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Dredging Operations and Environmental Research Program

Development and Testing of the Sediment Distribution Pipe (SDP)

A Pragmatic Tool for Wetland Nourishment

Timothy L. Welp, Brian D. Harris, Brian C. McFall, Zachary J. Tyler,
Colton T. Beardsley, Adrienne M. Eckstein, David W. Perkey,
Matthew R. Henderson, Alexander J. Freddo, Hayden J. Smith, and
Ram K. Mohan

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Abstract

Standard dredging operations during thin layer placement (TLP) projects are labor intensive as crews are necessary to periodically move the outfall location, which can have lasting adverse effects on the marsh surface. In an effort to increase efficiency during TLP, a novel Sediment Distribution Pipe (SDP) system was investigated. This system offers multiple discharge points along the pipeline to increase the sediment distribution while reducing pipeline movements. An SDP Modeling Application (SDPMA) was developed to assist in the design of SDP field applications by quickly assessing the pressure and velocity inside the discharge pipe and approximating the slurry throw distances. An SDP field proof of concept was performed during a two-phase TLP on Sturgeon Island, New Jersey, in 2020. The SDPMA was shown to be an accurate method of predicting performance of the SDP. The SDP was successful at distributing dredge material across the placement site; however, further research is warranted to better quantify performance metrics.

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Preface

This project was prepared for and funded by the US Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory, Dredging Operations and Environmental Research (DOER) program, under AMSCO Code o89500. Dr. Alan Kennedy was the DOER program manager. This study is part of a field-scale pilot investigation to explore improved means and methods of restoring coastal wetlands by thin layer placement of dredged material.

The work was performed by ERDC Coastal and Hydraulics Laboratory's Navigation Division, Coastal Engineering Branch and Field Data Collection and Analysis Branch, and Flood and Storm Protection Division, River and Estuarine Engineering Branch, and by Anchor QEA.

At the time of publication of this ERDC-CHL technical report, Ms. Lauren Dunkin was chief, Coastal Engineering Branch; Mr. Casey Mayne was acting chief, River and Estuarine Engineering Branch; Mr. William Butler was chief, Field Data Collection and Analysis Branch; Ms. Ashley Frey was chief, Navigation Division; Mr. David May was acting chief, Flood and Storm Protection Division; Mr. Charles E. Wiggins, CHL Technical Programs Office, was the ERDC technical director for Navigation. The deputy director of ERDC-CHL was Mr. Keith W. Flowers, and the director was Dr. Ty V. Wamsley.

Anchor QEA, LLC, provided data analysis and document production support under contract to ERDC. The authors express appreciation to Ms. Susan Bailey and Mr. Ben Emery of ERDC for critically reviewing this report and providing constructive comments, which enhanced the value of this report to the practitioner.

The commander of ERDC was COL Christian Patterson, and the director was Dr. David W. Pittman.

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1 Introduction

1.1 Background

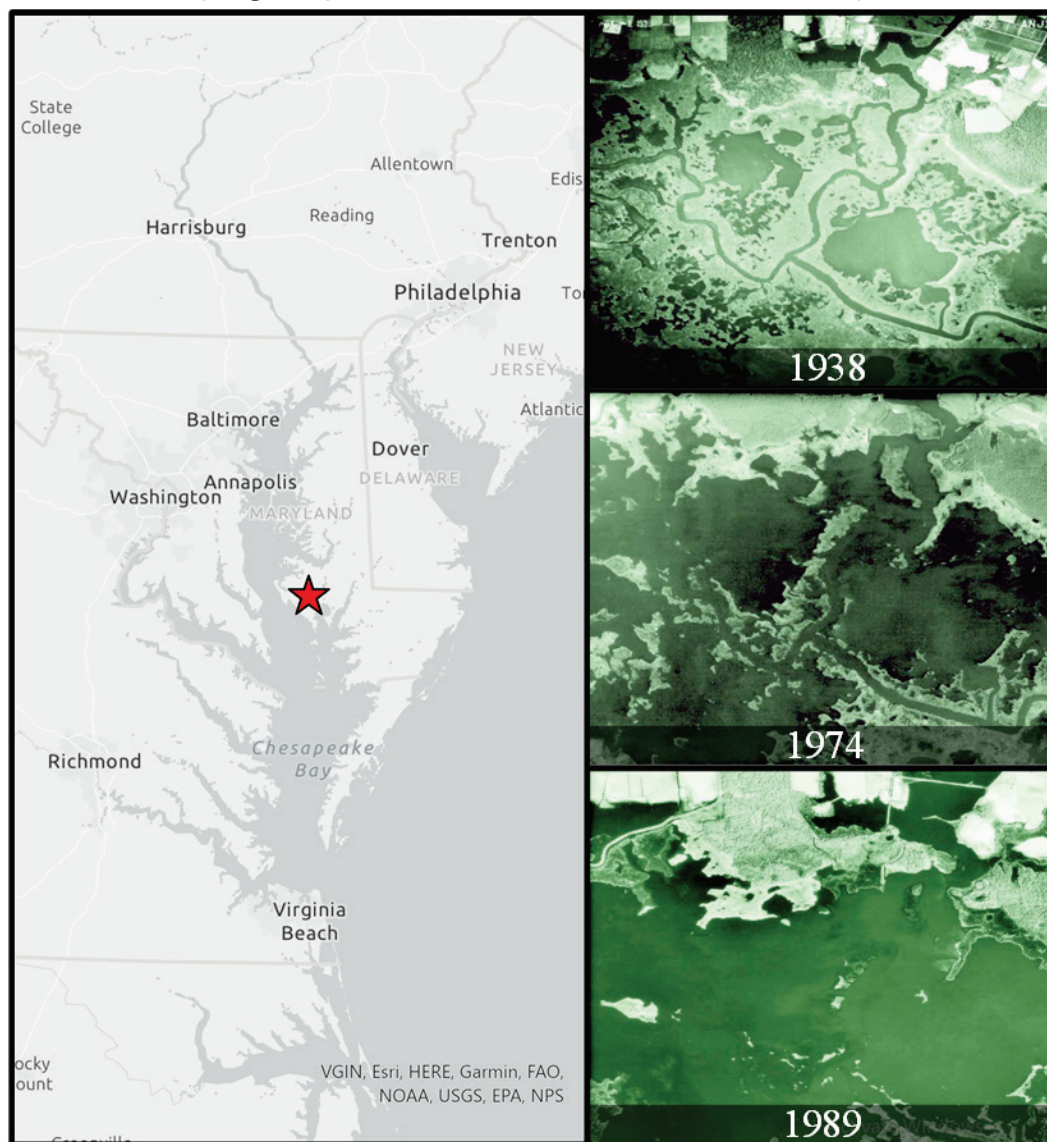
Coastal wetlands provide important ecosystem services such as filtering stormwater drainage back to coastal waters and buffering storm impacts, which provide flood protection; offering areas for recreational activities; and creating critical habitat for diverse ecological interaction (including serving as valuable nurseries for juvenile fish and other marine organisms) (Saleh and Weinstein 2016; Twilley et al. 2016). Partially as a result of the ecological diversity and habitat functions offered by wetlands, it is estimated that United States commercial and recreational fishing supported 1.7 million jobs and generated more than \$72 billion in economic revenue in 2018 (NOAA, “Habitat Conservation,” n.d.). However, coastal wetlands acreage has been shrinking as a result of increased human activity and natural processes. Urban and rural development and alterations of the natural hydrology (e.g., irrigation for agriculture) have led to wetland loss while climate change and erosion also contribute to accelerated wetland loss trends. The US Fish and Wildlife Service (USFWS) estimates in its study *Status and Trends of Wetlands in the Coastal Watersheds of the Conterminous United States* that approximately 59,000 acres/yr¹ of wetlands were lost between 1998 and 2004 (Dahl 2006). This wetlands loss trend increased to greater than 80,000 acres/yr during the 2004 to 2009 period (USEPA 2024).

