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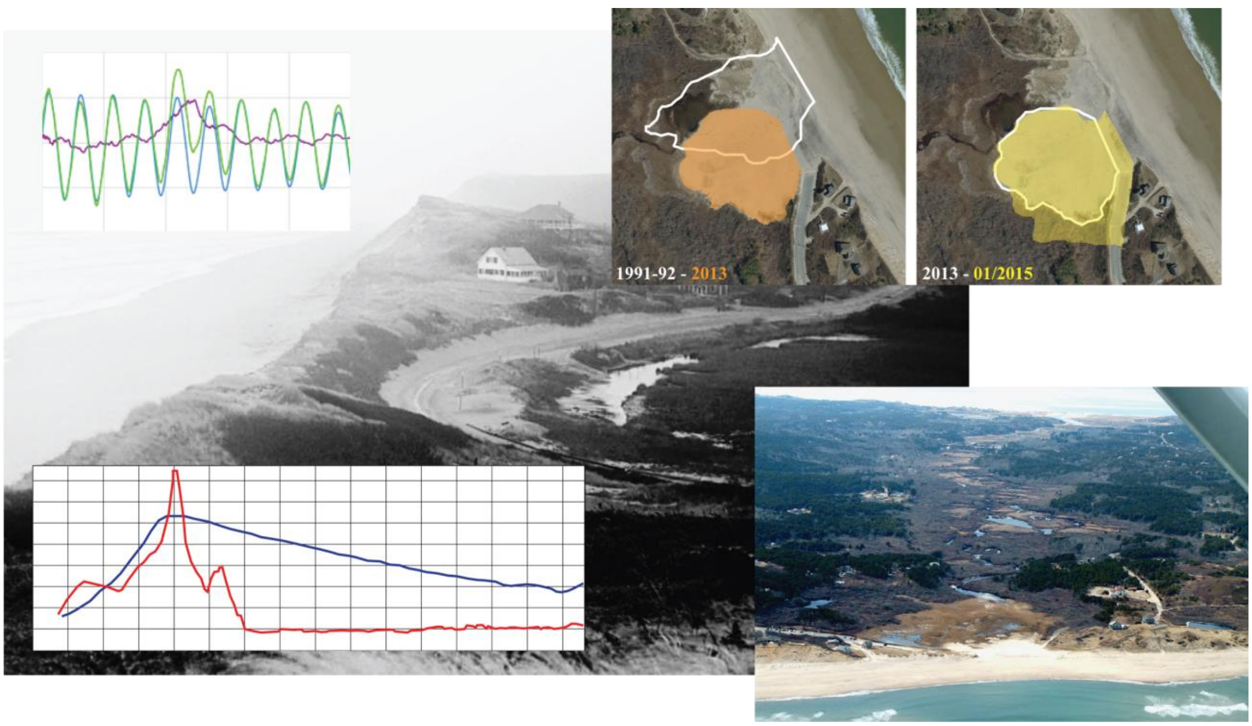
Ballston Beach Overwash: Understanding Overwash Events for Science-based Management



Center for Coastal Studies, Provincetown Massachusetts
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Submitted to the Town of Truro | CCS-DMG Report: 16-01

EXECUTIVE SUMMARY

The area immediately landward of Ballston Beach in Truro, Massachusetts in the Upper Pamet River has experienced several major overwash events since 2013. Historically this area has experienced overwash events but at a much lower frequency. These recent events are in large part due to the unnaturally low elevation of this area caused by the tidal restrictions installed downstream in the 1800 and 1900s. These restrictions have prevented the influx of sediment that would have deposited onto the marsh surface and allowed it to keep pace with sea level rise. Had the surface of the salt marsh increased in elevation there would not be the ongoing 'elevation deficit' and washover events would be much less severe as the water would not have a basin to flow into.

The recent washovers have deposited more than 50,000 yd^3 of sand on more than 5 acres of the Upper Pamet River immediately landward of Ballston Beach. These storms have had several beneficial impacts such as increasing the elevation of these areas and reduction of potential future storm events. Due to the increased elevation of this area future storms of the same intensity and water levels will have less of an impact. As the basin into which ocean water would have flowed fills up, less water will be able to enter, given a storm of similar magnitude. Further, larger storm events will also have less of an impact than they might have had due to this same reduction of the elevation deficit.

It is recommended that the town pursue several courses of action in the short-, medium- and long-term. First, the asphalt from the northernmost section of the town parking lot should be removed to allow this area to return to more natural conditions. This will allow the 'southern' dune (the dune adjacent to the parking lot) to migrate naturally and be better suited to respond to rising sea levels and future storm activity. Second, the sand removed from the parking lot after the January 2015 storm should be returned to the area after the asphalt is removed. This sand is critical to helping the system return to a more natural elevation. Third, future steps should not be taken to manage the southern dune, it should be allowed to erode, accrete and migrate as natural processes dictate. The goal is to have the dune share the same type of profile as the natural dune to the north

Cover image: Lower left and lower right photo taken from safeharborenv.com of the overwash site. Fourth, the restoration of tidal flow to the entire Pamet River should be pursued, this will take many years to design, permit and realize, but should be a focused long-term goal. Lastly, to aid the achievement of these recommendations we suggest the town develop a strategy to engage residents. Both the project and the town will benefit from harnessing the abilities of multiple stakeholders.

INTRODUCTION

This report was commissioned by the town of Truro to document the 2013 and 2015 washover events, place them in historical context, and discuss potential management options going forward. Though the impacts of these washover events affect chemical and biological phenomena this report focuses on the physical impacts to the system with regards to sediment transport, system evolution and coastal processes.

The science-based management of coastal systems is critical within the current regime of climate change and sea level rise. This report is based on analyses of field data collected in 2013, 2015 and 2016 at the study site in the upper Pamet River directly landward of Ballston Beach. Other analyses include historical and recent storms using the long term water level station in Boston (1921 – present). Of particular interest were the four storms, 1 in 2013, 2 in 2015 and 1 in 2016 that resulted in overwash events at Ballston Beach. After each of the storms staff from the Center for Coastal Studies collected high resolution elevation data using a science-grade Global Positioning System (GPS) instrument.

