RESILIENCE OF UPLAND CONFINED DISPOSAL FACILITIES AND BENEFICIAL RE-USE OF DREDGED MATERIAL FOR COASTAL PROTECTION

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ABSTRACT

Superstorm Sandy wrought havoc along the New York- New Jersey coastline in 2012. While much of the damage to homes, roads, and ports are well documented, the impact to the marine transportation system (MTS) as a whole extended far beyond news reports and publications. In the immediate aftermath of Superstorm Sandy, the New Jersey Department of Transportation’s Office of Maritime Resources (NJDOT-OMR) was newly tasked with recovering and maintaining the NJ MTS. With the help of on-call consultants, led by WSP | Parsons Brinckerhoff, the team surveyed and sampled over 370 nautical kilometers (km) in 209 state-marked and maintained channels in less than 3 months and identified 2.3 million cubic meters (m^3) of sediment requiring dredging, with about 612,000 m^3 attributable directly to Superstorm Sandy. Given the high percentage of fine-grained sediments identified, availability of capacity in confined disposal facilities (CDFs) would be critical to promptly return the NJ MTS to a state of good repair. An initial damage assessment of representative confined disposal facilities (CDFs) revealed significant damage to several CDFs. This initial assessment was followed by a more extensive condition evaluation for FEMA reimbursement involving the inspection of 22 upland CDFs in total, covering approximately 1/3 of the CDFs in the state. These more detailed inspections identified key features which contributed to CDF damage or resilience, including presence of barrier marsh, dike compaction & geotechnical composition, geomorphology, and proximity to inlets. Viewing dredged material as a valuable resource rather than an encumbrance, details for beneficial re-use of dredged material are also presented along with two brief case studies of dredging contributing to coastal resilience: 1) Keansburg CDF and 2) Fortescue Thin-Layer Placement (TLP). Due to public outreach, the Keansburg CDF project incorporated a CDF into a coastal protection system at the request of township officials. As a result, CDF dikes were raised and maintenance dredging included both a beach replenishment and filling of the CDF. Fortescue TLP is a pilot project conducted in coordination with NJDOT-OMR, NJDEP, USACE, and others to use dredged material from a neighboring channel to restore marshland that has been degraded due to sea level rise. Based on lessons learned post-Sandy, recommendations are provided for enhancing upland CDF resilience and for the potential for beneficial use of dredged material to boost long-term MTS resilience and combat coastal sea level rise.

Keywords: Hurricane Sandy, Superstorm, thin-layer placement, marsh erosion, sea level rise.

INTRODUCTION

The New Jersey (NJ) Marine Transportation System (MTS) is comprised of over 930 km of engineered waterways, thousands of docks, berths, and ramps, and two internationally significant ports with associated facilities. The NJ MTS can be divided into three major regions: the NY/NJ Harbor, the Delaware River, and the Atlantic Shore. In all, the NJ MTS supports activities ranging from tourism and recreation to commercial fishing and international trade, driving an economic engine worth over $50 billion annually. In order to maintain the MTS, dredging is required to remove millions of cubic meters of sand, silt and gravel which are transported into this channel network every year. Historically, dredged material was disposed of in the cheapest and most convenient way available, frequently without consideration for environmental or aesthetic impact. Many open water disposal sites were used in NJ, and the NJ coast is littered with upland confined disposal facilities (CDFs), some used, some abandoned. Currently, increased environmental awareness and competition for coastal land has made disposal unsustainable, and the recurring objective is to reduce dredging need wherever possible; reduce contamination; and apply beneficial re-use

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wherever possible. The Office of Maritime Resources of the New Jersey Department of Transportation (NJDOT-OMR) has been the agency charged with developing strategies for dredging and dredged material management statewide since the 1990’s. However, in late 2012, this role was about to expand.

On October 29, 2012 at about 8 PM EDT the eye of “Superstorm Sandy” made landfall near Atlantic City, New Jersey. A full moon made the high tides approximately 20 percent higher and amplified the record storm surge. The destructive “right hook” of Sandy’s hurricane wind pattern devastated the New Jersey and New York coastline from Cape May to Long Island. As a result, the Superstorm brought unprecedented storm surge and winds to shore communities and cities alike, spreading devastation across the region. As the extent of damage to the NJ MTS was defined, it became clear that the evaluation and recovery effort was going to require changes in responsibility. At the request of NJ Governor Chris Christie, NJDOT-OMR was charged with recovery and long-term maintenance of the State channel network.

DAMAGE ASSESSMENTS & RESILIENCE OF UPLAND CONFINED DISPOSAL FACILITIES

In order to determine the storm’s impact on the navigable waterways, and to assess the general dredging needs of the NJ MTS, an extensive investigation program was initiated by NJDOT-OMR within months of the storm. A comprehensive side-scan sonar and bathymetric channel survey was performed to determine the locations of sunken debris and the extent of channel shoaling caused by the storm surge. Side-scan surveys extended from channel areas to wide sections of the NJ back-bay areas. Thousands of sunken targets were identified, ranging from cars and boats to pilings and crab pots. It was impossible to know how much of this debris was storm related and how much was already in place, but nonetheless, contractors were hired to remove as much of it as possible. Given the long maritime history of the area, the State Historic Preservation Office needed to review all of the data and approve its removal before the contractors could act.