Coastal wetland restoration is becoming increasingly popular with the noticeable decline in wetland acreage, combined with the effects of coastal shoreline retreat (Figure 1). Three methods for the restoration of Wetlands are as follows (USEPA 2023):

- Restoration: enhancing the marsh platform or other means of repairing the lost functions of a wetland
- Reestablishment: rebuilding a former wetland back to its former footprint
- Creation: strategically building a new wetland in open water

1. For a full list of the spelled-out forms of the units of measure and unit conversions used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office 2016), 248–52 and 345–347, respectively. <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

Figure 1. Wetland loss over time at Blackwater National Wildlife Refuge, Maryland.
(Image adapted from Whitbeck et al. 2016. Public domain.).



Traditionally, wetland restoration has been expensive due to the logistics associated with obtaining suitable material, transporting the material to the wetland site, and placing without causing adverse environmental effects. Since the mid-1980s, the US Army Corps of Engineers (USACE) has promoted beneficial use (BU) of dredged material (DM), which involves productive reuse of DM as a resource to benefit the environment (Walker et al. 2022). Since then, several USACE programs (e.g., Dredging Operations and Environmental Research [DOER], Ecosystem Management and Restoration Research Program, Engineering With Nature® [EWN®], Dredging Operation Technical Support, and Regional Sediment Management) have promoted active BU, including wetland

restoration. Use of DM to restore wetlands offers a cost-effective approach as the USACE is mandated to maintain many coastal waterways given its federal authority to provide coastal navigation, aligned with national security. Likewise, wetland restoration offers a sustainable BU option for the DM, compared to placing it upland in a confined dredged disposal facility or offshore, which completely removes the sediment from the natural system. In doing so, the DM is viewed as a resource instead of a material that needs to be disposed of.

There are many means and methods to beneficially use DM. Thin-layer placement (TLP) is one of those methods, and it is the purposeful placement of sediment or DM in a manner that produces a specific layer thickness or ground surface elevation necessary for achieving the overall project objective. TLP is an ideal means of restoring degraded coastal marsh surface elevations in net depositional areas, where accretion rates are naturally low and when sea level rise is too large, causing a concern for long-term net elevation loss to the marsh (Berkowitz et al. 2017). TLP has traditionally been performed either by spraying slurry directly from a hydraulic dredge or discharging through a long pipeline, which may be open ended, or may have a nozzle or spreader plate attached to further direct or distribute the slurry (Figure 2). It is difficult to achieve desired elevations across the site or in specific locations with these point discharge methods. Further, these traditional methods often include labor-intensive installation of containment structure to ensure that the placed material remains in the desired area without impacts to adjacent habitat.

Figure 2. Standard methods of thin layer placement (TLP): (A) direct spray from a dredge; (B) spray from a pontoon barge or small boat (fed by pipelines); (C) traditional pipeline application. (Image reproduced from Piercy et al., in preparation. Public domain.)²



1.2 Objective

The goal of this study is to document the performance of the sediment distribution pipe (SDP) during a two-phase TLP project on Sturgeon Island, New Jersey, in 2020; to investigate the impact it had on the dredging process and nourished wetland; and to assess the performance of

2. Piercy, C., T. Welp, and R. K. Mohan. *Thin Layer Placement Guidance for Wetlands and Near-Shore Environments*.

a sediment distribution pipe modeling application (SDPMA) tool for predicting behavior of slurry from an SDP.

1.3 Approach

Standard laboratory methods were used to evaluate the grain size characteristics of the sediments obtained from the New Jersey Intracoastal Waterway (NJIWW) prior to dredging. Elevation surveys were performed pre-, during, and post-SDP deployments to monitor elevation gain and throw distances while surficial grab samples were collected to assess sediment distribution capabilities. Multiple SDP configurations were utilized (e.g., elevated off the marsh surface, on the marsh surface, as containment, and discharging off the marsh edge) to assess performance under multiple conditions. Slurry characteristics and flow conditions exiting the SDP were evaluated in a future paper.

2 Review of Thin-Layer Placement (TLP) Equipment

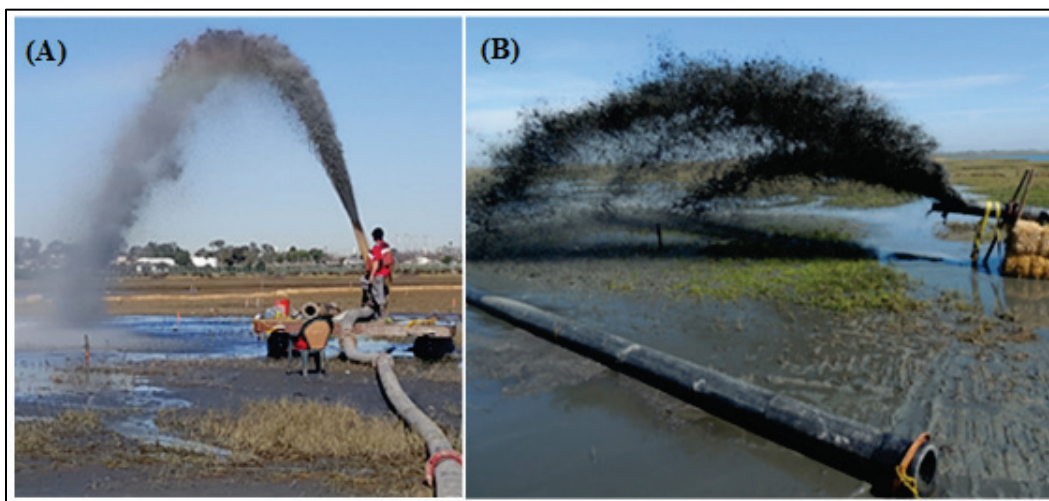
Sediment nourishments have been implemented at various scales across the United States, with most projects implemented at pilot or field demonstration scale (Mohan et al. 2021). The equipment commonly utilized has limited spray or distribution distance, requiring frequent movement of the pipeline to obtain larger coverage across the entire project area. Pipeline access often involves corridors that vary from 50 to 100 ft widths to lay the pipeline and operate them during construction, which requires restoration postconstruction. The outer diameter of the pipeline ranges from 10 in. to 36 in., and due to their size and weight, the pipelines are traditionally moved via marsh buggies or excavators. The more the pipeline moves, the larger the resulting disturbance will be to the native marsh platform and vegetation. This section presents a high-level review of the equipment considerations and lessons learned from select case studies, representing various regional project considerations.

