Dredging and Dredged Material Management in the NJ Atlantic Coastal Zone

Authored by: W. Scott Douglas

Introduction

The NJ Marine Transportation System

The Atlantic coastal region of New Jersey (NJ) is a densely populated and heavily utilized shore ecosystem that not only contains diverse dune, beach, marsh and coastal forest habitats, but also hosts a large and complex marine transportation system comprised of Federal, State and local engineered waterways, berths, marinas and private slips, supporting a $50 billion shore economy. This report covers conditions and procedures used in the Back Bay portion of the region; the front beaches are managed separately.

The US Army Corps of Engineers (USACE) operates and maintains the NJ Intracoastal Waterway (NJICWW), which runs for over 117 miles (188 km) between the barrier island and the mainland NJ from Manasquan Inlet to Cape May. In addition, the USACE is responsible for four coastal inlets from Shark River to Cape May that connect the NJICWW to the Atlantic Ocean. Between Sandy Hook and Cape May, the NJ Department of Transportation (NJDOT) operates and maintains another 200 nm of waterway in 199 marked channels that provide local access to the NJICWW (Figure 1). These two significant maritime assets have enabled the development of a vibrant shore community with 400 marinas, 325 boat ramps, 235 commercial fishing slips, 57 recreational charters and 250 water dependent businesses as well as 40,000 private boat slips (Figure 2). Access from shore facilities out to the State or Federal waterways is a local municipal responsibility, and private berths and marinas are dredged by the respective landowners. By our best estimate this comprises another 8.5 square miles of potential dredging area (Figure 1).

Dredging Need

Since 2014, OMR has been charged with the restoration and maintenance of the State's portion of the New Jersey Marine Transportation System (NJMTS) in the back bay area of the Atlantic coastal zone. In the wake of Superstorm Sandy, the NJ Dept of Transportation – Office of Maritime Resources (NJDOT/OMR) determined that more than half of the State's channels were moderately to severely shoaled and over 3 million cubic yards of sediment would need to be dredged to restore the system to full navigability. A quarter of this material could be attributed directly to Superstorm Sandy. Since that time, OMR has restored over 100 channels to full navigability. The over 1.9 million CY of sediment dredged to date has been placed on beaches (25%), in CDFs (40%), used for habitat restoration (26%) or otherwise used beneficially (9%). Despite this progress, OMR estimates that there is 2.25 million CY of backlog still in the system, mostly because even at our accelerated rate of dredging, ongoing

Channels and Areas with Dredging Needs

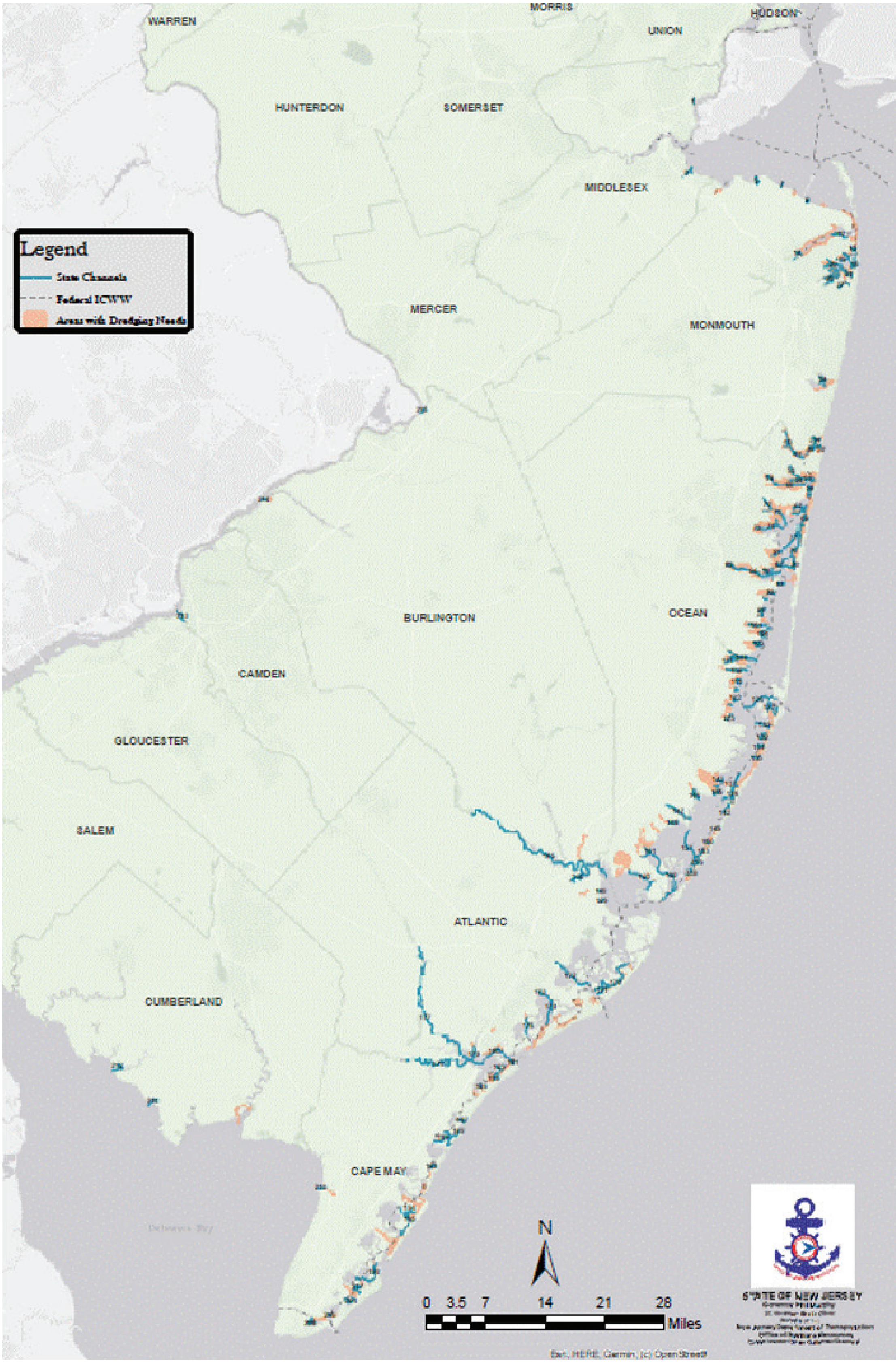

Figure 1. Engineered waterways and municipal boating areas in the Atlantic coastal zone.

New Jersey Marine Transportation System

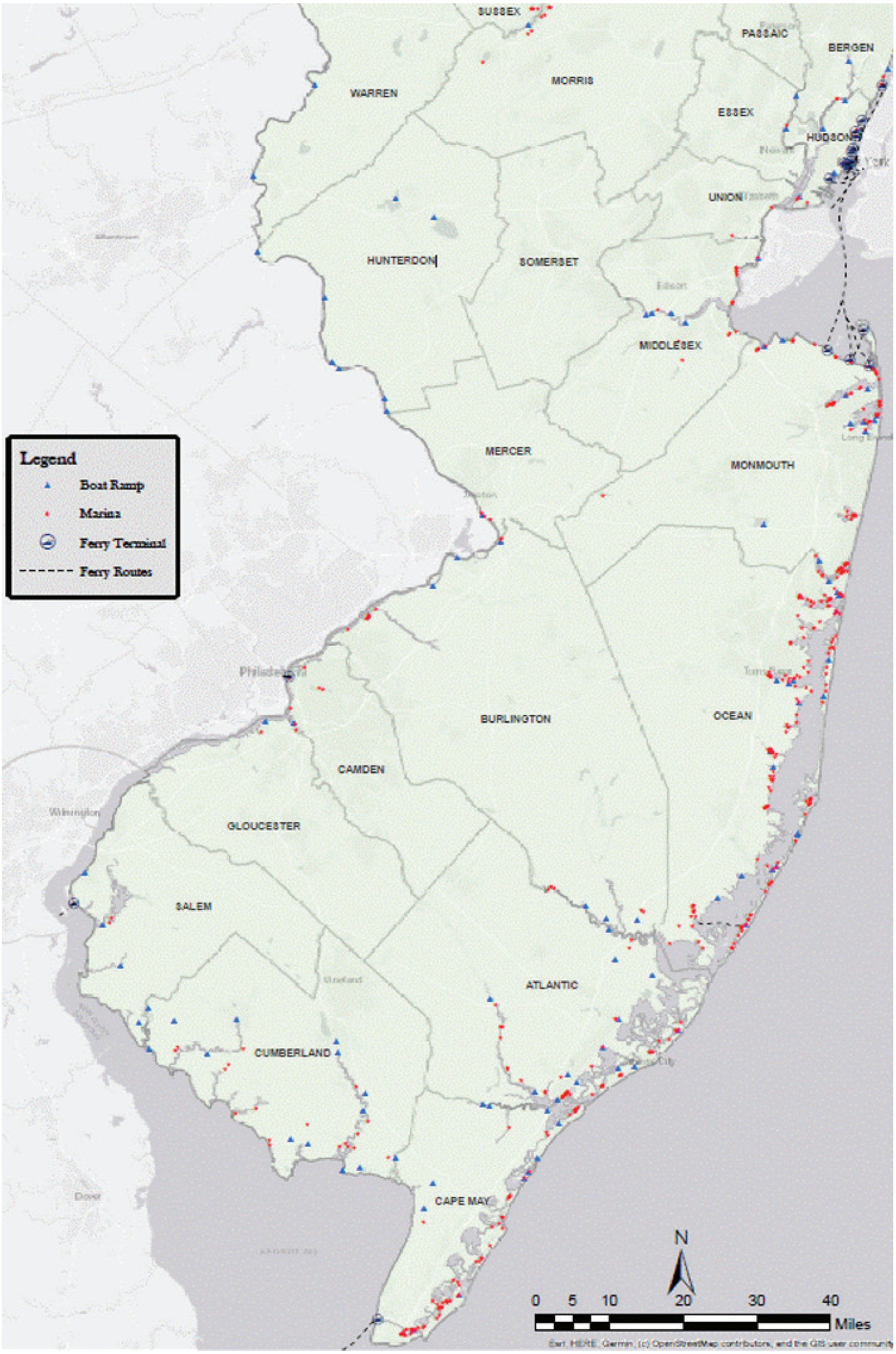

Figure 2. Marine Transportation System facilities in the Atlantic coastal zone.

Table 1. Navigational dredging needs in the Atlantic Coastal zone of NJ.

Jurisdiction	Waterway	Extent	Current Need (CY)	Annual Need (CY)	Actual (CY)
Federal	NJICWW	117 nm	150,000	65,000	30,000
	Inlets	39.2 nm		75,000	
State	199 channels	206 nm	2,300,000	550,000–650,000	375,000
Local	Slips/lagoons	6.5 sq. mi.	6,000,000	350,000–650,000	Unknown
Private (marinas)	Marinas	2.0 sq. mi.	2,000,000	100,000–200,000	Unknown

shoaling system-wide is even greater. Just keeping up with this shoaling requires an annual maintenance dredging program of 550-650,000 CY.

The NJICWW requires the immediate removal of as much as 150,000 CY to restore full navigability (Monica Chasten, *personal communication*). After those shoals are cleared, the annual need for the ICWW is about 60,000 CY. The 4 inlets (Shark, Manasquan, Cold Spring, and Barnegat) actively maintained by the Corps add another 75,000 CY of annual dredging need. Most of this material is placed on the beach, but some has been placed into CDFs if not beach suitable. Capacity for management of sediment from Corps projects (other than Cold Spring/Cape May) is provided by the State of NJ.