A comprehensive synoptic bathymetric survey had never been done in the State’s history. The first challenge was actually cataloging all of the State’s navigation channels. While the New Jersey Department of Environmental Protection (NJDEP) Bureau of Coastal Engineering (BCE) had been evaluating and marking safe passage for decades, full engineering level surveys had not been done, or were no longer available, on many channels. NJDOT-OMR assembled key staff from various agencies and eventually was able to map out the State’s network from Liberty State Park in Hudson County in the north to Cape May County in the south. In total, 209 channels were identified for surveying, covering about 370 km. It is important to note that these channels are only those that the State claims responsibility for; it excludes Federal, local, and private berths and channels.

After channel identification, marine surveyors were dispatched to collect hydrographic data. To supplement the survey data, thousands of vibracore samples were also collected and reviewed in order to determine the amount of sediment deposited in the channels by the storm. Daily coordination calls between NJDOT-OMR, key stakeholders, and the design team, led by WSP | Parsons Brinckerhoff (WSP|PB), were held to provide progress updates and to identify coordination needs, significant in-channel debris, and shoal locations. The surveys were completed within 3 months of notice to proceed, and analysis of these data revealed over 2.3 million m^3 of sediment requiring dredging, with at least 612,000 m^3 attributed to Superstorm Sandy alone. Assessing the data revealed that over half of the channels could be considered significantly shoaled, and one-third of the channels were severely shoaled or impassable. Dredging is not possible without identified suitable locations to manage the sediment. The State uses a variety of techniques to manage dredged material statewide, ranging from ocean disposal to processing and upland beneficial use. Most of the shore channels are maintained using hydraulic dredging and placement into CDFs. Given the record high tidal surge associated with Superstorm Sandy, damage to CDFs was expected.

Upland Confined Disposal Facilities

In addition to the thousands of sediment core samples and hundreds of kilometers of bathymetric surveys completed by NJDOT-OMR and the design team in the initial months following Sandy, a multi-stage CDF damage assessment was also performed. This assessment included many of the CDFs used to store fine-grained sediment that are spread out along NJ’s Intracoastal Waterway (ICWW) and the Raritan Bayshore. Of these 84 CDFs within the NJ Marine Transportation System (MTS), 55 upland CDFs are located along the Raritan Bayshore and ICWW, which were directly impacted by the storm. These upland CDFs are fairly small, with the largest investigated having a total primary dike perimeter of approximately 2,450 linear meters (m) and the majority with perimeters under 900 m. Nevertheless, these CDFs are strategically positioned to support both state- and federally-maintained channels.

Methodology

In order to assess damages for FEMA reimbursement, an initial visual assessment of 22 CDFs was performed by boat in February 2013 to identify those CDFs most critically damaged from the storm. This preliminary assessment was followed by a detailed on-the-ground damage assessment and conditions survey performed on 6 of these 22 CDFs between June & September 2013 followed by inspections of 7 other CDFs between September 2013 & March 2014. Further damage assessments were later performed for design & research purposes on 9 additional CDFs in 2014 & 2015 (3 in 2014 & 6 in 2015). Since no major storms struck the NJ coastline during this time and these CDFs were unused and unrepaired, it was assumed that the observed conditions were representative of post-Sandy conditions. Figure 1 shows the locations of the 22 CDFs investigated.

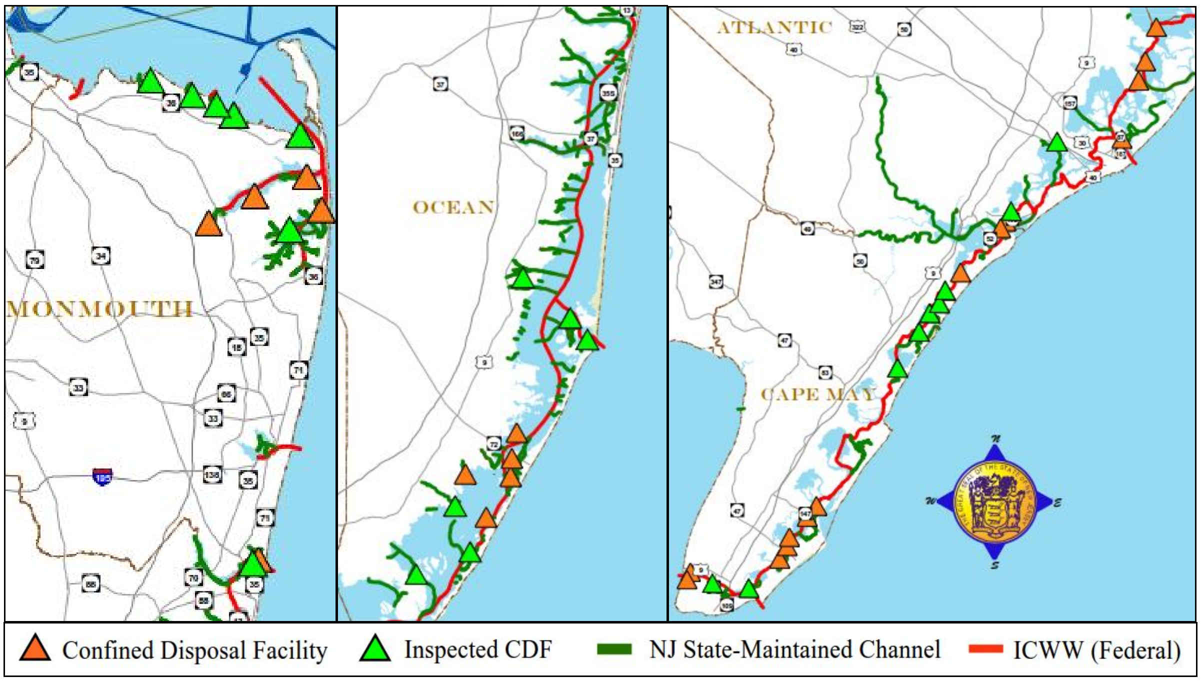

Figure 1. Locations of Inspected CDFs along Raritan Bay & ICWW:
Raritan Bayshore (Left), Ocean County (Center), and Atlantic & Cape May Counties (Right).