2.1 Seal Beach National Wildlife Refuge (NWR), California

The Seal Beach National Wildlife Refuge (NWR) project used an 8 in. hydraulic dredge (with a 2 in. debris screen) to place approximately 16,900 yd³ of clean DM over the low-marsh area in the refuge. The project owners decided that use of traditional pipeline discharge (from an 8 in. or 12 in. pipeline) would have caused unacceptable surface sediment disturbance on the existing marsh. Therefore, the following high-pressure discharge nozzle designs were developed to spray the material to reduce the impact stress at the placement site for the 8 in. dredge: (1) a 4 in. round nozzle was able to disperse the material, but the impact forces were determined to still be excessive; (2) to further reduce the scour, a deflector (plate) was attached to the upper part of the round nozzle, dispersing the material farther but also reducing the lateral placement distance, which was an unintended effect; (3) a round nozzle with the deflector attached to the bottom portion was tested, which placed materials farther with lower impact force; and (4) an elliptical discharge nozzle was also tested (Figure 3 A), which eliminated the need to use the deflector while providing even distribution of material with less impact force. When dredging was required for hard-packed sands and clays, a larger (12 in.) dredge was used, which increased production as well as slurry solids content (by as much as 10%). This larger dredge pipe was fitted with a spoon system

(Figure 3*B*), which comprised a crescent-shaped (upward deflection) section at the discharge end, increasing the width of placement at the expense of longitudinal distance (when compared to the elliptical nozzle). Sloane et al. (2021) state that use of a booster pump with the larger dredge would have increased the spray distance to between 80 to 100 ft and thus increase overall efficiency. It was determined that the elliptical nozzle outperformed others, as long as the overall dredge production was acceptable. Close monitoring of discharge is recommended to prevent material mounding.

Figure 3. (A) Elliptical-shaped nozzle sediment application at Seal Beach National Wildlife Refuge (NWR) and (B) spoon nozzle sediment application at Seal Beach NWR. (Image reproduced with permission from Sloane et al. 2021.)

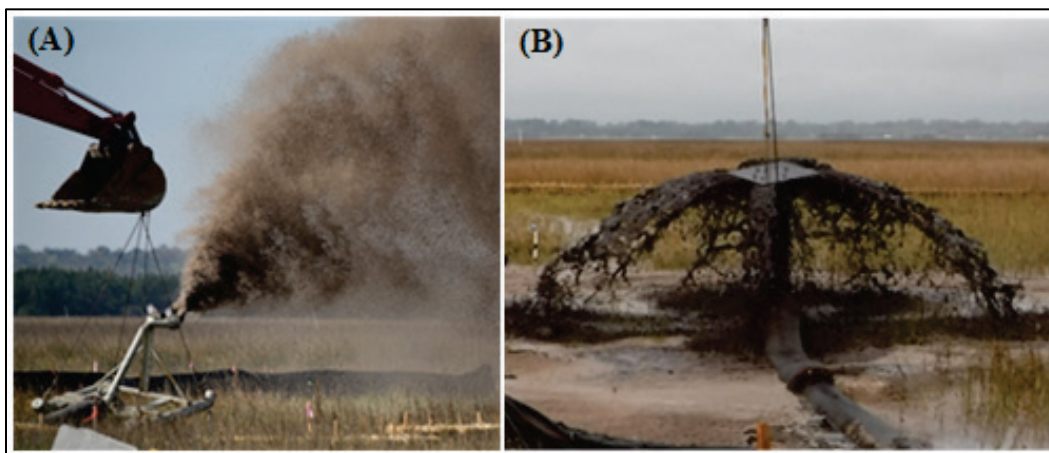


2.2 Brunswick Estuary, Georgia

A unique TLP project to restore and remediate legacy contaminated wetlands was undertaken at a demonstration scale in Brunswick Estuary, Georgia, in 2018 (Mohan et al. 2021). The pilot project was implemented to test thin-layer cover (TLC) placement methodology and performance in advance of future full-scale marsh restoration that is currently ongoing (in 2023). The pilot involved placing 6 in. to 9 in. of material in a two-thirds-acre marsh area. Two material types (i.e., sand and higher organic content fines) were tested. The contractor identified the appropriate equipment, means, and methods to hydraulically convey and place the TLC material within the pilot area in accordance with stated performance objectives. A mat-based access road was installed to enable equipment to move the pipeline and spray nozzle for fine placement control within the pilot marsh area. The TLC placed in the field ranged from 6 in. to 12 in. thick (versus

the design thickness of 6 in. to 9 in.) to meet the minimum required thickness and account for over placement. A 30° to 45° spray yielded the best distribution of materials for the equipment used (Figure 4A). Placement of sandy material was faster and more uniform than fines due to the material's ease of distribution (Figure 4B). A modified topsoil-fines mix with a baffle plate eventually yielded optimal placement of fines within the study area while maintaining the target organic content (Figure 4B). The mat-based access road initially experienced some settlement due to loading on the soft sediments and marsh root mat. The road required restoration following project completion. Physical and vegetative monitoring conducted in 6-month increments over 2 yr indicated strong natural recolonization of vegetation and the reestablishment of benthic species, including fiddler crab (Mohan et al. 2021).

Figure 4. TLP at Brunswick, Georgia: (A) closeup of specialized nozzles for coarse sediments and (B) for finer sediments. (Image reproduced with permission from Sloane et al. 2021.)



2.3 Blackwater NWR, Maryland

The Blackwater NWR, maintained by the USFWS, has been subject to ongoing degradation of its marsh habitat due to a variety of factors, including sea level rise. A 40-acre demonstration project to increase the resiliency (and thus improve habitat quality) of tidal marsh within the refuge was implemented in 2016 (McCullough et al. 2021). A 12 in. cutter suction hydraulic dredge was used, which discharged to an on-ground 6 in. swivel spray nozzle. The contractor used a miniature pontoon excavator (Figure 5A) to reposition the nozzle and discharge, when needed. Tidal creeks were protected by sand wrapped in biodegradable coir mats, and adjacent vegetated marsh was used to filter the effluent from sediment placement operations (laterally, in lieu of containment). DM thickness was

monitored using witness boards (Figure 5*B*), with the upper board set at the maximum permitted elevation, while the lower board was set at the 2-week post-settlement elevation, postplacement. Monitoring during placement indicated that material had flowed approximately 150 ft radially during placement. The pipeline and nozzle were repositioned 300 ft out from the prior location, and once witness boards indicated that the target TLP thickness was achieved at the location, the process continued. Postplacement monitoring indicated that while target elevations were achieved in approximately 80% of the site, the areas were not uniform in thickness. In general, coarser material stacked up at the discharge point, with flatter slopes and finer material toward the periphery.

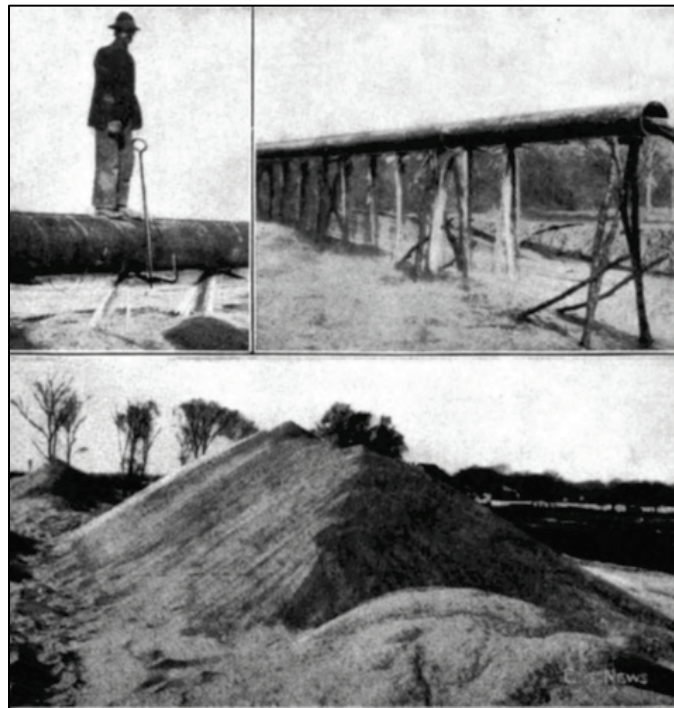
Figure 5. (A) Pontoon excavator relocation equipment and (B) witness boards for tracking TLP elevations. (Image reproduced with permission from McCullough et al. 2021.)



