



Local, Short-Term Tidal Datums and Salt Marsh Elevations for Three Coastal National Parks:

Assateague Island National Seashore, Fire Island National Seashore, and Gateway National Recreation Area-Sandy Hook Unit

Natural Resource Report NPS/NCBN/NRR—2017/1462



ON THE COVER

Salt marsh during different tidal stages from the same day at William Floyd Estate, Fire Island National Seashore (S. A. Rasmussen April, 2015).

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Natural Resource Report NPS/NCBN/NRR—2017/1462

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June 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Rasmussen, S. A., A. J. Neil, M. Bradley, and J. Lynch. 2017. Local, short-term tidal datums and salt marsh elevations for three coastal national parks: Assateague Island National Seashore, Fire Island National Seashore, and Gateway National Recreation Area-Sandy Hook Unit. Natural Resource Report NPS/NCBN/NRR—2017/1462. National Park Service, Fort Collins, Colorado.

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Executive Summary

Three coastal parks in the Northeast Coastal and Barrier Network (NCBN) of the National Park Service (NPS) were impacted by Hurricane Sandy in October 2012: Assateague Island National Seashore (ASIS), Fire Island National Seashore (FIIS) and Gateway National Recreation Area (GATE). These parks have salt marsh ecosystems susceptible to future storms and sea level rise. To better understand how these dynamic systems may change, a series of water level loggers were deployed at different salt marsh sites within these three parks. The duration of these deployments ranged from 5-32 months. In 2014, the University of Rhode Island-Environmental Data Center (URI-EDC) partnered with the National Park Service Northeast Coastal and Barrier Network (NCBN) to collect elevation, water level and vegetation data at salt marsh sites at ASIS, FIIS, and GATE-Sandy Hook Unit. We calculated tidal datums, mean high water (MHW), mean low water (MLW), and mean sea level (MSL) from these data at each of these marsh locations combined with marsh surface elevations using Real Time Kinematic Global Positioning System (RTK-GPS). Mean tidal datums from the short-term deployments and marsh surfaces were tied to a fixed orthometric datum (the North American Vertical Datum of 1988 (NAVD88)) (Geoid 12A) to insure inter-site comparisons and relatability to other data such as LiDAR.

Introduction

Salt marshes play a critical role in coastal ecosystems. They act as habitat for wildlife, buffer inland areas from storms, help control erosion, and they act as natural water filters. Low lying areas in National Parks such as salt marshes are especially vulnerable to inundation from sea level rise (Holgate and Woodworth, 2004; Kemp et al., 2011, Murdukhayeva et al., 2013) and changing intensity of storms (IPCC, 2013). As sea levels change, coastal ecosystems will also change. Understanding the impacts of these changes is a crucial part of protecting parkland and managing coastal resources. Salt marsh habitats are comprised of vegetation zones which exist at elevations corresponding with local tidal datums such as Mean High Water (MHW), Mean Sea Level (MSL), and Mean Low Water (MLW). The elevation of these vegetation zones sometimes differ by only a few centimeters (Takekawa et al., 2013). Salt marshes typically accrete as local sea levels rise (Cahoon, 2006), but if sea level rises faster than the marsh can accrete, these habitats may not survive. Complete and accurate local water level data coupled with salt marsh elevation measurements is critical for natural resource planning in these environments.

The NPS has a history of monitoring water level data in their parks by investing in low-tech water loggers (e.g. HOBO loggers, YSI pressure sensors, etc.) to provide short term, localized characteristics and have partnered with other agencies such as NOAA and the USGS to collaborate on higher-tech microwave and pressure gauges for more permanent, long term measurements. Third party researches such as universities have also operated water level devices in the parks. A complete historical record of a tidal database for each park can be found from NPS report, Database of Tidal Data Coverage in and Near Northeast Region National Parks (Neil and Babson, 2015). This is a compilation of historical tide gauge information from online resources including NOAA's Tides and Currents website as well as the USGS's National Water Information System Mapper. It also includes NPS staff and third party collaborators that have contributed other sources of water level information for the parks. In most cases, we did not use published tidal datums from NOAA CO-OPS because of the variability of water level observations at site specific locations (Ullman et al 2016) and because these datums use a tidal epoch (1983-2001) that does not capture recent (this decade) relative sea level rise (NOAA, 2017). In addition, there are not enough of these long term stations to be of use for ecological modeling of salt marsh dynamics on at the scale of the three parks in our study (NOS, 2014).

For this report, we present our data and water level analysis of 30 salt marsh sites that are part of Northeast Coastal and Barrier Network (NCBN) monitoring protocol. In addition, we developed some tidal flooding visualizations for each marsh using NOAA 2014 topo-bathy LiDAR.

Methods

Water Level Measurements

URI-EDC

Two different types of pressure sensor loggers were used for this project; a Sea-Bird Electronics (SBE) 26plus and the HOBO U20-001-04-TI. The SBE Seagauge Wave and Tide Recorder emits and records pressure readings to obtain water level measurements unaffected by wave action. It uses a quartz pressure sensor to provide wave and tide recording with mm resolution and an accuracy of 0.01% of full scale (SBE, 2013). The unit was strapped to a 55 lb cinder block and pinned to the bay floor with stainless steel rods driven in 2-3ft. Total weight of the system was 75 lbs. An RTK-GPS rover target was added to the mount in order to precisely survey the same location of the mount system (Figure 1). Raw data is uploaded from the unit and converted to psi units via SBE data processing software, Seasoft for Waves. Sampling intervals for the SBE were programed to 6 minutes with 180 second durations.

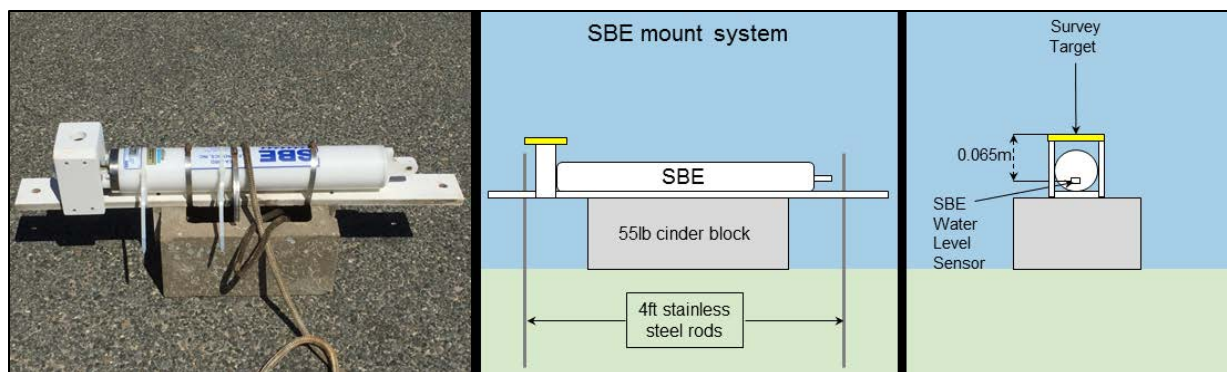


Figure 1. The Seabird mounting system.

The HOBO logger also measures pressure and converts to water height via HOBOWare-Pro software package, with a typical accuracy of 0.3cm (Onset, 2016). The HOBO was housed in a PVC container which was mounted to a 55lb cinder block and pinned to the bay floor with stainless steel rods driven in 2-3ft. A survey target was affixed to the PVC housing cap so repeated surveys could be performed on the same location in relationship to the logger sensor (Figure 2). The HOBO was attached to the end of the housing cap with galvanized steel wire. This method provides easy access to the HOBO for downloading data without disturbing the submerged mount system. Water heights above the sensor were manually checked at the time of deployment and retrieval and compared to the logged data to verify accuracy and account for movement and sensor drift. Sampling intervals for the HOBO logger were set to 6 minutes.

The atmospheric pressure needs to be accounted for and removed from the tide data for both logging units. Barometric pressure was downloaded from a second HOBO pressure sensor strapped to a tree located near the deployment site and used to subtract the atmospheric pressure via processing software. Final data output is expressed as depth in meters and exported as a CSV file. Finally, the

data are analyzed and archived with the Aquarius software package in accordance to NCBN Methods Document (Curdts, 2017).

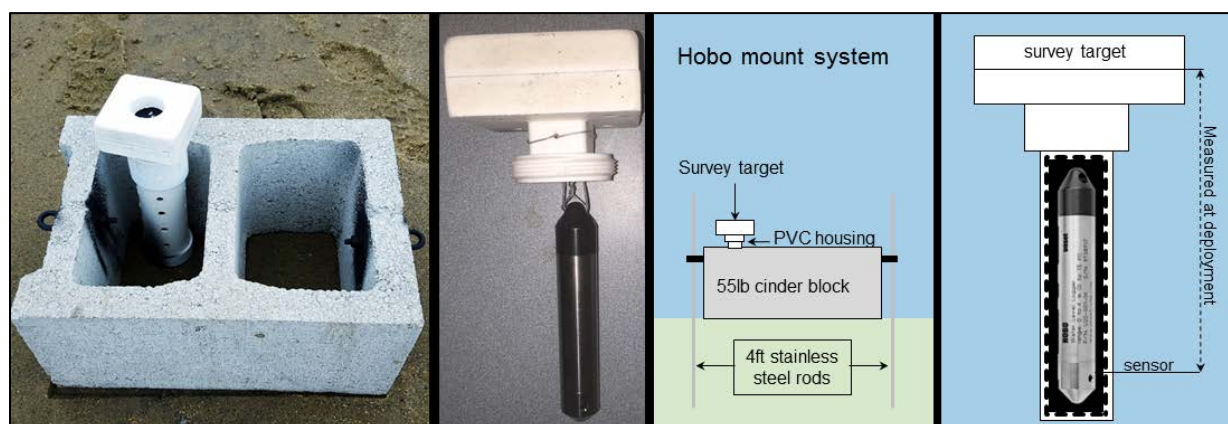


Figure 2. The HOBO mounting system.

NCBN

Data were collected by trained park or network staff using HOBO water level sensors (Figure 3) that collected measurements every 15 minutes when deployed. Measurements were typically collected from the spring (April/May/June) through the fall (Oct/Nov). Sensors were not always installed over the winter due to issues with ice. The datasets contain raw water level data that have been corrected to remove atmospheric pressure and provides the depth of water above the HOBO pressure sensor. This was done using the proprietary HOBOWare software.

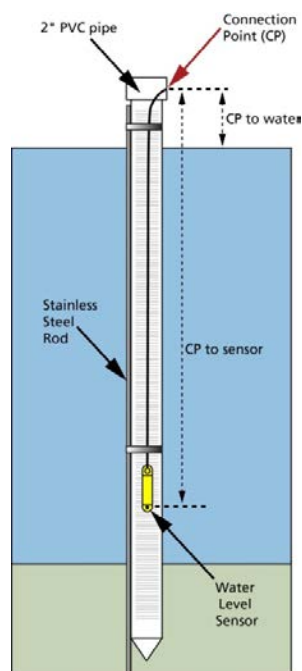


Figure 3. NCBN HOBO mounting system.

Tidal Datum Calculations

NCBN HOBO loggers were the sources of tidal datum calculations for each of the salt marsh sites at ASIS and FIIS. Additional water level observations were made by the URI-EDC at the Horseshoe and Spermaceti Marshes (M1 and M2) at the Sandy Hook unit of GATE. Because of its proximity, NOAA tide gauge 8531680 at Sandy Hook was used for marsh 3 (M3) and parts of M2 at Sandy Hook. Tidal datums such as MHW and MLW for the deployment periods were determined in an excel spreadsheet, which picked out high and low level values of each day, and manually verified as defined by NOS (2003). All sites are semi-diurnal, experiencing two high and two low water events each day. Measured water level values were converted to NAVD88 (Geoid 12A) values based on the average of the RTK-GPS elevation measurements performed on the water logger sensor at the times of deployment and retrieval.

Final tidal datum calculations used here represent conditions during the time of logger deployment and have not been tied into a NOAA-CO-OPS long term control station. Traditionally, observations at secondary and tertiary stations are not usually sufficient for a precise independent determination of tidal datum (NOS, 2003). Results may be obtained by comparison with simultaneous observations at a suitable control tide station (NOS, 2003). At long-term National Water Level Observation Network (NWLON) stations, where the required 19-year dataset is available, datums are computed directly by averaging monthly mean values over the entire National Tidal Epoch (NTDE). To derive datum elevations at a location with a shorter data record, monthly mean values are compared with values from a nearby long-term control station. Published datum elevations at the control station are used as baseline elevations. Computed datum elevation differences between the short term and control station, over the time period of the short term observations, are used with the accepted datum elevations at the control site to determine datum elevations at the short term site.

We did not tie our water level observations to the long term NOAA CO-OPS network because water levels in estuaries can be affected by restrictive channels and dominant wind directions, and therefore, caution should be used when tying to a control station that falls outside this zone (NOS, 2014). Furthermore, NOS (2014) has identified Chincoteague Bay, MD and the Great South Bay, NY as areas which fall within a gap polygon which lacks adequate long term water level data for datum derivations.

Tools such as NOAA's VDatum can be used to calculate tidal datums in areas that do not possess a long term control station. However, considerations in a variety of factors should be made over accuracy of these calculations, "including variations in tidal range, bathymetric and coastal features, the density and proximity of nearby geodetic and tide stations used in the corrections" (NOS 2012). NOS (2012) further states larger errors in the calculations are more likely to appear in upstream river environments and marshes.

Salt Marsh Elevations

Elevations of the salt marsh study sites were collected by kinematic GPS observations using survey grade Trimble R10 GNSS receivers and following NCBN protocols (Neil et al., 2017). A 20m grid was created within each study site in ArcMap v10.3 and exported as a CSV file into the GPS handheld controller. Grid points were navigated to via a stakeout survey style and surveyed using

either RTK or PPK (post processing) survey styles. Vertical accuracies of the points ranged from 2-4cm. A second benchmark with known coordinates was surveyed during the job to serve as a “Check-In” and was used to validate the accuracy of the survey. The raw elevation data were imported into Trimble Business Center (TBC) v3.5 for processing. All elevations were recorded in NAD83 (2011) and NAVD88 (Geoid 12A) meters and projected to UTM zone 18N coordinates.

Tidal Flooding Extent

Tidal Flooding maps are an additional aid to visually comprehend the extent of tidal flooding for each marsh site. They represent a “bathtub” (2D) model of flooding without the influence of wind or storm surge. Geographic extents of MHW and MLW are based on NOAA topobathy LiDAR (2014) data sets, which have been clipped at the values of MHW and MLW derived from data of the short term deployment for that site.

Assateague Island National Seashore

Data

Assateague Island National Seashore (ASIS) is a barrier island in Maryland and Virginia separating Chincoteague Bay from the Atlantic Ocean (Figure 4). Chincoteague Bay is connected to the ocean at Chincoteague Inlet to the south and Ocean City Inlet to the north. NCBN has maintained three HOBO water level loggers at marsh sites M5, M6, and M8 from March 2012 to the present. Four additional HOBO loggers were installed in September, 2014 at marsh sites 0.5KM, Developed Area (DA), Tingles (TN), and Big Levels (BL), and are currently deployed. Locations of these water loggers and salt marsh sites are labeled in Figure 4.

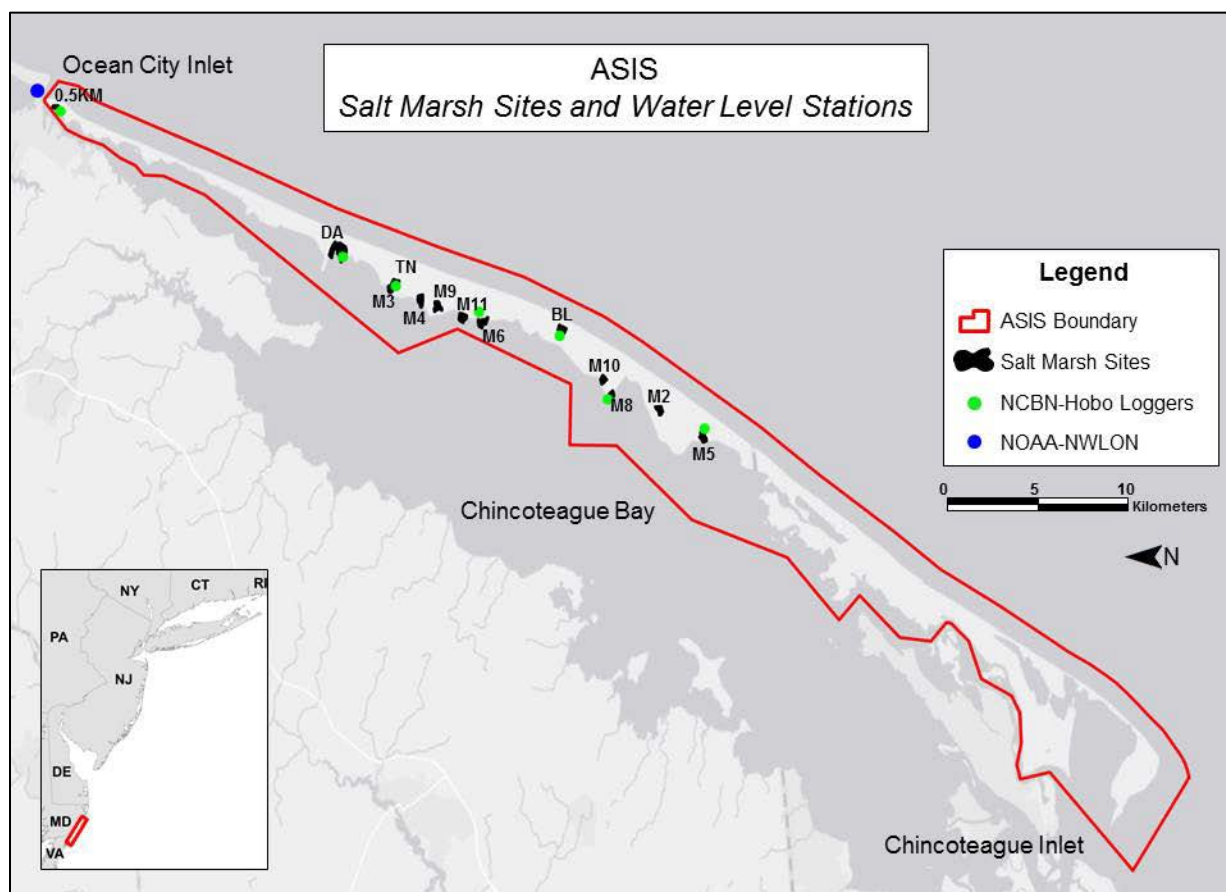


Figure 4. Location of salt marsh sites and water level loggers at ASIS. NWLON station at Ocean City for reference.

Results

RTK-GPS elevation points were collected in the fall of 2014. A total of 2218 points were taken on the marsh surface at 16 different sites. Points located on an upland or beach were mapped but were taken out of the analysis in order to represent the marsh surface. Figures 5-21 (from north to south) display the relationship of the marsh surface and local water levels at each marsh site. Marsh

elevation points are symbolized relative to local tidal datums (e.g., above or below MHW) derived from each water level logger.