Damage assessments were performed by a professionally-licensed geotechnical engineer with the intent of quantifying undamaged and damaged dikes via GPS survey at various representative cross-sections along each CDF perimeter. Visual assessments focused on signs of dike damage as well as the presence and amount of marsh serving as a buffer to the CDF dikes. Tide gauge records were used to compare the extent of CDF damage to recorded storm surge elevations, while general location of the CDFs to inlets was also noted. Historic aerial images were evaluated to assess if the sites had a history of erosion prior to Superstorm Sandy.

Five qualitative levels were established to categorize damage to the CDF dikes during the investigation:

1) No Damage
2) Low Severity Damage (L): Some damage but not likely to breach if the CDF were to be used for placement of dredge material (DM)
3) Moderate Severity Damage (M): Significant damage; repairs may be needed prior to placement of DM to avoid a potential breach
4) High Severity Damage (H): Significant damage; repairs likely needed prior to placement of DM to avoid a potential breach
5) Very High Severity Damage (VH): Presence of a breached dike

Combinations of the above categories were occasionally used, with Low to Moderate (L-M) Severity indicating significant damage not likely resulting in breach if used for placement of DM, and Moderate to High (M-H) Severity indicating a higher likelihood for dike breach if used without any repairs.

As part of the initial damage assessments, engineers used a hand auger sampler to classify the material composition of the existing dikes and retained dredged material. This information was later supplemented during design with soil borings and/or piezocone penetrometer testing (CPTu) at ten CDFs and five CDFs, respectively. All soil classifications employed the Burmister Soil Identification Method. Using the visual inspection and classification of dike material composition, supplemented with the subsurface investigation information, the geotechnical composition, original compaction/construction methods, and general shear strength of the materials was assessed.

Results of Damage Assessments

Of the 22 CDFs investigated, six experienced no damage because of previous design considerations: three were located above the storm surge line, one featured a partial bulkhead along the exposed dikes, one was built into a dune coastal protection system, and one was protected by a stone revetment along a man-made waterway. At one other CDF, it was impossible to determine damage because a special permit condition required the remaining dikes to be pushed in after the last DM placement prior to the storm. Two additional CDFs were damaged prior to Superstorm Sandy, so determining the impacts from Sandy alone was not possible.

The remaining 13 CDFs were located within existing marsh and without armoring, essentially exposed to the elements. As such, these 13 CDFs presented an opportunity to evaluate natural and geotechnical conditions which could be vulnerable to damage or contribute to its resiliency. Two CDFs investigated showed less than low severity damage, while the remaining 11 CDFs contained low to high severity damage to the primary dikes. In general, damage was caused by storm surge and wave action leading to erosion and progressive sloughing of the primary dikes. Several active sloughs were observed, along with dike loss above recorded storm surge elevations and wave heights, most notably at the Ludlam Thorofare No. 2 CDF (Figure 2). Dikes at half of the 13 CDFs exhibited sufficient erosion to expose the complete dike cross-section, often at multiple locations, allowing for the composition of the dikes to be directly viewed (see Figure 2). A summary of the CDF damage assessment is presented in Table 1, with CDF listed by location from North to South.

Figure 2. Damaged Dike at Ludlam Thorofare No. 2 CDF (Left) and Exposed Geosynthetic at Broad Thorofare No. 1 CDF (Right):

Table 1. CDF Damage Assessment Summary.

CDF Name	Total Approx. Dike Length (m)	Approx. Length of Damaged Dike (m)	Geo-synthetic Present	Typical Generalized Dike Composition	History of Coastal Erosion
N61	880	115		cf Sand (North) Silt to Clay (South)	x
Long Branch Reach	2,450	830		cf Sand or Silt (top 0.3m); Clayey Silt to Silty Clay core	
Gull Island	820	0		Variable*	^
Oyster Creek	1,120	0		Sand to Silty Sand	
High Bar Harbor	770	330	x	Variable*	x
Parker Island	550	215		Sand to Silty Sand	x
Story Island	720	665	x	Sandy Silt to Silt	
Broad Thorofare No. 1	525	80	x	mf Sand cap (top 0.3-0.6m) over Silty Clay core	x
Blackman Island	530	150		Silty Clay w/ clayey Sand lenses	
Crook Horn Creek	540	275		Silty Clay (top 0.6m) over mf Sand	
Devil’s Island	885	565		mf Sand (top) Silty Clay (bottom 0.6m)	
Bend Hands Thorofare	560	180		-	
Ludlam Thorofare No. 2	810	335		mf Sand cap over Silty Clay w/ Sand lenses	x

* Varies along dike perimeter from Sand to Clay moving from dredged material discharge point toward weir box
^ Site has history of sedimentation / accumulation of sand & existing bulkhead on storm-exposed sides

Analysis of the data collected at these 13 CDFs revealed that dike geotechnical composition, original dike construction features, history of shoreline erosion, proximity to inlets, and presence of a marsh or beach buffer, separately or in combination, contributed to dike damage (or resilience).