All elevations are reported using the 'North American Vertical Datum 1988 (NAVD88) unless otherwise stated. The NAVD88 datum is a standard vertical datum and is critical for comparing water level elevations through time and to those elevations collected on land using GPS equipment. All water level elevations are taken from the water level station in Boston (Station #8443970) that is operated and maintained by the National Oceanic and Atmospheric Administration (NOAA).

Glacial History and Pamet River

Cape Cod was constructed during the retreat of the Laurentide ice sheet which reached its maximum southern position about 20,000 year ago (Uchupi et al., 1996). Sometime prior to 18,000 years ago the lobate ice front in the Cape Cod region was composed of the Narragansett-Buzzards Bay lobe to the west of the Elizabeth islands, the Cape Cod Bay lobe at the northern edge of upper Cape Cod, and the South Channel lobe to the east of Cape Cod just north of Great South Channel (Figure 1).

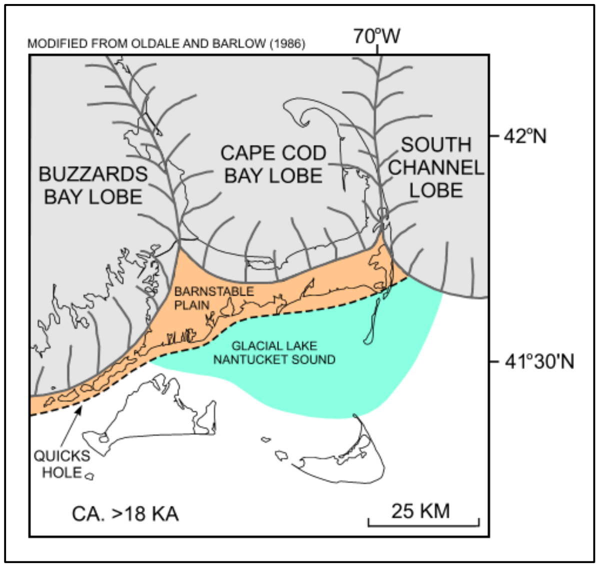

Figure 1. Lobes of retreating glaciers in southeastern New England. After Poppe et al. (2006)

The outwash plains of lower Cape Cod were deposited by braided streams originating in the South Channel lobe located about 2 to 5 miles east of the present coast. The Pamet River was created as one of these freshwater braided streams that feed into what is now Cape Cod Bay as glaciers receded from outer Cape Cod. The Pamet River only became a tidally-influenced embayment as sea levels rose and ocean water from Cape Cod Bay inundated the formally freshwater river basin. Some freshwater does naturally occur in the Pamet River but this is 'baseflow' or ground water that discharges from an aquifer.

Ballston Beach

Ballston Beach, a barrier beach, is a very popular recreational destination within Cape Cod National Seashore. The beach is managed by the Town of Truro and vehicles are allowed entry in the summer with a town beach parking sticker. Ballston Beach is a dynamic open ocean beach that increases in width and height throughout the summer and early fall and narrows and lowers in the winter and early spring. This dynamic beach is in large part due to the Seashore's policy of allowing the coastal bluffs to erode, thus providing a constant supply of sediment. Regardless of winter storms and associated erosion typically seen between December and March the beaches in August and September will be 'high and wide'. In fact, for most years the more erosion that occurs during the winter months the larger the summer beaches will be, as most of the eroded sand that comes off the beach during storm events is slowly pushed back on the beach by fair-weather waves.

The glacial material that make up the large bluffs along most of the shoreline in Truro are not present at Ballston Beach because of the glacial processes discussed above. Further, it has been suggested by some scientists that a phenomenon called ‘wave focusing’ could exist off of Ballston Beach due to the presence of the ‘paleo’ or relict river channel filled by sand, but effected by waves in such a way that a disproportionate amount of wave energy is directed at this site.

Inlet Formation and Pamet River

Occasionally stories appear in the media that state ‘given the right conditions North Truro and Provincetown could become an island’. Given the current and future (decades to centuries) configuration(s) of the Pamet River area there is no possibility of an inlet forming that would connect the open ocean beach with Cape Cod Bay. In the very unlikely event that elevated storm waters were to connect seawater from the bay with sea water from the open ocean there would not be enough ‘negative relief’ (deep enough basins) for that connection to persist. A channel or basin large enough to accommodate very large amounts of water many times the size of Pamet Harbor along the entire length of Pamet River would be required. Though it is hypothetically possible for a thin layer of water to connect the bay and the ocean there would not be a deep enough basin to fill in and continue to flow as storm surges subsided. Further, basin depths would have to be deep enough to accommodate water flow at low tide for an inlet to be maintained. Although the Pamet River is unnaturally low it is not deep enough to accommodate such tidal flow. Further, if a complete tidal restoration of the Pamet River were completed no inlet formation in this area would possible (Giese et al., 1985).

Coastal Evolution and Anthropogenic Alterations

The Upper Pamet River is currently well below its natural elevation, which effectively increases the volume of water that flows into the Upper Pamet during overwash events. If the Pamet was a natural tidal estuary along its entire length this would not be the case. In 1869 the town built Wilder’s Dike to replace a bridge (Giese et al., 1985). This prevented any tidal flow from reaching the Upper Pamet. The dike was fitted with a clapper valve and a culvert to prevent seawater inflow during high tides as well as allowing freshwater to outflow when needed (Portnoy, 2001).