Marsh Half Kilometer (0.5KM)

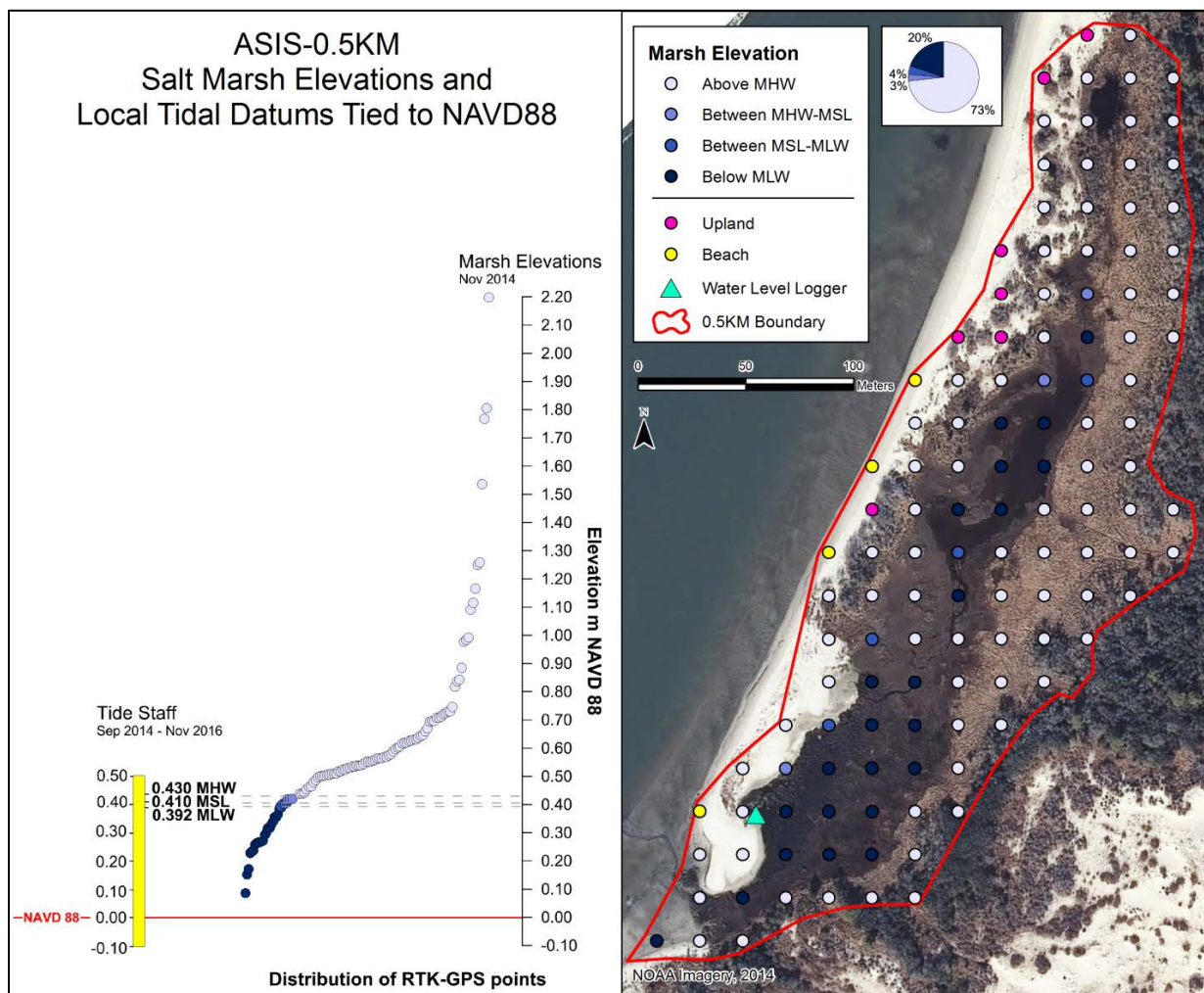


Figure 5. Relationship of salt marsh elevations with local tidal datums. Water logger was on site. *Note the water within the marsh becomes stagnant during low tides when the marsh is cut off from the bay via the narrow tidal inlet.

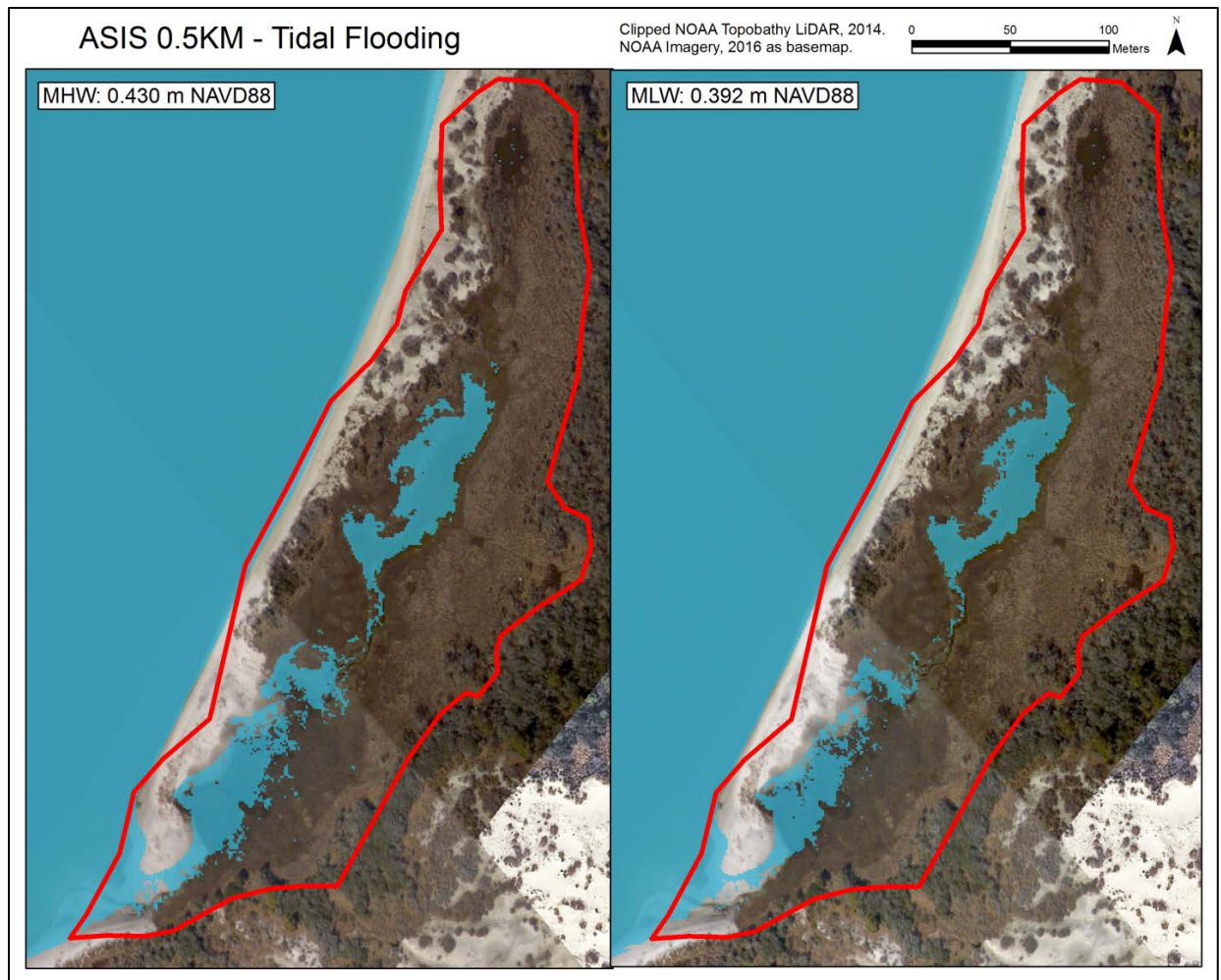


Figure 6. Extent of tidal flooding under MHW and MLW conditions at 0.5KM marsh. Water logger was on site. Geoid 12A used for GPS elevations.

Developed Area 1 (DA1)

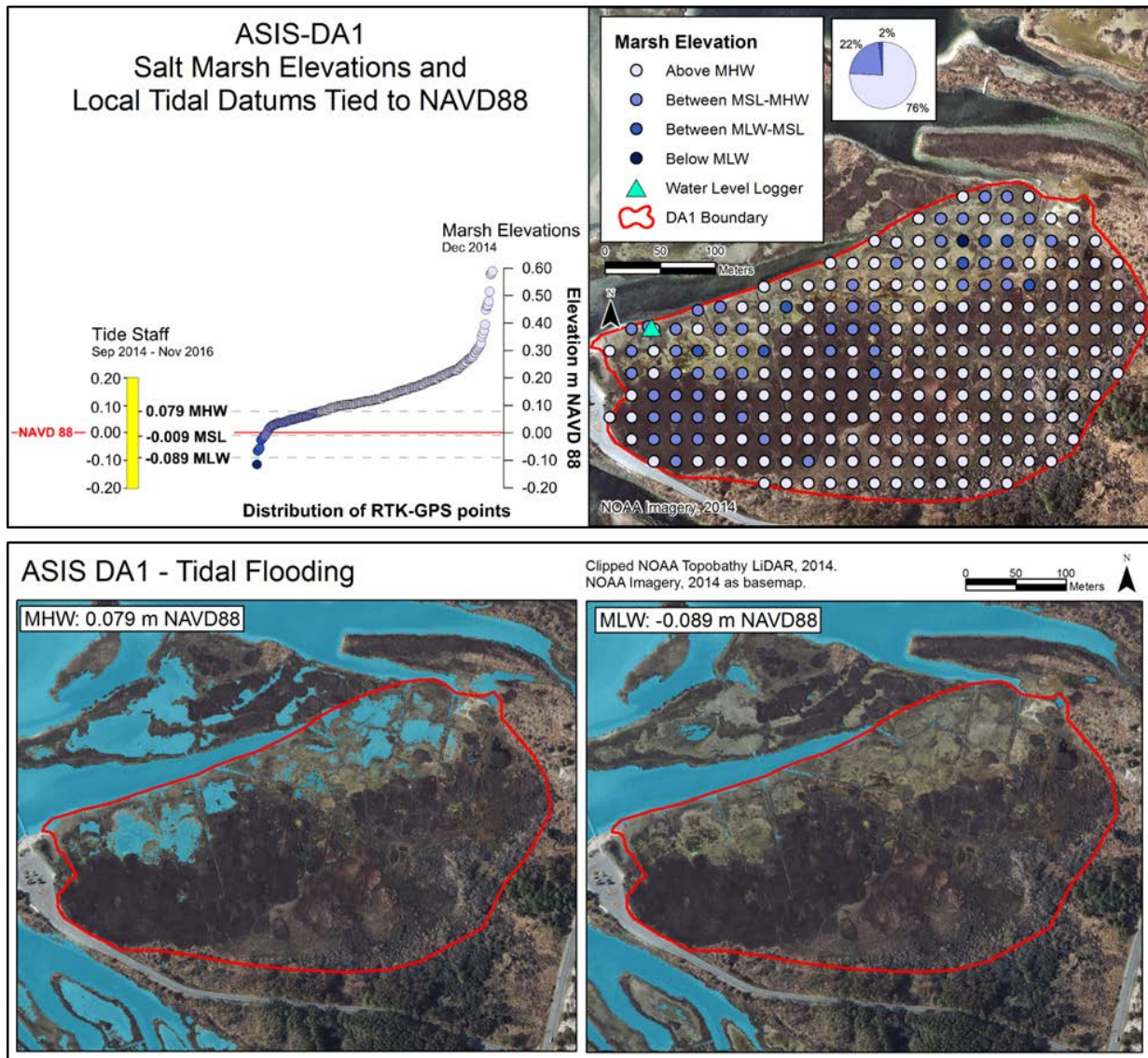


Figure 7. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at DA1 marsh. Water logger was on site. Geoid 12A used for GPS elevations.

Developed Area 2 (DA2)

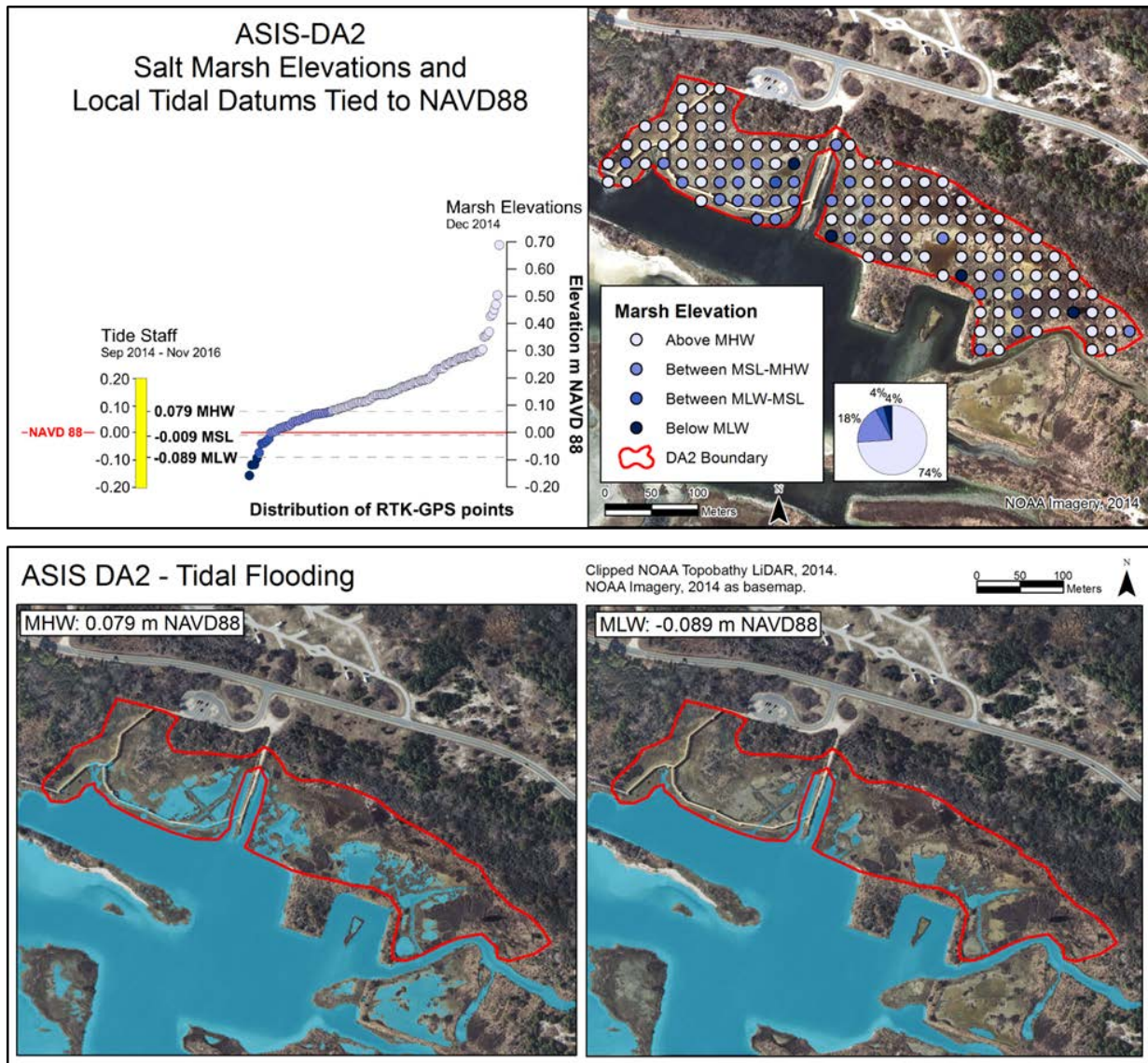


Figure 8. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at DA2 marsh. Tidal datums used from DA1. Geoid 12A used for GPS elevations.

Developed Area 3 (DA3)

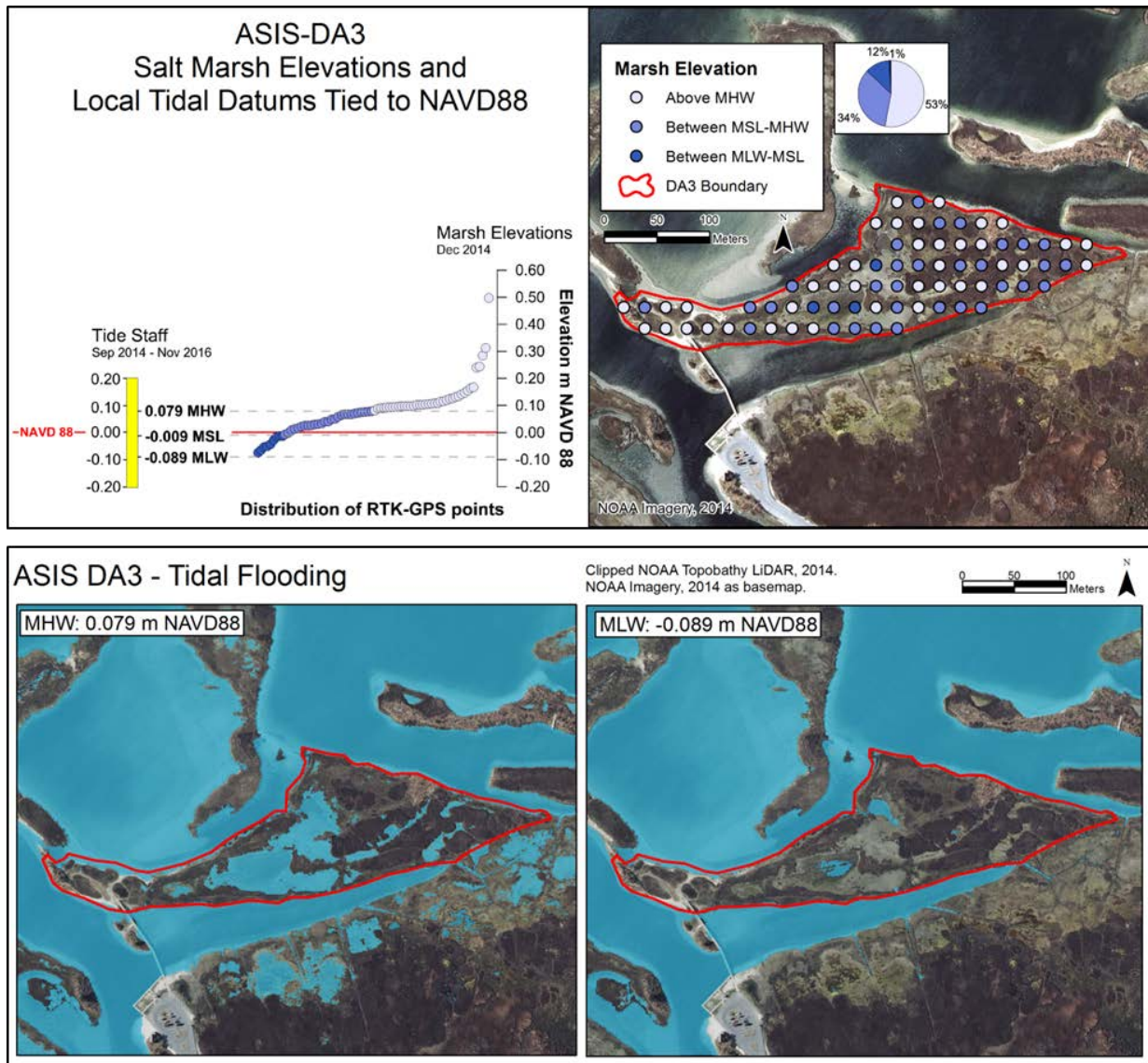


Figure 9. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at DA3 marsh. Tidal datums used from DA1. Geoid 12A used for GPS elevations.