Impacts of Geomorphology on CDF Damage

One goal of this investigation was to better understand the relationship between geomorphology and propensity for dike erosion during major storms. Figure 3 clearly shows the relationship between historical coastal erosion or marsh loss and damage to three representative CDFs. Two other CDFs listed in Table 1 showed the same relationship (figures not shown). Unlike those sites with a history of coastal erosion, the Gull Island CDF regularly accumulates sand seaward of the CDF and is protected by over 90 meters (300 feet) of barrier marsh and an old bulkhead on the exposed sides. This CDF showed no signs of damage as a result of Superstorm Sandy, despite its close proximity to the Manasquan Inlet. When marsh and sand bar buffers did not exist on sites proximal to inlets, however, the risk of CDF damage increased, as indicated at the Story Island and High Bar Harbor CDFs. These damage assessments appear to indicate that geomorphology of the CDF site has a direct relationship to its resilience. However, further research would be needed to expand the data set and confirm this correlation.

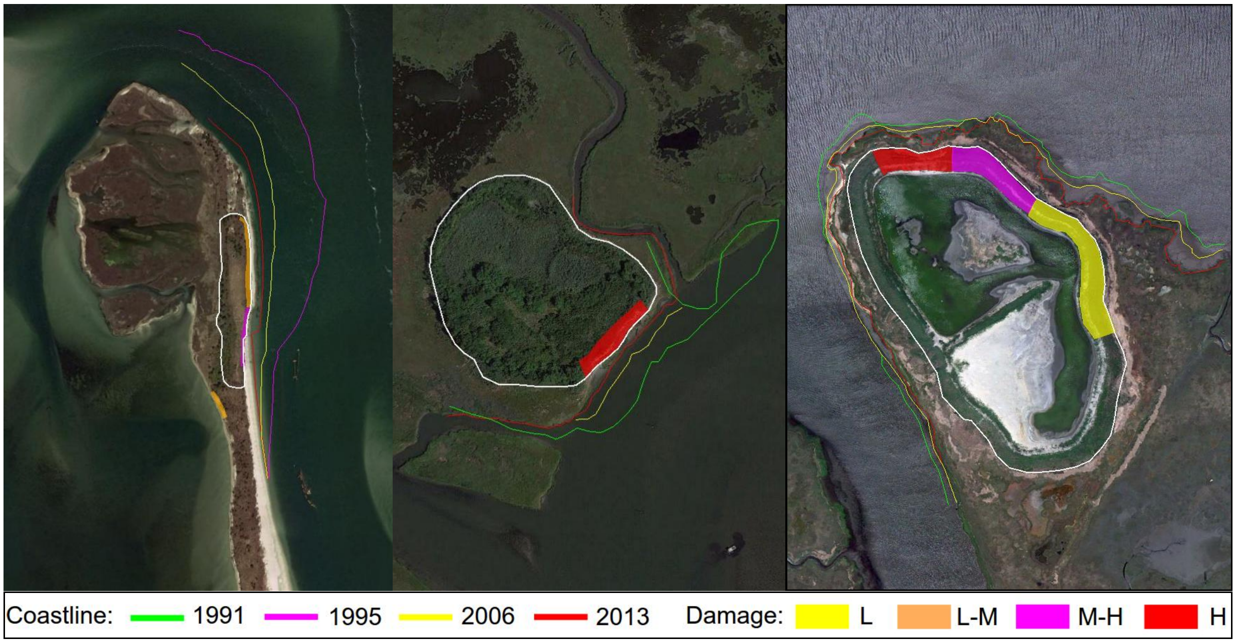

Figure 3. History of Erosion from 1991-2016 and Observed Sandy Damage at High Bar Harbor CDF (Left), Broad Thorofare #1 CDF (Center), & Ludlam Thorofare #2 CDF (Right).

Impacts of Geotechnical Considerations on CDF Damage

Additional geotechnical features of the CDF were also found to influence the resilience of the CDF dikes. Many of these CDFs had been constructed prior to the US Army Corps of Engineers publishing their original CDF Design Manual (USACE 1987). The CDF composition and construction methods employed at the time were non-uniform, with many dikes constructed with minimal, if any, compaction. From the observed damage patterns, dikes with a core comprised of silty clay or clay and covered by sand or silt will tend to lose its outer layers readily, while the underlying cohesive soils provide more resistance to erosion. In general, the use of clayey soils appears best for CDF resilience, followed by sand. Dikes composed predominantly of silt, on the other hand, tended to experience the most CDF damage as evidenced by the Story Island CDF.

In some cases, geosynthetic was observed within the dikes between the overlying sand and clay core. The original intended purpose of this liner is unknown, as the material appeared to serve as neither a waterproof membrane nor a barrier to soil migration. As shown in Figure 2, this liner provided a sliding surface for the overlying soil resulting in exposure of, and damage to, the geosynthetic. However, though exacerbating erosion of the overlying soils, the geosynthetic did appear to provide limited resistance to further damage by providing confinement to the underlying soil. Despite this, the presence of the geosynthetic is not expected to considerably increase the resilience of the CDF and may have an overall net zero effect. More sites will need to be investigated to expand the data set and assess the overall impact, if any, of similar geosynthetics on CDF resilience.

Impacts of Marsh & Beach Buffer on CDF Damage

Lastly, the amount of marsh or beach buffer present in front of the CDF dikes clearly affected the amount of CDF damage sustained. From visual inspection and surveyed data, the extent of damage and presence of existing buffer was recorded and categorized around the perimeter of each CDF. This relationship is portrayed in Figure 4, which shows the generalized damaged areas along with the existing marsh for 3 representative CDFs, as does Figure 3.