It is much harder to estimate the amount of local and private dredging need, backlog or otherwise. Local channels are not formally recorded, nor is the current status of marinas or private berths. Some private berths and lagoon communities have not been dredged since they were originally constructed, and there is little agreement on who is responsible. Assuming that there is at least a foot of material available to be dredged and assuming shoaling rates similar to the State network, this would add another 7-8 million CY of backlog material, and 450-850,000 CY more every year in maintenance.

Dredged Material Management

This sediment must be dredged to maintain safe navigation, and historically this has meant placing the material upland on the nearest available open land; usually marshes or beaches. Since the late 1970s, New Jersey has placed dredged material either on beaches or in confined disposal facilities (CDFs). A CDF is an enclosed earthen dike fitted with an outflow weir into which hydraulically dredged sediment slurry is pumped (Figure 3). The weir is used to manipulate the water level in the CDF to facilitate dewatering of the slurry. Clear water is discharged through the weir to the adjacent water body. Dozens of these facilities were constructed over time in New Jersey, and 34 are still in existence today. Most CDFs are on State-owned land, but some are in municipal or private ownership, and a few are owned by the US government. Regardless, most CDFs in coastal NJ are at or near capacity and land to site new ones is either protected or developed. CDFs can, and have, been "mined" for construction material, however many were located for ease of use by dredgers and are not suitable for excavation without extensive and invasive road construction in sensitive habitats. OMR has been working to safeguard the existing CDFs and construct improvements to allow for periodic excavation and capacity renewal. However, the bottom line is that for almost half of the NJMTS, there are no viable traditional dredged material placement sites (Figure 4).

Figure 3. Oyster creek confined disposal facility.

Figure 4. Areas with no available traditional dredged material management facilities

Since 2013, the NJDOT/OMR has been charged with the recovery and maintenance of the State Channel dredging network, and providing capacity for the Federal NJICWW when requested. When available, traditional methods have been, and will continue to be used. However, where there are gaps, OMR has aggressively pursued alternative methods, including passive and mechanical dewatering followed by upland beneficial use, but also beneficial use for the restoration of benthic and marsh habitat (natural and nature-based features). These projects have included the filling of dredged holes, enhancement of coastal marshes, elevation of mud flats, shoreline protection and the creation of upland habitat (Figure 5). The potential capacity for more of these projects is enormous, far exceeding the transportation need (Table 2). However, there are considerable differences in opinion in how this should be accomplished, and there is no regulatory framework or uniform technical guidance for beneficially using dredged material in sensitive coastal ecosystems.

Table 2. Estimated capacity for various dredged material management options in the Back Bay region.

Placement Type	Constraints	Current Capacity (CY)	Estimated Potential Capacity (CY)
Upland Confined Disposal (CDFs)	Limited to dredging projects within 5 miles. Any placement of contaminated material restricts future beneficial use	2,900,000 CY (at current berm height)	5,500,000 CY (potentially unlimited with excavation and bu, but location matters)
Upland Beneficial Use	Residential/Non residential cleanup criteria/impact to groundwater, dewatering usually required	645,000	unknown
Beach Replenishment			
Bathing	>90% coarse, little or no gravel	Essentially unlimited, but requires CAFRA permit	Essentially unlimited, requires CAFRA permit
Non Bathing	>75% coarse		
Restoration			
Marsh Platform	Upland eco criteria or “like on like”	Only sites with open permits are Forsythe (Brick A, Brick B, Good Luck Point) SMILL capacity?	40-80 Million
Shoreline Stabilization	Primarily coarse	35,000 at Cattus Is.	
Confined Benthic (dredged holes)	Varies across and within project	600,000 at DH25 and DH86, DH61 in design	3.4 Million
Unconfined Benthic (mudflats, nearshore)	In water eco criteria	unknown	unknown

Dredged Material Management Locations

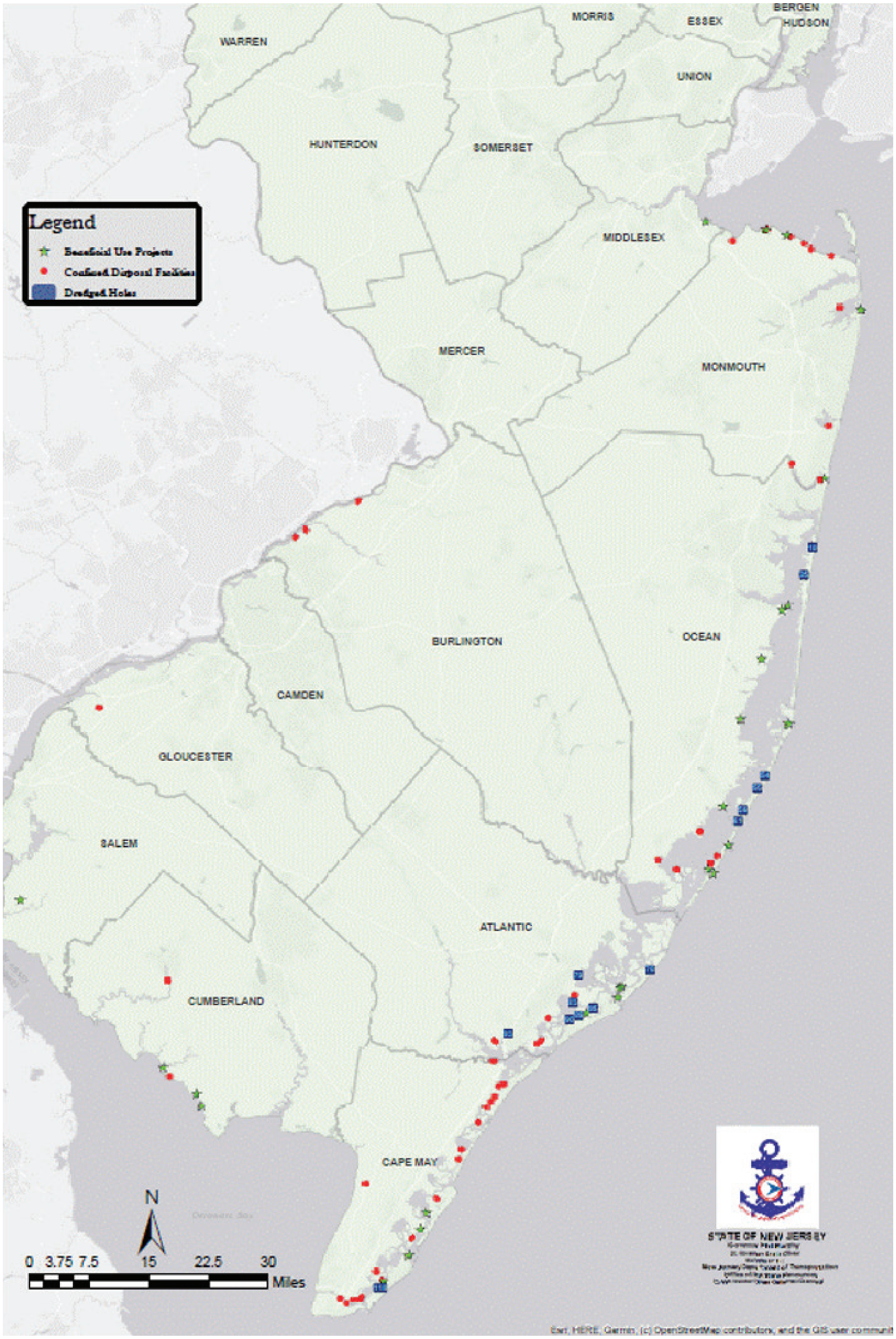

Figure 4. Dredged material management locations in the Atlantic coastal zone.

Dredging Methods Used in the NJ Back Bay Region

The vast majority of dredging in this region is hydraulic, but there is some mechanical dredging performed, particularly in small jobs close to shore such as marinas and boat ramps.

Hydraulic methods

Cutterhead pipeline- This is the primary method for dredging channels and berths in the back bays of the NJ ACZ. The dredge is comprised of a mechanical arm fitted with a rotating head that agitates the sediment so that it can be easily suctioned up by a powerful hydraulic pump and pushed to the placement location via a pipeline. The size of these dredges is indicated by the pipeline diameter and typically ranges from 8 to 18 inches (Figure 6). Larger cutterheads are available but are limited by draft to working outside of the barrier islands. Note that from a practical perspective, there are limits to the distance that the dredge can pump the sediment slurry. Distances between the dredge site and the placement site of over a mile will require the use of booster pumps, and as a rule of thumb, the maximum distance is about 5 miles.

Trailing suction hopper – These dredges are self-propelled work vessels that utilize a mechanical arm that lowers to the bottom and suctions sediment up into an onboard reservoir. When the reservoir is full, the dredge is moved to the placement site and the slurry discharged to the bottom or into a pipeline to shore. In NJ, this equipment is primarily used for large beach replenishment projects, but the USACE has used small hopper dredges for dredging the inlets at Manasquan and Shark River. The USACE often utilizes the dredge McFarland to dredge on the Delaware River. Since there are no permitted open water disposal sites in NJ ACZ, this method is only used for coarse material (typically greater than 90% sand). The material is discharged directly into the nearshore of the oceanfront beaches and the material is eventually pushed up onto the beach by the tide (Figure 7).

Figure 6. Cutterhead pipeline dredge.

Figure 7. USACE Dredge McFarland, a trailing suction hopper dredge.

Environmental Concerns – The primary concern with these types of dredges is benthic community disruption through the direct removal of sediment or the generation of suspended sediment plumes at either the dredging or discharge point. For maintenance dredging operations, disruption of the benthic community in the footprint of the engineered waterway is unavoidable. However, typically permits restrict work to periods of time with the least amount of impact to wildlife and shellfisheries. While all dredging creates suspended sediment in and around the dredge, the concentration and extent of the plumes generated by the cutterhead is typically equivalent or less than that generated by wind driven events in this region (Michael Baker International, 2021). This is likely due to the confined nature of maintenance dredging activities and the fact that the hydraulic pump is powerful enough to minimize the dispersal of sediment. Despite this, this method is not suitable for use in contaminated sediments mostly because of the amount of contaminated water generated that would need to be managed. The plumes generated at the placement location are specific to the material being dredged, the rate at which it is placed, and the hydrodynamic conditions at the site. The potential impacts should be modeled and monitored to ensure that impacts are minimized to the greatest extent practical. Project timing can be used to avoid potential impacts to sensitive resources. However, it is important to know that our experience in NJ has been that the turbidity generated by these activities are significantly less than the turbidity generated by natural events (Douglas et al 2021b; Michael Baker International, 2021; McKenna et al, 2024).

Navigation and Positioning Systems – These dredges are either built with sophisticated modern positioning equipment or can easily be outfitted with it. The operator (leverman) usually refers to a computer simulation that shows the location of the suction point relative to the dredge face in real time. This software produces a color-coded figure that provides a clear visualization of the progress of the dredge.

Mechanical methods

Mechanical dredging utilizes a variety of digging buckets to capture sediment and these buckets are raised and lowered by the dredge, which is a land-based piece of equipment mounted on a floating platform. Buckets and dredges are often interchangeable to some extent, so they are described separately below.

Hydraulic Excavator Dredge – This dredge is essentially a conventional excavator mounted on a barge. The buckets can be either mechanical or hydraulic. Size of the bucket is dictated by the reach and horsepower of the excavator but can be extremely large. The depth of dredging is limited by the reach of the excavator's arm, usually no more than 50-55 feet. The bucket can be sealed or unsealed. The excavator is used to remove the sediment and it is placed directly into a scow positioned alongside. Deck barges with attached rails can also be used for collecting the sediment. Once full the scow is moved to the placement site and can either be unloaded mechanically, or hydraulically. This method is highly accurate and can be used where there are concerns about infrastructure, but it is typically much slower than hydraulic dredging (Figure 8).