Developed Area 4 (DA4)

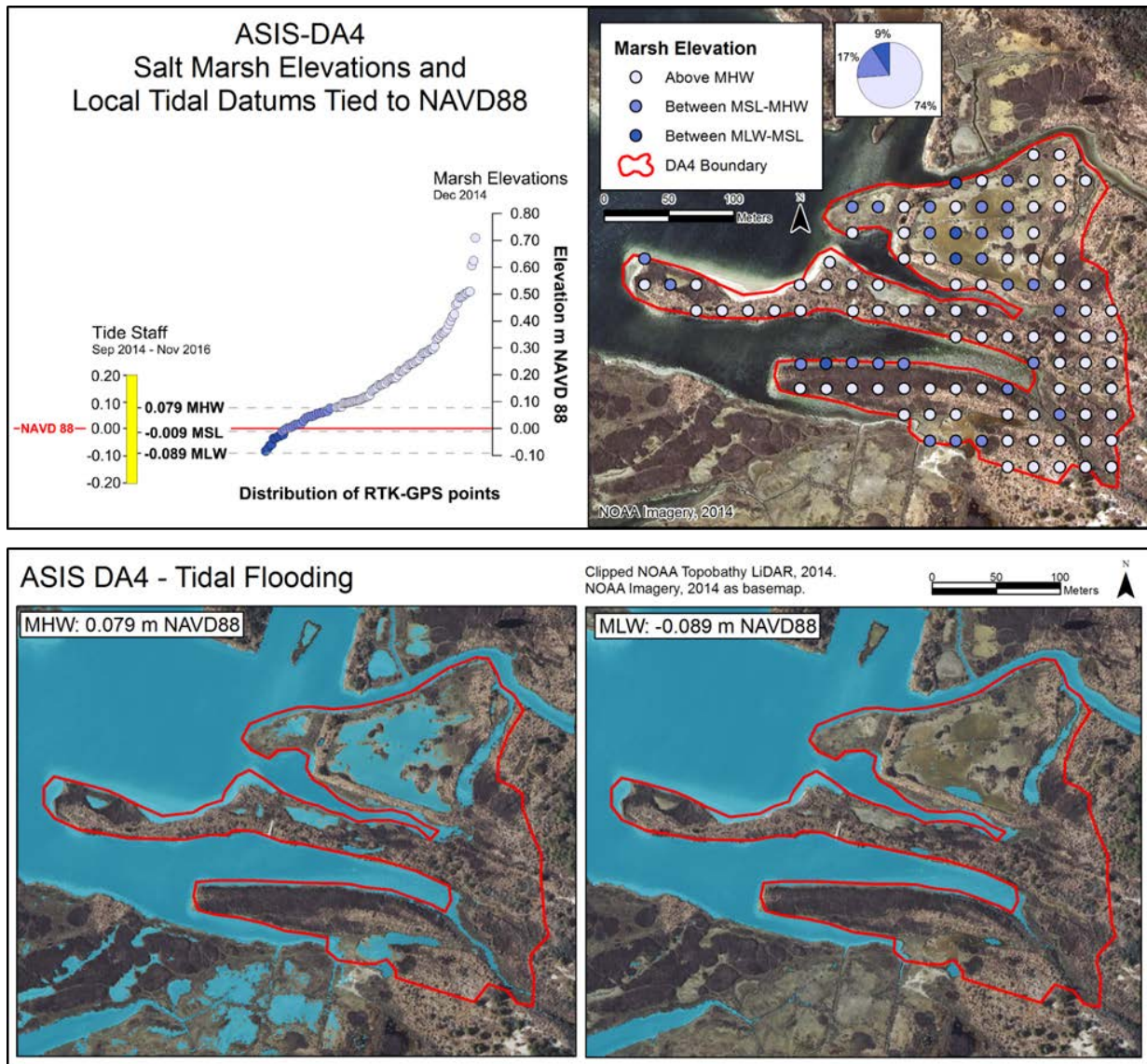


Figure 10. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at DA4 marsh. Tidal datums used from DA1. Geoid 12A used for GPS elevations.

Marsh 3 (M3)

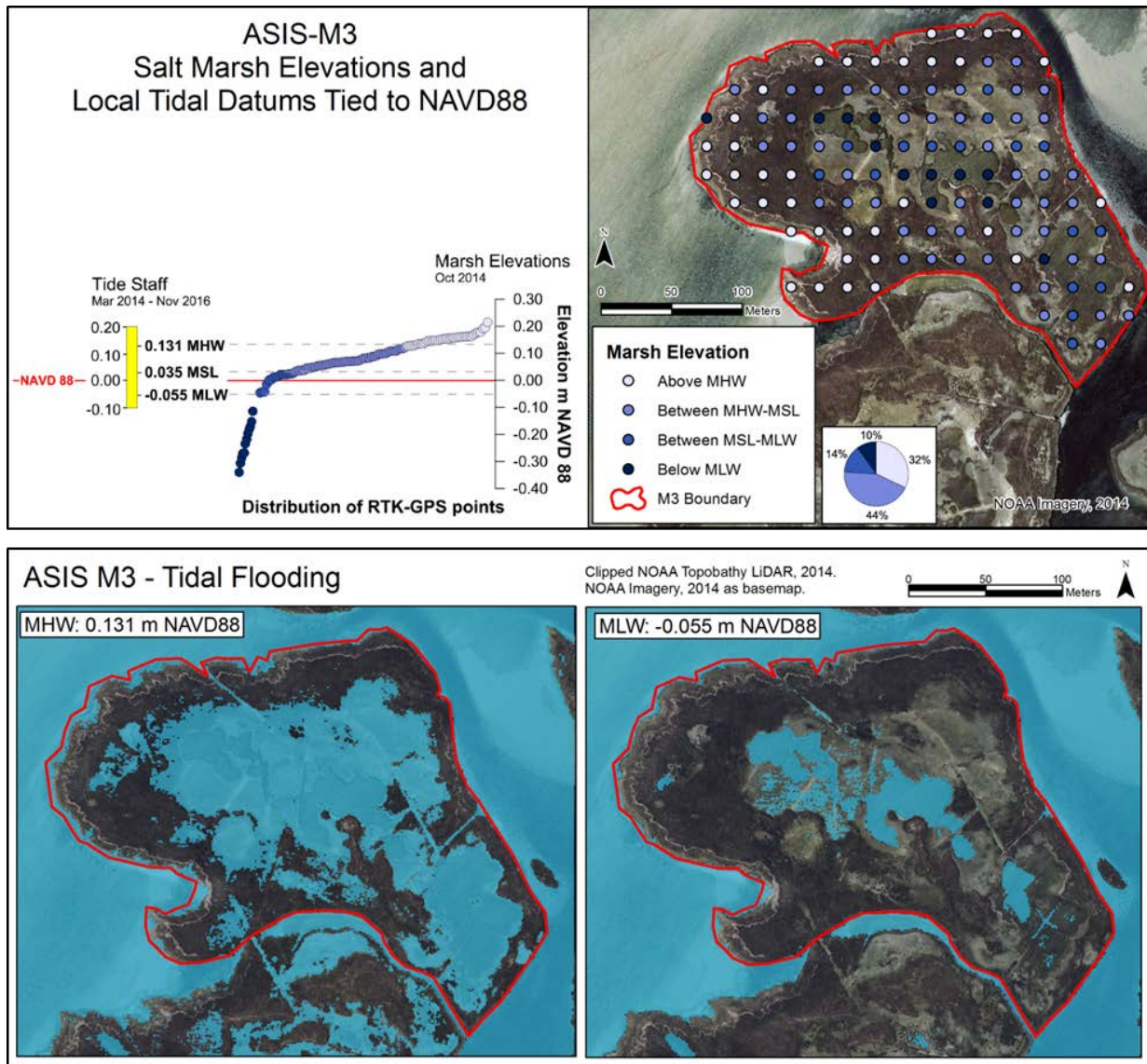


Figure 11. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M3 marsh. Tidal datums used from TN. Geoid 12A used for GPS elevations.

Tingles (TN)

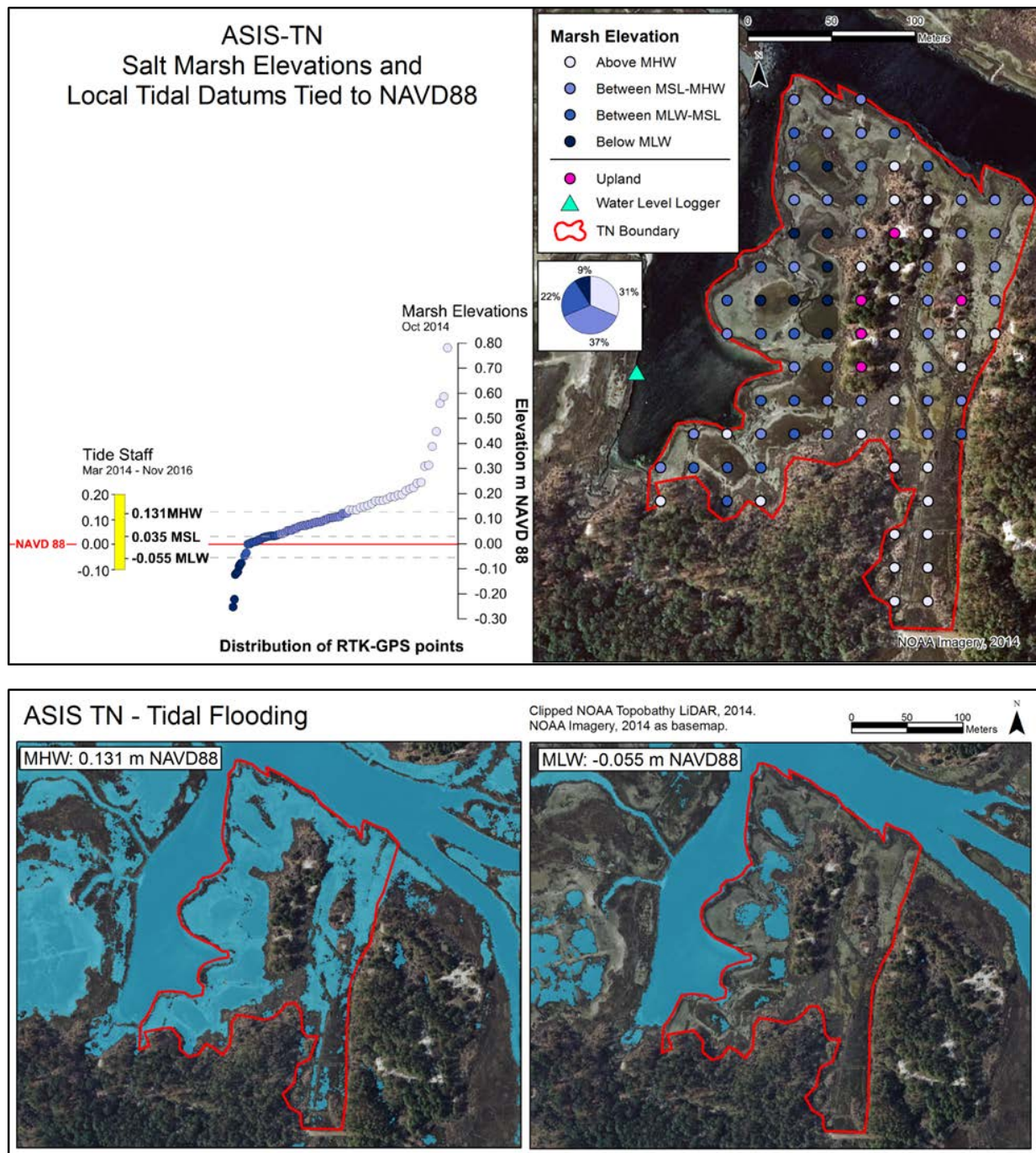


Figure 12. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at TN marsh. Water logger was on site. Geoid 12A used for GPS elevations.

Marsh 4 (M4)

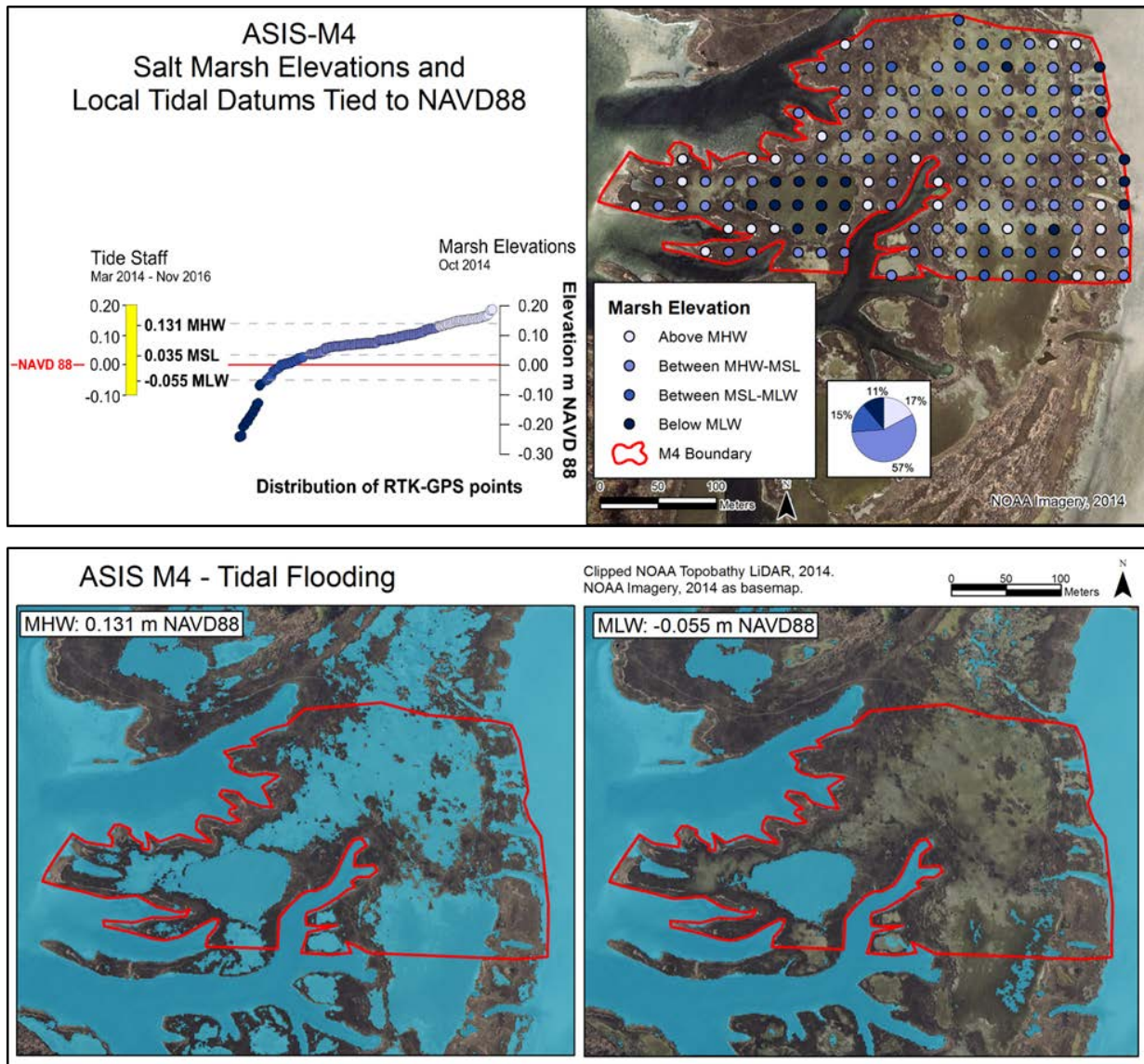


Figure 13. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M4 marsh. Tidal datums used from TN. Geoid 12A used for GPS elevations.

Marsh 9 (M9)

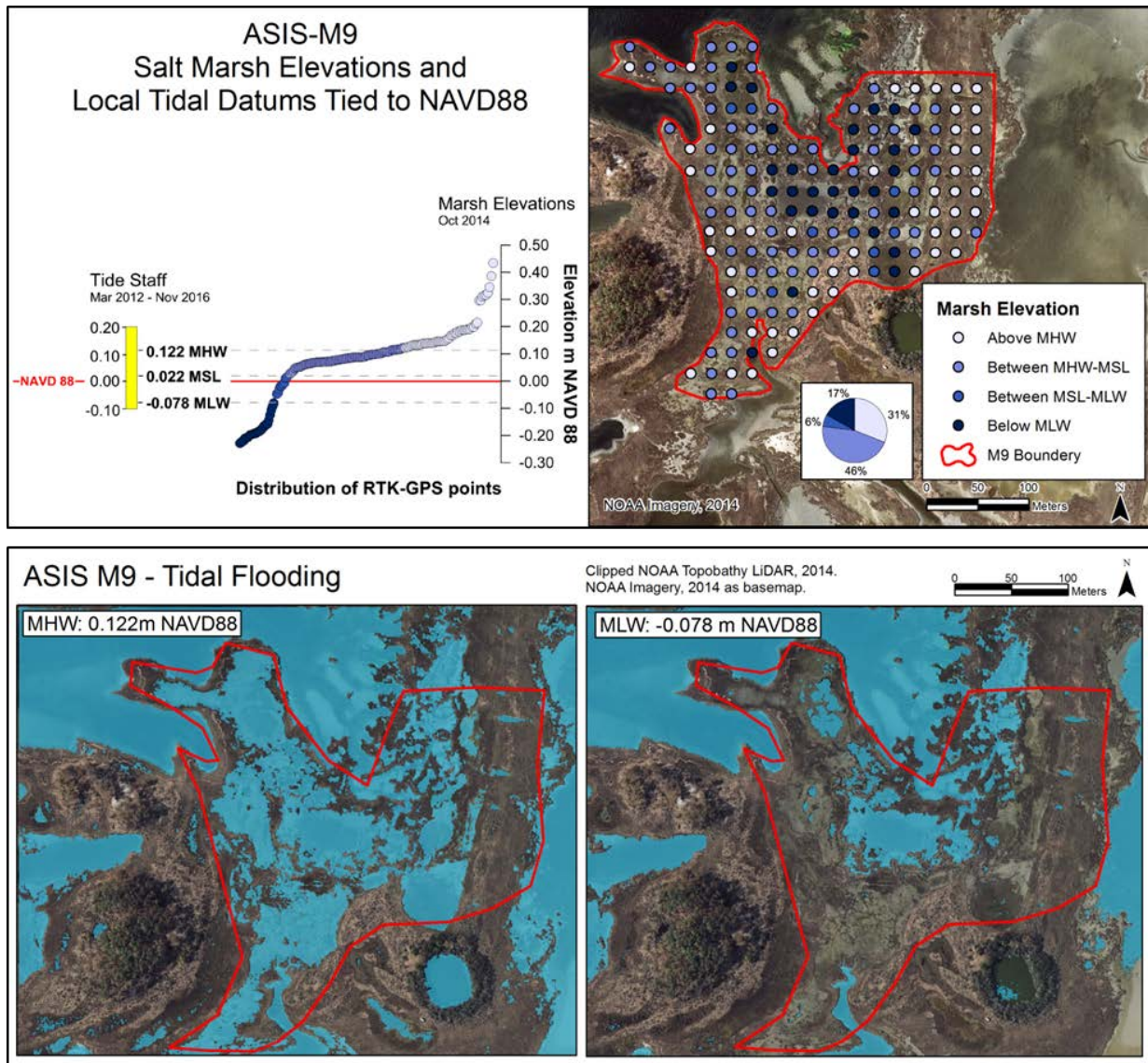


Figure 14. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M9 marsh. Tidal datums used from M6. Geoid 12A used for GPS elevations.

Marsh 11 (M11)

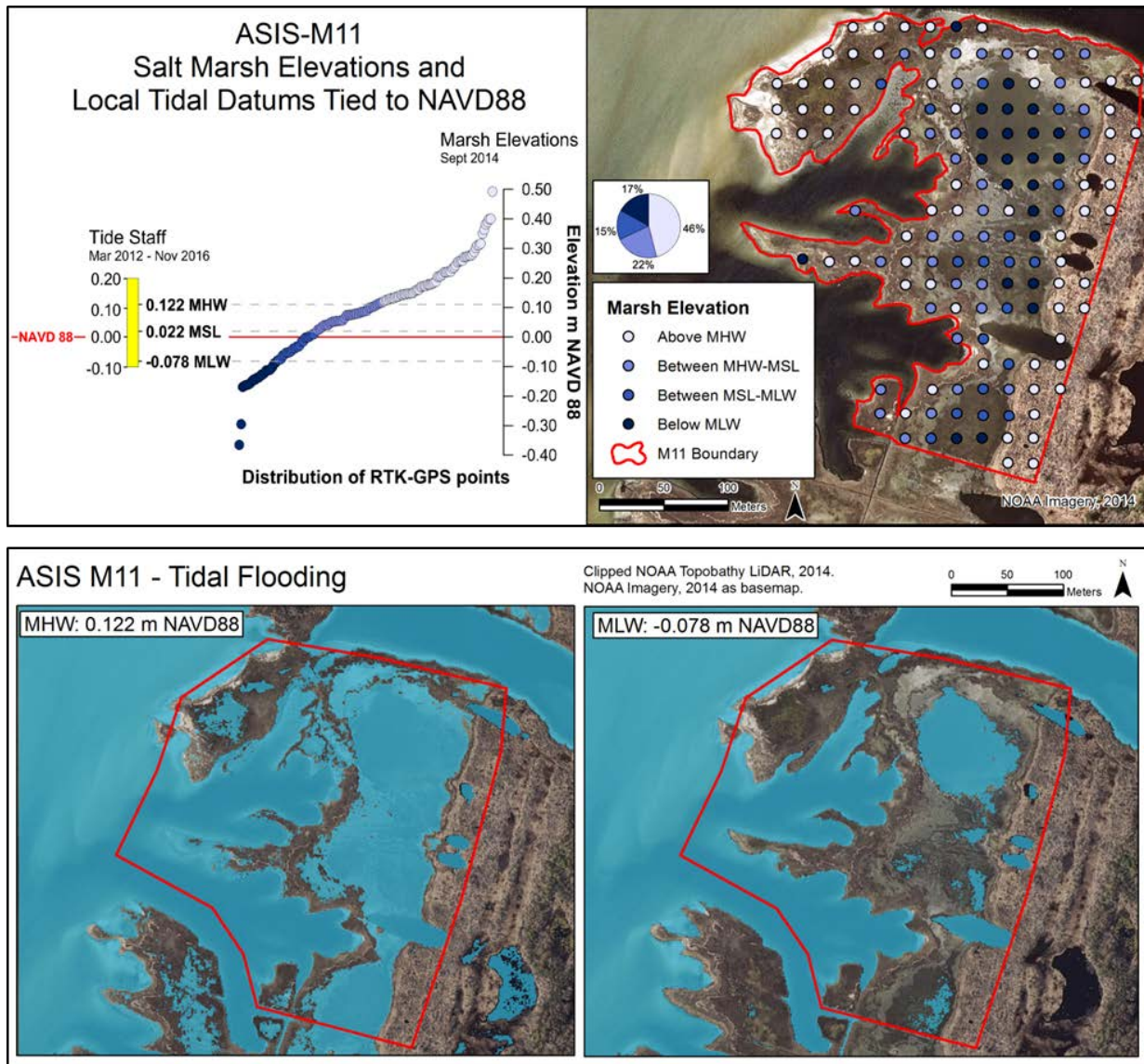


Figure 15. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M11 marsh. Tidal datums used from M6. Geoid 12A used for GPS elevations.