The effects of the dike can most easily be seen by comparing environments above and below the dike. Below the dike, near Pamet Harbor there is a hearty saltwater ecosystem. The semi-diurnal (twice daily) tidal cycle brings organic and inorganic sediment into the system during flood tides. Some of that material is deposited onto the salt marsh allowing it to grow vertically and keep pace with rising sea levels. Above the dike, however, there is little to no saltwater and the ecosystem is a freshwater wetland. While these types of wetlands still provide some level of ecosystem services they are well below the value of salt water wetlands. Additionally, and perhaps most importantly, the tidal restriction caused by the dike has prevented the influx of material typically brought in with tidal waters and thus this wetland has not been able to keep pace with sea level rise. In addition to the lack of incoming sediment, compaction and subsidence have reduced the surface of the wetlands by approximately 2 feet (Giese et al., 1990).

Background and Natural Processes

The process of ocean water flowing over low-lying coastal areas during episodes of elevated water (storms, spring-tides, etc.) is called overwash. The landforms (broad, flat, sandy areas) left after overwash events are called washover fans. Some of the seminal work done on these processes and features was done in the 1970s and 80s on Cape Cod and elsewhere (Leatherman, 1976; Leatherman, 1979; Pierce, 1970).

Overwash is a critical process for low-lying coastal areas for several reasons. First, as seawater overwashes these areas during storms, or other high water events, sediment is brought into the area and is deposited. This deposition increases the elevation of the area allowing it to keep pace with sea level rise. As sea levels rise, these areas become corresponding higher, future storms superimposed on this sea level rise bring in more sediment during overwash events thus the area naturally keeps pace with sea level rise. Second, washover fans are valuable habitat not easily reproducible by human intervention, and due largely to human activities such as coastal development, areas suitable for the formation of washover fans are becoming increasingly rare.

Storm history

Outer Cape Cod is a high energy, open ocean shoreline exposed to powerful nor'easters and occasional hurricanes (Table 1). It is a dynamic coast with large volumes of sediment moving northward along the shoreline (Giese et al., 2011). The first well-documented washover events occurred during the The Blizzard of 1978, the 'No-Name' or 'Perfect storm' in 1991 and the December 1992 storm (Portnoy, 2001).

Table 1. Maximum Water Levels for Boston Harbor Since May 3, 1921. Highlighted dates are major overwash events at Ballston Beach that have been documented.

Boston Harbor (Station #8443970)
Highest Recorded Water Levels

Rank	Date	NAVD88 (Ft.)	MLLW (Ft.)
1	2/7/1978	9.59	15.11
2	1/2/1987	8.69	14.21
3	10/30/1991	8.66	14.18
4	1/25/1979	8.53	14.05
5	12/12/1992	8.52	14.04
6	12/29/1959	8.49	14.01
7	4/18/2007	8.29	13.81
8	5/25/2005	8.27	13.79
9	2/19/1972	8.19	13.71
10	12/27/2010	8.19	13.71
11	5/26/2005	8.16	13.68
12	1/27/2015	8.13	13.65
13	5/26/1967	8.11	13.63
14	6/5/2012	8.07	13.59
15	3/4/1931	7.97	13.49
16	11/30/1944	7.87	13.39
17	1/20/1961	7.85	13.37
18	4/21/1940	7.83	13.35

METHODS

Detailed elevation and spatial surveys of washover fans are critical to understanding not only the overwash events that formed them but also provide insight into the evolution of the coastal landform within the context of climate change, sea level rise and anthropogenic alterations. A Trimble® R8 GNSS receiver utilizing Real-Time-Kinematic GPS (RTK-GPS) was used for positioning and tide correction. The Center subscribes to a proprietary Virtual Reference Station (VRS) network (KeyNetGPS) that provides virtual base stations via cellphone from Southern Maine to Virginia. This allows the Center to collect RTK-GPS without the need to setup a terrestrial base station or post-process the GPS data in any way, reducing costs and effort related to field work.

The Center undertook a rigorous analysis of this system to quantify the accuracy of this network (Mague and Borrelli, in prep). Over 25 National Geodetic Survey (NGS) and Massachusetts Department of Transportation (DOT) survey control points, with published state plane coordinate values relating to the Massachusetts Coordinate System, Mainland Zone (horizontal: NAD83; vertical NAVD88), were occupied. Control points were distributed over a wide geographic area up to 50 km away from the Center.

Multiple observation sessions, or occupations, were conducted at each control point with occupations of 1 second, 90 seconds, and 15 minutes. To minimize potential initialization error, the unit was shut down at the end of each session and re-initialized prior to the beginning of the next session. The results of each session (i.e., each 1 second, 90 second, and 15 minute occupation) were averaged to obtain final x, y, and z values to further evaluate the accuracy of short-term occupation. Survey results from each station for each respective time period were then compared with published NGS and DOT values and the differences (error) used to assess and quantify uncertainty. Significantly, there was little difference between the error obtained for the 1 second, 90 second, and 15 occupations. The overall uncertainty analysis for these data yielded an average error of 0.008 m in the horizontal (H) and 0.006 m in the vertical (V). An RMSE of 0.0280 m (H) and 0.0247 m (V) and a National Standard for Spatial Data Accuracy (95%) of 0.0484 m (H) and 0.0483 m (V).

The GPS data are imported into ESRI's ArcGIS software and overlain against the relevant aerial photographs. The lidar data were downloaded from the NOAA Digital Coast webpage in a raster format and brought into ESRI's ArcGIS software where the raster is divided into smaller tiles. These lidar tiles are then brought into QPS's Fledermaus data visualization software. While acquired by CCS as an integral component of its Seafloor Mapping Program, the Fledermaus software package has proven to be an ideal platform for analyzing large three-dimensional datasets, such as lidar.

The long term data set from the Boston water level station (NOAA Station #8443970) beginning in 1921 through to the present is the highest quality data set of its kind. Though waves play a major role in coastal processes the long term water level data is a better dataset to place past storms and overwash events into historical context. Tidal ranges, cycles and phases are very similar for Boston, Cape Cod Bay and to a lessor extent the northern part of the outer Cape.