Crane Mounted Bucket Dredge – This dredge is a crane mounted on a barge fitted with a cable operated bucket, either open or closed. The advantage to this type of dredge is that there are no limits on the depth of digging, and the size of the bucket is limited only by the lifting power of the crane. Sediment is held and transported using the same methods as the excavator dredge. These units are rarely needed in the ACZ (Figure 9).

Open (Digging) Bucket – These buckets are used in hard digging applications such as compact clays, sand and or loose rock, and rarely used in maintenance operations. There are a number of different designs of open bucket, and they can either be hydraulically or cable operated. The bucket is open on top to allow water to drain freely. Material is removed from the cut and placed into a scow or deck barge with rails positioned alongside. Overflow of excess water is typically allowed in this type of material and allows the operator to maximize the size of a load. Split hull scows are often used to allow quick unloading at the placement site. Size ranges from less than a cubic yard to extremely large (Figure 10).

Figure 8. Hydraulic excavator dredge.

Figure 9. Crane mounted bucket dredge.

Figure 10. Open digging bucket dredge

Hydraulically Activated Bucket – These buckets are typically used in maintenance dredging especially for fine grained unconsolidated sediment. They are comprised of two halves of a clamshell that are hinged at the top and brought together hydraulically. The buckets can be fixed or on a swivel to allow for maximum flexibility to achieve close grades. The bucket can be fitted with GPS to allow for high precision real time positioning. Material is removed from the cut and placed in a scow or deck barge with rails positioned alongside. This type of dredge is used frequently for maintenance work, and typically barge overflow is not allowed. Size ranges from ½ cubic yard to about 15 cubic yards (Figure 11).

Closed Clamshell Environmental Bucket – This dredge can be either cable operated from a crane or hydraulically operated by an excavator. The two halves of the bucket are sealed. The bucket is hinged at the top and is designed to open fully to the sediment surface and surgically cut the sediment flat to the design grade. Flaps on the top of the bucket allow the bucket to be lowered slowly to the sediment surface with minimal disruption of the sediment bed. The flaps retain the water and sediment until discharged into a holding scow. Thus, turbidity is minimized if properly used. The sediment is placed directly into a scow positioned alongside. The scow is then transported to the placement site and can be unloaded using mechanical or hydraulic means. This device is used primarily for contaminated sediments or if there are concerns about suspended sediment transport in sensitive habitats. Since most of the sediment in our area is clean, this device is rarely required in the Atlantic Coastal Zone. Positioning sensors can be attached to determine when the bucket is fully closed and its precise position in the dredge prism. Size ranges from less than a cubic yard to greater than 30 cubic yards (see Figure 12).

Environmental Concerns – Most of the concerns regarding mechanical dredging are similar to hydraulic dredging and can be minimized through the use of timing restrictions (environmental windows) and or best management practices such rate of dredging, barge overflow restrictions, and spillage control. While mechanical dredges have more potential to generate suspended sediments than hydraulic methods, the amount of sediment generated is less than what can be expected from normal wind driven storm events in our area. If there are unavoidable concerns regarding turbidity, turbidity curtains can be used to retain sediment at either the dredging site or the placement site (or both).

Navigation and Positioning systems – Whether the project is new construction, maintenance or environmental remediation, a properly calibrated onboard software system is used to allow the operator to know precisely where the bucket is in three-dimensional space. This allows for more efficient removal of the sediment to target grades and minimizes excess dredging which can increase costs and reduce valuable placement site capacity. Various levels of precision and accuracy are available.

Figure 11. Hydraulically activated bucket dredge.

Figure 12. Closed clamshell environmental bucket dredge.

Dredged Material Management in the Back Bays of NJ Atlantic Coastal Zone

Once sediment has been dredged, it must be placed somewhere. Historically, dredged material has been placed in the nearest available location, either on a beach if sand or sidecast into a marsh if not. This was usually done with little or no regulatory oversight. This has not been the case since the 1970s. With oversight came the advent of confined disposal facilities, or CDFs.

Based on the most recent data, only about 10 percent of material is suitable for bathing beaches (greater than 90% coarse), another 15 percent is suitable for non-bathing beaches (greater than 75% coarse). Up until very recently, the remaining material was placed into confined disposal facilities (CDFs). Today, most of the CDFs in coastal NJ are at or near capacity and land to place new ones is either protected or developed. Consequently, for almost half of the NJMTS, there are no viable dredged material placement alternatives. Beach and marsh erosion are not only a problem for human and natural communities in the coastal zone, but they are particularly troublesome for marine transportation system managers. Erosion of marsh platforms or beaches results in increased shoaling in berths and channels, which in turn increases the frequency and cost of dredging. While this problem has not arisen overnight, the increased frequency of storms has exacerbated the problem and drawn attention to the need to restore and maintain safe navigation channels.

Upland Confined Disposal

After the advent of the Wetlands Act of 1970 (N.J.S.A. 13:9A-1 *et seq.*), efforts were made to regulate the upland placement of dredged material and to confine the placement to designated areas. These confined disposal facilities, or CDFs, were settling basins designed to retain dredged slurry and allow the sediment time to settle out. Once the sediment has settled, clear water is discharged through a weir structure back to the surrounding waterway. While the berms on the site can be periodically raised to accommodate future dredging cycles, capacity is limited unless efforts are made to remove the sediment once dewatered. While it is possible to construct new CDFs, suitable locations have been difficult to find. Upland sites are typically targeted for development, whereas marsh sites are protected and would require expensive mitigation to utilize. Efforts have been made to restore capacity through beneficial use of dewatered dredged material, however costs for this have been even higher than direct beneficial use. New CDFs, such as Gateway (located on the marshes outside of Atlantic City), are being designed with periodic excavation in mind.

Beach Replenishment

Probably one of the oldest and most widely used methods of beneficial use utilizes coarse-grained material to replenish beaches. Over the decades, millions of cubic yards have been dredged and placed on NJ's barrier island beachfront. Historical beach replenishment has focused on recreational beaches in NJ, however, recent efforts have been made to place coarse-grained material on natural beaches to improve habitat for beach nesting birds and other wildlife displaced by human activity (Douglas, 2021c). Rutgers is currently evaluating the amount of sand that could be used in this manner.

Shoreline Stabilization

Both marsh and beach shorelines are threatened by coastal storms and sea level rise. Rising waters and increased wave and current energy erode sand and soil away from natural features and create problems for both navigation managers and resource managers, as well as reducing the protection these features offer to coastal communities. Replacing the sediment is not straightforward, as the placed sediment is often even less resistant to erosion than the existing material. Placement techniques, therefore, need to account for retention of solids not only during dredging but also during a period of consolidation and stabilization. Several techniques have been attempted including rock revetments, geotubes, and natural berms such as coir logs. Wave attenuation and sediment retention devices such as concrete pilings and oyster castles exist but have not been utilized in dredging projects in NJ to date. The primary objections to these techniques have been cost, appearance, and longevity. There has been success pumping coarse sand into the nearshore region and allowing waves and wind to move the sand against the shoreline, replacing or enhancing a natural sandy strip (Barone et al., 2023). The Lighthouse Camp site in Waretown has recently been identified as a potential living laboratory to test these techniques and others. The technique manual authored by Stevens Institute of Technology provides a good baseline of methods for assessment, design and construction (Miller, 2016), but does not specifically address the issues associated with the application of dredged material. For these and other methods in the paragraph below, one key lessoned learned is the need to understand and model the coastal processes at play at the target restoration site to inform the design. This will likely be even more important for projects utilizing dredged material.

Marsh Enhancement

Marsh enhancement, often also called thin layer placement, is utilization of dredged sediment to stabilize and increase the elevation of the marsh platform in the absence of adequate natural accretion. The goal is to provide enough sediment to improve the marsh, but to do this in a way that results in a restoration of or increase in marsh vegetation, rather than a conversion to uplands. A good understanding of the hydrology of the system is essential in order to design the project and ensure that the post construction hydrology will allow for an adequate daily cycle of flooding and draining. The size and capacity of the site will dictate the rate of dredging and the retention of solids on the marsh. The jury is still out on the importance of matching sediment types; it may be that a combination of coarse- and fine-grained materials may be best for restoring severely damaged platforms. If paired with navigation dredging projects, it may be necessary to have multiple placement locations that can utilize different sediment types in order to ensure that the navigation project can be completed (Douglas et al, 2021a).

An excellent overview of the lessons learned from early work on marsh platforms can be found at TNC et al., 2021. Some items of particular relevance to using dredged material during construction:

- Realize that the maximum pumping distance without using booster pumps will vary with the size of the dredge and the characteristics of the dredged material.
- The time available to dredge and place dredged material may limit how much marsh can be enhanced, which may limit the achievement of project objectives, or the timing of the overall project.
- As these construction techniques are in an early stage of development, the success of marsh enhancement projects depends heavily on adaptive management.
- The maximum distance that hydraulically dredged sediment can be sprayed onto a marsh will vary with the equipment used and is likely limited to 150–200 feet.
- Both heavy equipment and extensive equipment use on the marsh can damage it and slow marsh recovery after dredged material is placed.

The US Army Corps of Engineers, in partnership with the Wetlands Institute has established a living laboratory at Seven Mile Island in Cape May County. Numerous techniques have been piloted here and provide a wealth of monitoring information including consolidation and loss of fines during placement. Some of the key takeaways so far are:

- Avoid overengineering. Hydraulic placement projects are primarily water management problems. Try to position sediment using innovative tools during placement rather than trying to move after placement. Be flexible; allow the slurry to move across the site and be repositioned by tide and currents.

- Containment causes more problems than it solves.
- Elevation building may require multiple applications.
- Planting should be deferred for at least two years as the site equilibrates. It may not be necessary at all if seed bank is sufficient.
- Do not expect rapid recovery/response; be patient.
- Consider ecological trajectories, traditional metrics do not tell whole story.
- Consider intermediate benefits.
- Limit data collection to what will inform design or adaptive management.

Marsh and Island Restoration

In areas where marsh has converted to open water, a combination of techniques is needed to replace the lost infrastructure. The primary challenge is to create a facility that will hold the dredged material long enough for it to consolidate while also sculpting a naturally appearing shoreline that will be resilient to waves and currents. These projects have a potential to provide large volumes of capacity for dredging projects but they have been notoriously difficult to permit due to the permanent conversion of benthic habitat. Loss of islands has been particularly damaging to coastal resilience in Barnegat Bay, where it is documented the loss of 13 islands since 1931, resulting in exposure of traditionally well protected bayside homes and businesses to increased damage from storm surges and wind induced waves (Kimberly McKenna, Stockton Coastal Research Center, personal communication). A pilot project was conducted by the USACE at Mordecai island in 2015 (USACE, 2019), as well as work at Gull and Sturgeon islands at the Seven Mile Island Living Laboratory (SMILL) (Chasten *et al*., 2022). To date there are no engineering guidelines published for this work.

Unconfined Benthic Enhancement

Intertidal and subtidal habitat is critical for healthy shore ecosystems. Sea level rise results in decreased light penetration and eventual migration of these areas following shoreline recession. While migration of this habitat is possible, it is limited in the same way as marsh migration, and eventually these habitats will be lost. Side-casting of navigational dredged material into nearby shallows can augment the shallow water habitat, provided that the layering is not too frequent or thick. The main operational challenges are to be able to place the sediment in such a way as to retain fine-grained material and to limit placement to those areas that are already too deep to support a healthy benthic community. A corollary to this technique is to reintroduce shoaled sediment into the swift moving water which carried it there, but on the opposite tide. This has been done for sand shoals at the Hereford Inlet in southern NJ, a deep and swift inlet with a large and important network of ebb tide shoals, but also notorious for rapid flood tide shoaling in channels and marinas. Simply pumping dredged material slurry into the ebb tide and allowing it to augment ebb shoals has proven successful (Farrell et al, 2018). Both of these techniques are relatively straightforward and affordable but have required extensive up-front evaluations and monitoring to obtain permits.