Marsh 6 (M6)

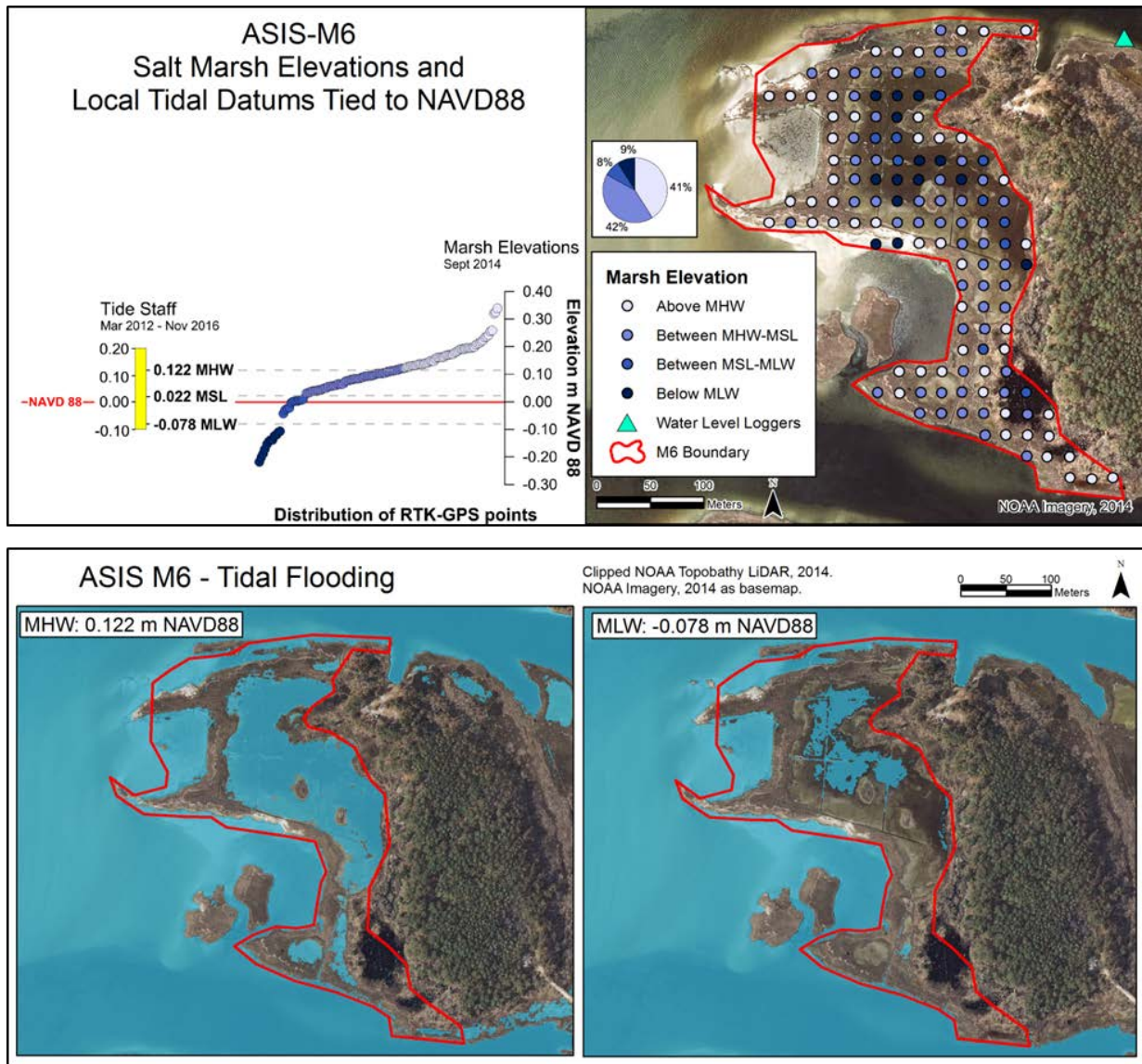


Figure 16. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M6 marsh. Water logger was on site. Geoid 12A used for GPS elevations.

Marsh Big Levels (BL)

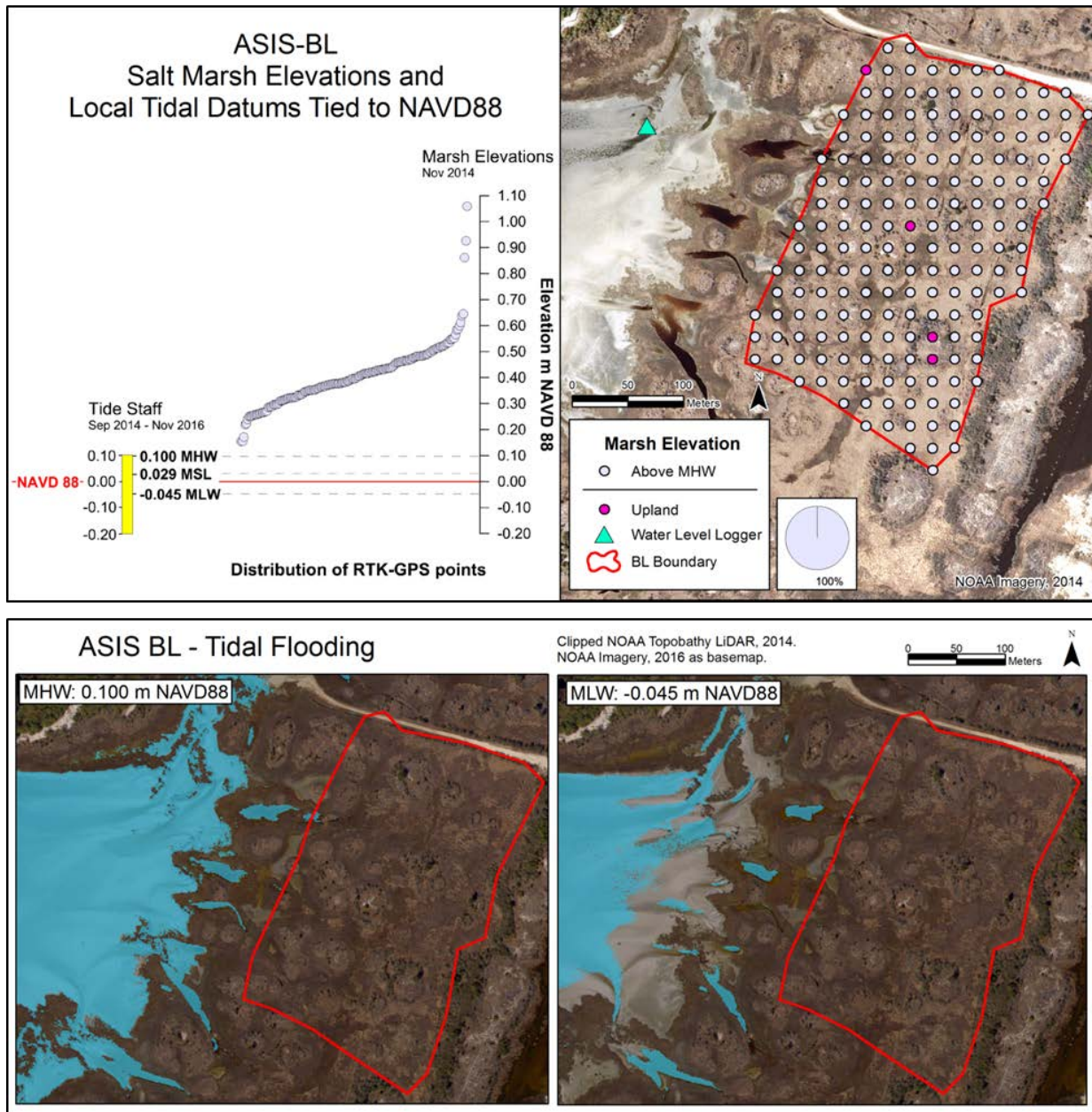


Figure 17. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at BL marsh. Water logger was on site. Geoid 12A used for GPS elevations.

Marsh 10 (M10)

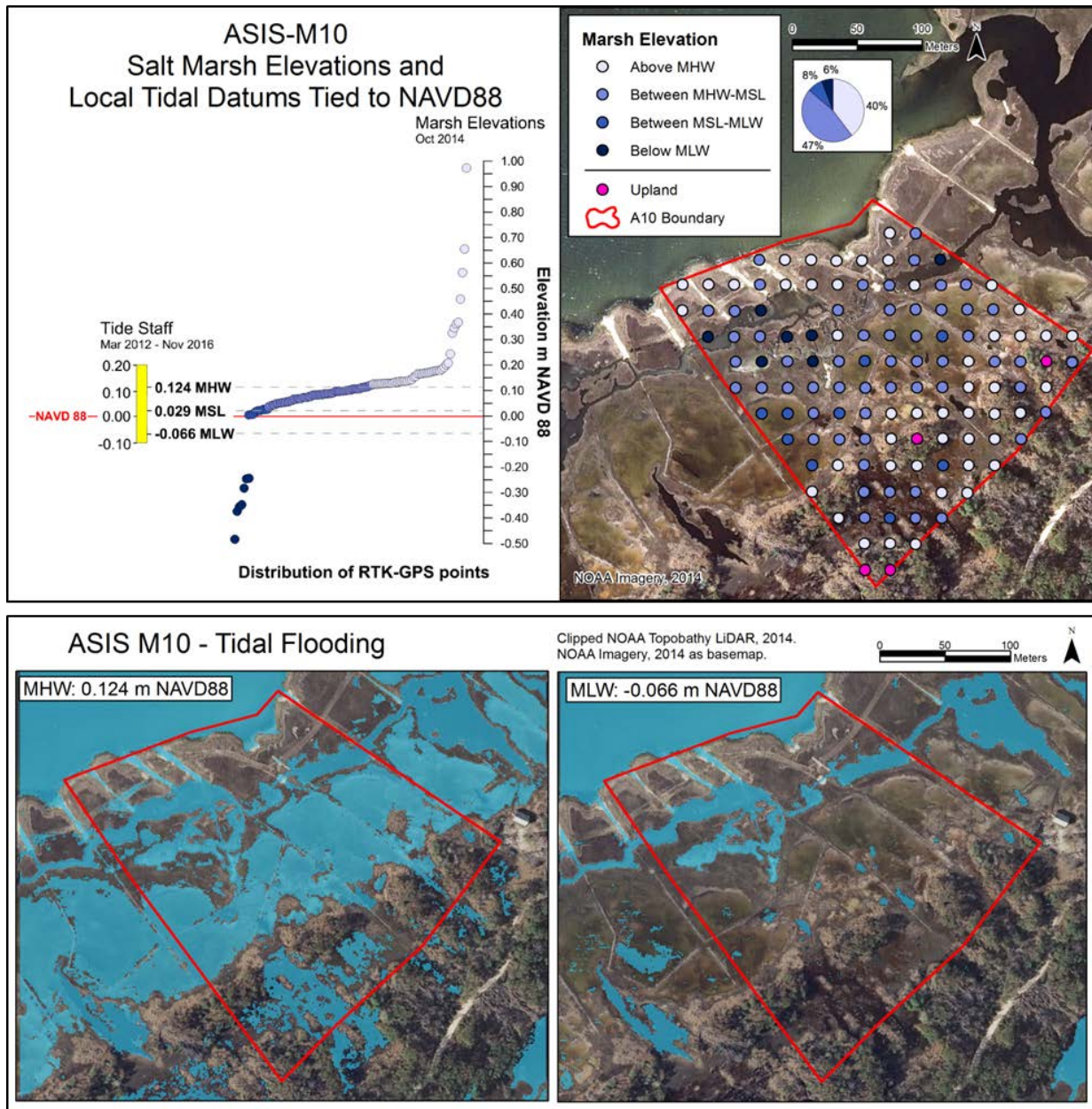


Figure 18. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M10 marsh. Tidal datums used from M8. Geoid 12A used for GPS elevations.

Marsh 8 (M8)

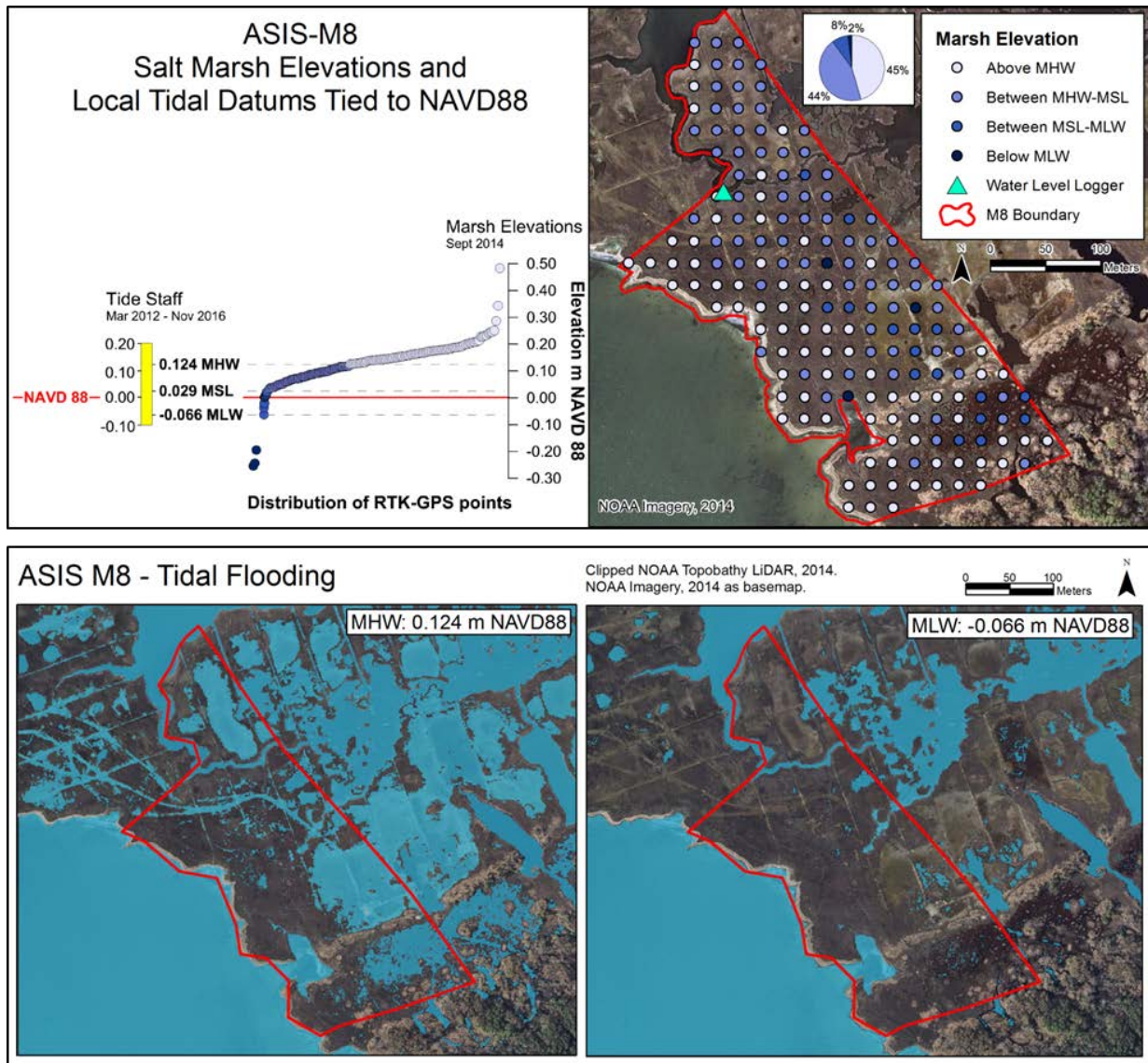


Figure 19. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M8 marsh. Water logger was on site. Geoid 12A used for GPS elevations.

Marsh 2 (M2)

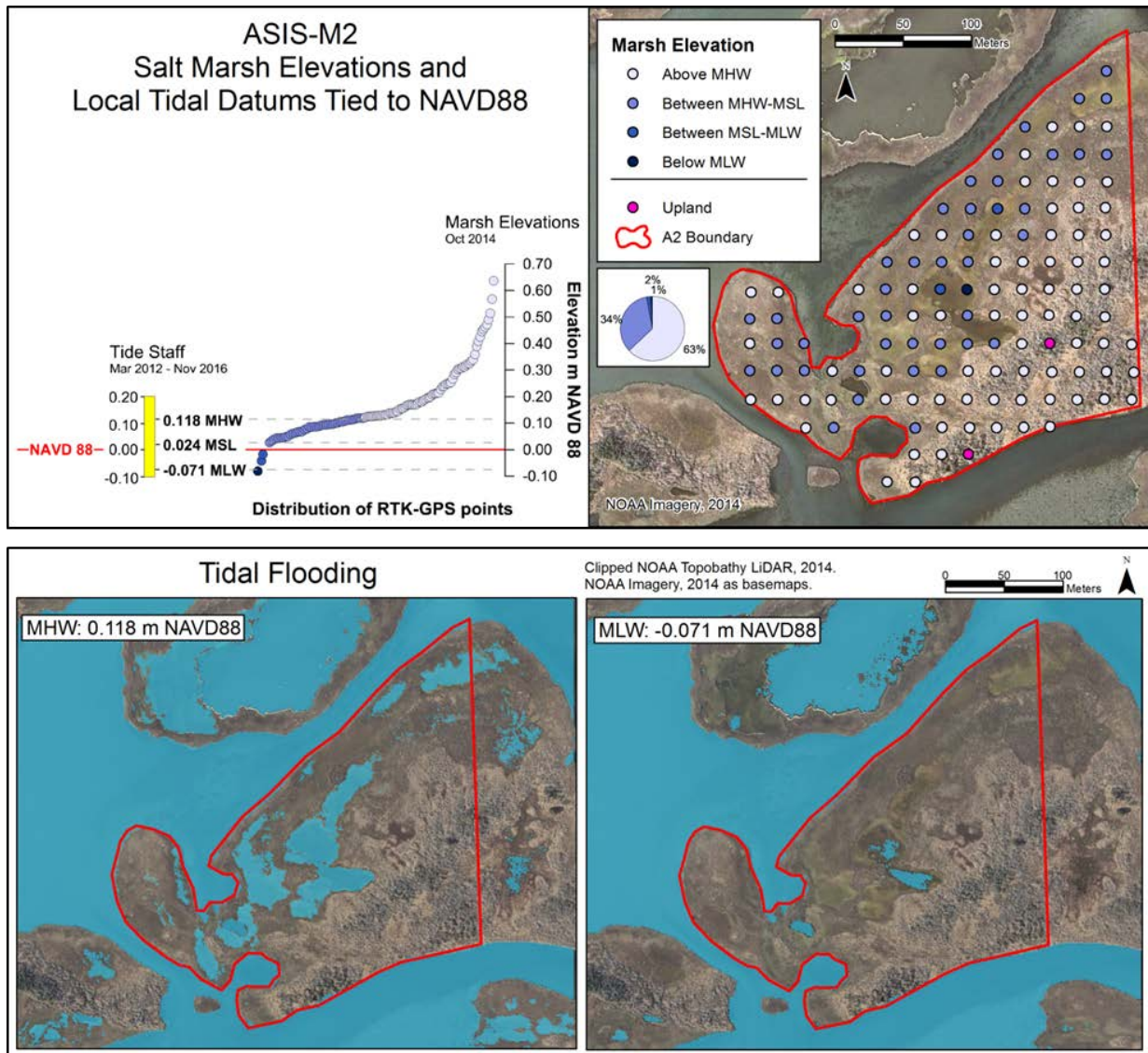


Figure 20. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M2 marsh. Tidal datums used from M5. Geoid 12A used for GPS elevations.