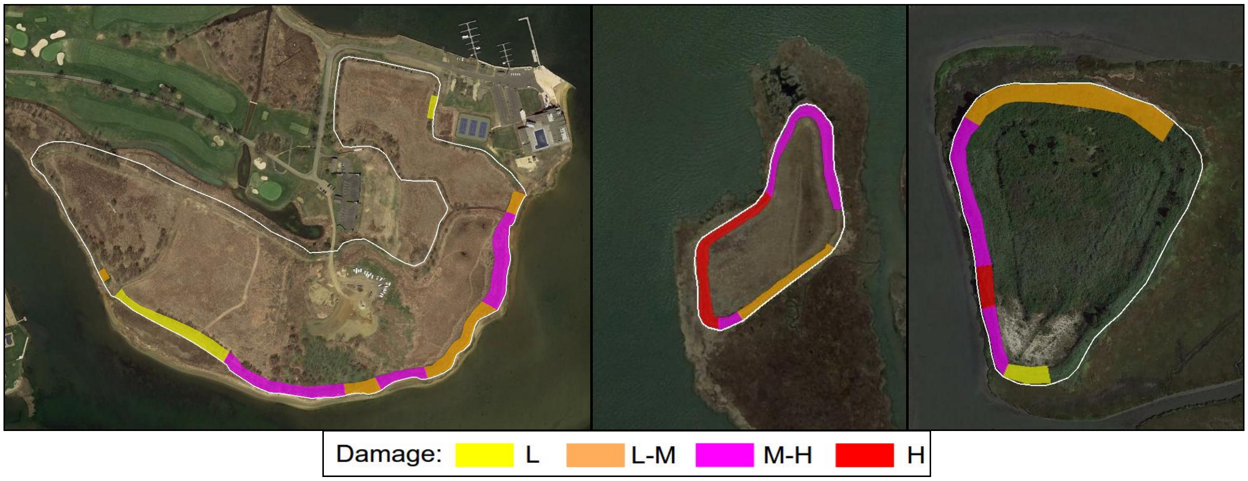

Figure 4. Observed Sandy Damage with Marsh Buffer at Long Branch Reach CDF (Left), Story Island CDF (Center), & Devil's Island CDF (Right).

The correlation between buffer widths and dike damage was assessed by organizing the buffer extent into subsets. These subsets were buffers greater than 90 meters (300 feet), greater than 60 meters (200 feet), greater than 45 meters (150 feet), greater than 30 meters (100 feet), less than 45 meters (150 feet), and less than 30 meters (100 feet). The amount of damage was then plotted against the percent of buffer for each CDF. Table 2 presents a summary of the comparison.

As indicated in Table 2, the percentage of dike damage significantly increases as the extent of marsh/beach buffer decreases. Comparing the extent of dike damage with width of the buffer yields consistent results at all distances, with decreasing damage (i.e. increased resilience) noted with increasing buffer width. Figure 5 illustrates these trends across all buffer distances.

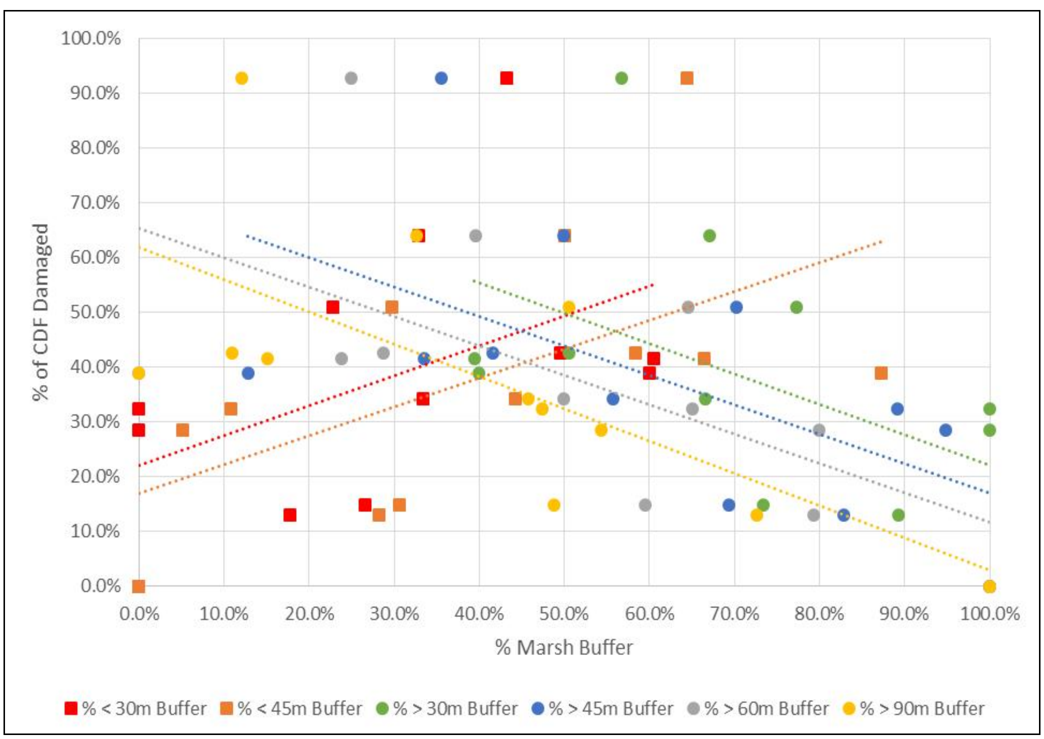

Figure 5. Percentage of CDF Damaged versus Percentage of CDF with Designated Buffer Width.