RESULTS

This report is focused on detailing recent overwash events that have deposited washover fans (Figure 2). Portnoy (2001) discussed the ecological impacts of the overwash events in October 1991 and December 1992. While it is understood that waves do occasionally break at the base of the dune itself and ocean water does overtop the dune the overwash event from March 2013 is the first event examined in detail here, through to the January 2016 overwash event.

Figure 2. Extent of washover fans mapped for this project (2013 – 2016). 1991-92 extent was inferred from the 1994 aerial. Upper left: the red line is approximate location of profiles shown in Figures 4, 7, 10 and 11.

March 2013

The first overwash event discussed here occurred during a late winter storm on 08 March 2013 (Figure 3). The area was not mapped until 25 July 2013, this was done at the request of Cape Cod National Seashore. The Seashore held a public meeting in the Truro Town Library in August of 2013. The speakers included Drs Mark Borrelli and Graham Giese from the Center for Coastal Studies discussing the 2013 overwash event and Pamet River geomorphology respectively. Presentations about the hydrology, a recent groundwater study and the ecology of the Pamet River were also delivered.

At 7:56am on 08 March water levels peaked at 7.39 ft NAVD88 at the Boston tide station, this was over 2 feet lower than the Blizzard of 1978 yet a major overwash event occurred. Elevated water levels were seen for days before the peak of the storm which would have very likely caused erosion in front of the dune. This may have played a role as waves eroding Ballston Beach prior to the peak of the storm would have allowed waves to break further up the beach and in turn would have enabled more water to overwash the dune at high tide. Interestingly, the storm surge (3.16 ft) peaked at approximately 3:42pm on 08 March, one hour after low tide. Had the storm surge peaked at high tide the overwash would have been much more extensive.

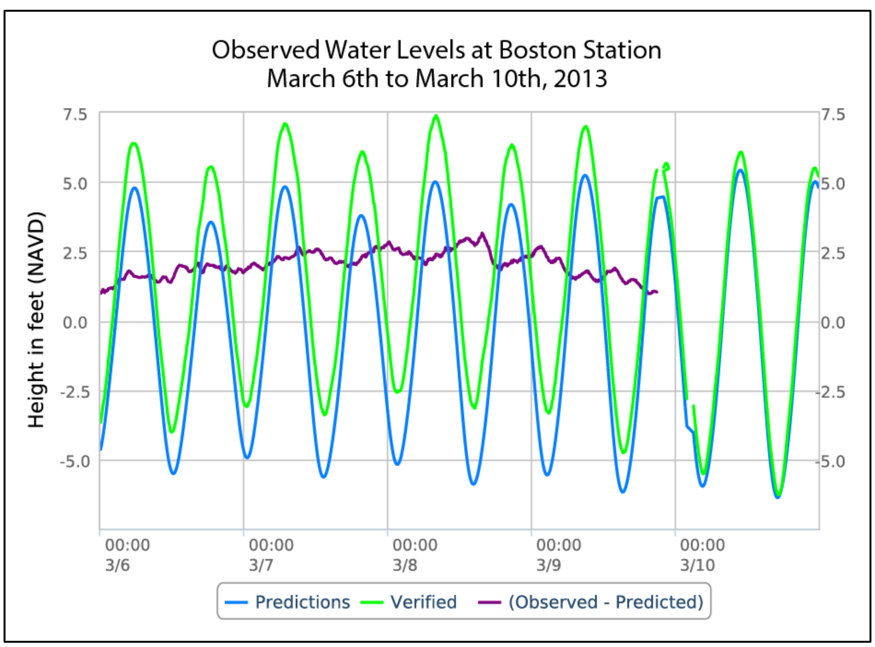

Figure 3. Water level data from the Boston tide gauge for 06 – 10 March 2013. Note the peak storm surge (purple line) occurs at low tide. Data source: https://tidesandcurrents.noaa.gov/waterlevels.html?id=8443970: 'Observed – Predicted' was not available for the latter part of this record at the time of publication.

Although no other overewash events occurred between the March storm and the July RTK-GPS survey of the washover fan some compaction and/or subsidence may have decreased the elevation of the feature. Conversely, over the course of four months aeolian (wind-blown) deposits may have increased the elevation of the washover fan. However, as seen in Figure 4 the change in elevation in these areas document a very large depositional event and could only have been deposited by an overwash event of the magnitude witnessed by many in the March storm. Videos of the overwash event are publicly available.

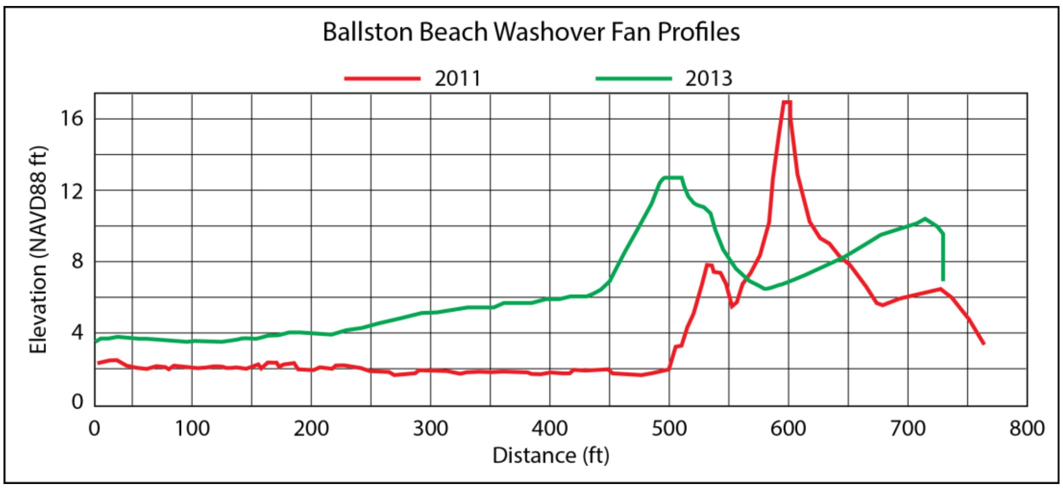

Figure 4. The 2011 profile was extracted from lidar data that was downloaded from the NOAA Digital Coast webpage (https://coast.noaa.gov/dataviewer/). The profile from 2013 was collected on 25 July 2013. The storm occurred on 08 March 2013.