Marsh 5 (M5)

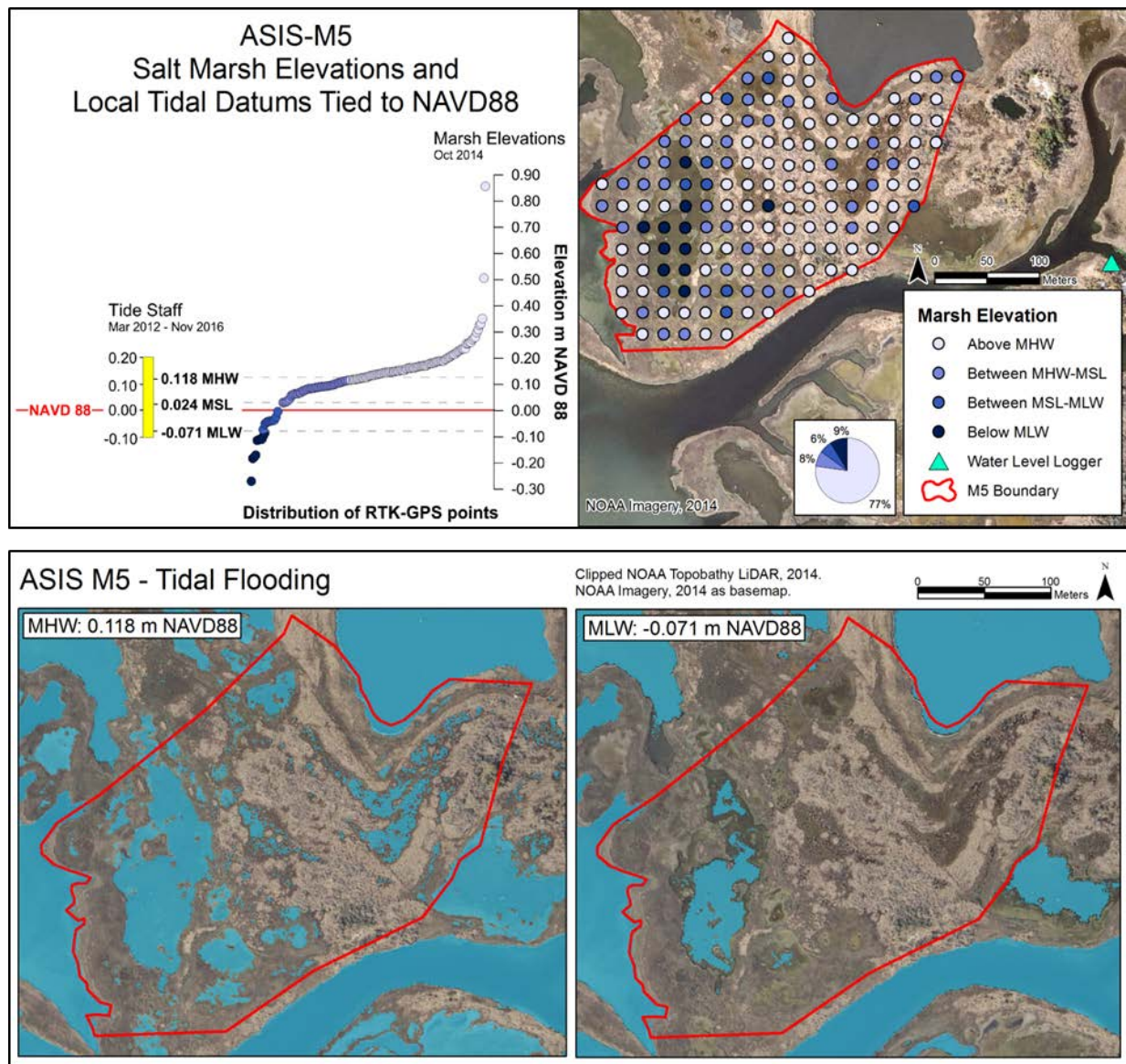


Figure 21. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M5 marsh. Water logger was on site. Geoid 12A used for GPS elevations.

Tidal Comparisons

Data from the NCBN loggers were compared to NOAA's NWLON tide station at Ocean City inlet for a sample deployment period of 1 month. Tidal patterns in Chincoteague Bay generally follow the same trend as recorded water levels at Ocean City (Figure 22); however the tidal prism from the short term loggers show a large attenuation due to the constrictive inlets at the north and south ends of Chincoteague Bay. These "choke points" inhibit water levels during a flood tide (rising tide levels) to reach the same heights in the bay as compared to that from the open ocean. Subsequently, the Bay cannot drain during ebb tides (falling tide levels) before tidal forces from the ocean overpower. Great

Diurnal (GT) ranges (difference of MHHW and MLLW) at the short term loggers ranged from 19-25cm compared to 75cm at Ocean City.

Water levels at 0.5KM and BL became stagnant during this period. During an ebb tide, the water level of the bay is lower than the sill (lowest elevation) of the tidal inlet which connects the marsh to the bay. At this point the marsh cannot drain and therefore, portions of the marsh remain flooded. Highest tide levels at 0.5KM marsh are nearly identical to nearby NOAA gauge at Ocean City however, lowest levels in the marsh reach ~0.30m NAVD88 (Geoid12A). The lowest water levels at BL reach ~0.00m NAVD88 (Geoid 12A). High tide levels at BL reflect similar levels as nearby NCBN water loggers.

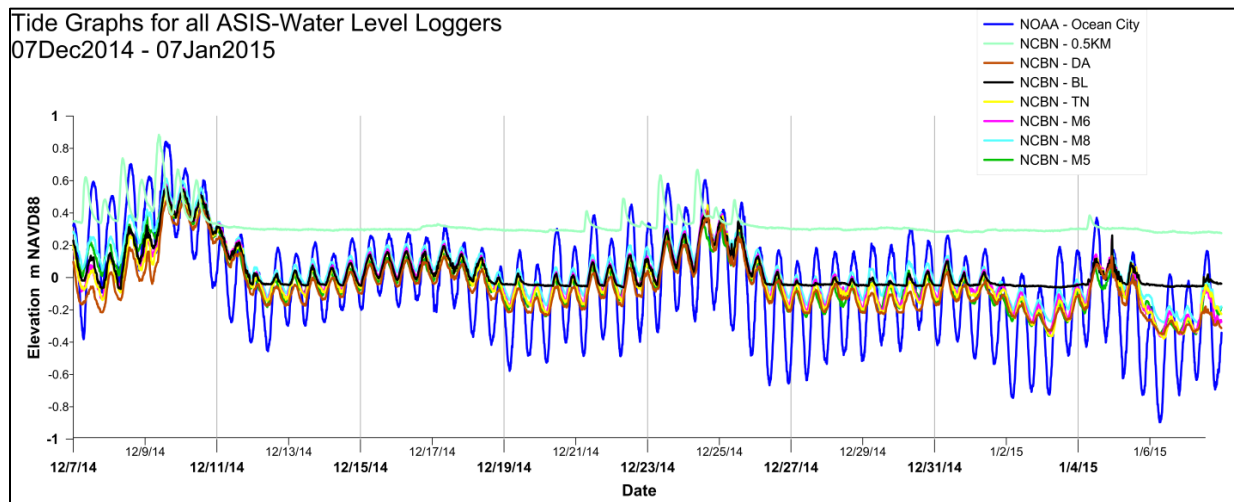


Figure 22. A one month sample of simultaneous comparison of tide graphs for all ASIS water level loggers and at the NOAA Ocean City Inlet Gauge.

Fire Island National Seashore

Data

Fire Island National Seashore (FIIS) is located on a narrow barrier island separating the Atlantic Ocean and Great South Bay. Great South Bay is connected to the Atlantic Ocean via Fire Island Inlet to the west and Moriches Inlet to the east. In October 2012, storm surge from Hurricane Sandy breached the island at Hospital Point (HP), located in Otis Pike High Dune Wilderness. The newly breached tidal inlet remains open.

NCBN has maintained three HOBO water level loggers at marsh sites M4, HP, and GG from June 2012 to the present. Four additional HOBO loggers were installed in September, 2014 near marsh sites Saltaire (SA), M1, M2, and at William Floyd (WF3), and are currently deployed. Locations of these water loggers and salt marsh sites are labeled in Figure 23.

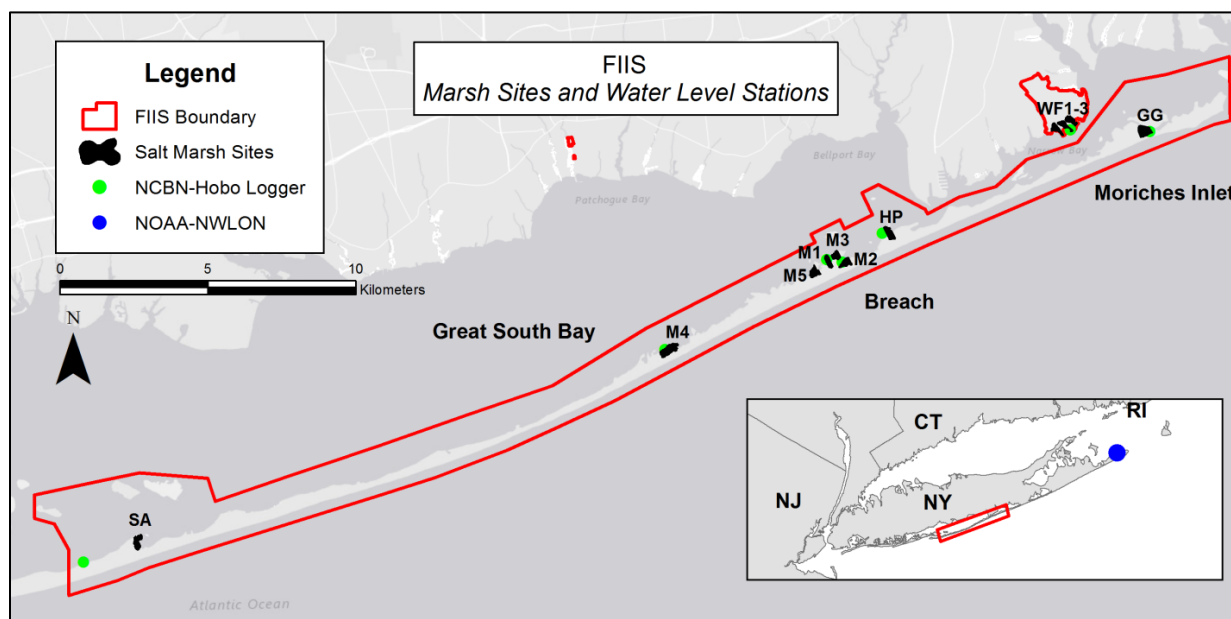


Figure 23. Location of salt marsh study sites and water level loggers at FIIS. NWLON station at Montauk for reference.

Results

RTK-GPS elevation points were collected in the spring/summer of 2015. A total of 1899 points were collected on the marsh surface at 11 different sites. Figures 24-34 (from west to east) display the relationship of the marsh surface and local water levels at each marsh site. Marsh elevation points are symbolized relative to local tidal datums (e.g., above or below MHW) derived from each water level logger.

Saltire (SA)

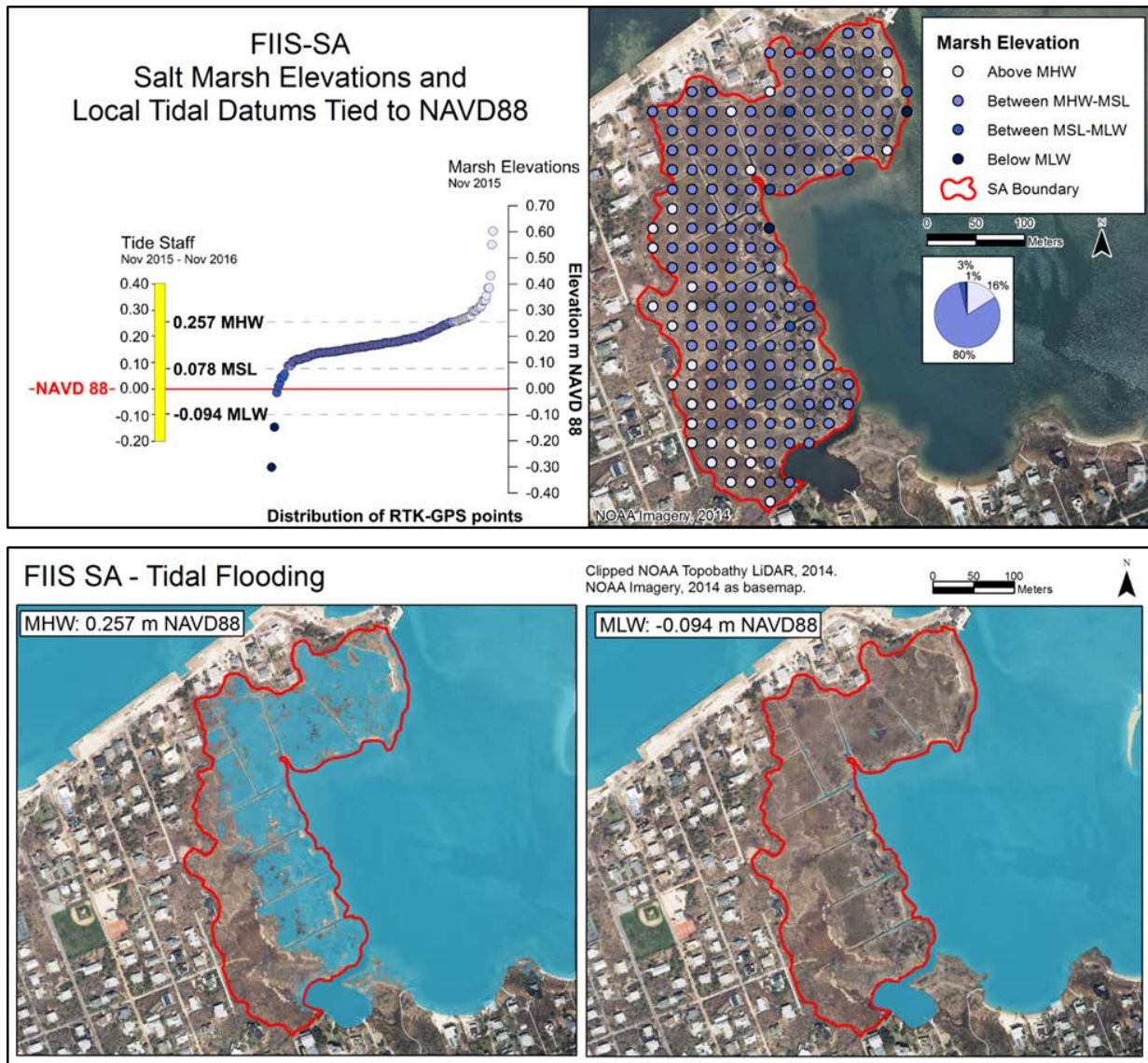


Figure 24. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at SA marsh. Water logger was at an NPS pier near the Fire Island lighthouse, approximately two kilometers away. Geoid 12A used for GPS elevations.

Marsh 4 (M4)

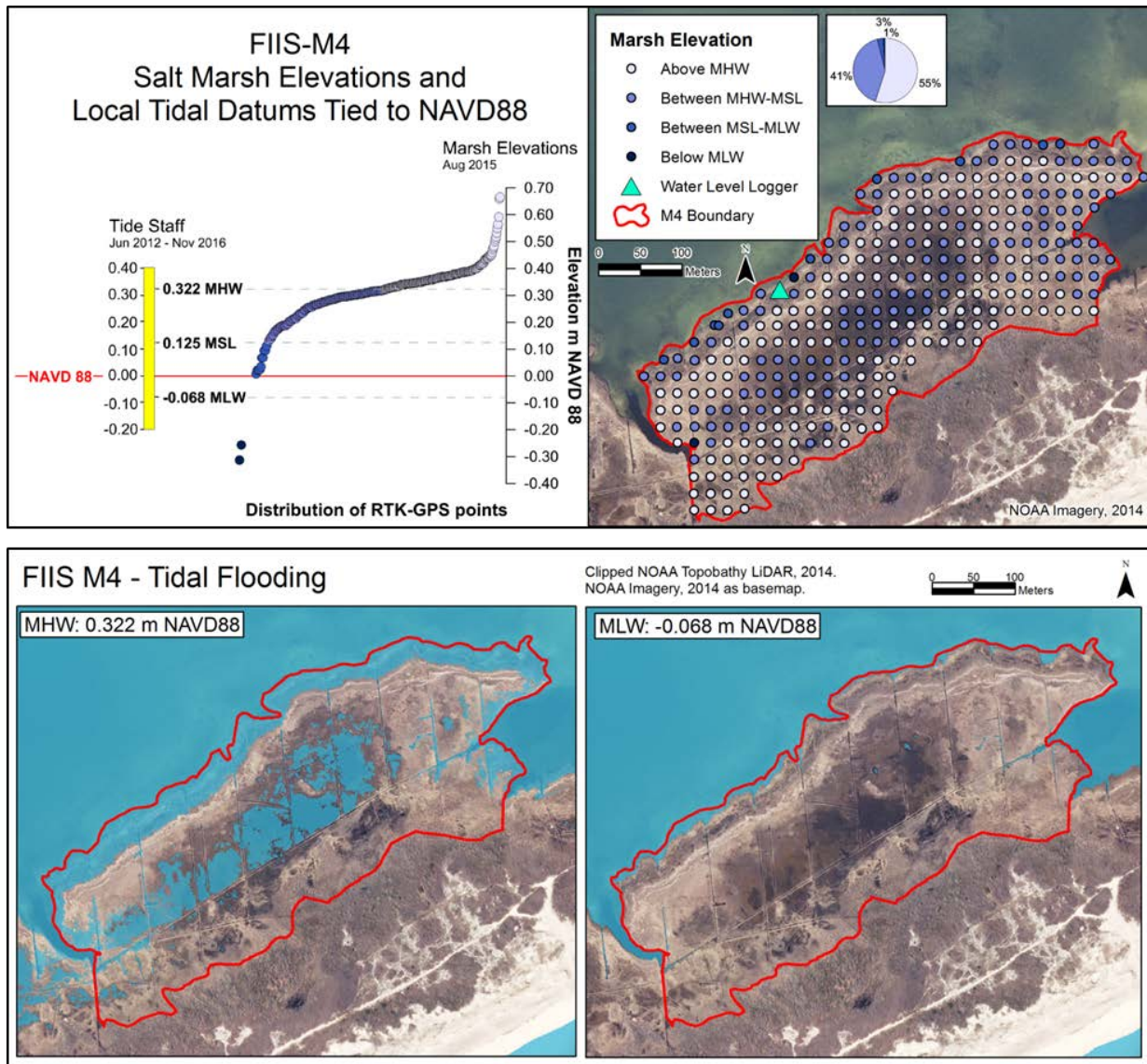


Figure 25. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M4 marsh. Water logger was on site. Geoid 12A used for GPS elevations.