Table 2. Summary of CDF Dike Damage and Total Marsh/Beach Buffer Comparison.

CDF Name	% of CDF Damaged	% of CDF w/ M-H Severity Damage	% of CDF w/ > 90 m Buffer	% of CDF w/ > 45 m Buffer	% of CDF w/ < 30 m Buffer	% of CDF w/ > 90 m Buffer w/ M-H Damage	% of CDF w/ < 30 m Buffer w/ M-H Damage
N61	13	13	13	83	18	0	100
Long Branch Reach	34	15	46	56	33	0	45
Gull Island	0	0	54	65	31	0	0
Oyster Creek	0	0	100	100	0	0	-
High Bar Harbor	43	17	11	42	50	0	34
Parker Island	39	17	0	13	60	-	28
Story Island	93	72	12	36	43	0	100
Broad Thorofare No. 1	15	15	49	69	27	0	55
Blackman Island	29	29	54	95	0	0	-
Crook Horn Creek	51	41	51	70	23	33	82
Devil’s Island	64	31	33	50	33	0	95
Bend Hands Thorofare	29	19	47	89	0	6	-
Ludlam Thorofare No. 2	42	21	15	34	61	0	34

The trendlines in Figure 5 show a general proclivity for increased damage with reducing buffer widths. Likewise, a consistent decrease in damage was observed with increasing marsh buffer distance. More damage to dikes with lesser buffer widths is also confirmed by general comparison across buffer width categories, as increasing percentages of damage occur to dikes with reducing buffer distances (Figure 6).

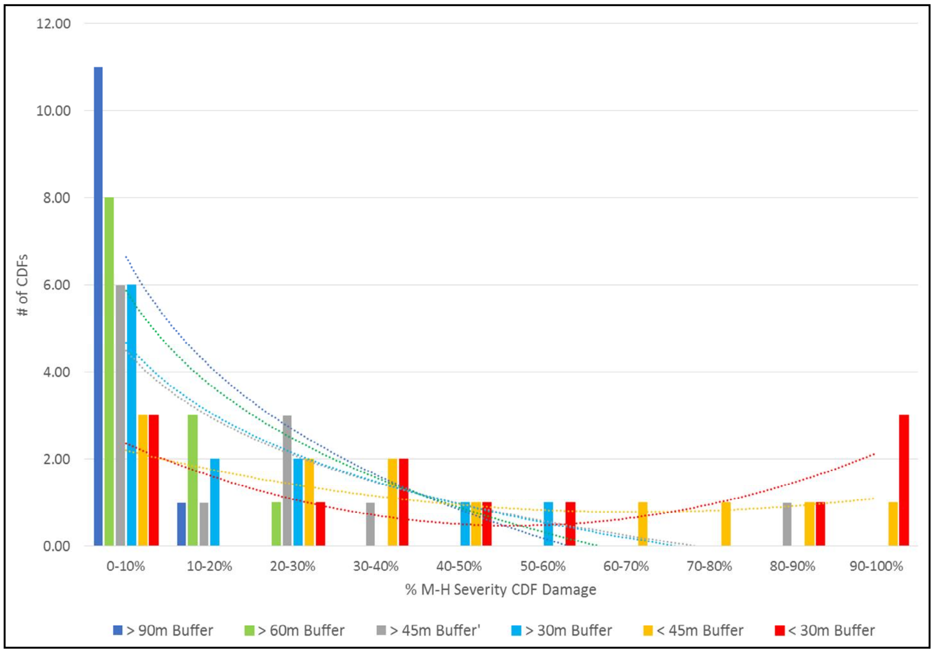

Figure 6. Comparison of Extent of Moderate to High Severity Damage with Designated Buffer Widths.

As indicated in Figure 6, the extent of significant damage increases with reducing buffer widths. While there appeared to be an increased tendency for damage of sections with less than a 30-meter buffer compared to those with less than a 45-meter buffer, there was no discernable difference between the trends for sections with greater than a 30-meter buffer and with greater than a 45-meter buffer.

Based on the results of the damage assessment, the following conclusions may be made:

1) Buffer distance (marsh or beach) directly influences the amount and severity of damage to CDF dikes
2) CDF dikes in areas of historic coastal erosion exhibited increased damage, while those in areas of historic sedimentation experienced no significant damage
3) CDFs located above the storm surge elevation or armored below the storm surge elevation exhibited no significant damage.
4) Cohesive soils within CDF dikes exhibited increased resistance to erosion when compared with sands, which in turn provided greater resistance than silts.
5) Presence of a geosynthetic between cap material and cohesive cores resulted in the sliding of overlying materials with only limited protection for underlying soils.

While these conclusions were drawn from investigation of the NJ upland CDFs post-Sandy, additional research in other regions is recommended in order to confirm the findings. Nevertheless, it appears that increased buffer distance increases resilience of CDF dikes, especially when they are constructed below the design storm surge elevation or left unarmored. Two projects recently completed in New Jersey demonstrate different approaches to providing this buffer and increasing both CDF resilience and coastal protection through the beneficial re-use of dredged material: one via incorporation of a CDF into a coastal dune protection system with beach fill on Raritan Bay and the other using thin-layer placement of dredged material from an adjacent channel to restore barrier marsh along Delaware Bay.