The build up of the dune fronting the Pamet River prior to the 2013 storm was considerable. In May 2011 the top of the dune was over 16 ft (NAVD 88) and the elevation of the Pamet River just behind the dune was ~2 ft (NAVD 88). It is likely that the dune maintained its peak elevation, if not increasing in height prior to the 2013 storm.

After the overwash events of 19901 and 1992 there had been concerns of seawater contaminating water wells if storms continued to bring ever increasing amounts of salt water into the Upper Pamet. The fear that water could be impounded behind the clapper valve and drinking wells could be contaminated as the standing salt water infiltrated into the aquifer was prevalent in some circles. However, no contamination of water wells from overwash events has ever been verified in the Upper Pamet River.

There had been occasional events of water washing over the dunes during storms, rarely had these smaller washed over areas extended down into the Upper Pamet (Figure 5). A project was designed to increase the elevation of the dune in order to lessen the amount of overwash that reached the Upper Pamet in the hopes of reducing the likelihood of energetic storm events moving large amounts of water into the area and potentially contaminating wells. The project was very successful in achieving its intended goal of increasing dune elevation. By working with the natural processes, Safe Harbors Environmental inserted sand fencing, with and without connecting wire and planted beach grass both of which helped capture wind blown sand that slowly built the dune. This is a simple, yet effective way to mimic coastal processes to aid in achieving a desired goal and natural phenomenon (increasing dune elevation and size) with little disturbance of the natural ecosystem. This method was so successful that multiple 'reinsertions' had to be employed as the sand fencing was buried in the accreting dune.

Figure 5. Example of relatively small overwash event from 2009. Image taken from Peabody and Gorczynski, 2010 and modified here to demonstrate landward extent of flowing water. This image does not capture water actively flowing but the landward extent of water flowage is estimated by the solid white line.

After the material that had been captured by the dune building project had washed away in the March 2013 storm the Town of Truro placed approximately 4,000 yd^3 of sand in the area that connected the beach to the washover fan and planted beach grass and re-inserted sand fencing in an effort to repeat the past success.

The dune building project had several beneficial consequences, both intended and unintended. First, as intended, it likely prevented overwash events from occurring, that given certain conditions, may have had a negative impact on town infrastructure as well as private property and structures. Second, as designed, it built up the sand in the dune. One unintended, though beneficial result, was the transportation of the sand stored in the dune into the Upper Pamet during the January 2015 storm. Had this dune not been built up much less sand would have been deposited during the overwash event. This sand was vital in increasing the unnaturally low elevations, or reducing the 'elevation deficit', in the Upper Pamet.

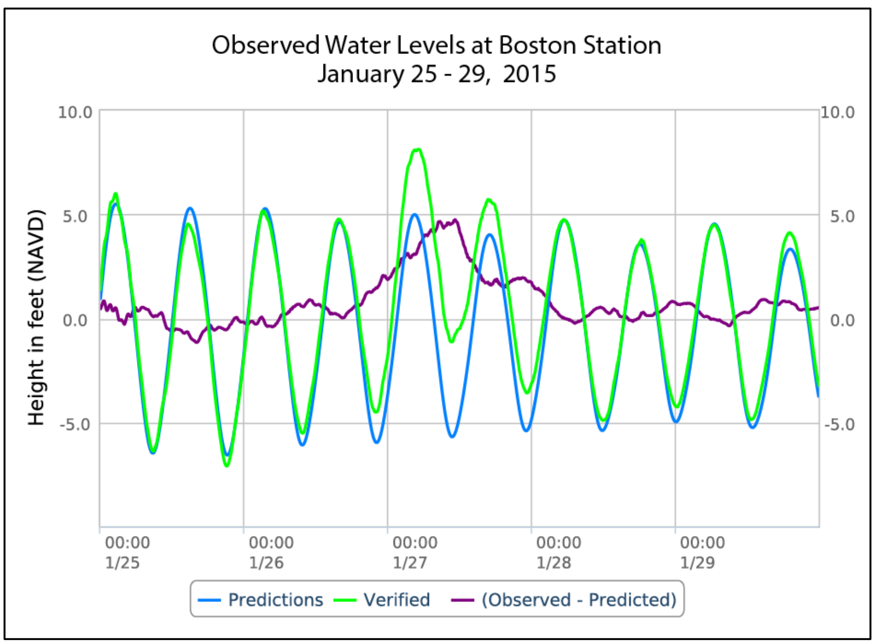

Figure 6. Water level data from the Boston tide gauge for 25 – 29 January 2015. Note the peak storm surge (purple line) occurs at low tide. Data source: https://tidesandcurrents.noaa.gov/waterlevels.html?id=8443970

January 2015

A large Nor'easter moved through the eastern United States in late January 2015. On 27 January the storm, then a blizzard, struck Massachusetts and a large overwash event occurred at Ballston Beach. Water levels peaked 4:42am on 27 January, reaching 8.053 ft (Figure 6). This was the 12th highest water level ever recorded at the Boston tide gauge since records started being kept in 1921.

Most remarkably the storm surge of 4.5 ft, peaked 6.5 hours later at approximately 11:12am, one hour after low tide. Had the peak storm surge occurred at high tide rather than low tide, water levels would have likely reached beyond the Blizzard of 1978 and flooding would have been much more extensive. Also, the January 2015 storm occurred during a neap tide, had the storm occurred during a spring tide still more overwash would have occurred. Although, as mentioned above due to the shape of the basin in the Upper Pamet River there would have been no threat of an inlet forming in Pamet River even with unprecedented levels of storm surge. The Blizzard of 1978 is the storm of record for the area.