Marsh 5 (M5)

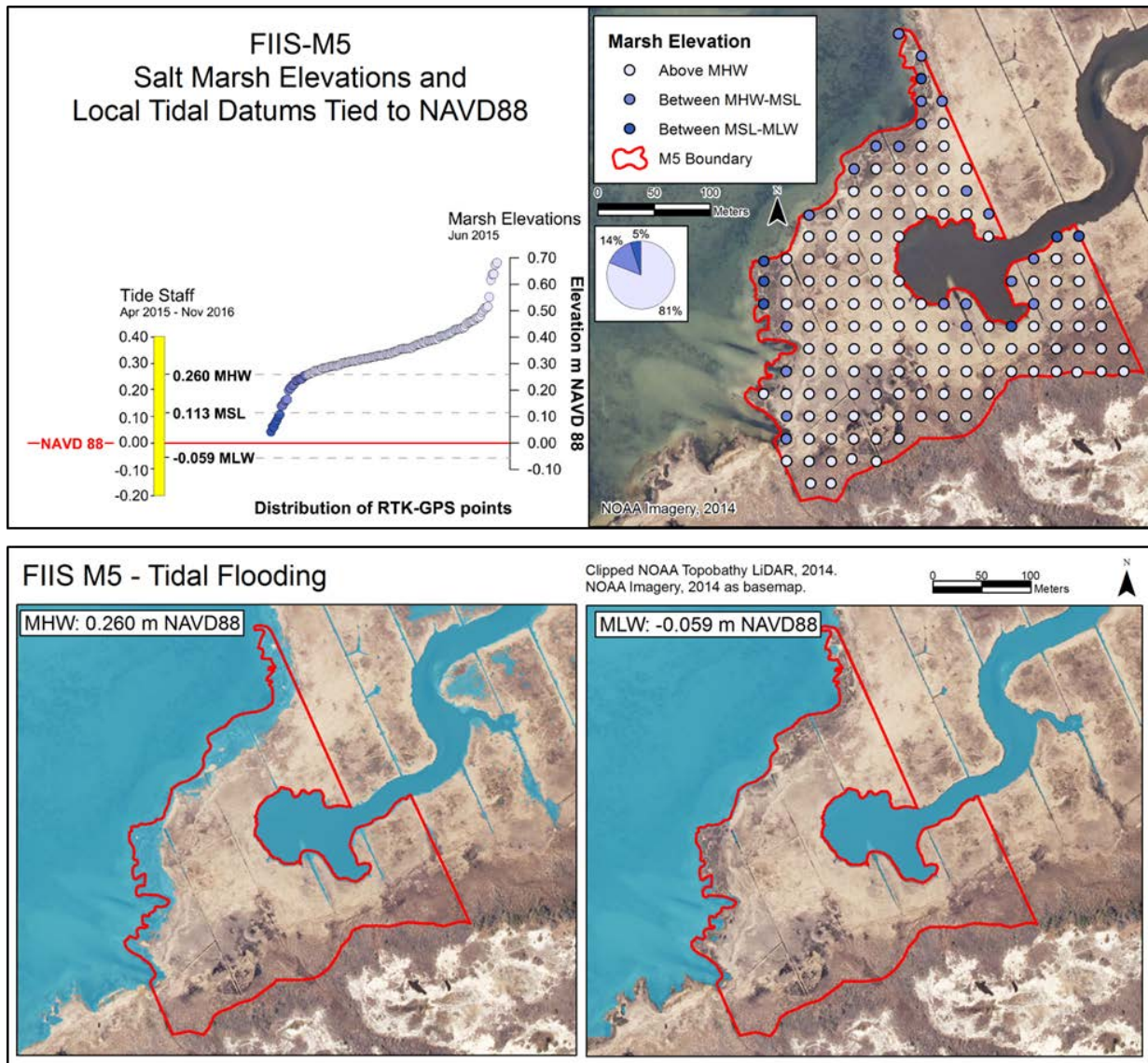


Figure 26. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M5 marsh. Tidal datums used from M2. Geoid 12A used for GPS elevations.

Marsh 1 (M1)

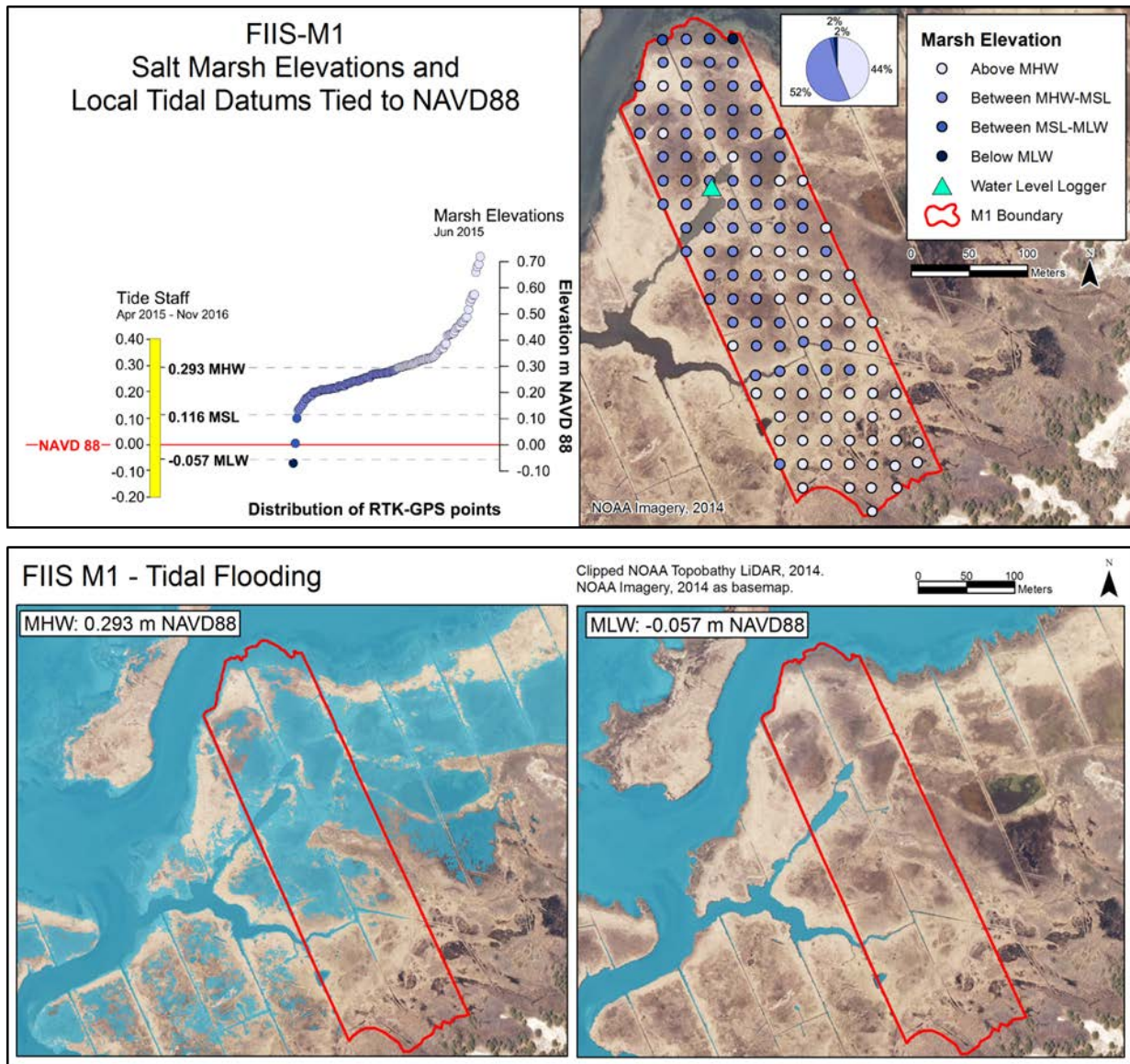
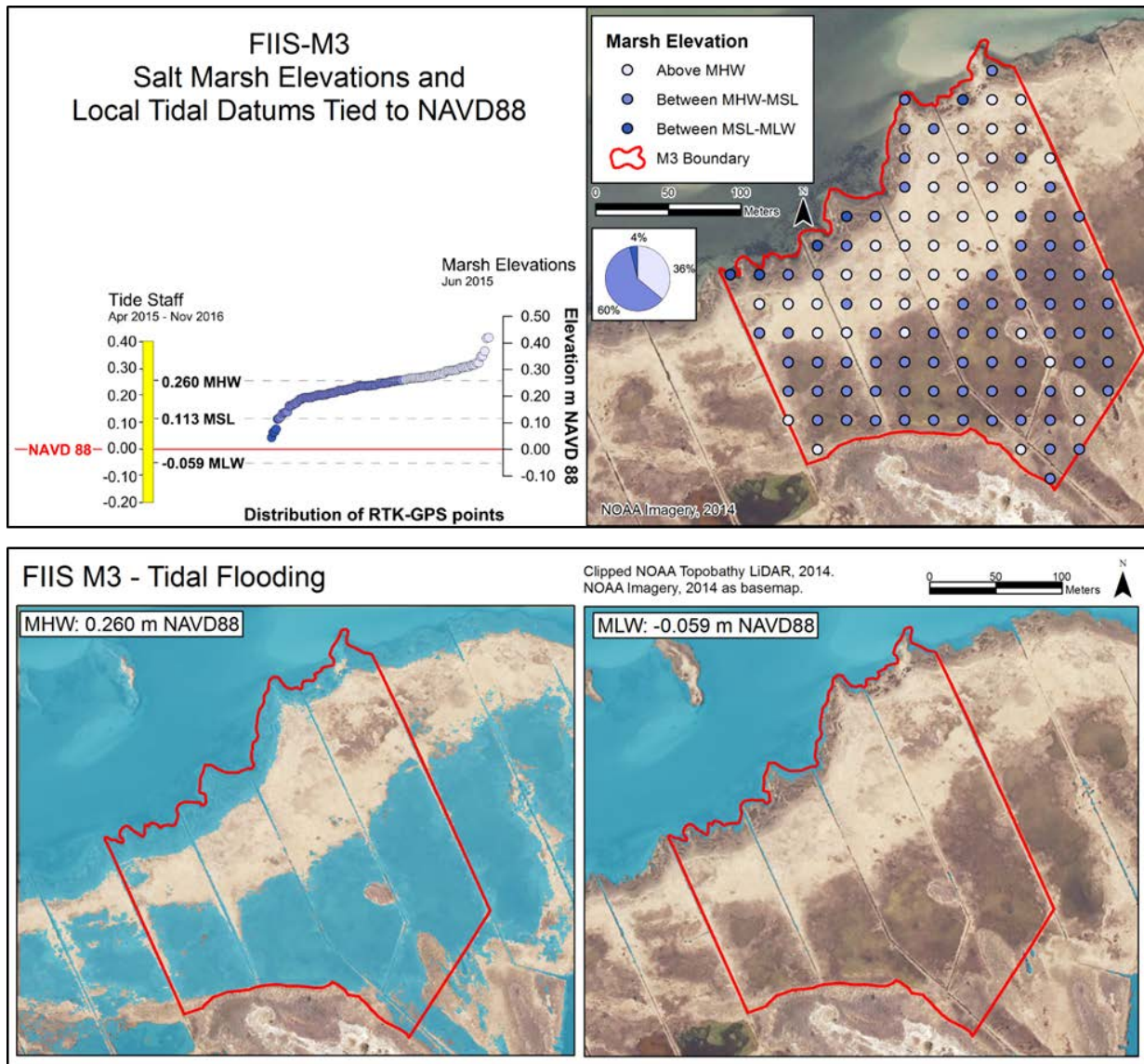


Figure 27. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M1 marsh. Water logger was on site. Geoid 12A used for GPS elevations.

Marsh 3 (M3)



Marsh 2 (M2)

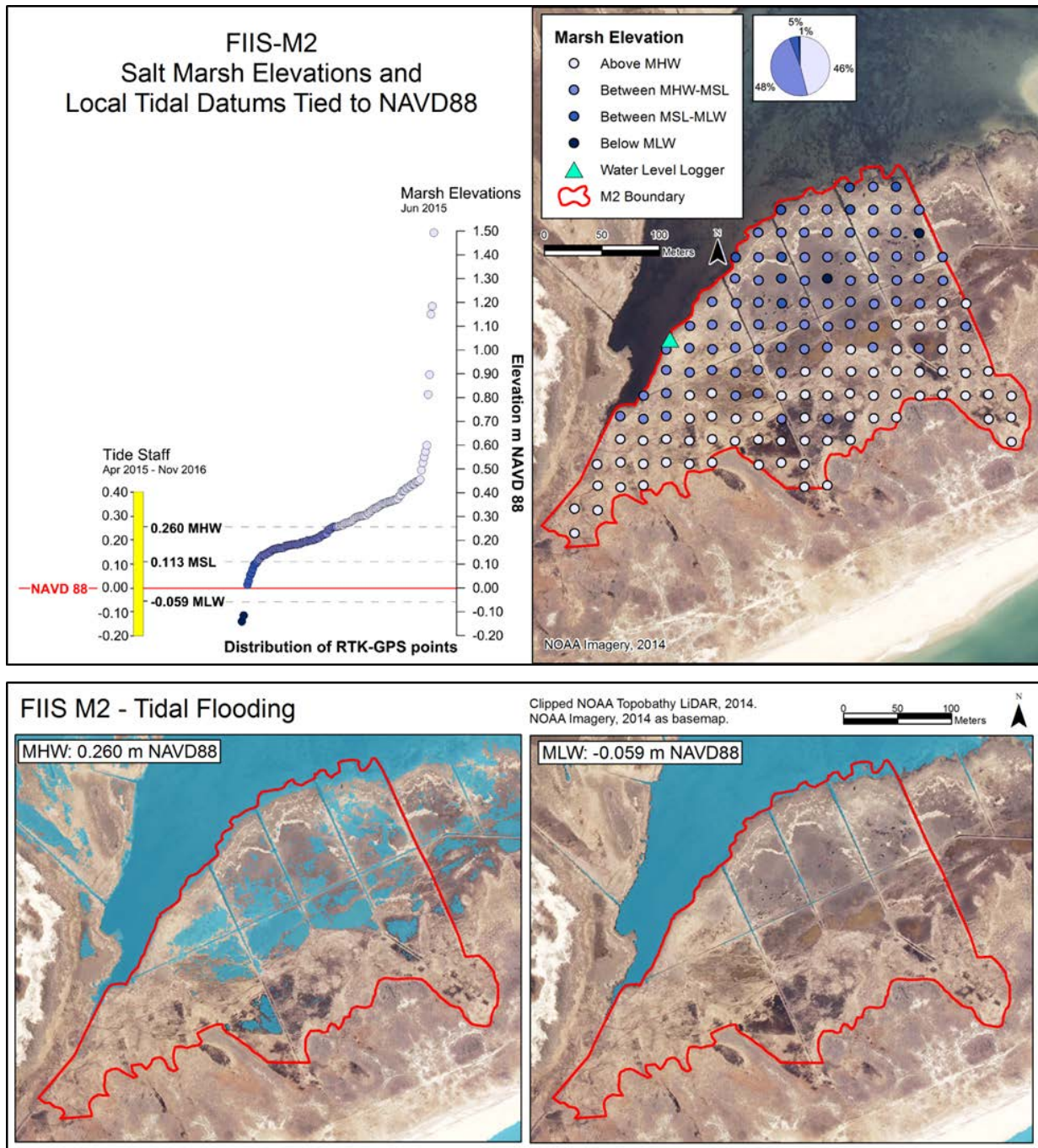


Figure 29. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M2 marsh. Water logger was on site. Geoid 12A used for GPS elevations.

Hospital Point (HP)

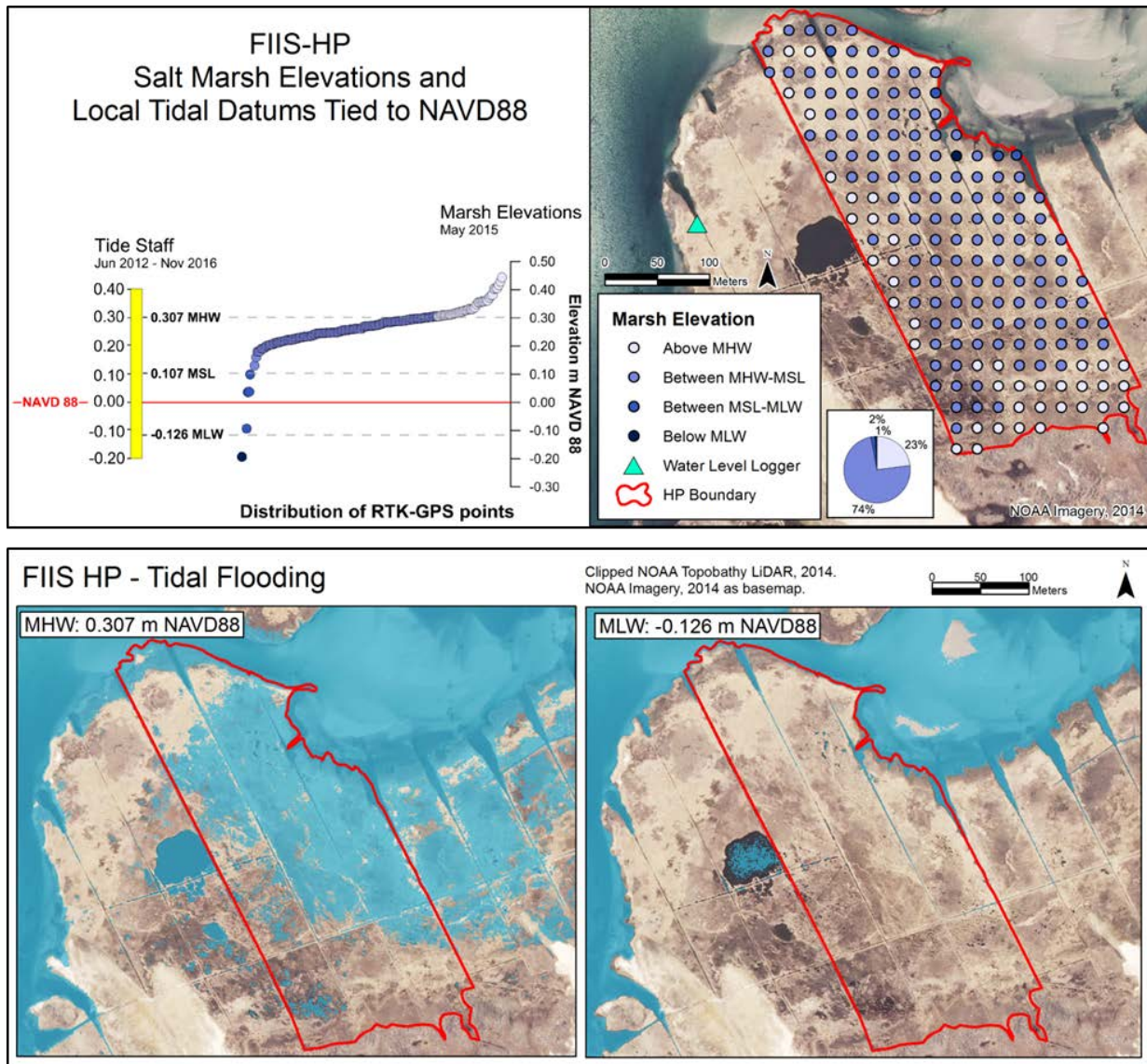


Figure 30. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at HP marsh. Water logger was on site. Geoid 12A used for GPS elevations.