3 Sediment Distribution Pipe History

In the past, coarse-grained DM was used to create levees by using shutter pipe technology (Allen 1914). A shutter pipe consisted of a hydraulic dredge's discharge pipeline that was elevated on a trestle foundation that had openings in the pipe's bottom (invert). This in-line separation methodology was used to build the levees by distributing the sand in a linear configuration. Huston (1986) referred to this technique as a bleeder pipe and noted that this in-line separation technology was often used to build levees (Figure 6). The hydraulic dredge discharge line is laid along the centerline of the proposed levee on elevated *H* or *X* cribbing. Holes varying in size from 2 in. by 2 in. to 6 in. by 6 in. were cut into the underside of the pipe. The operational assumption is that when the dredge is pumping, the larger materials drop out at the holes while the silts and fine particles stay suspended and are carried to the end of the pipeline at the placement site. Historically, this system was used extensively when graded fill materials were required, such as for levees or dams or beach placement. Unfortunately, this placement technique, now known as the SDP, has been poorly documented, and no performance metrics or design guidance exist for its implementation.

Figure 6. Historic representation of a bleeder pipe, often used as an in-line separation technology to build levees. (Image reproduced from Allen 1914. Public domain.)



Because there is a need to develop better restoration construction technologies, the SDP is currently being studied by the DOER program, in conjunction with the EWN[®] program, for use as a more efficient method of sediment dispersion so that larger swaths of areas can be restored without double handling postplacement.

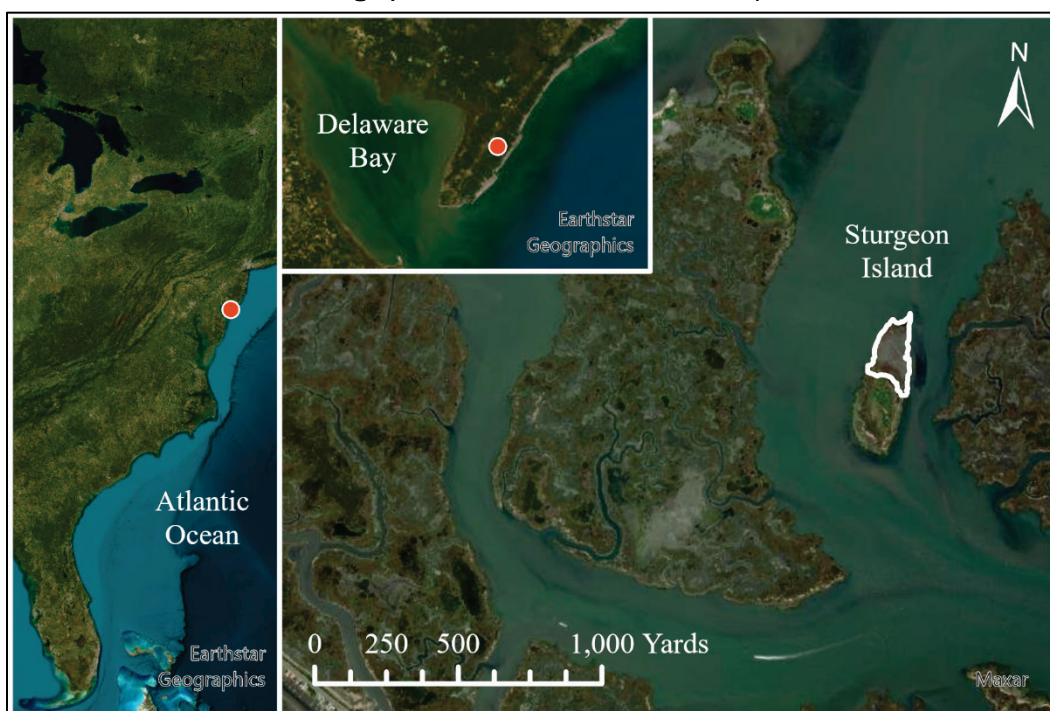
Data from DM placement sites show that sand falls out of suspension by the hydraulic sorting process closer to the pipeline discharge, and as one moves farther away from the discharge point, the DM content becomes finer (USACE 1987; Cherry et al. 2021). This SDP applied research and development project is being conducted to investigate if this physical process can be utilized to provide a significantly improved targeted placement capability (focusing on natural sorting and distribution) to expand the BU of DM.

4 Field Demonstration

4.1 Location

A proof-of-concept field demonstration of the SDP was conducted on Sturgeon Island, New Jersey (Figure 7), to quantify the efficacy to nourish a wetland, demonstrate functionality, and begin quantification of its sediment distribution performance metrics. Sturgeon Island is part of the Seven Mile Island Innovation Laboratory (SMIIL) established by the USACE Philadelphia District (NAP), in conjunction with the State of New Jersey and The Wetlands Institute (TWI), in 2019. SMIIL was set up to evaluate innovative DM management practices and alternatives in coastal New Jersey to advance and improve dredging and marsh restoration techniques through research, collaboration, knowledge sharing, and practical application. The New Jersey coastline from Cape May to Sandy Hook is experiencing an average relative sea level rise of approximately 0.2 in./yr, which is equivalent to a change of 1.7 ft in 100 yr (NOAA, “Tides and Currents,” n.d.). Relative sea level rise accompanied with New Jersey’s increased number of storms along the coast exacerbates the state’s increasing flooding, shoreline retreat, and erosion.

Figure 7. Location of Sturgeon Island, New Jersey. (Images adapted from Earthstar Geographics and Maxar. Public domain.)



Sturgeon Island is a 13.5-acre island adjacent to the NJIWW. The site is owned by TWI and received material from NJIWW dredging operations prior to 1970. The island provides habitat for many colonial nesting bird species, and more than 30% of the wading birds in the state are nesting on Sturgeon Island and adjacent islands. Sturgeon Island was selected for this field study to test new approaches to increasing elevation to preserve and enhance a critical wading bird nesting colony, test innovative DM management approaches, and gain knowledge for future innovative DM placements. The average elevation of the impacted site prior to DM placement was 1.5 ± 0.5 ft North American Vertical Datum of 1988 (NAVD 88).

4.2 Field Study Objective

The Sturgeon Island SDP project's long-term goal is to provide a robust targeted-placement methodology that can accomplish some or all of the following:

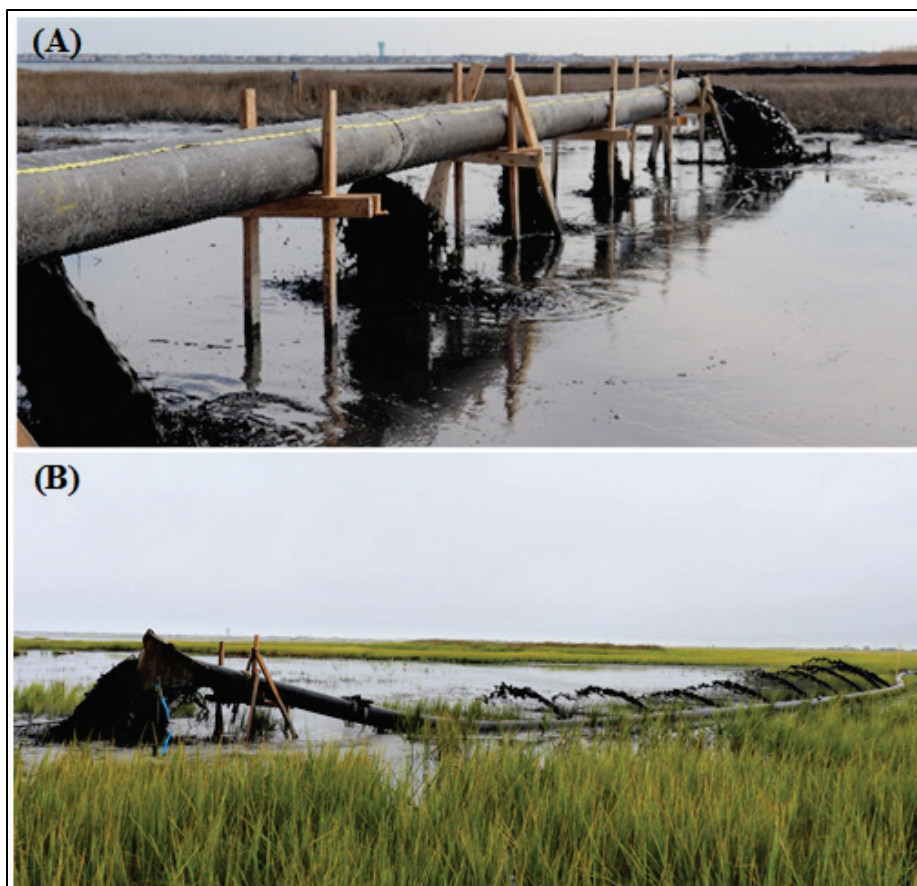
- Distribute sediment more efficiently while dredging.
- Separate sand and coarser fraction from the finer fraction and mud.
- Create a sand berm.
- Reduce the number of pipeline moves in order to minimize the marsh surface disturbance.
- Demonstrate a novel solution to implement TLP effectively.

The data collected during this pilot field campaign will support the development of guidance for this methodology to address the objectives and validate the SDP modeling application for prediction of placement behavior for construction planning (Section 6).

4.3 Basic Configurations of the Sediment Distribution Pipe (SDP)

To expand upon the design of the historic bleeder pipe, the underlying physics has been revisited. The historic method operated under the assumption that the coarser particles in the dredged slurry would be transported along the bottom of the dredge pipe such that they would be deposited to form a sand levee while the finer particles would remain in suspension. To test this theory, the first concept for the new SDP study was to create an elevated section of pipe with 2 in. to 6 in. holes placed along the bottom (Figure 8A) to test under what flow conditions this sorting behavior was detected (Perkey et al. 2024). By using a range of slurry velocities, the presence and efficiency of sediment sorting at varying velocities and associated slurry regimes could be assessed. The second SDP configuration placed the SDP on the marsh surface with holes placed at a 45° angle from the horizontal axis of the pipe (Figure 8B). This configuration focused on measuring throw distance for validation of the SDPMA, and the slurry was discharged on the downhill side of the SDP.

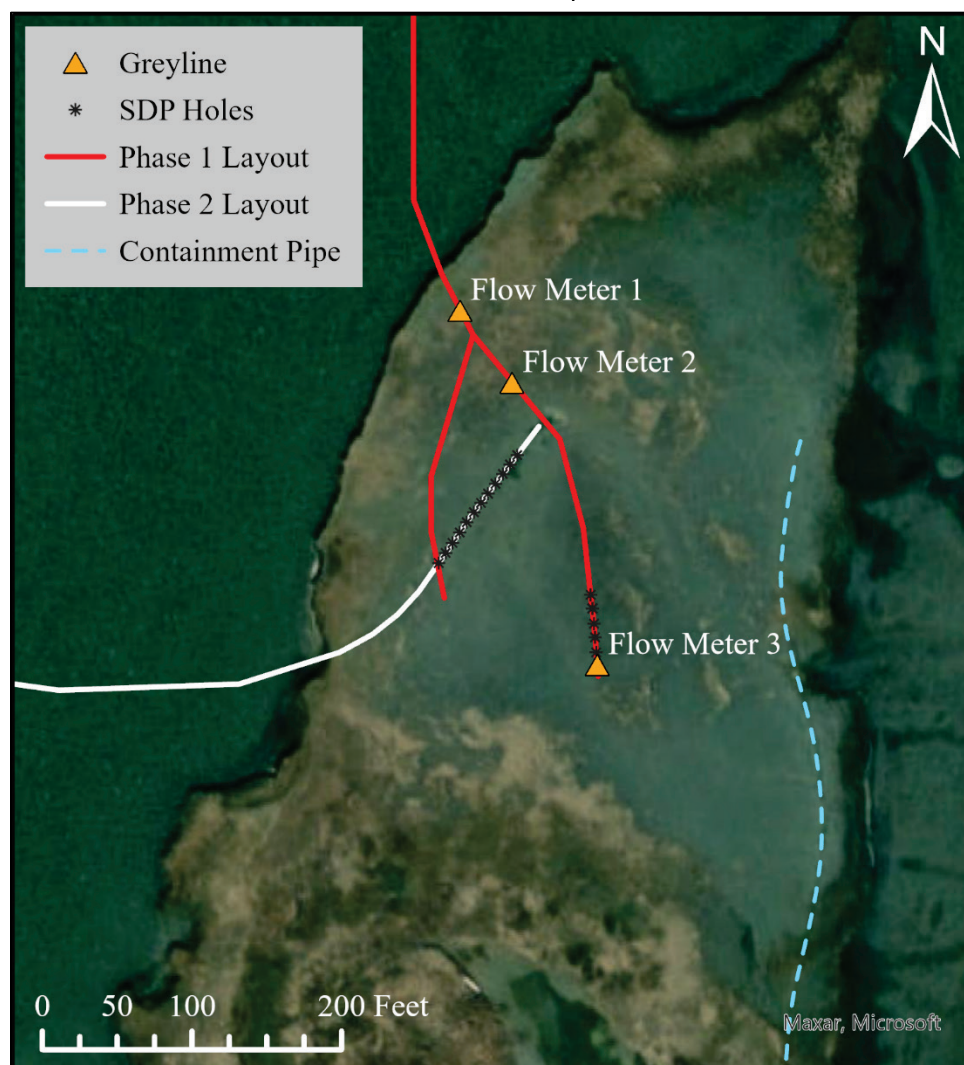
Figure 8. (A) Elevated and (B) ground testing setups of the sediment distribution pipe (SDP) system.



4.4 Study Approach

DM placement at Sturgeon Island occurred during two separate phases, with Phase 1 occurring spring 2020 and Phase 2 occurring in the fall 2020. Three distinct configurations of the SDP were applied over the NJIWW maintenance events and are shown in Figure 9.

Figure 9. Pipe configurations during the Phase 1 (spring) and Phase 2 (fall) dredge maintenance events, hole locations on the SDP, containment, and Greyline velocity measurement locations. (Images adapted from Earthstar Geographics and Maxar. Public domain.)