Upland Habitat Creation

In many places in NJ, shore nesting birds and other wildlife must compete with humans and domestic animals for use of the beach. Residential communities attract predators that not only feed on human refuse but also terrorize wildlife. Strategic placement of small volumes of coarse material on isolated coastal marshes can create refugia for nesting shorebirds that are free of humans and associated animals. While creating these upland islands reduces marsh, these areas appear to quickly recover if not overly extensive or high in elevation. Periodic refreshing of these sites will not only improve wildlife habitat but also provide programmatic predictability for dredging projects. A series of sites of this type have been built in the marshes of southern NJ, including Ring Island in Atlantic County, and proven highly successful from the perspective of wildlife managers (TNC et al., 2021). More sites like these could be permitted, but large sites might prove difficult to permit and/or manage. An alternative that might provide economy of scale for dredging projects would be to permit a series of smaller scale projects and use them cyclically to maintain channels on a local or regional scale.

Confined Benthic Restoration

The use of sediment for commercial purposes has resulted in the creation of underwater borrow pits, or "dredged holes" throughout coastal NJ (Murowski, 1969). These features are often many acres (hectares) in size and significantly deeper than surrounding water by 10-20 ft (3-6 m) or more, resulting in retention of poor quality sediments and anoxic conditions in the bottom, and inadequate circulation of water in the surrounding area. Dredged holes in close proximity to dredging projects have been identified as good candidates for restoration using dredged material (Howard *et al.*, 2015). The resulting bottom can be designed to mimic desired habitat conditions for SAV, fish and/or shellfish. The features can be filled mechanically or hydraulically at an affordable cost with minimal impacts to the surrounding healthy habitat. Obviously, the capacity of dredged holes is finite.

Since taking over the recovery and maintenance of the State's channel network in 2014, NJDOT/OMR has dredged over 1.9 million cubic yards of sediment. While over half of this material has been managed in a traditional manner on beaches or in CDFs, a large portion has been managed in creative and innovative ways (Figure 13). To date, dredged material has been dewatered and utilized as fill (19%), used to fill degraded underwater borrow pits (22%), used to restore marshes and dunes (3%), or placed directly into open water to augment shoal islands, stabilize shorelines or create fringe beaches (3%). Case studies of these projects are summarized in the next section.

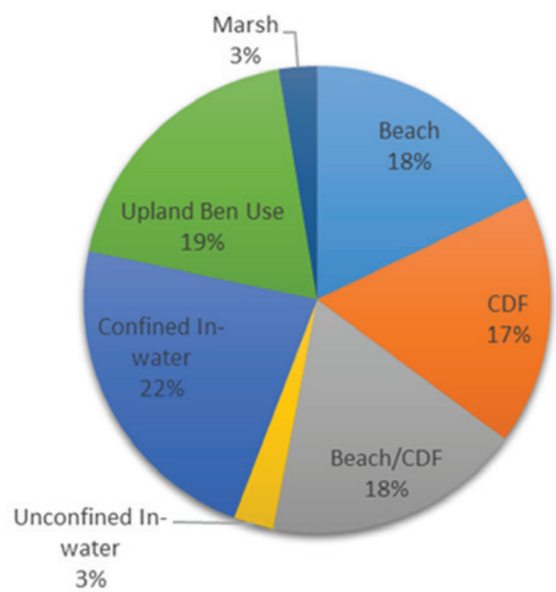

Figure 13. Dredged Material Management Techniques Utilized in State Channel Dredging since 2014.

Beneficial Use Case Studies

While the use of beach replenishment and CDFs are long standing practices, the use of dredged material for upland beneficial use or restoration of marsh and benthic habitat is relatively new. In recent years a number of projects have been conducted locally by the USACE and the NJDOT in conjunction with the NJDEP and USACE.

While much more can be done to understand impacts and increase efficiencies, a lot has been learned. The following case studies summarize experiences with implementing different types of beneficial use projects in the Back Bay region of the ACZ.

RING ISLAND

Beneficial Use Type:

Upland Habitat Creation

The Ring Island Marsh, is an 600-ac (240-ha) saltmarsh island located in Avalon, Atlantic County, NJ. It was comprised of stunted and sparse vegetation, mixed with bare areas. The objectives of these two experimental projects were to: (1) increase the elevation of a low-lying marsh by spraying a thin-layer of sandy dredged material (96% fine sand), 3 and 6 inches [in.] (7.5 and 15 centimeters [cm]) thick onto two (2) 0.5 ac (0.2 ha) areas of the marsh platform, ultimately resulting in increased cover and vigor of native salt marsh vegetation, and (2) create elevated nesting habitat (ENH) for the State-endangered Black Skimmer (*Rynchops niger*) and other colonial nesting shorebird species of concern. The dredged material for these projects came from a nearby short reach of the NJIWW. In August 2014, approximately 1,000 CY (765 m^3) of fine-grained sand were sprayed on two (2) 0.5-ac (0.2-ha) sections of the existing marsh, and approximately 6,000 CY (4600 m3) of the sand were used to create an approximately one ac (0.4 ha) colonial shorebird ENH (TNC *et al*., 2021).

Construction start: 8/2014

Construction completion: 9/30/2014

Total Dredging Days: 45

Dug Volume: 7,000 CY

Cost of engineering and permitting: $42,000

Cost of construction and oversight: $450,000

Cost of monitoring: $214,000

Lessons Learned:

- Multiple applications may be required to achieve project goals if mitigation for coastal processes is not provided.
- Long term management efforts may be required to maintain as-built conditions. In this case, vegetation re-established in sand areas quickly post construction, reducing the desirability of site for the target species.

Figure 14. Clompleted Ring Island elevated nesting in Avalon

MORDECAI ISLAND

Beneficial Use Type:

Island Restoration

Mordecai Island is an undeveloped 45-ac. (18-ha) marsh island in Barnegat Bay, on the western shore of Beach Haven, Ocean County, NJ. It shelters and protects the highly developed bay shore of Beach Haven from the brunt of wind and waves coming across Barnegat Bay, but over the years had been reduced and fragmented by the same wind and waves. The local citizenry, led by the Mordecai Land Trust, had long advocated for the repair and enhancement of the island for wildlife and coastal resiliency.

In 2015, the USACE, dredging sand shoals in the NJIWW, hydraulically placed 25,000 CY (19,100 m^3) of sand in the area of shallow water between two of the larger marsh fragments, effectively joining them. To protect extensive beds of submerged aquatic vegetation (SAV) adjacent to the island, a system of hay bales and silt curtain was deployed to retain the solids (USACE, 2019). Besides effectively joining the two fragments, the project created valuable shorebird breeding habitat and restored the coastal protection provided to Beach Haven. Additional applications of material have been made since first constructed to replace consolidation losses and to raise the area high enough to avoid nest losses during storms.

Construction start: winter 2015 (primary lift)

Construction completion: winter 2017 (secondary lift)

Total Dredging Days: 42

Dug Volume: 28,000 CY

Cost of engineering and permitting: $125,000

Cost of construction and oversight: $831,000

Cost of monitoring: $25,000

Lessons Learned:

- Multiple applications may be required to achieve project goals due to consolidation and losses from coastal processes that caused the initial loss.
- Be prepared for unintended wildlife utilization which may result in the need for adaptive management.

Figure 15. Completed island restoration at Mordecai Island, Beach Haven.

AVALON

Beneficial Use Type:

Marsh Enhancement

The Cape May Wetlands Wildlife Management Area (WMA) is a 1000-ac (400-ha) saltmarsh comprised of eroding marsh edge, increasing pool size, and stunted and/or sparse vegetation on the marsh platform located in Avalon, Cape May, NJ. The objectives of the project were to (1) convert unstable, expanding pool/panne complexes into stable and vegetated marsh plain, and (2) create more resilient native salt marsh plant communities. It was decided that maintenance dredged material from the nearby NJIWW would be suitable for this purpose.

In order to hold sediment in the targeted pool areas, approximately 15,300 ft (4,660 m) of coconut fiber coir logs were manually installed. In some cases, the logs were stacked to provide sufficient containment for the hydraulically dredged slurry.

The project was conducted in two phases: In Phase 1, approximately 6,000 CY (4600 m3) of fine-grained dredged material (65% silt/clay, 34% fine sand) was hydraulically dredged using a 10-in. (25-cm) cutterhead pipeline dredge and sprayed across 7 ac. (5.4 ha). In Phase 2, a total of 49,300 CY (37,700 m3) of fine-grained dredged material (72% silt/clay, 27% sand) was hydraulically dredged using a 14-in. (36-cm) cutterhead pipeline dredge from the same area and sprayed and/or pumped across 45 ac. (18 ha) (TNC *et al.*, 2021).

Construction start: 12/29/2014 (phase 1)

Construction completion: 2/20/2016 (phase 2)

Total Dredging Days: 98

Dug Volume: 55,300 CY

Cost of engineering and permitting: $302,000

Cost of construction and oversight: $2,024,500

Cost of monitoring: $470,000

Lessons Learned:

- Establish project goals and adaptive management strategies before the start of construction.
- If containment cannot be avoided, remove containment materials as soon as possible. The containment was not always effective at retaining the dredged slurry at the targeted location, however, it did reduce normal tidal exchange resulting in alterations of sediment chemistry (pH, redox, sulfides) that caused temporary vegetative die off.
- Be patient, recovery takes time. The recovery of the saltmarsh vegetation required several years, even after the containment was removed and despite planting efforts.

Figure 16. Placement activities at Avalon marsh restoration site.

FORTESCUE MARSH

Beneficial Use Type:

Shoreline Stabilization, Marsh Enhancement

The Fortescue Marsh is located within the 1300-ac (525-ha) Fortescue Wildlife Management Area (WMA) in Downe Township, Cumberland County, NJ. The marsh has a tidal range of 6 ft (1.8 m) with salinities ranging from 14-20 parts per thousand (ppt) and contains both high and low marsh habitats with vegetation typical of the region. The marsh had been evaluated and was impacted by considerable shoreline erosion as well as subsidence of the marsh platform caused by poor drainage brought on by sea level rise (Kreeger *et al.*, 2015). Stakeholders agreed that adding sediment to the marsh had the potential to reverse the damage and restore the marsh (TNC *et al*, 2021).

The remote fishing village of Fortescue, on the shore of the Fortescue Marsh, is completely surrounding by the Fortescue WMA. Local commercial and recreational fisherman are heavily reliant on the 3800-ft, 9-ft deep state-maintained Fortescue navigation channel for access from Fortescue Creek to the Delaware Bay. Condition surveys indicated that over 80,000 CY (61,000 m^3) of sediment would need to be dredged to return the channel to its full authorized depth.

Over the course of two dredging seasons, 37,140 CY (28,400 m^3) of sediment was dredged from the Fortescue channel and placed on the marsh and beaches using a 12-in (30-cm) cutterhead pipeline dredge. Approximately 8500 CY (6500 m3) of fine-grained sediment was pumped directly into the marsh via a network of high density-polyethylene (HDPE) pipelines and valves. Sediment slurry was contained on the target areas using approximately 20,000 ft (6100 m) of compost-filled polyethylene tubes. Another 21,000 CY (16,000 m^3) of course grained material was used to reconstruct an 1,100-ft (335-m) long by 100-ft (31-m) wide protective dune on the leading edge of the marsh. The sand was placed into a surge pit constructed on the marsh and the sand removed using an excavator and bulldozed into place. The remaining 7000 CY (5400 m3) of coarse-grained material was utilized to replenish two nearby beaches; one a remote wildlife beach, the other a village bathing beach (Douglas *et al.*, 2021a).