The storm surge at the Boston tide gauge peaked very close to low tide. As such storm waves were likely able to erode higher up the beach thus allowing the waves at high tide to also erode still higher up the beach. This would have allowed more water to flow over Ballston Beach and into the Upper Pamet River. Although peak storm surge did occur at low tide, which drastically reduced flooding, a large overwash event still occurred due in large part to the overall intensity of the storm.

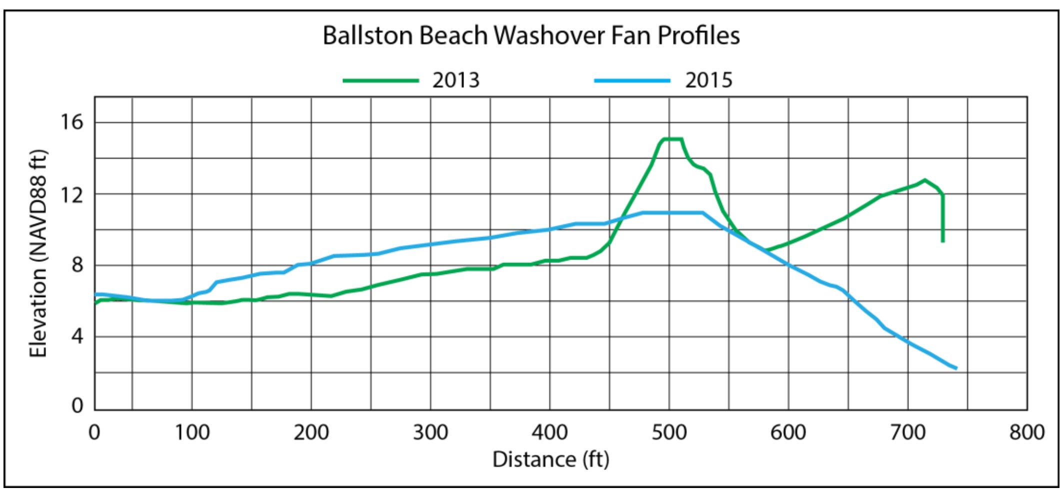

Figure 7. The profile from 2013 was collected on 25 July 2013. The storm occurred on 08 March 2013. The profile from 2015 was collected on 14 February after the storm event on 27 January.

The increasing elevation of the beach, from approximately 600 ft to 725 ft in the 2013 profile in Figure 7 is typical of an accreting summer beach, the profile was collected in July 2013. The crest of the dune lost 4 feet in elevation from 2013 to 2015 and a nearly uniform 2 ft of sand had been deposited along 400 feet of the washover fan along the profile (~100 ft – 450 ft).

February 2015

Another blizzard, though less intense than the January blizzard, moved through the area several weeks later. On 15 February water levels peaked at 7:18am reaching 6.61 ft, high tide occurred soon after at 7:44pm. This storm surge was 1.44 ft lower than the January storm and a much smaller overwash event occurred. The storm lasted over three high tides with only the last high tide experiencing a significant storm surge (Figure 8). The peak storm surge coincided with high tide, but the tidal phase was transitioning from a neap tide to a spring tide and therefore tides could have been higher had the storm occurred a few days later. It should be reiterated that a small increase in water elevation can have a profound difference in coastal flooding levels. However, in this instance, it is likely that the much smaller washover event was more a function of the January storm depositing so much material prior to this storm.

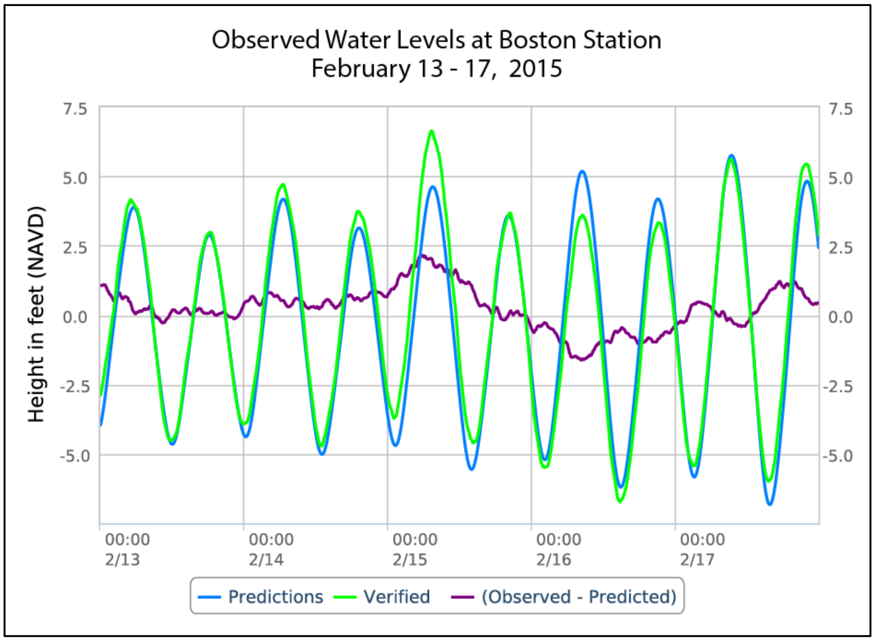

Figure 8. Water level data from the Boston tide gauge for 13 -17 January 2015. Note the peak storm surge (purple line) occurs just before high tide. Data source: https://tidesandcurrents.noaa.gov/waterlevels.html?id=8443970

Comparison profiles were not useful for these two closely spaced events because, as stated above, the January event increased the elevation to such an extent that the February overwash was primarily restricted to the southern portion of the January washover fan and primary transect (upper left of Figure 2), showed little change. Even though the elevation of the February storm was lower than the January storm, 6.61 ft and 8.05 ft respectively, some overwash still occurred.