USE OF CONFINED DISPOSAL FACILITIES TO ENHANCE COASTAL PROTECTION

After the completion of the channel assessment phase, the WSP|PB team was awarded a follow-on contract to assist the NJDOT-OMR in developing and executing a program for design, permitting, and construction of recovery and maintenance of the State channel system. Given that the system comprises over 200 nautical miles of channel, one of the first questions was where to start.

The Borough of Keansburg in the Raritan Bayshore region of New Jersey was severely impacted by Superstorm Sandy after being hit by tidal surges more than 2.8 meters above mean high water elevations. Because Keansburg actually sits below the mean high water line, the US Army Corps of Engineers (USACE) created a flood protection levee and installed a tide gate on the Waackaack Creek back in the late 1960's. Navigation channels (Waackaack Creek and Thorns Creek) that serve the Keansburg marinas run from deep water in the Raritan Bay, through the tide gate, and into the marshlands surrounding the town (see Figure 7). Shoaling in this area had been bad prior to the storm, with contract documents already prepared and environmental permits issued. A total of approximately 24,100 m^3 had been identified for dredging. The nature of the material to be dredged was beach-quality sand in the outer channel and a more fine-grained material in the channels inside the floodgate.

The placement of sand on the beach and/or restoring or creating protective dunes is an excellent example of the dual benefits of dredging and coastline resilience provided by this program. The channels are cleared to their permitted design depth and the dredged material can be used to protect the coastline from tidal surges and flooding. Since State regulations dictate that only material 75% sand or greater can be used on the beach, this limits the application of this beneficial use.

The Keansburg CDF was actually located at the top of a coastal dune, parallel to the coastline (see Figure 7). Contrary to the typical procedure, and due to the limited land available for construction of a CDF, this site had been used for the placement of fine-grained material, followed by capping with clean sand. After placement, the filled CDF would actually be more stable than a dune made solely of sand since fine-grained material has more natural cohesion (see Section A-A on Figure 7).

Figure 7. Project Map with Section A-A of the Keansburg CDF

Unfortunately, at the time of the project, the site was already filled to capacity. NJDOT-OMR approached the Borough with the prospect of removing the DM from the Keansburg CDF for beneficial use elsewhere. To the surprise of many, the Borough did not accept this proposal, as they viewed this coastal CDF, and the material in it, as added storm protection. In fact, they said that the area immediately behind the CDF had been the only part of the town not to flood during the storm, which they attributed to the protections offered by the CDF and the tide gate.

The design team took this idea and ran with it. If the proposed CDF stayed within the original permitted footprint, the team could use some of the material on the inside of the CDF to raise the confining dikes, thereby creating more capacity. This would allow for the placement of the fine-grained material into the raised portion of the CDF and provide the town with an even larger natural barrier to Raritan Bay storm surges. The coarse-grained material from outside the floodgate was designed into a dune-like feature simply by extending the top of the confining dike’s elevation waterward for a set distance, and then transitioning down to the existing beach grade at a 3 horizontal to 1 vertical (3H:1V) slope. The slope met the existing beach grade well upland of the mean high water elevation line (Figure 8).

The dual benefits of the long-awaited dredging of Waackaack Creek and Thorns Creek, combined with a naturally hardened section of coastline, had the Borough so pleased that they suggested that the State construct more CDF’s along their portion of coastline. The CDF’s could be aligned linearly and parallel to the coastline adjacent to the outermost road. Not only will this strategy ensure storm protection for Keansburg, but could provide dredged material management capacity for as many as 35 State channels in the immediate area. The State and the Borough are currently in negotiation with the NJDEP to determine the best pathway to make that concept a reality.

Figure 8. Keansburg CDF in Use (top) and Construction of Beach Fill (bottom)

MARSH ENHANCEMENT FOR COASTAL RESILIENCE

In 2014, two demonstration projects were conducted by the Philadelphia District of the USACE to restore marsh habitat using dredged material in Avalon and Stone Harbor, NJ (Piercy et al. 2015). Building on these efforts, a TLP pilot project was initiated by NJDOT-OMR in late 2015 along Delaware Bay in Fortescue, NJ that used dredged material from a state channel to restore adjacent degraded marsh. The project team was extensive; with representatives from several agencies, including NJDEP's Division of Fish and Wildlife, NJDOT-OMR, The Nature Conservancy, as well as a group of private consultants which included designers from WSP|PB and Gahagan & Bryant Associates.

Design

A detailed channel sediment sampling and laboratory testing program was established, with a full-time geotechnical engineer providing on-site classification of collected sediment samples in order to provide a greater level of detail for the sediment profile within the channel. Following this investigation, the channel was segmented into general areas based on sediment identified above the channel design template: Sta. 21+30 to 38+30 (greater than 90% sand), Sta. 8+10 to 18+65 (Sand above EL. -5 overlying fine-grained sediment), and Sta. 18+65 to 21+30 and 0+00 to 8+10 (mostly fine-grained material).

Sediment greater than 90% sand was identified for restoring an eroded dune along the south side of the marsh, while sediment classified as 75% to 90% sand was used in restoring a nearby beach that had been classified as prime habitat for horseshoe crab spawning. For the TLP on the marsh, fine-grained sediments were expected to sheet flow over the marsh and settle out naturally due to gravity. Since it was expected that some coarser-grained material would accumulate closer to the discharge pipe outlets, the outlets were proposed in areas intended for higher elevations, i.e. restoration of high marsh habitat. Based on the sediment characteristics, a complex pipeline and valve network was designed. The network included a number of outlet points to optimize dispersion of dredged material on the marsh, with primary and secondary confinement (compost filled silt socks) placed between and around different marsh zones (Figure 9).