Construction start: 1/27/2016

Construction completion: 4/12/2017

Total Dredging Days: 41

Dug Volume: 37,140 CY

Cost of engineering and permitting: $486,654

Cost of construction and oversight: $4,114,090

Cost of monitoring: $600,000

Lessons Learned:

- Consider the physical characteristics of the dredged material available and have placement locations defined for all material, with contingencies for over-runs.
- Carefully consider the need, type and amount of containment. Installment of containment resulted in extensive, albeit temporary damage to the marsh platform.
- Avoid over-engineering. As with containment, there is a concern that construction of elaborate distribution systems will result in more damage to marsh platform. Using a marsh excavator to move the pipeline appears to be operationally acceptable, while minimizing damage.

- Consider pre and post construction hydrology. High tide events, combined with wind and precipitation, may help to distribute material across the marsh in a less intrusive manner than using mechanical equipment.
- Tidal redistribution and consolidation will result in a loss of elevation over time. Multiple applications of material may be needed to maintain target elevations, particularly in areas vulnerable to sea level rise.
- Marsh platform enhancements can be protected with shoreline stabilization. Recent inspections of the project indicate that the rate of shoreline loss in front of the dune has been significantly reduced.

Figure 17. Placement at Fortescue marsh restoration site.

ST. GEORGE'S THOROFARE

Beneficial Use type:

Beach Replenishment

The St. George's Thorofare in Brigantine is a state channel that provides access from the sheltered bay on the south side of Brigantine City to the Absecon Inlet. Because it is a narrow channel situated between the inlet beach and saltmarsh, and is adjacent to the high energy of the Absecon Inlet, it shoals in rapidly with high quality beach sand. This shoaling is best managed by pumping the sand back onto the inlet beach, combating erosion and ensuring that the homes in Brigantine that front on the Inlet are protected from storm surge. This dredging is required every 2-3 years, depending on weather and the amount of sand placed on the front beach.

In 2022, 67,731 CY of sand was dredged from St. George's Thorofare using a hydraulic cutterhead pipeline dredge and placed on the beach. Some of the sand was used to provide protection for an eroding vegetated dune, while the remainder was evenly distributed across a section of the main beach and graded down to the surf.

Construction start: 8/5/2022

Construction completion: 8/28/2022

Total Dredging Days: 16

Dug Volume: 67,731 CY

Cost of engineering and permitting: $98,458

Cost of construction and oversight: $1,880,668

Cost of monitoring: N/A

Lessons Learned:

- The design and construction of these projects has been thoroughly worked out over many decades, they should continue to be built the same way
- Dredged material, as opposed to offshore borrow sand, is often dark and can have a tidal odor. This dissipates quickly in the sun once graded out.
- Material can be placed where needed, but the water needs to be allowed to return to the ocean. This will require digging a trench to allow a flow path for the slurry and time for the sand to settle out.
- Material can also be placed directly into the intertidal zone, or even in an offshore berm and can either be graded or allowed to distribute naturally.

Figure 18. Beach replenishment underway at Brigantine Inlet beach.

MANASQUAN PHASE II

Beneficial Use type:

Upland Beneficial Use

The Manasquan area is served by 12 State channels that connect to the Manasquan Inlet federal channel and provide access to the Atlantic Ocean as well as the start of the Intracoastal Waterway. The area serves numerous marinas, waterside businesses, a commercial fishery, emergency services and numerous private berths and docks. In 2016/17, OMR dredged 6 channels and placed material either on the Manasquan Beach, the Dog Beach (Fisherman's Cove), or in the Gull Island CDF. At the end of the cycle, Gull Island CDF was unable to accept additional material. In order to dredge the remaining 6 channels (88,250 cy) an alternative dredged material management option was required. Because of the time required to design and permit the rehabilitation of the Gull Island CDF, an interim measure was sought.

Coarse grained material (greater than 75% sand) was placed at the Fisherman's Cove beach behind Manasquan (locally known as the Dog Beach). Fine grained material was pumped to the site of the proposed parking lot for Fisherman's Cove and dewatered using geotextile tubes. Once suitably dewatered, this material was trucked off site to the Monmouth County Reclamation Center (MCRC) for use as daily landfill cover.

The project was started in the summer of 2021 with placement of 44,500 cy of sand at the Dog Beach. Once the parking lot site was cleared and graded, another 36,300 cy of fine-grained material was pumped to the site and dewatered using geotextile tubes. In total, 21 tubes ranging in size from 150 to 259 feet long and 95 feet wide were arranged in four layers to contain the material. After allowing a minimum of 32 days to dewater, the tubes were opened and the material trucked to MCRC over ten weeks. Trucking operations ended on 4/28/2022.

Figure 19. Geobag dewatering underway at Manasquan beach parking lot.

Construction start: 8/1/2021

Construction completion: 5/31/2022

Total Dredging Days: 46

Dug Volume: 81,742 CY

Cost of engineering and permitting: $299,586

Cost of construction and oversight: $7,303,309

Cost of monitoring: N/A

Lessons learned:

1. Careful and nearly continuous in-person monitoring of sediment slurry and concurrent adjustment of flocculant dosing improves the quality of the dewatered product and lessens dewatering time.
2. Removing material from site for beneficial use will require a negotiated truck route and good municipal coordination.
3. Timing of removal is dependent on dewatering time. Monitor progress of dewatering in the textile bags.

BEACH CREEK

Beneficial Use type:

Unconfined Benthic Restoration

Beach Creek is a state navigation channel that connects the western shore of North Wildwood with Hereford Inlet, providing access to the Atlantic Ocean for several marinas and a large number of residences. Unfortunately, the highly dynamic nature of the Hereford Inlet moves a considerable amount of sand through the area, and the mouth of Beach Creek shoals regularly making safe navigation impossible. Previous projects have pumped the sand to the front bathing beach, however, this requires running a pipeline through the Inlet itself, which is dangerous. In addition, the navigation channel is shallow draft (6 ft (1.8 m) mean low water [MLW]) and only 100 ft (31 m) wide, making it necessary to use small dredging equipment. The volume of sediment required to be dredged to restore navigation is typically less than 25,000 CY (19,000 m3) making an economy of scale difficult to achieve. Consequently, a cheaper, easier and safer alternative was sought.

Following Winter Storm Jonas in 2016, an emergency permit was granted to hydraulically dredge the storm induced shoal and place the material into the ebb tide of the Absecon Inlet, with the desired effect of having the tide take the sand out to the ebb shoals (valuable wildlife habitat) or the recreational beach to the south. In 2016, 11,350 CY (8680 m^3) of sand was hydraulically dredged from Beach creek using a 12-in. (30-cm) cutterhead pipeline dredge and placed into the ebb tide of the Inlet. The inlet bottom in the vicinity of the pipe discharge was surveyed prior to project start, and turbidity was monitored regularly during placement. At the end of the project, only a small amount of sand, directly below the pipe outfall, was able to be identified as having come from the project. The inlet is over 45 ft (14 m) deep in this area, so no navigation impacts were anticipated from this action. It is assumed that the majority of the material found its way to either one or more of the ebb shoals or to the bathing beach, but this could not be confirmed. No turbidity was detected above background conditions at any time during the process. Drone overflights conducted during the placement were also unable to detect a visible plume from the activity (Farrell, 2018).

Figure 20. Dredging in Beach Creek with open water placement at Hereford Inlet.

Construction start: 12/1/2017

Construction completion: 1/22/2018

Total Dredging Days: 23

Dug Volume: 11,350 CY

Cost of engineering and permitting: $ 94,348

Cost of construction and oversight: $ 342,775

Cost of monitoring: $39,435

Lessons learned:

1. Placement of coarse-grained material into a dynamic inlet is an effective way to manage this type of sediment.
2. No negative impacts to navigation were observed
3. No negative impacts to water quality were observed.
4. The sediment was assumed to be transported to a more beneficial site by natural processes

DREDGED HOLE 18

Beneficial Use type:

Confined Benthic Restoration

Dredged Hole 18 is a 9-ac (3.6-ha) subaqueous borrow pit in northern Barnegat Bay, Ocean County that was originally mined in the early 1960s for beach replenishment projects. The hole was more than 20 ft (6 m) below MLW and had nearly vertical sides. (Average depth in this portion of the bay is less than 4 ft (1.2 m) below MLW.) The unnatural bottom configuration impeded normal tidal circulation resulting a stratified water column in the hole. Evaluations of water quality and benthic life performed by Stockton Coastal Resource Center in 2014 and 2015 indicated low dissolved oxygen and a no benthic life in bottom sediments (Howard *et al*., 2015). In contrast, the adjacent sand flats contained valuable habitat with annually occurring SAV including widgeon grass (*Ruppia maritima*). The site had been previously identified by the USACE as a good candidate for restoration using dredged material from nearby navigation projects (Murawski, 1969).

The NJDOT/OMR identified more than 240,000 CY (183,500 m^3) of dredged material in nearby State channels that could be used to fill the dredged hole and restore the benthic habitat. The material varied in quality and characteristics from clean sand to silty clay that was contaminated with metals, pesticides, and petroleum at levels slightly above residential soil remediation standards. The sediment was dredged mechanically, transported to the site, and placed into the hole. The more contaminated silty material was placed at the bottom, followed by coarser and cleaner material.

A 3100-ft (945-m) turbidity curtain was deployed around the entire site to prevent loss of fines. Twice daily monitoring of turbidity uptide and downtide of the site revealed that turbidity from the operation was rarely able to be discerned from the current conditions, and when it was, it was associated with wind driven events. In all cases the observed turbidity was less than that seen in a storm event. It was decided that the turbidity curtain was unnecessary for the operation and it was removed. Subsequent events were monitored, with similar results (Douglas et al, 2021b).

Approximately 83,500 CY (63800 m^3) of coarse-grained material (> 75% sand) were reserved for the required 2-ft (0.6-m) thick cap. Placing this material at the top of the fill resulted in rapid consolidation and stabilization of the site. An additional 35,000 CY (27,000 m^3) of clean sand was added one year later following an evaluation of the thickness and grain size of the cap.

Monitoring of elevation, SAV and benthic infauna was completed in 2024 (McKenna *et al*., 2024). Results indicated that the benthic assemblage was similar to surrounding assemblages and that SAV recruitment, while sparse, was beginning. It was also determined that additional settling had occurred over time, and that the site would benefit from additional sand cap to prevent siltation from accumulating.

Construction start: 10/26/2018

Construction completion: 1/22/2020

Total Dredging Days: 177

Dug Volume: 244,106 CY

Cost of engineering and permitting: $558,723

Cost of construction and oversight: $18,286,259

Cost of monitoring: $218,214

Lessons learned:

- Carefully evaluate the need and size of turbidity curtains. Turbidity from operations was rarely detectable, however wind-induced turbidity was common in the shallow embayment (Douglas *et al*., 2021b).
- Expect consolidation of material over time. Additional applications of cap material may be necessary to maintain target elevations.

Figure 21. Placement at Dredged Hole 18 with turbidity curtain deployed.

GOOD LUCK POINT

Beneficial Use Type:

Marsh Enhancement, Shoreline Stabilization

The Good Luck Point Marsh is a 20-ac (8-ha) saltmarsh located within the Edwin B. Forsythe Wildlife Refuge in Berkeley Township, Ocean County, NJ. The marsh was previously identified as a candidate site for marsh enhancement by the US Fish and Wildlife Service as part of a larger effort to identify marshes at risk from erosion and sea level rise. The marsh suffered from extensive mosquito ditching and hydrologic impediments caused by surrounding high ground and a roadway. All tidal exchange was forced through two undersized culverts. This resulted in long periods of inundation that were slowly degrading the marsh platform. It was decided that raising the platform by 0.7-1.1 ft, (0.2-0.3 m) as well as replacing the culverts, would dramatically improve tidal flushing (AMEC and EA Engineering, 2016), improve vegetation coverage and health, and increase wildlife utilization. The amount of material needed to accomplish this was estimated to be 17,000 CY (13,000 m^3) of fine-grained material.