January 2016

During the writing of this report another overwash event occurred on 24 January 2016. Data were collected and a cursory examination is included here. The 2016 storm was similar to the February 2015 event. Water elevation peaked at 11:00 am (6.83 ft) with a storm surge of 1.45ft, the peak storm surge (2.54 ft) occurred 7 hours earlier at 3:42am an hour before low tide (Figure 9). The storm occurred one day after the spring tide.

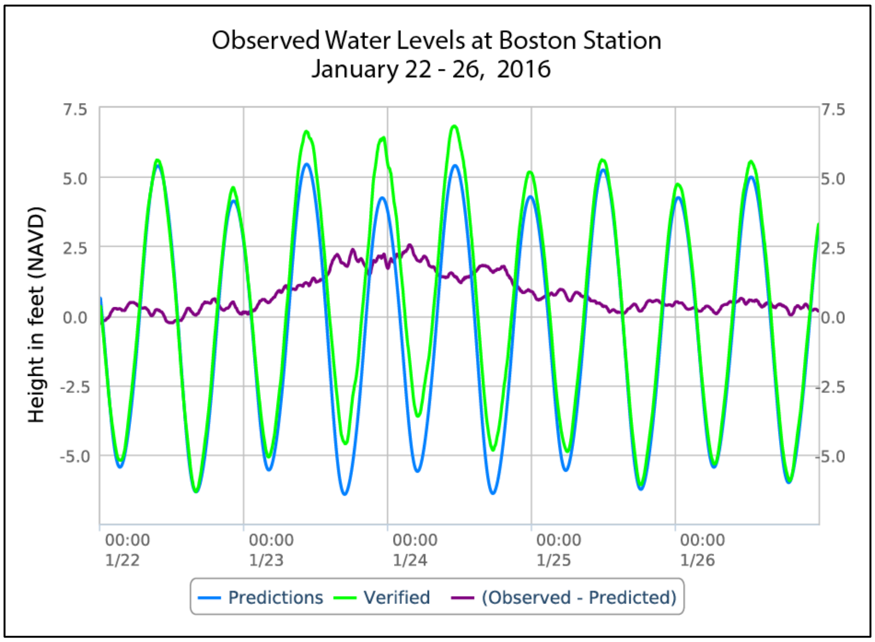

Figure 9. Water level data from the Boston tide gauge for 22 – 26 January 2016. Data source: https://tidesandcurrents.noaa.gov/waterlevels.html?id=8443970

The relatively mild fall and winter of 2015-2016 through January 2016 likely accounts for the higher beach seen in the profiles (Figure 10). The February 2015 washover fan was mapped on the 15th as storm waters were receding and as such no compaction or subsidence had occurred. Further, little if any deposition was seen along the primary transect in January 2015. Both these factors could account for the higher elevation in the 2015 profile relative to the 2016 profile on the washover fan.

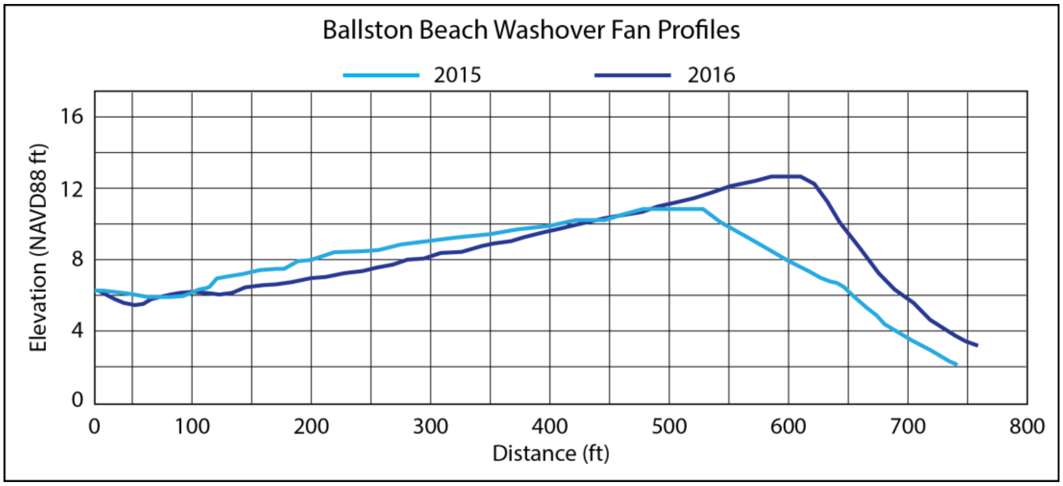

Figure 10. The profile from 2015 was collected on 14 February after the storm event on 27 January. The profile from 2016 was collected on 26 January two days after the storm.

Volume calculations did not include changes to the beach, but were made to were made on the washover fan only (Figure 2). The 2013 storm deposited a washover fan that covered 3.46 acres with over 25,000 yd^3 of material (Table 2). The 2013 storm deposited the largest amount of material of all four events. This was in large part due the availability of space for material to be deposited by the storm; a bigger basin accommodates more flowing water which in turn brings in more sediment. After the 2013 storm this area was much higher in elevation and the January 2015 storm accordingly deposited much more material to the south (Figure 2), as that was the area that was now the lowest in elevation. The January 2015 event had much higher water levels than the 2013 storm, 8.05 ft vs 7.39 ft, respectively, yet less sand was deposited.

Currently, the 'southern dune', the dune adjacent to the parking lot, looks very similar to the dune seen along the primary transect in 2011 (Figure 11). It has a very unnatural profile, rather than a long, slow decrease in elevation as is typical for naturally migrating dunes, the southern dune has an abruptly dipping landward profile, with an erosional scarp in places. This is largely due to the removal of sand that is deposited on the parking lot. If this sand were allowed to accumulate the dune would migrate landward as the northern dune is currently. This is one of the ways in which coastal areas respond to rising sea levels. In fact, the coastal system in this area has migrated landward for millennia (Giese et al., 1985), likely with a very similar morphology (size and shape) as is presently seen.