4.4.1 Phase 1: Spring 2020

During Phase 1, DM placement activities took place from 16 to 19 March 2020. Dredging was performed by the 1,300 hp *FULLERTON*, a cutterhead dredge (owned and operated by Barnegat Bay Dredging

Company) with a 14 in. discharge pipeline. The discharge pipe was positioned on the northern end of Sturgeon Island and equipped with a wye-valve, which directed material through either a branch segment of 12 in. pipe terminating in either a spreader plate or spray nozzle or the branch segment of 12 in. SDP. Figure 10 shows a photograph of the entire discharge pipeline network on Sturgeon Island. Outflow from the dredge was intermittently switched between the discharge line with spreader bar or spray discharge pipe and the discharge line with the SDP segment or flowed through both pipes throughout dredging activities. The SDP consisted of a 70 ft section of pipe toward the end of the eastern branch from the wye-valve. It was elevated 3.6 ft, and five square sorting holes were installed at 10 ft intervals in the bottom of the pipe, as shown in Figure 11. The most upstream (from the end of pipe) hole was designated as hole No. 1, and hole designations increased sequentially. Three square hole sizes were tested (i.e., 2 in. by 2 in., 4 in. by 4 in., and 6 in. by 6 in.) and centered on the 12 in., outside-diameter, high-density polyethylene pipe's invert. The 2 in. holes were tested first and immediately clogged with debris consisting of an assortment of material (e.g., shells, vegetative debris, and trash). The 2 in. holes were enlarged to 4 in. holes and subsequently 6 in. holes oriented to the original hole centers. Post DM placement, the average elevation across the impacted area increased from 1.5 ± 0.5 ft to 2.2 ± 0.5 ft.

Figure 10. Aerial photograph of the Phase 1 SDP configuration (*facing northwest*).

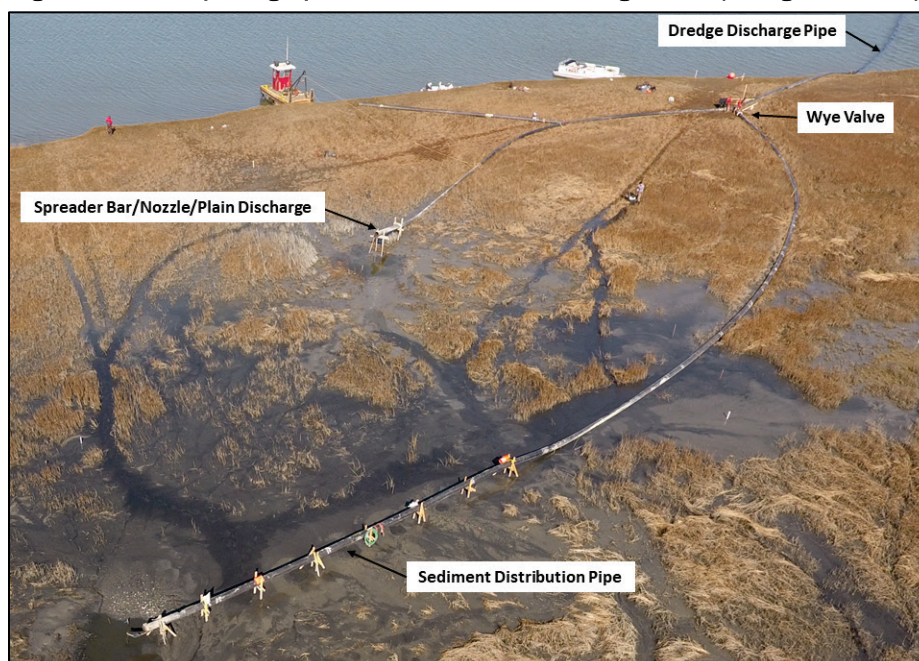
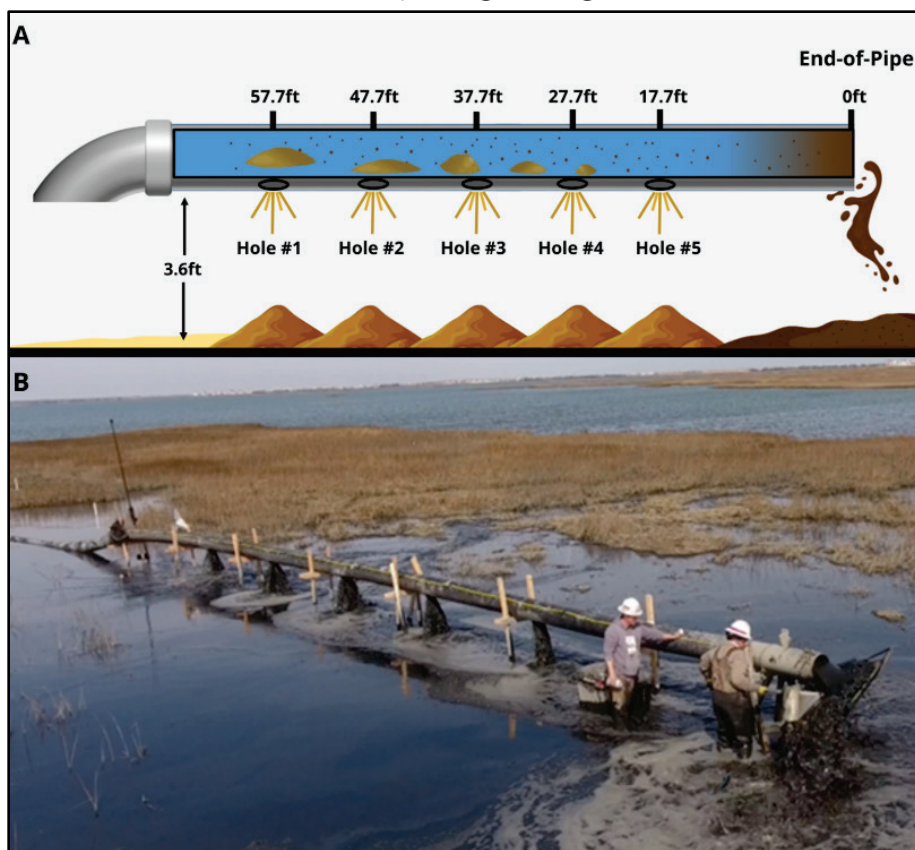


Figure 11. (A) Schematic of the SDP with hole configuration and (B) isometric view of the SDP operating on Sturgeon Island.



4.4.2 Phase 2: Fall 2020

Phase 2 DM placement activities took place from 9 to 30 September 2020. Dredging was performed by the 400 hp *MONTGOMERY*, a cutterhead dredge (owned and operated by Barnegat Bay Dredging Company) with a 12 in. discharge pipeline. The discharge pipeline was positioned directly on the wetland surface along the northern end of Sturgeon Island for 17 days (Figure 9). Holes were iteratively cut into the pipe to create an SDP that allowed material to flow toward the east. Several hole configurations were tested in this pipe layout, with round-hole diameters ranging from 2 in. to 4 in. cut into the pipe to discharge slurry 45° from the horizontal. The smaller holes tended to get blocked with debris (e.g., shells and vegetation debris) and were enlarged to reduce blockage. The final hole configuration consisted of nine 3 in. holes and three 4 in. holes as shown in Table 1. Post DM placement, the average elevation across the impacted area did not increase significantly; however, the standard deviation did decrease from 2.2 ± 0.5 ft to 2.2 ± 0.4 ft.

Table 1. Hole configuration during the fall dredging event.

Hole No.	Distance from End of Pipe (ft)	Hole Diameter (in.)
1	112	3
2	104	3
3	96	3
4	88	3
5	80	3
6	72	3
7	64	3
8	56	3
9	48	3
10	40	4
11	32	4
12	24	4

5 Methodology

A variety of methodologies were employed to monitor pre- and post-sediment placement elevations and sediment characteristics. Due to the different methods for DM placement employed during Phases 1 and 2 of the project, some of the data were collected only during either Phase 1 or 2.