In addition, it was observed that the leading edge of the marsh exhibited moderate to severe erosion, and that the narrow 1700-ft (520-m) beach that protected the marsh edge had slowly decreased over the years to a narrow ribbon a few meters wide. This isolated beach was not used for recreation, but was utilized by shorebirds and other wildlife. To protect wildlife without hindering the project, it was not desirable to utilize traditional placement and grading techniques.

The NJDOT/OMR partnered with the USFWS by providing 12,000 CY (9,200 m^3) of maintenance dredged material from nearby navigation channels. The material was a mix of coarse- and fine-grained material. Using a 10-in. (25-cm) hydraulic dredge, approximately 6000 CY (4600 m3) of fine-grained material was pumped onto the marsh. Based on the experience at Fortescue, containment was deployed strategically. Polyethylene filter socks filled with compost were installed in mosquito ditches and along the eastern side of the site, with the goal of preventing sediment from clogging the main drainage ditches feeding the tidal culverts. To evenly distribute the material, the discharge point was moved around the site using a marsh excavator.

Approximately 6000 CY (4600 m3) of coarse-grained material was hydraulically dredged and placed directly into the shallow open water along the beach placement area. The discharge end was mounted on a scow and the scow moved along the beach as areas were filled. Tidal currents and waves quickly integrated the sand into the existing beach.

Construction start: 12/1/2020

Construction completion: 1/4/2021

Total Dredging Days: 21

Dug Volume: 12,000

Cost of engineering and permitting: $578,643

Cost of construction and oversight: $2,192,827

Cost of monitoring: $120,000

Lessons Learned:

- Perform coastal modeling to better place sand for remote beach replenishment. A post-construction storm event moved the sand about considerably, but the majority of the sand settled within the project template, effectively enhancing and protecting 750 linear feet (230 linear meters) of marsh shoreline (Barone, 2022b, Barone *et al.*, 2023).
- Closely monitor sedimentation control structures. Sediment blocks were quickly overtopped during an above normal tide event and required intervention and enhancement during the project to prevent clogging of drainage pathways.

- Understand hydrology of the site. While a complete hydrologic model for the site was developed, damage caused by machinery access dramatically reduced drainage of a portion of the site, requiring repairs.
- Seek creative ways to achieve project goals. It was shown that dragging the discharge pipeline strategically across mounded areas was effective at leveling the placed material while avoiding having to traverse sensitive areas with heavy equipment.

Figure 22. Placement at Good Luck Point marsh restoration site.

BRIGANTINE

Beneficial Use Type:

Unconfined Benthic Enhancement

The Brigantine channel is a 6-mile (9.7-km) channel located in Absecon Bay on the western shore of Brigantine Beach, NJ. The channel provides access to the Absecon Inlet and the Atlantic Ocean for numerous private slips and a dozen marinas. Severe shoaling of hard packed sand at the southern end of the channel had resulted in partial channel closure. A condition survey conducted in November 2019 indicated that 27,000 CY (20,600 m^3) of sediment needed to be removed from a 2000-ft (610-m) reach to reopen the channel. Unfortunately, there were no available options for managing the material. Previous dredging had utilized unconfined placement on nearby Boot Island marsh, but this area was now the home of a heron rookery, eliminating it from consideration. OMR initially proposed placing the material on a sand spit off Boot Island, but this was not approved as it might result in human visitation that could disrupt the heron rookery.

While the Brigantine uplands are highly developed, the surrounding marshes and intertidal subtidal shallows are extensive and heavily utilized by birds and other wildlife. After consultation with resource agencies (NJ DFW, NMFS and USFWS), it was decided that the material would be used to increase shallow water habitat, stabilize the shoreline, and restore shellfish habitat adjacent to the Boot and Sunflower islands.

Approximately 7650 CY (5850 m^3) of material was hydraulically dredged with a 12-in. (30-cm) cutterhead pipeline dredge into the open water adjacent to Sunflower Island and integrated into the shoreline using a marsh excavator. The sand stabilized 550 ft (170 m) of shoreline and reintegrated two remnant portions of marsh back into the island. Another 9400 CY (7200 m) of material was placed into the 21.4-ac (8.7-ha) subtidal depression at Boot Island to achieve a final elevation of 2 to 3 ft (0.6 to 0.9 m) below MLW. In total, approximately 23.6 ac (9.6 ha) of benthic habitat were created.

Monitoring of elevation, SAV and benthic infauna was completed in 2024 (McKenna *et al.*, 2024). Results indicated that the benthic assemblage was similar to surrounding assemblages and that SAV recruitment, while sparse, was beginning. It was also determined that additional settling had occurred over time, and that the site would benefit from additional sand cap to prevent siltation from accumulating.

Construction start: 10/23/2020

Construction completion: 12/30/2020

Total Dredging Days: 42

Dug Volume: 21,823 CY

Cost of engineering and permitting: $243,637

Cost of construction and oversight: $1,289,835

Cost of monitoring: $144,835

Lessons Learned:

- Partner with resource managers to explore creative ways to keep dredged material in the ecosystem. While the site had not been previously identified as requiring restoration or stabilization, engaging with resource managers early in the process identified locations that would benefit from receiving the dredged material, eliminating costly upland processing and placement.
- Open water placement of coarse-grained material using hydraulic equipment was effective and efficient. Sand did not migrate outside of target areas.
- Open water placement of coarse-grained material using hydraulic placement was environmentally safe. While turbidity could be detected around the dredge and at the placement sites, it was not detected in the surrounding waters.

Figure 23. Placement activities at Sunflower Island shoreline stabilization site

Considerations for Beneficial Use Projects

Beneficial use projects will often require specialized engineering information and or analyses to inform the design, permitting and construction. This information is often time sensitive to the overall project schedule and must be carefully considered during the project planning process. Note that this section is focused on engineering and would be in addition to the information required by resource agencies to establish biological parameters for restoration. Some key milestones are described below as well as summarized in Figure 24.

Site Selection: For dredging to occur, sufficient capacity must be identified to place the dredged material. Agreements may be required for the use of the property by the dredging entity. In some cases, and usage fee may be required. In all cases, the owner of the site will be required to provide written permission to the dredging proponent as part of the permitting process.

For restoration projects, the site must be evaluated to show that there are existing conditions that will be significantly improved by placing dredged material at the location. This uplift potential may require extensive evaluation of wildlife and/or fisheries utilization, water and sediment/soil quality, and vegetation patterns. In addition, data on the geotechnical condition of the site may be required in order to determine placement constraints and methodology.

Coastal Engineering: Particularly with projects that propose shoreline stabilization, an evaluation of the wind, wave and tide excursion will be required. In marsh projects, it may be necessary to include shoreline stabilization components in order to protect newly established habitat or to allow for consolidation and vegetation recovery. For marsh sites exposed to open water, site specific information on periodic flooding by tide and storms is needed to inform the project design and filling strategies. This may require monitoring over several months to obtain sufficient information for design.

Material Characteristics: While all dredging projects require an evaluation of material characteristics including grain size and geochemistry of sediment, beneficial use projects often require additional samples to ensure proper characterization for design purposes. Additional information on the soil characteristics of the placement site may also be required.

Hydrology: One of the most important characteristics of a coastal marsh is the periodic filling and draining and the variability associated with that action. Modeling the existing hydrologic condition can be used to help justify the need for material on the marsh by showing that the site does not adequately perform hydrologically due to human intervention, sea level rise, or marsh erosion. Modeling the proposed condition can be used to show that the placement of dredged material at the locations and depths proposed will result in improved hydrologic performance.

Inflow Modeling: For large projects, and to minimize the amount of adaptive management actions, it may be necessary to model the placement of dredged material on a beneficial use site. This will allow project stakeholders to see how the material will behave when pumped utilizing the expected (or required) equipment. This model can also be used to establish limits on pumping rates and/or to define the number and location of placement locations.

Adaptive Management: Adaptive management is a particularly useful way to identify risks and monitoring techniques, action levels, and corrective techniques to be employed both during and after construction. It should be tied to measureable and objective triggers as often as possible to avoid misunderstandings. Because the expertise required and the techniques will differ between phases as well as between sites, it is important to have separate adaptive management plans for the construction phase and the post construction phase. The separation point between these two plans needs to be clearly defined and agreed to up front. The time between the completion of construction and the evaluation of construction success should be as short as practicable to minimize risk to the contractor and keep costs down.

The components of an adaptive management plan will need to include the overall project goals and success criteria, as well as the metrics that will be measured during each phase of the project. These metrics will be used to trigger specific corrective actions. The corrective actions need to be clearly defined, as well as the entity responsible for that action, and how the activity will be paid for.

Monitoring: Monitoring can be divided up into three distinct phases: preconstruction monitoring or evaluation, construction monitoring and post construction or long-term monitoring. The level of effort required for each type is dependent on the type of restoration project being contemplated, the size and location of the project, and the project schedule. The metrics being monitored can be divided into two distinct types: engineering parameters (hydrology, tides, elevation, consolidation, spread) or ecological parameters (wildlife utilization, vegetation, fisheries utilization). Monitoring plans should include schedule and sample locations, methods and data quality objectives. The entities responsible for each activity should be clearly defined and how that activity will be paid for.

Figure 24. Special considerations for Beneficial Use projects

NJDOT Dredging Project Process Flow

The Office of Maritime Resources utilizes a well-defined process to design, engineer, procure and construct dredging projects that is compliant with NJDOT policy and NJ State law (Figure 25). The process is essentially the same regardless of the complexity and whether or not beneficial use is utilized, however each project is unique and the level of effort required at each step may be different for different projects. The following describes the steps in that process.

Problem Formulation: In this step the dredging project is selected and potentially bundled for efficiency. Channels are selected for dredging in a given year based on available condition data on depth, the location and severity of shoaling, the nature of the dredged material, and the availability of a location to manage the dredged material.

Design

Conceptual: In this step the volume and characteristics of the sediment, as well as the extent of shoaling and potential options for managing dredged material will be used to establish a dredging and dredged material management strategy. This can be a very simple and rapid step, or take many months or years to complete, depending on the location. Very preliminary estimates on cost per cubic yard will be developed at this stage.

Preliminary: Using the preferred alternative from the conceptual design, a preliminary design will be developed and presented. The channel dredging templates will be established and the appropriate alignment chosen to minimize the dredging need and maximize the transportation efficiency for the current or proposed traffic use. The management site will be described and defined. The current capacity of the management site will be defined and any engineering required presented to increase capacity to account for material being dredged. The level of detail required is specific to the permits being obtained, but is typically at the 55-75 percent level.

Final: Once permits have been obtained, the final construction plans and specifications can be developed. These drawings will contain current and proposed project depths and conditions, current and proposed management site conditions, cross sectional details, positioning information, location of environmental sampling, and the route of material transport either in water or upland. Specifications are developed to provide the contractor with standard contractual obligations as well as project specific requirements, site specific information, order of work, schedule requirements, and permit conditions.

Permitting: Dredging permits are required by the NJDEP and the USACE. Army Corps jurisdiction in the ACZ is NY District from Sandy Hook to Manasquan, and Philadelphia District from Manasquan to Cape May. The NJDEP requires Individual Waterfront Development Permits and Water Quality Certifications for all dredging projects. The USACE requires (at a minimum) permits under Section 10 of the Rivers and Harbors Act as well as Section 401 of the Clean Water Act. Additional permits may be required from either or both agencies, depending on the project and location. A General Permit 24 is required for beneficial use projects that restore habitat.

Figure 25. NJDOT Dredging Process Flow Diagram

Procurement: Dredging projects are low bid solicitations under the NJDOT contracting authority. Bidders are required to be prequalified under work type navigational dredging or work type environmental dredging. There are currently no provisions for qualifications for specific beneficial use projects, although most would fall under environmental dredging. NJ Treasury mechanisms are also available, usually used by NJDEP. Process is three weeks minimum to advertise and two to four weeks (or longer) to obtain a notice to proceed, depending on the contractor and the specifics of the bid.