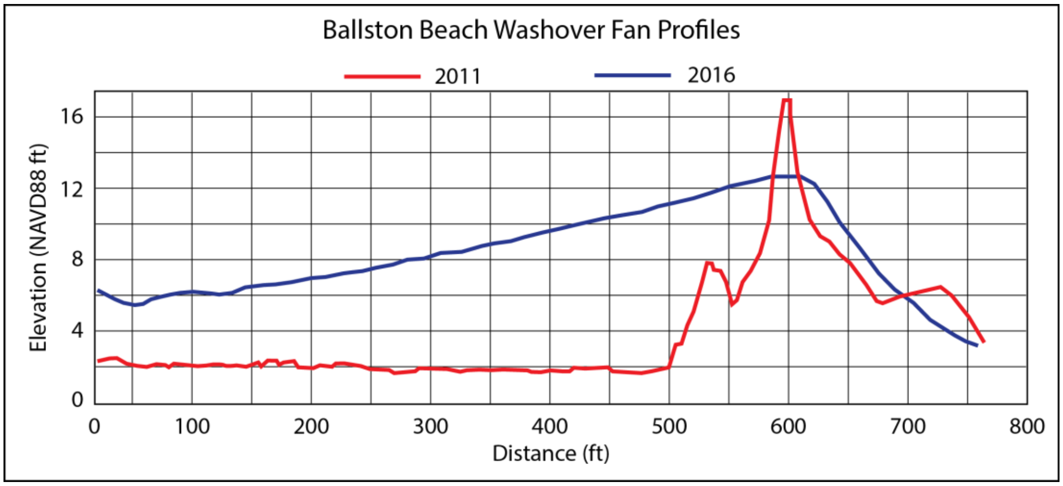

Figure 11. The 2011 profile was extracted from lidar data that was downloaded from the NOAA Digital Coast webpage (https://coast.noaa.gov/dataviewer/). The profile from 2016 was collected on 26 January two days after the storm.

The overwashing of Ballston Beach has several benefits. First, due to the elevation deficit of the Upper Pamet River the sand brought in by overwash events increases the elevation helping these areas keep pace with sea level rise (Figure 11). The cost of trucking in tens of thousands of cubic yards of sand would likely costs millions of dollars and and would require many thousands of trips with large dump trucks to deliver the material to the area. Second, with each overwash and deposition event the less likely a future storm will cause flooding or more deposition. If there had not been such a pronounced elevation deficit prior to the 2013 storm these overwash events would have been far less intense with much less seawater, and sediment, being brought into the area. As the system becomes more in equilibrium with the surround elevations storms of similar elevations will have diminishing impacts. However, the Upper Pamet River beyond the washover fans still has a significant elevation deficit which would likely be addressed, over time, if tidal flow were restored to the Pamet River.

Table 2. Spatial analysis of washover fans based on GPS data and corresponding formational overwash events.

EVENT	AREA (acres)	VOLUME (yd^3)	PEAK ELEVATION (ft)	STORM SURGE (ft)
08 March 2013	3.54	25,089	7.39	2.40
27 January 2015	5.04	21,947	8.05	3.10
15 February 2015	1.29	N/A	6.61	2.01
24 January 2016	3.68	N/A	6.83	1.44

MANAGEMENT RECOMMENDATIONS

Based on the findings of this study the following short, medium and long term recommendations are offered. These recommendations are based on balancing the needs of the town to provide visitors access to Ballston Beach as well as allowing the coastal system to evolve more naturally now and in the future. By working with the natural processes the Upper Pamet will return to providing pre-disturbance ecosystem services to the extent possible.

- Short-term recommendations should take place before the summer of 2016 -

Recommendation 1: <u>Remove asphalt from northern portion of parking lot</u>

Center scientists will work with Town staff to determine the practical extent of the asphalt to be removed from the northern portion of the parking lot. This step should be taken for two reasons, first by removing this asphalt the area will be returned to a more natural state thus allowing the dune to migrate landward. Second, as sand is deposited and beach grass and other native vegetation return this area will be better able to adapt and evolve to storms and sea level rise.

Recommendation 2: <u>Return sand deposited during January 2015 storm to low lying area</u>

After the January 2015 storm the sand that was deposited in the town parking lot was removed to allow beachgoers access to the parking spaces for the summer of 2015. Earth-moving equipment was used to remove the sand from the parking lot and was placed in the areas immediately adjacent to the parking lot. This material should be returned to the parking lot.

As discussed above overwash events deposit sand in the lowest areas that are closet to the overwash site. The sand in the parking lot was up to 6 feet deep in places. By returning this sand to the area future overwash events will be greatly reduced in frequency and severity.

- Medium- and long-term recommendations should be enacted in the next few years and in years to decades, respectively -

Recommendation 3: <u>Allow the 'southern dune' to evolve naturally</u>

A medium term goal of allowing the southern dune to evolve in response to natural processes is suggested. Currently the town removes sand landward of the southern dune in the parking lot. This practice should stop and the dune should be allowed to naturally migrate, accrete and erode. The northern dune has a much more natural profile and will be able to migrate landward as storms and sea level rise affect the area.

Recommendation 4: <u>Restoration of tidal flow to the Upper Pamet River</u>

The long term goal for the town is to return the site and the entire Pamet River to as close to pre-disturbance levels as is practical. By restoring tidal flow to the upper Pamet River the return of a coastal salt marsh ecosystem would be realized. These ecosystems are unparalleled not only in the value of the ecosystem services, providing habitat, nursery for finfish and shellfish, filtration of contaminants, flood control, etc., but they are also among the most aesthetically pleasing. Sea levels are rising and a tidally restored Pamet River will help the ecosystem and the town better adapt to future conditions.

Recommendation 5: <u>Resident Outreach Strategy</u>

The town should begin to develop a strategy to engage residents. Restoring tidal flow will be a complex process effecting many stakeholders. The project and the town would benefit from engaging residents now and in the future.

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