Great Gun (GG)

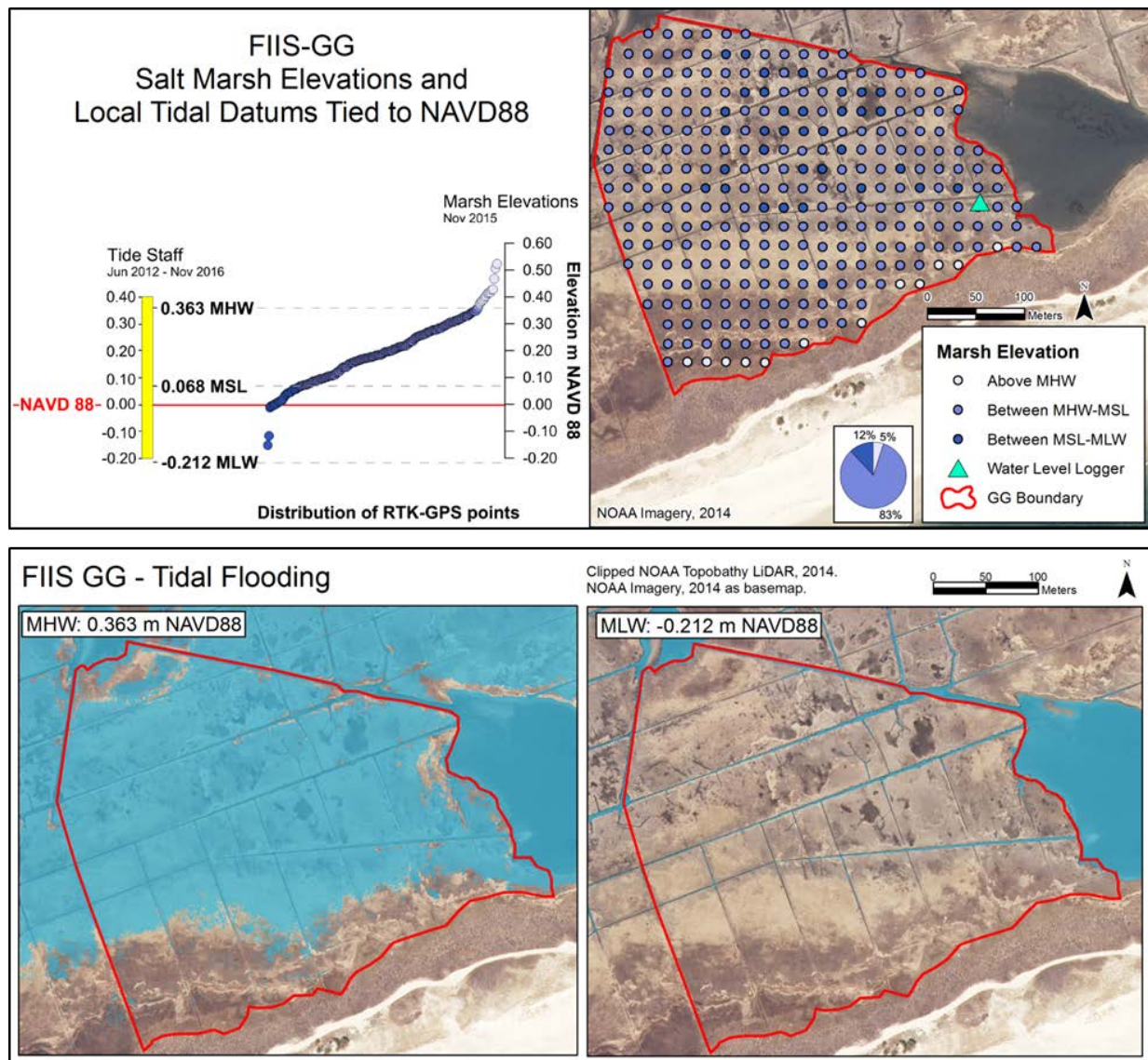


Figure 31. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at GG marsh. Water logger was on site. Geoid 12A used for GPS elevations.

William Floyd 1 (WF1)

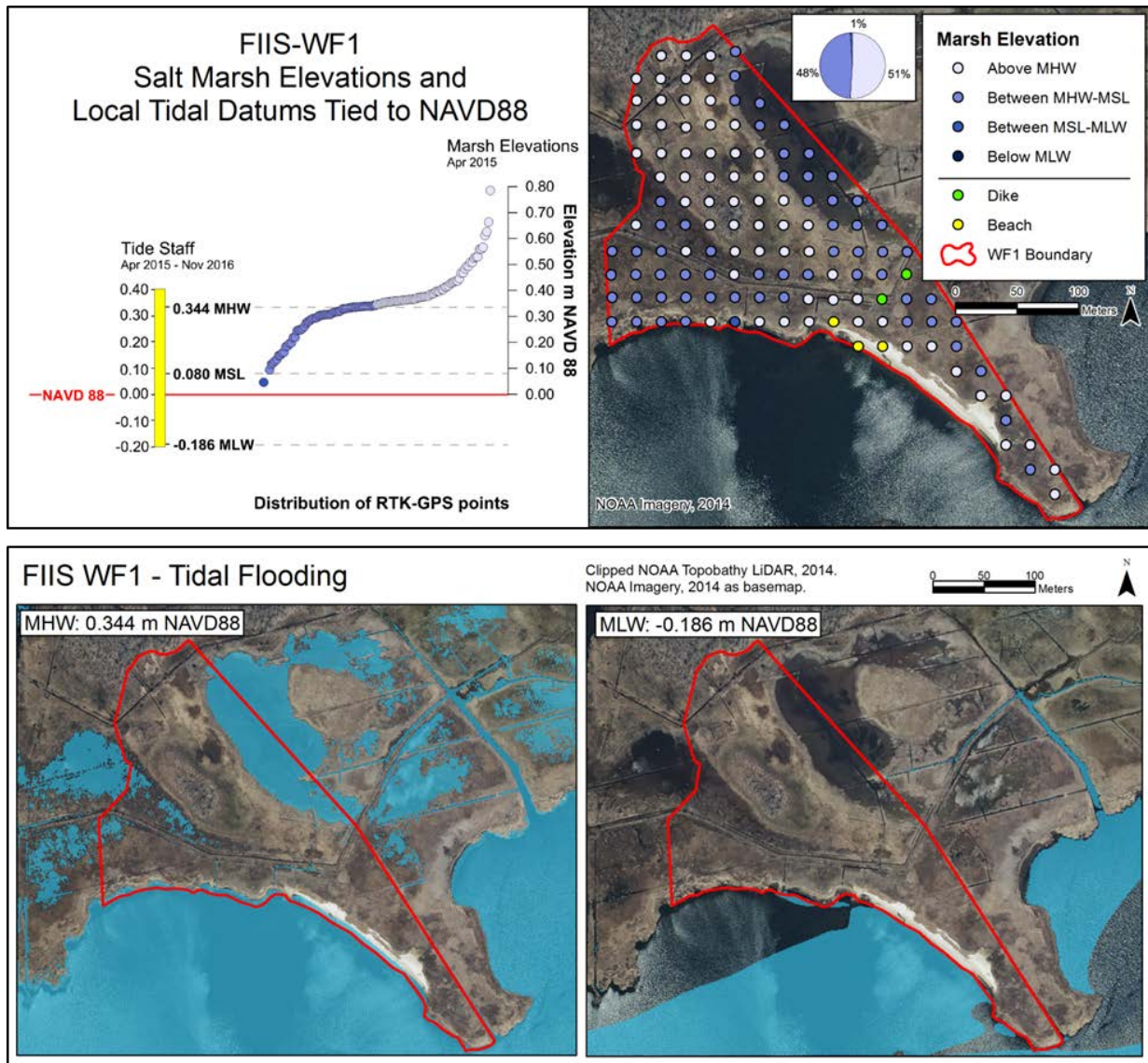


Figure 32. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at WF1 marsh. Tidal datums used from WF3. Geoid 12A used for GPS elevations.

William Floyd 2 (WF2)

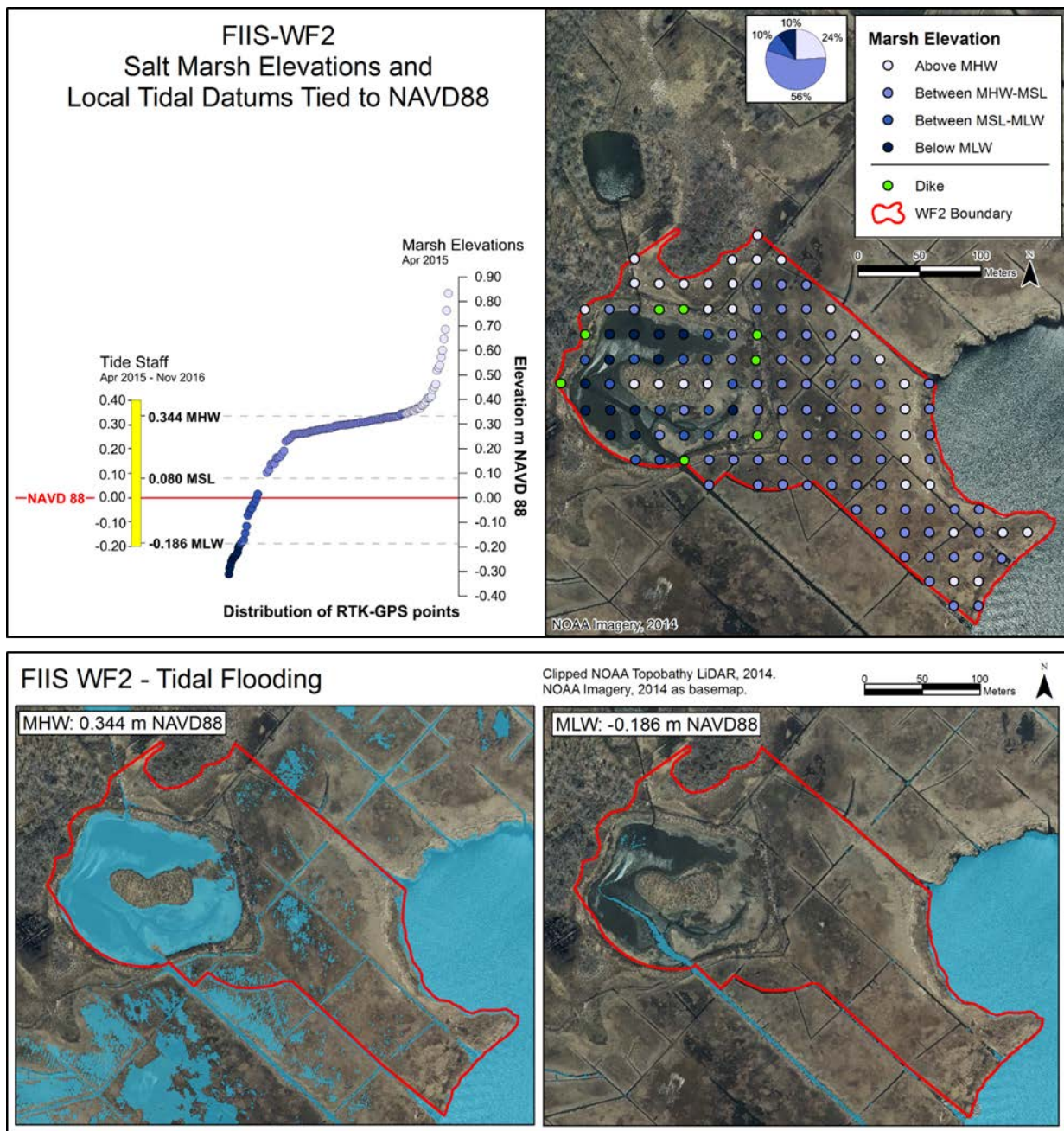


Figure 33. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at WF2 marsh. Tidal datums used from WF3. Geoid 12A used for GPS elevations.

William Floyd 3 (WF3)

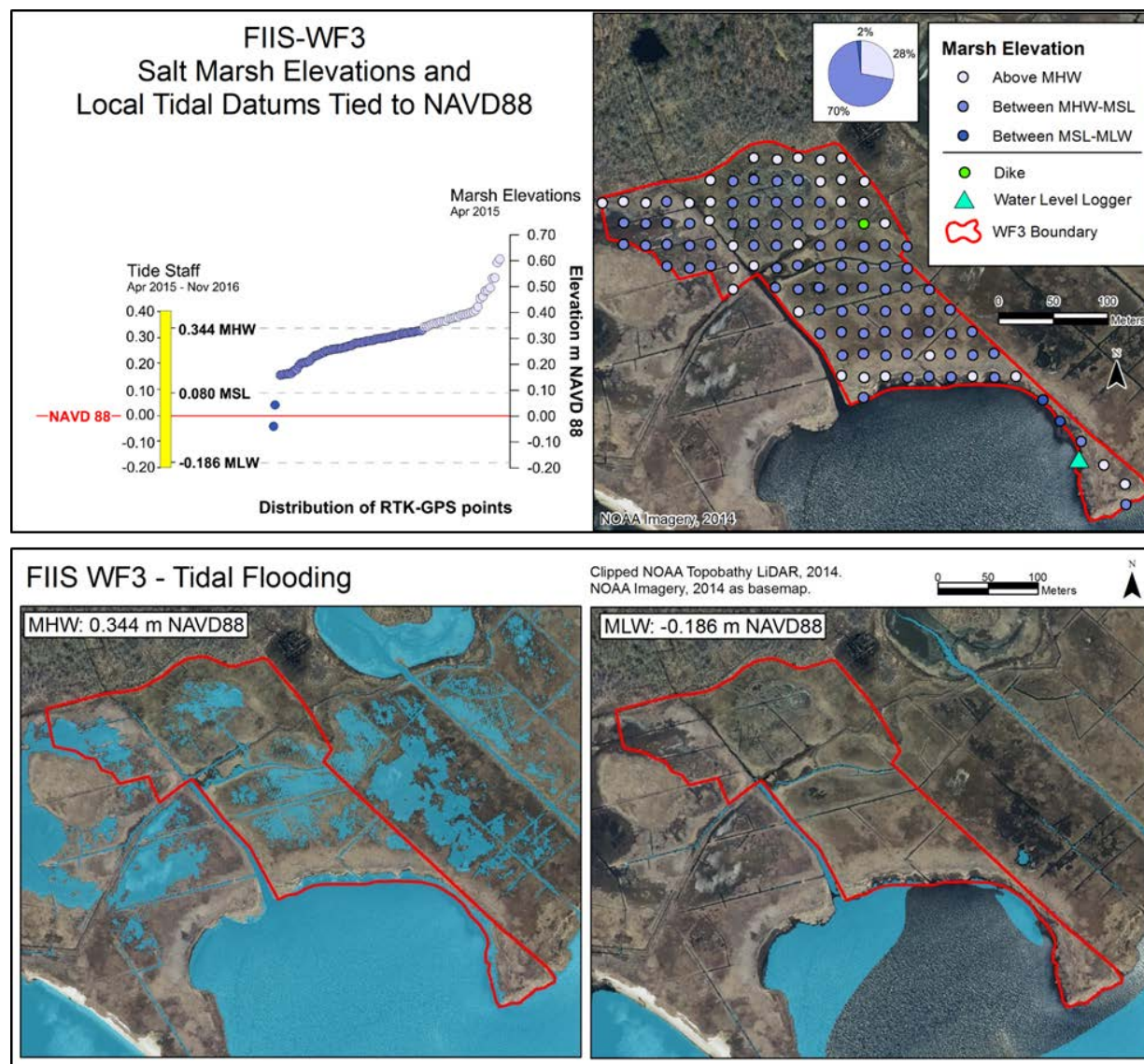


Figure 34. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at WF3 marsh. Water logger was on site. Geoid 12A used for GPS elevations.

Tidal Comparisons

Data from the URI-EDC logger were compared to NOAA's NWLON station at Montauk for the same deployment period. Tidal patterns in Great South Bay generally follow the same trend as recorded water levels at Montauk (Figure 35); however the tidal prism from the short term loggers show a large attenuation due to the narrowing passages at the west and east ends of Great South Bay. Great Diurnal (GT) ranges (difference of MHHW and MLLW) at the short term loggers ranged from 32-57cm compared to 77cm at Montauk.

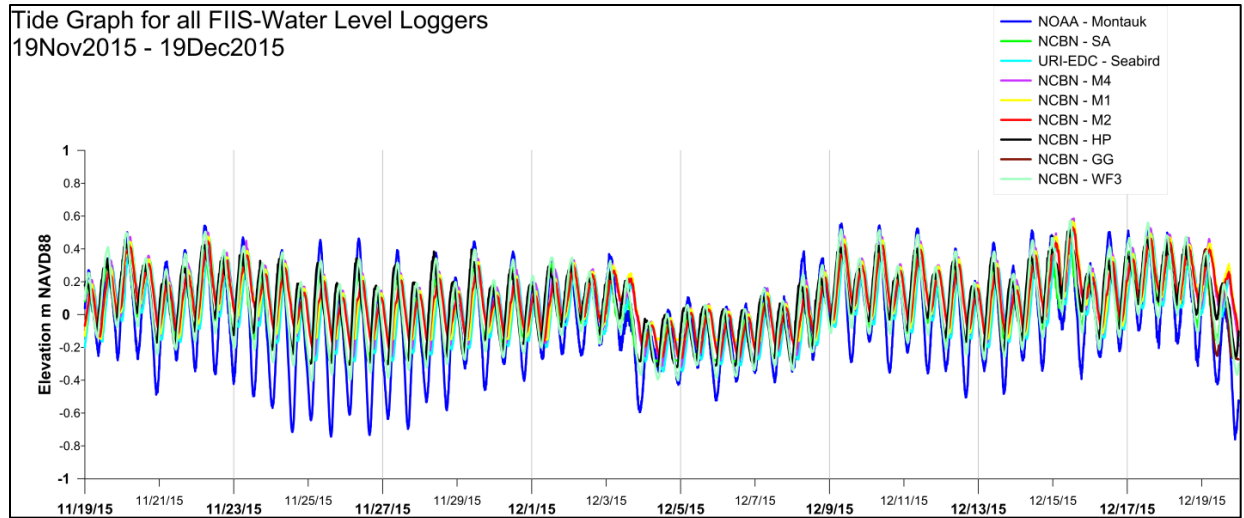


Figure 35. A one month sample of simultaneous comparison of tide graphs for all FIIS water level loggers and at the NOAA Montauk gauge.

Gateway National Recreation Area-Sandy Hook Unit

Data

The Sandy Hook unit of GATE is a barrier spit located at the northern end of the New Jersey shore. NOAA has maintained the current NWLON tide station at Sandy Hook since 1910. URI-EDC deployed a Seabird 26plus at marsh M1 and a HOBO pressure sensor in the northwest section of M2 from April 7, 2016 – Sep 8, 2016. Locations of these water loggers and salt marsh sites are labeled in Figure 36.

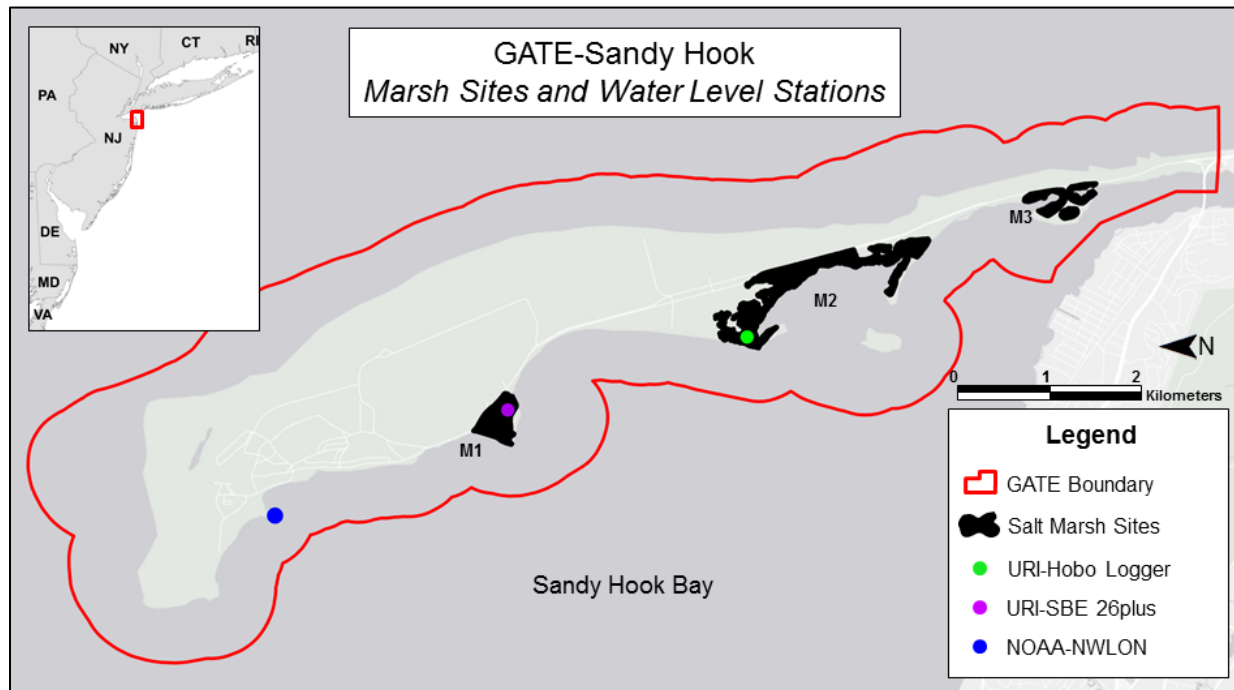


Figure 36. Location of salt marsh study sites and water level loggers at GATE-Sandy Hook.