Preconstruction: Between the NTP and construction start the contractor is required to submit contract paperwork, work plans, environmental compliance plans, and health and safety plans, and any other project specific paperwork. A preconstruction meeting will be held during this period with the contractor, local agencies and major stakeholders. Other relative agencies, particularly the permitting agencies are invited. A Before Dredge (BD) survey is requested at the end of this period to initiate the Construction phase.

Construction: During construction the NJDOT provides on-site inspection on a daily basis to observe the dredging and placement operations to ensure compliance with plans, specifications and permits. Daily and weekly reports are filed by the Resident Engineer. Weekly progress meetings are held on site. Monitoring will be performed and results discussed. Adaptive management actions for specific parameters that are triggered by monitoring need to be established up front. Daily dredging logs are submitted by the contractor and reviewed by the NJDOT team. When the contractor believes the project is complete, an After Dredge (AD) survey is requested. Payments are made based on the amount of sediment removed from the template plus over-dredging allowance as compared to the BD survey. When the project is accepted, final cleanup and punch list items are reviewed and discussed.

Post Construction: In most case in dredging projects, this involves repair of damaged facilities. However, in cases of beneficial use and restoration, additional work may be required to ensure that ecological damage has been repaired and/or material moved to comply with target elevations or extents or to restore drainage. Monitoring of ecological indicators will often be performed by the property owner or resource agency. All monitoring parameters and triggers for action should be identified up front and put into an adaptive management and monitoring plan. There should be a clear separation between the adaptive management components that are short term and related to construction or long term and related to habitat goals. The responsibility of long term monitoring and related adaptive management responsibilities needs to be discussed prior to the start of construction and should, in most cases, not fall under the dredging contract.

Dredging Project Constraints

In order to coordinate dredging projects with many beneficial use opportunities, but particularly for restoration projects, it is critical for all stakeholders to understand the constraints that are imposed upon both the dredging side and the restoration side. We will address the constraints of the dredging side in this white paper. It is assumed that the constraints of the restoration side will be addressed elsewhere.

Navigation dredging in the ACZ is constrained by equipment type and availability, contractor experience and schedule. While there may be some opportunity for small scale pilot projects to be performed with specialty contractors, routine NJDOT navigation dredging projects are procured using a low bid process on a list of pre-approved contractors. The size of the equipment is limited to smaller 8-18 inch cutterhead dredges and barge-mounted mechanical dredges drafting 5 feet or less. The hydraulic dredges, with the help of booster pumps, can pump the sediment up to about 5 miles. Mechanical dredging into scows can increase the potential distance between the source and placement site, but distance will dramatically impact cost and schedule. In most cases, NJDOT prefers to use hydraulic dredges as they are less costly and more efficient. Efficiency is extremely important in this region due to the limited dredging season (see discussion on schedule).

Precision placement of dredged material can be somewhat problematic as well. Hydraulic cutterhead dredges are best operated continuously with little or no restriction to flow. While there are some experimental methods using innovative pipeline arrangements, most work is performed with a single pipe, or occasionally a single Y valve arrangement to allow the dredge slurry flow to be controlled and to allow the placement to alternate between two locations on the marsh. The pipe can also be moved from location to location using a marsh excavator or similar tracked device, but each movement can result in increasing damage to the marsh platform. While in our experience this damage is temporary, it may or may not be acceptable to the land manager and may require corrective action. The best arrangement (least costly, least damaging) is to pump into an open, or large confined space, allowing the dredge to pump at full power and continuously. This allows the material slurry to flow out over the marsh. The particles will separate out by grain size, with sand falling out near the outflow, and the remaining water and fine grained materials being carried out over the marsh and depositing at a 1:500-1:800 slope.

Note that the maximum height of the slurry during pumping is NOT the same as the maximum height of the retained material. The slurry is typically 80% water or more. Another important consideration is that over the near term the settled material is likely to move as the tide moves in and out over the site. These two facts create an uncertainty that makes it impossible to predict the point by point final elevations and extent of the material placement. Final elevations can, however be expressed in terms of a "not to exceed" range. This is a critical concept for all stakeholders, and regulators, to understand. Permit drawings will need to show the maximum extent of impact in terms of elevation and extent, as at any given point in the site, those conditions may exist. However, it is highly unlikely that those conditions will exist across the entire site due to the physics of the application. What can be predicted is the amount of area likely to be covered to any given depth across the site. What this comes down to is open flow hydraulic placement is not a suitable technique if there are defined and limited places that can receive material or if large areas of the site cannot be flooded due to wildlife concerns. Even more directed placement using high pressure hydraulic nozzles will result in the flooding of adjacent marsh during placement. In cases where direct placement is desired, either containment or mechanical equipment will be required.

The time allowed for dredging is limited both by channel usage and permit. Since most channels are providing access for recreational vessels, dredging in the summer season between Memorial Day and Labor Day is discouraged. If dredging must occur during the summer season, it is often with considerably reduced efficiency to accommodate recreational traffic. Channel closures are possible, but not preferable. Dredging permits often have timing restrictions to protect birds, wildlife and fisheries resources at both the dredging and placement sites. While every permit is case specific in this regard, the most common restrictions are for winter flounder EFH (Jan 1 – July 1), anadromous fish (Mar 1 – June 1), and nesting osprey (Apr 1 – Aug 31). Taken together, this usually results in a dredging season that is limited to between Labor Day and New Year's Day. Even tighter timelines have been imposed on some projects. When these tight timelines are combined with the constraints imposed by restoration sites, the costs of the project can escalate rapidly and there is a risk that it may become unaffordable.

Additional time should also be allowed for the evaluation of sites, preliminary design and permitting of beneficial use projects over traditional methods (Table 1). It may take up to twice as much time to go through this process, especially if a field season is required to collect the data necessary to evaluate baseline conditions for restoration projects.

Table 1. Schedule implications for beneficial use projects

Project	Dredged Material Management	Engineering Time[1]	Placed volume	Calendar Days	Dredging Days
Fortescue	Marsh/dune/beach	247	37,140	440	41
Good Luck Pt	Marsh/beach	579	10,200	35	21
Metedeconk	Confined Benthic	1135	244,106	453	177
Toms River North	Confined Benthic	526	24,070	53	33
Lakes Bay	Confined Benthic	2129	138,310	47	35
Beach Creek 2	Unconfined Benthic	591	11,350	52	23
Beach Creek 3	Unconfined Benthic		18,450	95	34
Brigantine	Unconfined Benthic	1752	21,823	68	42
Manasquan II	Upland/beach	174	81,742	296	46
Absecon	Upland Ben Use	2234	70,730	193	74
Shark River	Upland Ben Use	125	68,416	1441	129
St. George's 22	Beach	147	67,731	23	16
Nantuxent	Beach	354	35,990	28	12
Fortescue 22	Beach	213	37,772	80	37
Tuckerton	CDF	675	41,460	155	87
Waackaack	CDF	140	5,140	30	4
Cape May	CDF	261	96,898	273	104

[1]Time between start of engineering process and final PSE delivery

Dredging Costs and Benefits

Dredging and dredged material management costs vary widely depending on the location, size of project, complexity of management options, distance between dredging and placement sites, and permit constraints. However, it can be useful to view the trends observed in one area. The cost for some innovative beneficial use techniques can be comparable to traditional methods, but for others it can be more than twice as much (Figure 26). It is important to note that the costs shown here for more innovative techniques are for pilot projects, so these costs may come down with time and experience. While costs appear to be higher for innovation and beneficial use, there are greater benefits to be obtained.

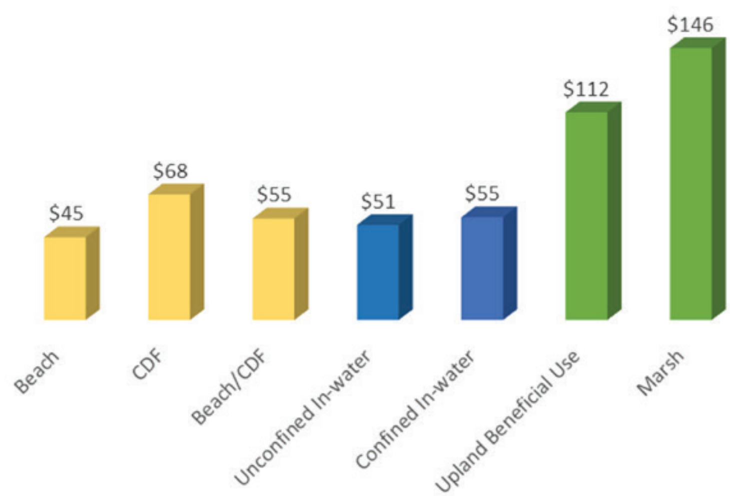

Figure 26. Average cost per cubic yard for construction and oversight of various dredged material management techniques utilized in the NJ State Channel Dredging Program.

Construction materials: Dredged material, once dewatered, is often suitable for structural and non-structural applications. Millions of cubic yards of dredged material have been used for construction aggregate (sand and gravel), capping material (processed fine grain), and as general fill for landscaping, berms, grading and construction. Dredged material can be used as a partial or complete replacement of fill requirements and has a value commensurate with the cost of alternative fill. The cost of dewatering, processing and transportation of the dredged material must be taken into consideration.

Beach replenishment: Dredged material can be suitable for replacement of sand on both bathing and non-bathing beaches depending on its characterization. In general, material greater than 90% coarse, but not containing significant gravel, can and has often been used on bathing beaches. Silt content, color and odor can be a factor in public acceptance. Beach placement is often much less expensive than even CDF placement and should be used when available. Dredged material that is greater than 75% coarse has also been used recently on non-bathing beaches to provide recreation and/or habitat for beach nesting birds and other coastal wildlife. Additionally, this material has also been placed nearshore to stabilize eroding shorelines and to restore shallow water habitats. Again, the cost of this placement is either less than or equivalent to traditional CDF placement.

Habitat restoration: Dredged material, particularly fine-grained material, can be used in a host of ways to restore coastal habitats including marshes, mudflats, and shallow water habitat. Elevating marsh platforms, filling in dredged holes, and direct placement in shallow water have all been successfully implemented at numerous sites, albeit small scale in New Jersey, as outlined above. The cost of these projects can vary widely, but in general are much higher than traditional disposal methods, often by a factor of two or three. The value of coastal habitats is difficult to quantify but can be based on acres or linear feet. Improvement of water quality through restored or improved circulation is also difficult to prove or quantify but can be an important benefit of some projects. Consideration should be given to both the recreational value, the support of conservation efforts/requirements, and the value of the habitat as green infrastructure (water quality, stormwater management, storm resiliency).

Table 2. Summary of NJDOT dredging projects since 2013.

Dredged Material Management	Volume placed since 2013 (CY)	Avg Cost/CY placed *	Channel Miles Cleared (nm)	Additional value added
Beach	331,555	45	7.96	331,555 CY beach fill
CDF	322,232	68	11.25	None
Mixed CDF/Beach	441,950	55	16.36	105,974 CY beach fill
In water	470,649	54	34.5	33 acres subtidal/intertidal habitat
Upland	353,334	93	11.11	353,334 CY fill
Mixed Beach/marsh	49,140	146	2.11	12 acres marsh, 2,350 ft shoreline 34,600 CY beach

*construction and oversight only

Community Resiliency: Recent efforts to improve the resiliency of coastal communities to sea level rise and increased frequency and severity of coastal storms has increased awareness of the value of green infrastructure such as marshes, islands, coastal forests, beaches and dunes. The value of coastal communities themselves is relatively easy to quantify, however the benefit and/or cost avoidance generated by individual parcels of habitat may be more difficult to quantify. Efforts should be made to improve our understanding of the protection provided by these habitats.