5.1 Topographic Surveys

To monitor wetland surface elevations pre- and post-sediment nourishments, a combination of Real Time Kinematic–Global Positioning System (RTK-GPS) and lidar surveys were used. RTK-GPS surveys were conducted on Sturgeon Island in March 2020 to serve as the preplacement reference.

Two lidar surveys were utilized in this study: plane-mounted and drone-mounted. The plane-mounted survey was performed in July 2020 by the USACE’s Joint Airborne Lidar Bathymetry Technical Center of Expertise and generated topobathy lidar elevations on a 1 m grid spacing with a horizontal and vertical accuracy of 1 m and 0.2 m at a 95% confidence level (OCM Partners 2022). A second lidar survey was conducted by the Natural Hazards Reconnaissance Facility (i.e., commonly known as the RAPID Facility) in July 2021 using a large copter drone that produced a decimated grid spacing of approximately 1 ft.

5.2 Slurry Velocity

During Phase 1, slurry pipeline velocities were measured at two locations on the pipeline discharge network using two Greyline 5.1 noncontacting portable doppler flow meters (PDFMs) (Figure 12). From 16 to 17 March 2020, the Site 1 flow meter was located 20 ft upstream of the wye-valve, and the Site 2 flow meter was located 40 ft downstream of the wye-valve. On 18 March 2020, the Site 1 flow meter was relocated to Site 3 on the elevated SDP, 9 ft upstream of the pipe’s discharge and remained there through 19 March 2020.

Figure 12. Greyline 5.1 noncontacting portable doppler flow meters (PDFM) with ultrasonic sensor clamped to pipeline.



Two slurry velocities were tested and qualitatively described as high production and low production. High production was defined as the case with the maximum operational velocity that the dredge could produce, and low production was defined as the case with the slowest velocity that the dredge leverman felt comfortable would not clog the discharge pipe.

During Phase 2, slurry pipeline velocities were measured using two Greyline 5.1 noncontacting PDFMs. The velocity was not intentionally altered during the second phase, and the contractor dredged at full production velocity. From 9 to 14 September 2020, Flow Meter 1 was located 10 ft upstream of the end of pipe, and Flow Meter 2 was 2 ft downstream of the reducer. On 15 September 2020, Flow Meter 2 remained 2 ft downstream of the reducer, and Flow Meter 1 was moved to each of the hole locations for a period of time (e.g., 24 ft from end of pipe [EOP], 32 ft from EOP, to measure the velocity between holes. No flow meters were installed from 17 to 21 September 2020.

5.3 Throw Distances

To evaluate how far the slurry discharges away from the SDP (i.e., throw distance), the minimum and maximum distances of the impact areas from the SDP were measured, and the average of those values was calculated for comparison to the modeling application (Section 6).

5.4 Sediment Sampling

Sediment cores were collected within the NJIWW and placement areas to determine the geotechnical characteristics. Within the channel, a combination of 6 in. inner-diameter (i.d.) cores down to approximately 3.3 ft depth and 2 in. i.d., cores down to 1.6 ft depth were collected with PVC core liners during the March 2020 field investigation. Sediment samples were used to determine grain size distribution using a laser diffraction particle size analyzer (Beckman Coulter LS 13 320).

During Phase 1, shear vane measurements were taken with a Humboldt H-4227 shear vane to indicate the undrained shear stress of sediment placed in the immediate vicinity of the SDP.

During Phase 2, terrestrial core sediment samples were collected along four transects moving away from the pipeline. During a July 2021 field investigation, a Russian peat borer was used to determine the depth of dredged sediment into the underlying native marsh material. Upon sampling, the DM was distinguished from native marsh based on the darker color of the soft DM and vegetative roots in the native marsh surface. The depths of the DM within the cores were measured and the samples collected for laboratory analysis based on classification and color observed in the field. Grain size distribution of the sediment samples was determined using a laser diffraction particle size analyzer (Beckman Coulter LS 13 320).

6 Sediment Distribution Pipe Modeling Application (SDPMA)

6.1 Model Introduction

Tools are required to assist planning SDP operations to prevent uneven sediment distribution, which would then require manual redistribution or, at worst, sediment buildup in the pipe that significantly reduces effectiveness. Users require a means by which to generate predictions of the system behavior prior to implementation in a way that is accurate and quick. The ability to rapidly generate these predictions allows for more design iterations before field implementation and potential design changes based upon field observations. In the latter case, these predictions allow users to alter the design and mitigate the risk of system failure or improve system performance through the parametric study of alternative designs.

To meet this need, a Python-based modeling application has been developed to give engineers rapid predictions of the SDP behavior. The SDPMA is a novel application that allows users to design an SDP with an interactive graphical user interface and generate predictions for the slurry's behavior. A number of models are already incorporated into the application; however, in its current form, it largely serves as a proof of concept, and more robust modeling will be used for more accurate predictions in future plans. The current model uses mass continuity and momentum continuity to calculate solutions to the one-dimensional pipe flow with the influence of cut holes and pipe friction being considered. Holes are modeled as a loss of stagnation pressure and mass flow through the pipe, with pipe friction reducing stagnation pressure along the length. This application also provides estimates for the ejection distances of the slurry jet from the cut holes, which can give users indications of the final placement of the sediment or serve as a qualitative way to validate the prediction results based upon field observations. Modeling coefficients can be changed, as well as numerical solution parameters, to generate more accurate predictions.

This section will detail the SDPMA and serve as an introduction to ongoing methods that will help improve future SDP field deployment and successful restoration of wetlands.

6.2 Modeling Methods

The SDPMA computational model is implemented in Python as a one-dimensional algorithm to iteratively solve pipe flow based on user specifications.

6.2.1 Pipe Friction

Solving for the internal pipe flow pressure and velocity requires modeling the loss in stagnation pressure due to shear friction along the pipe length. This friction is modeled along pipe sections between holes using the Darcy-Weisbach equation, which describes the pressure loss due to friction as linearly related to the product of the dynamic pressure and length-to-diameter ratio of the pipe through a coefficient known as the Darcy friction factor (De Nevers 1970). The application gives users the options of neglecting frictional effects, specifying the Darcy friction factor directly, or performing a calculation of this factor through the numerical solution of the implicit Colebrook-White equation, which is provided in Equation 1 (Keady 1998):

$$f_d^{\frac{1}{2}} = -2 \log_2 \left(\frac{\epsilon}{3.7D} + \frac{2.51}{Re} f_d^{\frac{1}{2}} \right), \quad (1)$$

where

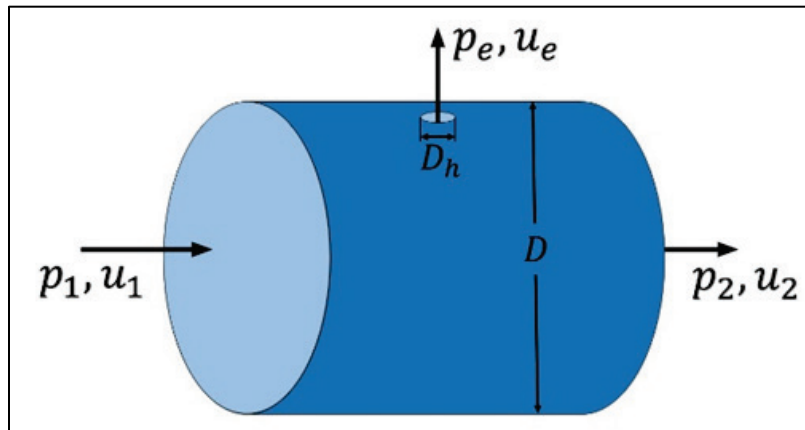
- f_d = Darcy friction factor,
- ϵ = characteristic pipe roughness height,
- D = pipe i.d., and
- Re = diameter-based Reynolds number.

