Profiler
CO-OPS	Center for Operational Oceanographic Products and Services
CM	Centimeter
CORS	Continuously Operating Reference Station
DCP	Data Collection Platform
DEM	Digital Elevation Model
FT	Feet
GIS	Geographic Information System
GOES	Geostationary Operational Environmental Satellites
GPS	Global Positioning System
GT	Great Diurnal Range
KGPS	Kinematic Global Positioning System
MHHW	Mean Higher High Water
MHT	Mean High Tide
MHW	Mean High Water
MLLW	Mean Lower Low Water
MM/YR	Millimeters Per Year
NAVD88	North American Vertical Datum of 1988
NAIB	National Aquarium in Baltimore
NCCOS	National Centers for Coastal Ocean Science
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NWLON	National Water Level Observation Network
RHF	Radio High Frequency
RC	Restoration Center

Acronym	Term
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service