Results

RTK-GPS elevation points were conducted in the spring of 2016. A total of 736 points were collected on the marsh surface at 3 different sites. Points located on an upland, beach, or dike were mapped but were taken out of the analysis in order to represent the marsh surface. Figures 37-40 display the relationship of the marsh surface and local water levels at each marsh site. Marsh elevation points are symbolized relative to local tidal datums (e.g., above or below MHW) derived from each water level logger.

Marsh 1 (M1)

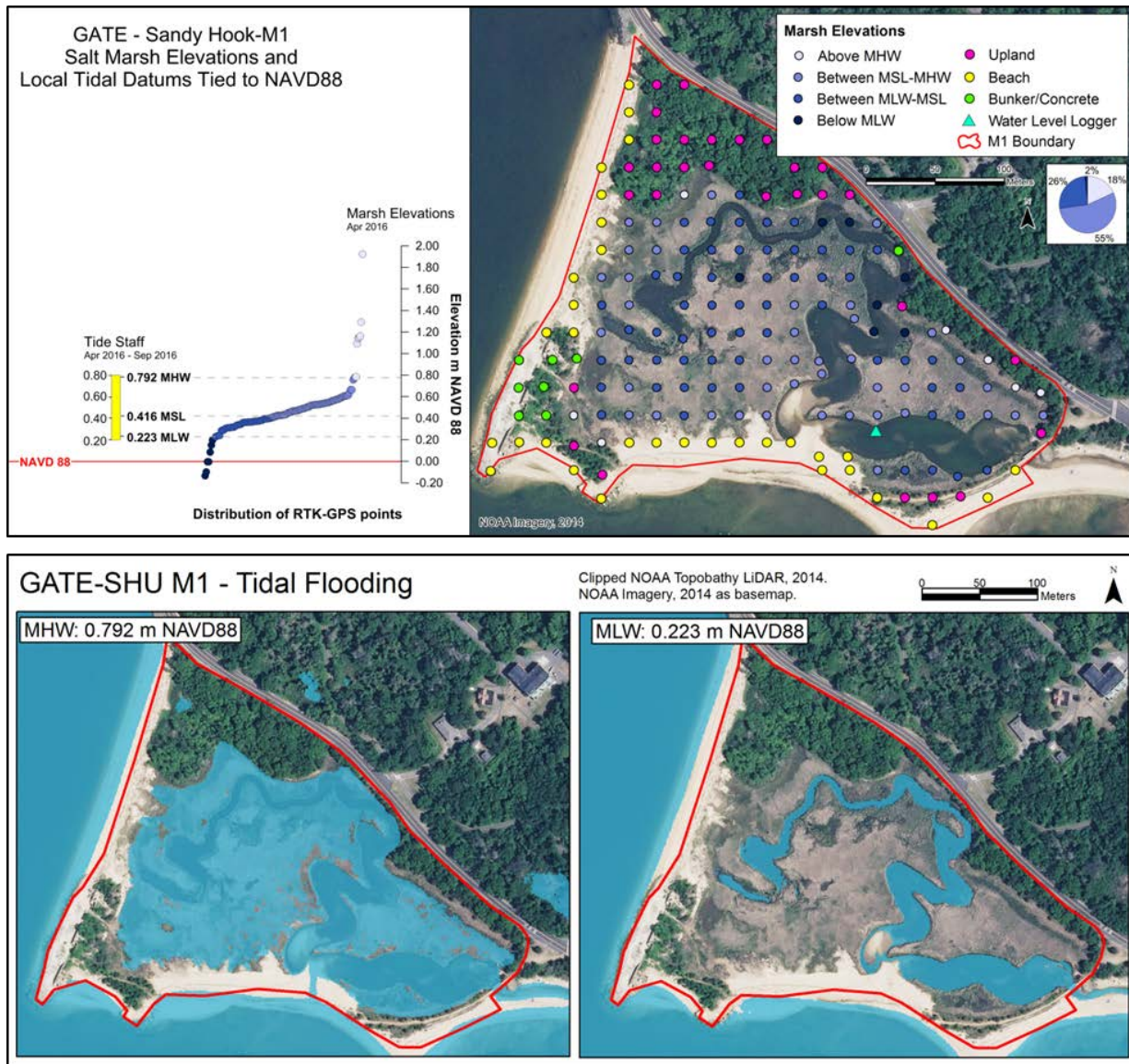


Figure 37. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M1 marsh. Water logger was on site. Geoid 12A used for GPS elevations.

Marsh 2 & Marsh 2 zone A (M2, M2A)

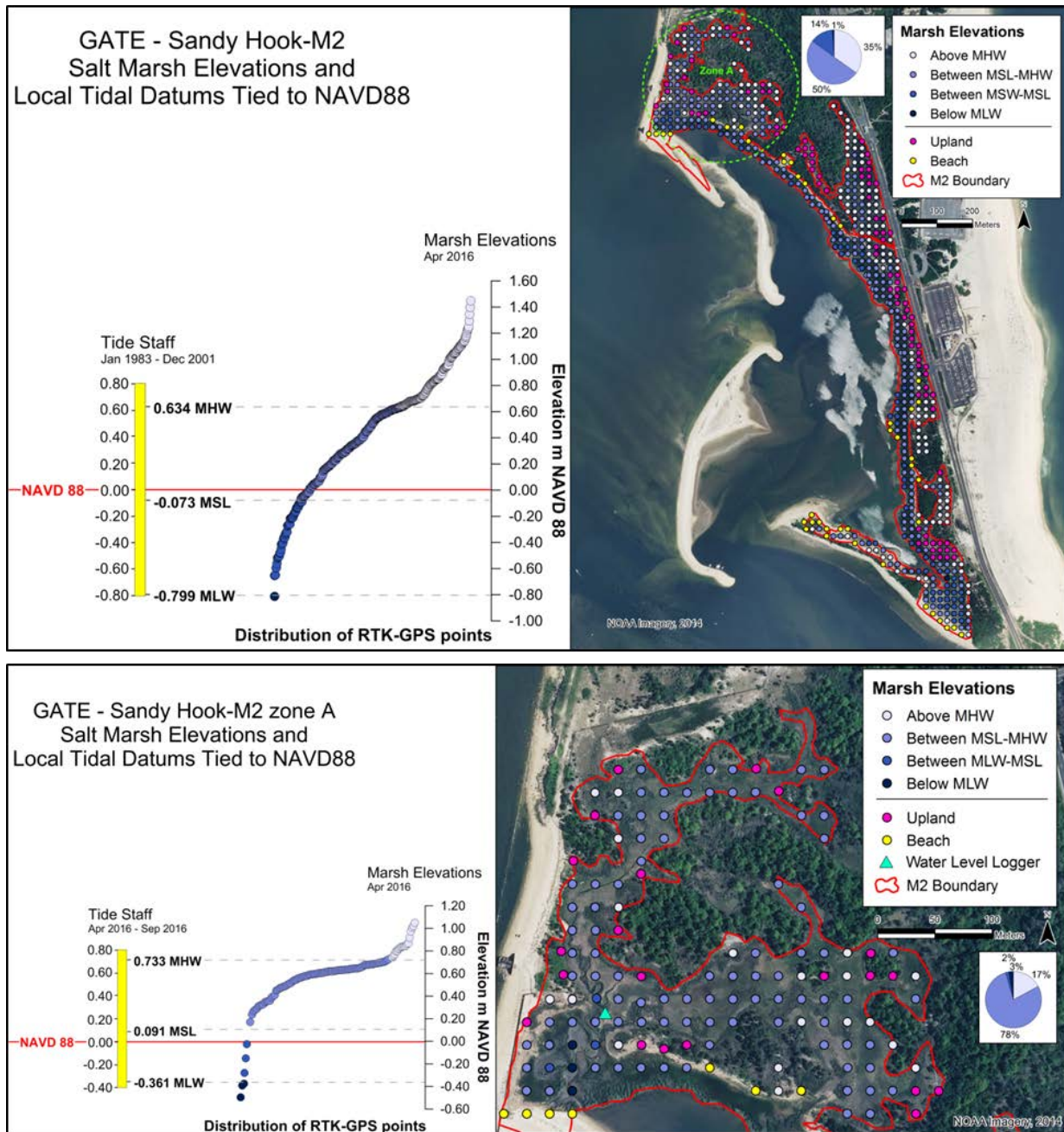


Figure 38. Above: Relationship of salt marsh elevations with tidal datums calculated from the Sandy Hook NWLON station. Below: Relationship of salt marsh elevations with local tidal datums. Water logger was on site and only applies to elevation points within zone A of SH2 marsh. Geoid 12A used for GPS elevations.

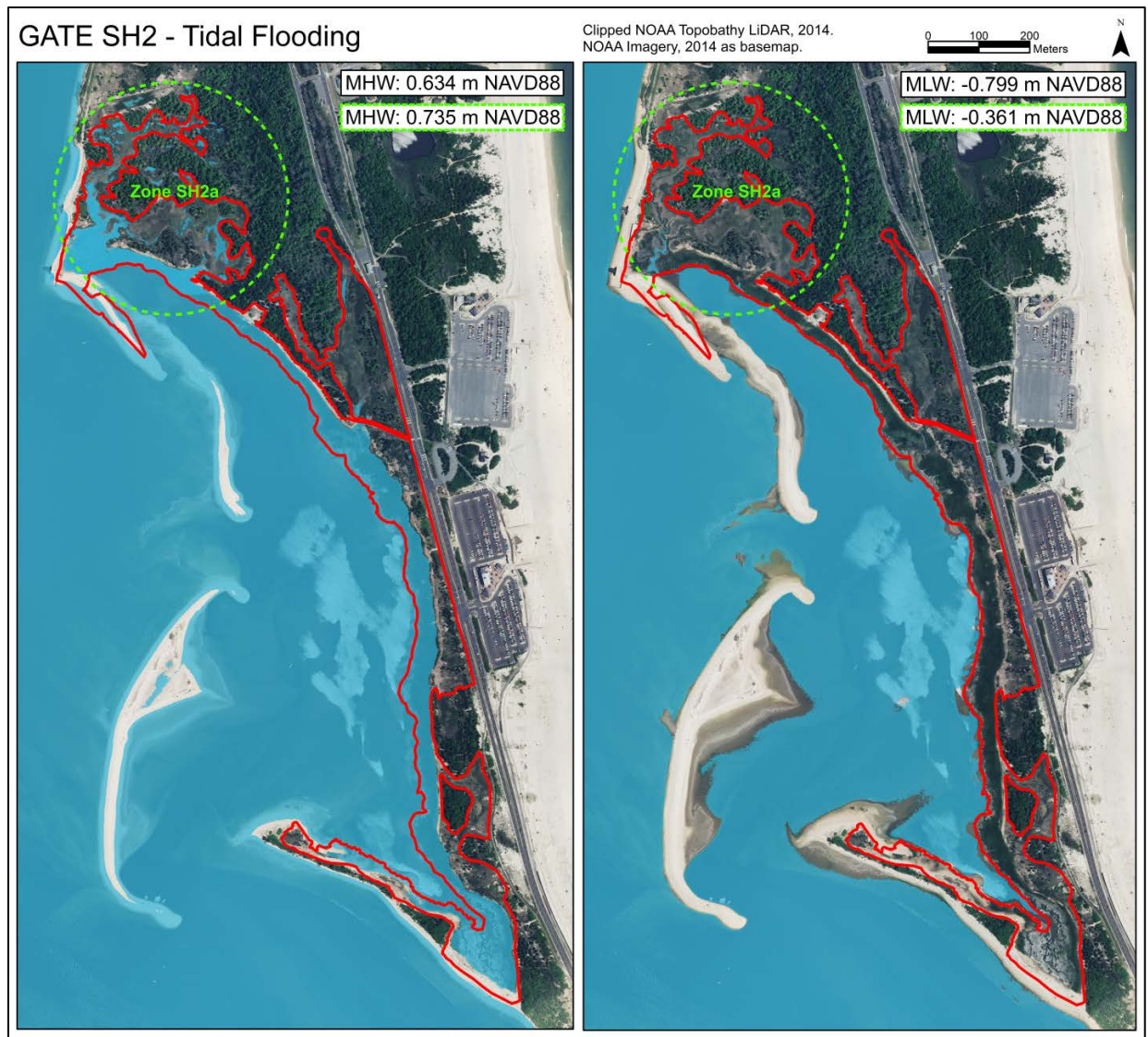


Figure 39. Extent of tidal flooding under MHW and MLW conditions at SH2 marsh. Tidal datums used from Sandy Hook NWLON station.

Marsh 3 (M3)

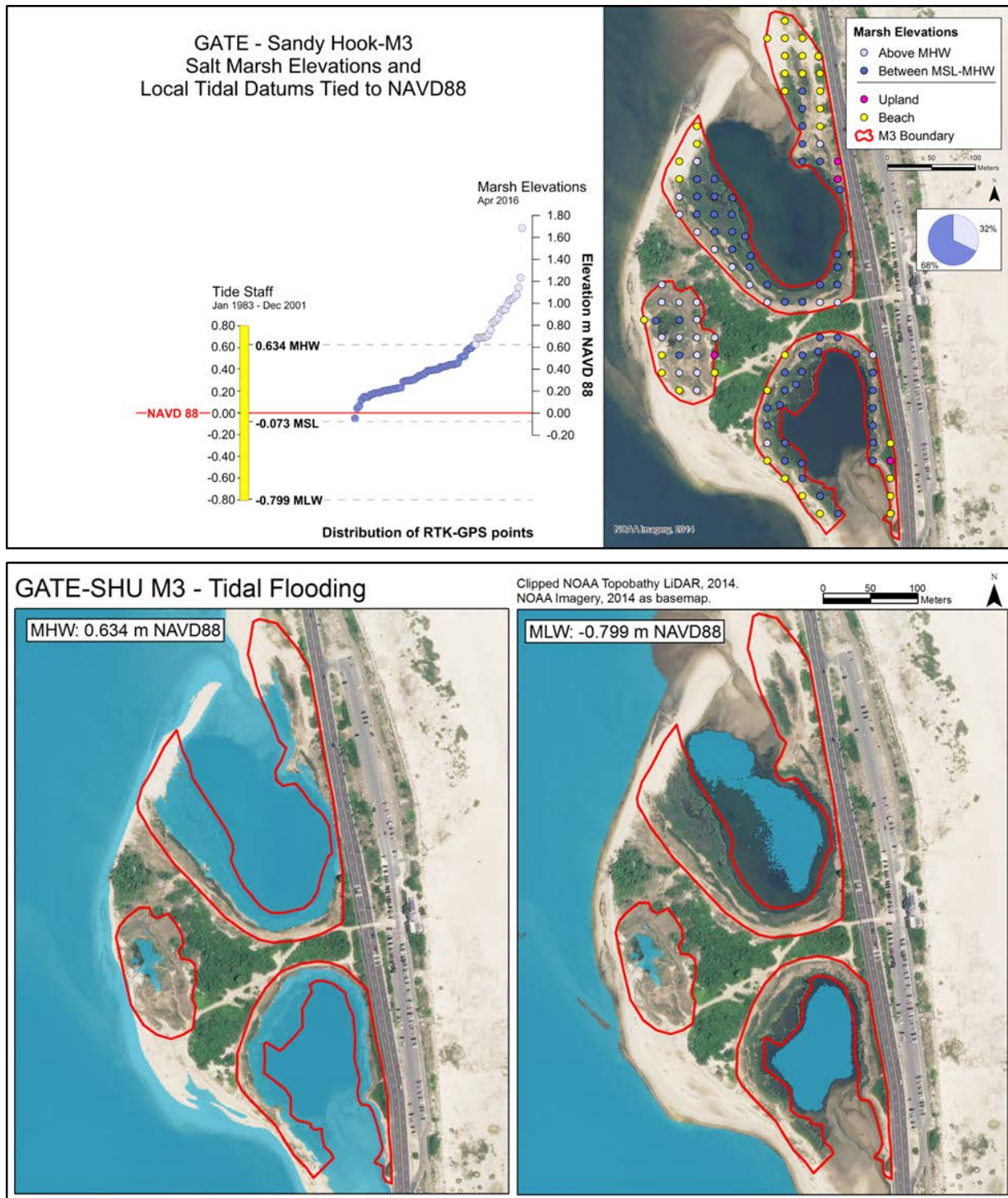


Figure 40. Above: Relationship of salt marsh elevations with local tidal datums. Below: Extent of tidal flooding under MHW and MLW conditions at M3 marsh. Tidal datums used from Sandy Hook NWLON station. Geoid 12A used for GPS elevations.

Tidal Comparisons

Data from the URI-EDC logger were compared to NOAA's NWLON station at Sandy Hook for the same deployment period. Tidal patterns from the marsh deployment sites generally follow the same trend as recorded water levels at Sandy Hook (Figure 41). The extents of high tide elevations are nearly identical while low water levels are restricted from the narrow widths and elevations of the sills of the creek that connect the marshes to the bay. The marsh cannot completely drain before the overpowering tide floods the area. Great Diurnal (GT) ranges (difference of MHHW and MLLW) at M1 and the northwest section of M2 ranged from 66 cm to 1.19 m respectively compared to 1.59 m at Sandy Hook. The remaining portion of M2 would have the same tidal signature as Sandy Hook.

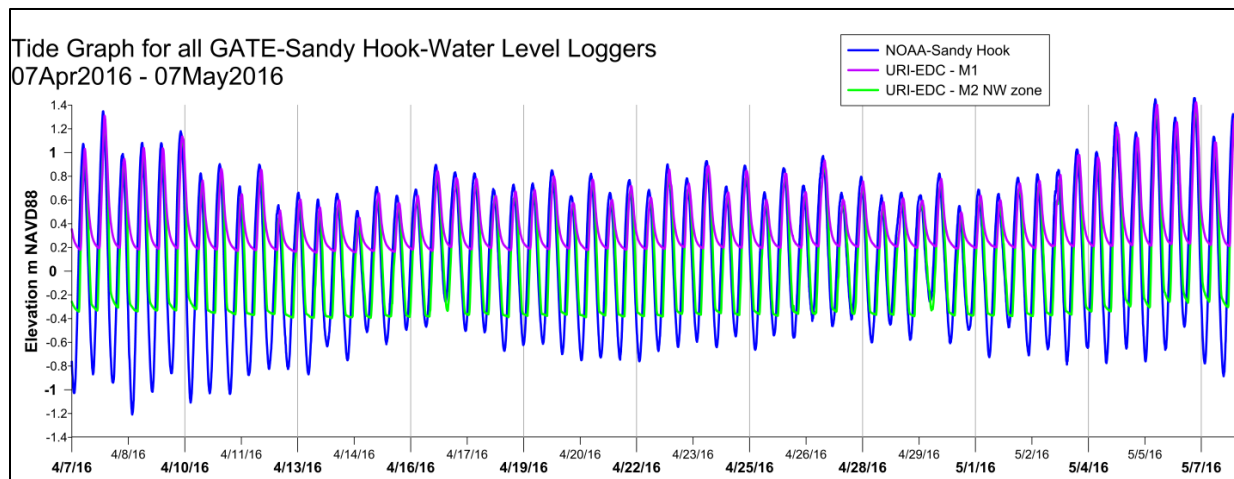


Figure 41. A one month sample of simultaneous comparison of tide graphs for all GATE-Sandy Hook water level loggers and at the NOAA Sandy Hook gauge.

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NPS 622/138790, 615/138790, 646/138790, June 2017

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