Dredging Decision Tree

Because the back bay area contains many channels, some in relative close proximity to each other, it is often prudent to group channels together into a dredging project rather than do them singly. This increases efficiency and can make some beneficial use projects more viable by providing a greater amount of sediment. While in some cases, there are relatively few dredged material management options, in others there are multiple options, each with different cost, schedule and material type constraints as outlined above. The process by which NJDOT/OMR evaluates and scopes dredging projects is based on many years of experience and with a firm understanding of the permitting and procurement processes (Figure 27).

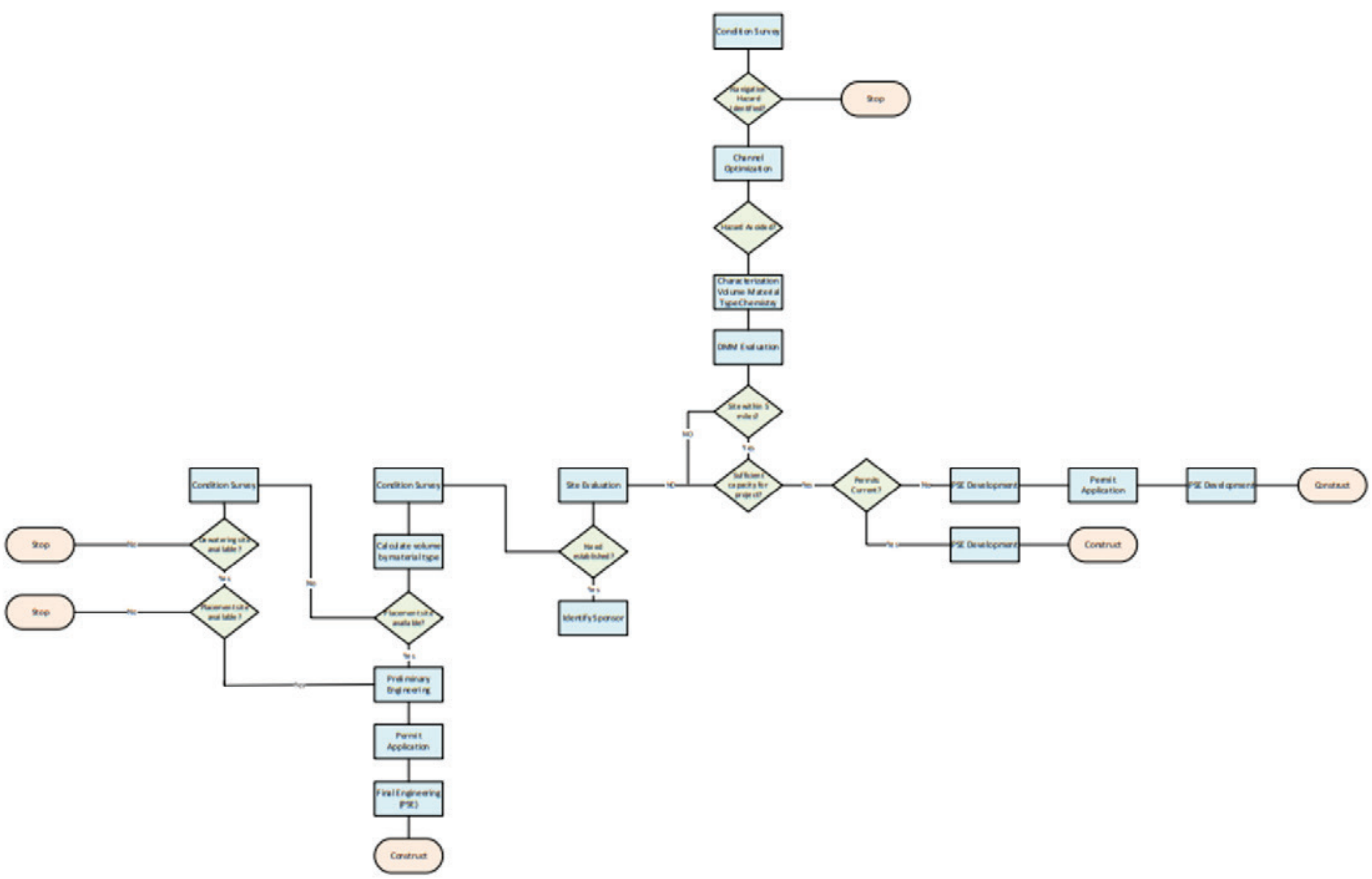

Figure 27. NJDOT/OMR dredged material management decision tree.

Conclusions

The following conclusions are relevant to furthering the planning process:

- There is a greater estimated need for sediment in habitat and resiliency projects than is currently available in the navigation channels system wide;
- Not all sites that need sediment will be suitable for receiving dredged material from navigation projects;
- Not all sediment from navigation projects is suitable for habitat and resiliency projects;
- Not all navigation projects are in close enough proximity to beneficial use projects to be practicable and visa verse;
- The cost of some beneficial use options is higher than traditional methods. Traditional methods will continue to be a significant component of dredged material management going forward;
- Benefits from habitat and resiliency projects need to be quantified so that they can be combined with navigation benefits in order to provide a complete cost benefit picture for sustainable beneficial use; and
- The constraints associated with some beneficial use options may require longer project timelines both from a planning/design and execution standpoint.

Refrences

Barone, D., (2022a). "Turbidity monitoring report: active turbidity monitoring at Dredged Hole #86 placement area, final report to Office of Maritime Resources. NJ Department of Transportation, Trenton, NJ.

Barone, D. (2022b). "Monitoring and evaluation of nearshore placement of dredged materials for shoreline restoration at Goodluck Point." Final Report to Office of Maritime Resources. NJ Department of Transportation, Trenton, NJ.

Barone, D., R. Miskewitz and W. Douglas (2023). "Nearshore placement of dredged material for estuarine shoreline restoration in Berkeley Township, NJ." *Shore and Beach,* 91(1).

Chasten, M., Goldberg, K., Pasquale, J., Piercy, C., Welp, T., and Golden, D. (2016). "Recent experience with channel dredging and placement to restore wetlands in New Jersey," *Proceedings of the 21st World Dredging Congress (WODCON XXI), Miami FL., USA, June 13-17, 2016*.

Chasten, M., Tedesco, L., and Kopkash, G. (2022). "Advancing sediment solutions in the seven mile island innovation lab," *Proceedings, 37th International Conference on Coastal Engineering*, December 2022, Sydney, Australia.

Douglas, W.S., Marano, M.J., Flanigan, S, Fanz, D, and S. Mars (2019). "Ensuring sustainable marine transportation by beneficially using dredged material to support marsh ecosystems in coastal New Jersey" *Proceedings of the Western Dredging Association Dredging Summit & Expo '19*, Chicago, IL, USA, June 4-7, 2019.

Douglas, W.S., Henderson, W., Heeren, J., Minnich, S. and C. Mullan (2020). "Utilization of passive and active mechanical dewatering technologies to process navigational dredged material on a small footprint." *Journal of Dredging*, 18(1) 20-35.

Douglas, W.S., Yepsen, M., and S. Flanigan (2021a). "Beneficial use of dredged material for marsh, dune and beach enhancement in a coastal New Jersey wildlife refuge." *Journal of Dredging*, 19(3) 1-23.

Douglas, W.S., Henderson, W., Marano, M., Koster, O., and S. Flanigan (2021b). "Restoration of historical subaqueous borrow pits for management of navigational dredged material in coastal New Jersey." *Proceedings of the Dredging Summit & Expo '21*, Western Dredging Association, Bonsall, CA.

Douglas, W.S. (2021c). “Incorporation of coarse-grained dredged material into marsh and shoreline restoration projects in coastal New Jersey.” *Shore and Beach* (89(4) 41-51.

Douglas, W.S., Marano, M.J, Lunemann, M, Flanagan, S and Heeren, J. (2022). “Experiences with beneficial use of dredged material in sensitive habitats in coastal New Jersey. USA” P*roceedings of the Western Dredging Association Dredging Summit & Expo ’22*, Houston, TX, USA, July 24-28, 2022.

Farrell, S. (2018). “Dredged material monitoring report for the 2018 dredging of the Beach Creek 1 (NJ Channel #198), North Wildwood, Cape May County, NJ. Final report to Office of Maritime Resources. NJ Department of Transportation, Trenton, NJ.

Heeren, J.D., Wall, J., Douglas, W.S., Minnich, S., and Mullan, C. (2022). “Utilization of a natural and nature-based solution for dredged material management in a navigational dredging project,” *Proceedings of the Western Dredging Association Dredging Summit & Expo ’22, Houston, Tx.*

Howard, B.S., Barone, D.A., and K.K. McKenna (2015). “State channel maintenance capacity: evaluation of dredged holes, final report to the NJDOT Bureau of Research Project No 3013-10 (FHWA NJ-2015-001).” Coastal Research Center, Stockton University, Stockton, NJ. Final report to Office of Maritime Resources. NJ Department of Transportation, Trenton, NJ.

Kreeger D, J Moody, M Katkowski, M Boatright and D Rosencrance. 2015. Marsh Futures: Use of Scientific Survey Tools to Assess Local Salt Marsh Vulnerability and Chart Best Management

Practices and Interventions. Partnership for the Delaware Estuary, Wilmington, DE. PDE Report

No. 15-03.

McKenna, K., Robine, C., Deibert, M., and S. Doganay (2024). “Turbidity, SAV, and benthic organism monitoring at Boot Island and Sunflower Island Atlantic County, New Jersey.” Year 3 report to Office of Maritime Resources, NJDOT Basic Agreement No. Stockton200802, Task Order 10. NJ Department of Transportation, Trenton, NJ.

McKenna, K., Robine, C., Deibert, M., and S. Doganay (2024). “Dredged Hole 18 post construction monitoring.” Final Report to Office of Maritime Resources, NJDOT Basic Agreement No. Stockton200802, Task Order 9. NJ Department of Transportation, Trenton, NJ.

Mengak, L., A.A. Dayer, R. Longenecker, and C.S. Spiegel. 2019. “Guidance and best practices for evaluating and managing human disturbances to migrating shorebirds on coastal lands in the northeastern United States”. U.S. Fish and Wildlife Service, Hadley, MA 109p.

Michael Baker International, 2021. “Lakes Bay Channel (174) and Dredged Hole #86 UAS dredge monitoring report”, Final report to Office of Maritime Resources. NJ Department of Transportation, Trenton, NJ.

Miller, J.K., Rella, A., Williams, A., and E. Sproule (2016). “Living shoreline engineering guidelines, ST-DL-14-9-2942.” Stevens Institute of Technology, Hoboken, NJ, 102p.

Murawski, W.S. (1969). “A Study of Submerged Dredge Holes in New Jersey Estuaries with Respect to Their Fitness as Finfish Habitat.” New Jersey Department of Environmental Protection, Bureau of Marine Fisheries, Trenton, NJ.

The Nature Conservancy and New Jersey Department of Environmental Protection (2021). “Beneficial use of dredged material to enhance salt marsh habitat in New Jersey: Project summary and lessons learned.” NJ Department of Environmental Protection, Trenton, NJ 128p.

United States Army Corps of Engineers. (2019). N*ew Jersey Intracoastal Waterway, Mordecai Island fact sheet*. U.S. Army Corps of Engineers, Philadelphia District, Philadelphia, PA.

Yepsen, M., Moody, J. and E. Schuster, eds (2016). “A Framework for developing monitoring plans for coastal wetland restoration and living shoreline projects in New Jersey.” *A report prepared by the New Jersey Measures and Monitoring Workgroup of the NJ Resilient Coastlines Initiative*. NJ Department of Environmental Protection, Trenton, NJ. 57p.