Figure 9. Plan Views of Marsh Placement Zones (Left) and of Beach Placement Area (Right)

Construction

Construction activities began in January 2016 with the intent of dredging the 27,500 m^3 of sediment from within the Fortescue channel. Due to the TLP techniques being fairly new to the NJ region, a learning curve resulted in a delayed effective start date of dredging and limited the number of cubic meters dredged in the 2016 dredging season. Despite front-end construction delays and a permitted dredging window of only 3.5 months, a total of 10,100 m^3 were successfully dredged and pumped onto the marsh and the horseshoe crab beach. In order to partially restore navigation, half of the channel width was cleared to the project depth for its entire length. The remaining sediment would have to be removed in winter 2017 season.

Figure 10. Excavator Bucket Directing Dredge Slurry Flow to Low-Lying Areas during TLP Operations (Left) and Dredge Barracuda nearing Station 29+00 (Right)

In the time between dredging seasons, additional material deposited in the channel due to natural wind and wave energy of the dynamic Delaware Bayshore ecosystem. This material was added to the project when dredging resumed in February of 2017, for a total of 19,870 m^3.

At the time of this paper's preparation, work is underway to complete the project. Initial assessments of the marsh TLP indicated that much of the targeted areas were filled at or below the target elevations. Some damage to the marsh was observed by the equipment used to place the primary and secondary confinement; however, vegetation regrowth was seen in these areas after only one season. Nevertheless, while dredging and the dispersion of dredged material over the marsh was accomplished successfully (Figure 10), with tolerances of as little as 15 cm elevation change, immediate assessment of the marsh is imprudent, as new growth typically takes one to three growing seasons to reestablish after a TLP project (Ray 2007). Monitoring over the next 1-3 years will determine the need for any replanting, as well as a decision regarding the utility of TLP for marsh restoration along the NJ coastline.

The Fortescue TLP and two previous USACE-led marsh demonstration projects in NJ (Piercy et al. 2015) provide great potential for using dredged material management to enhance the resilience of the MTS and coastal communities and for combatting sea level rise along the mostly unprotected back bays. As sea levels have risen, coastal marshes have significantly degraded and eroded not only in NJ but along the Louisiana coast as well (Barras 2006, Creef & Mathies 2002). Using thin-layer placement to enhance/restore these degraded marshes employs dredged material as a valuable renewable resource for coastal protection rather than an encumbrance to be disposed of during dredging. As sea levels rise and marshes degrade, a cycle of restoration using TLP could be implemented to keep up with the rising sea elevations.

Though the benefits of beneficial re-use of dredged material for coastal protection and TLP projects appear sound, environmental regulations and cost could reduce wide-spread implementation in the short term. The cost of the Fortescue project will exceed $150 per cubic meter. Regulatory agencies have been leading members of the Fortescue project, and shifting agency perceptions of dredged material as a valuable resource for restoring marsh health could result in a more standard permitting process for regular projects. It is hoped that performing more TLP projects will standardize effective design, normalize expectations, and reduce cost.

The increased protection afforded by a TLP-restored healthy marsh, will serve as a multi-win solution by providing a barrier to protect landward communities (and/or CDFs); providing increased MTS storage capacity through beneficial re-use; restoring threatened or degraded coastal habitat and promoting marsh health; and combatting sea level rise, all of which will serve to enhance the overall MTS resilience.

CONCLUSIONS

While the devastating effects of a storm like Superstorm Sandy will provide a stressor to the MTS as a whole, certain planning and design considerations can enhance the resilience of the MTS. The New Jersey MTS is an extensive system that includes both deep draft access for the ports and shallow draft access for marine trades, fisheries and recreation. The Sandy recovery efforts of the Ports have been addressed by others (Wakeman et al 2015, Wakeman & Miller, 2013). This paper has focused on the impacts and recovery efforts of the shallow draft system. Since this part of the MTS uses different dredging and dredged material management techniques, as well as having a residential rather than commercial/industrial coastline, different resilience considerations were identified. One of the most significant issues identified was dredged material storage capacity. With 2.3 million m^3 of sediment in the channels, 612,000 m^3 of which were directly from the storm, the need to enhance or restore the storage capacity of the MTS became a critical element of system recovery. In addition, damage to CDFs needed to be evaluated and corrected in order to be able to dredge the channels to their design depths. Therefore, providing more resilient CDFs will enhance the overall resilience of the NJ MTS.

Based on the post-Sandy damage assessments and experience with the Keansburg CDF and Fortescue TLP projects, the following recommendations are presented to provide greater MTS resilience and to boost coastal protection through the beneficial re-use of dredged material:

- Ensure that upland CDF design & construction methods adhere to current USACE standards, including geotechnical design, compaction of dike material, and proper use of geosynthetics
- Locate new upland CDFs above the design storm surge elevation and/or in areas without a history of coastal erosion, preferably in areas of sedimentation, to provide additional protection to the dikes.

- Where existing upland CDFs are exposed and unable to be moved without considerable permitting efforts, provide either hard armoring of vulnerable dikes up to the design storm surge elevation or soft armoring to provide at least 30-45 meters of a marsh or beach protective buffer to minimize damage (provide greater than 90 meters for greater protection)
- Use TLP of dredged material to restore or provide these barrier marshes around CDFs, thereby enhancing both coastal habitat and resilience.
- Engage public/local stakeholders early to identify outside-the-box solutions, e.g. building a CDF into coastal dune protection.

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