This equation expresses the desired friction factor implicitly, thus requiring a numerical solution to the equation to solve for the desired value. For this simple analytic equation, the derivative of the equation is directly found with respect to the Darcy friction factor, which allows the use of a Newtonian root-finding method, which is easily implemented and converges quickly and reliably. The parameters pertaining to this method, such as the stopping tolerance, can be specified by the user in an Advanced Control pop-up submenu of the interface.

6.2.2 Hole Influence

The influence of a hole cut into the pipe is among the more complicated and important phenomena in the SDP system. In the current iteration of this application, this feature is simplified to a loss in mass flow to the interior pipe flow and a loss of stagnation pressure within the pipe (Figure 13). The principle of a constant stagnation pressure for nonviscous flows is used to express the exit velocity of the slurry jet. Because the flows being modeled are likely heavily influenced by viscous effects, a discharge coefficient (ξ) is introduced. This coefficient is the ratio of the resulting velocity to that of an ideal flow model. The resulting expression for the exit velocity through the hole (u_e) is provided in Equation 2 as a function of the discharge coefficient, the upstream pressure in the pipe (p_1), the upstream velocity in the pipe (u_1), and the fluid density (ρ).

Figure 13. Diagram of a representative control volume considered when determining the influence of a hole cut into the pipe (Beardsley et al. 2022; Image reproduced with permission from the Western Dredging Association.)



$$u_e = \xi \sqrt{u_1^2 + \frac{2p_1}{\rho}}, \quad (2)$$

where

- u_e = exit velocity through the hole,
- ξ = discharge coefficient,
- p_1 = upstream pressure in the pipe,
- u_1 = upstream velocity in the pipe, and
- ρ = fluid density.

To solve for the pressure downstream of the hole, a general formulation for the resistance imposed on a body in a free-stream flow is used. This principle states that the resistance force applied is directly proportional to the dynamic pressure of the fluid and a characteristic area of the body via a resistance coefficient. For this case, the characteristic area is chosen as the area of the cut hole. This force is applied by the hole to the fluid, with the assumption that it is distributed over the cross-section area of the pipe. This provides the pressure drop due to the viscous losses in the flow around the cut hole. There is also a pressure change due to the flow slowing within the pipe. These contributions can be summed to express the pressure downstream of the cut hole, which is provided in Equation 3.

$$p_2 = p_1 + \frac{1}{2}\rho(u_1^2 - u_2^2) - \frac{\kappa}{2}\rho u_1^2 \left(\frac{D_h}{D}\right)^2, \quad (3)$$

where

- p_2 = downstream pressure in the pipe,
- u_2 = downstream velocity in the pipe,
- κ = resistance coefficient, and
- D_h = diameter of the cut hole.

The users are, therefore, able to solve for the downstream conditions in terms of upstream conditions, pipe geometry, fluid density, and some modeling coefficients, namely, the discharge coefficient and the hole resistance coefficient.

6.2.3 Pipe Flow Solution Procedures

To facilitate a variety of modeling circumstances, three methods of inflow and outflow specifications are available to the users through this application. Most simply, the user can specify the inflow pressure and velocity at the upstream end of the SDP. This method allows for direct calculation of friction losses and hole influence sequentially along the length of the pipe to solve for the pressure and velocity of the pipe flow throughout its entire length.

For most practical uses of the SDP, the upstream pipe velocity is not explicitly known by the user without some measurement being taken. Alternatively, users are more often aware of the upstream pressure because this is often a performance metric of the dredge pump, as well as

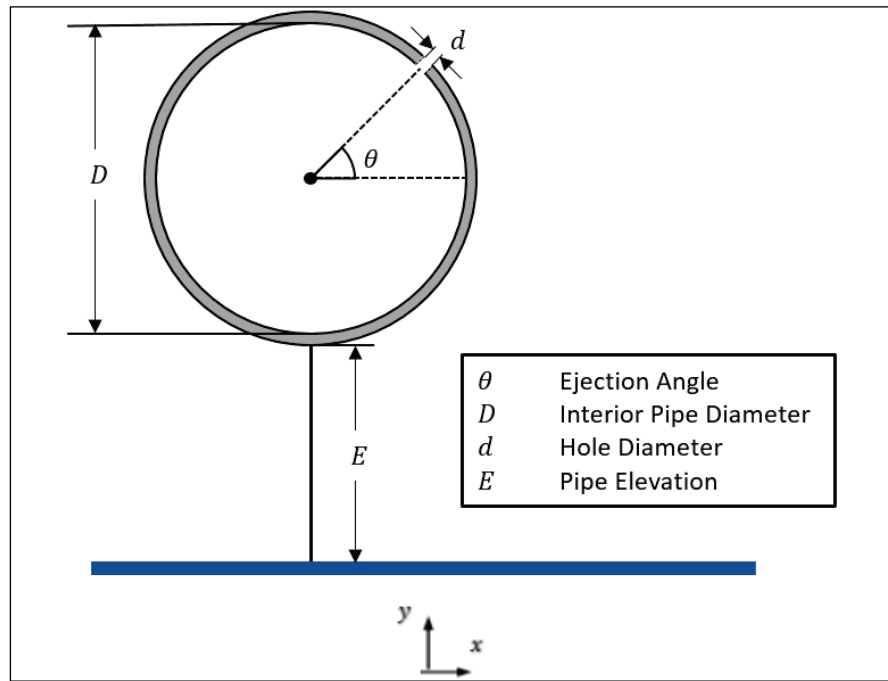
the pressure at the downstream end of the pipe, as this is often just atmospheric pressure due to this end being open to discharge the remaining DM in the pipe. Because the method described previously requires the upstream conditions to determine the downstream conditions, means are required to satisfy the pressure conditions at each end of the pipe by choosing the correct velocity in the pipe at the upstream end. To do this, an iterative process is used where the inflow velocity is guessed by the user and the solution is calculated through the pipe. Then, by comparing the resulting calculated exit pressure with the user-specified exit pressure, the guess is updated for the inlet velocity. Repeating this iteratively, a root-finding method is employed for the pressure residual at the downstream end as a function of the inlet slurry velocity. As an updating method, a secant method is used, which allows for fast and reliable convergence of the solution.

Finally, the previous method may be employed with the difference that the user specifies the inlet and exit velocities, where the downstream velocity residual is solved for with a secant root-finding method as a function of the upstream pressure. Note that this method may not be very useful in many practical use cases but may be helpful in later validation cases depending on the availability of empirical flow data within the pipe.

6.2.4 Throw Distance Prediction

The final feature of the application is the ability to predict the throw distance for the slurry jets as they eject from the holes cut into the pipe (Figure 14). There are several reasons that this information is of potential use to users. For high internal pressures, throw distances may be fairly long, and the user must be able to have some prediction of this length to accurately anticipate the location of sediment placement. Another potential use is as a means of validating the model in the field after cutting only a few holes in the pipe. The modeling parameters may be changed to reflect test cases more closely before extrapolating the model to a distribution system with more holes with the intention of improving the predictive capability.

Figure 14. Diagram of the elevated pipe above the wetlands from the perspective of the downstream end.



The throw distance is calculated simply by modeling the fluid jet as a projectile under the influence of air drag that is proportional to the square of the velocity magnitude and acting in a direction opposing the velocity vector. The resulting differential equations that describe this motion are nonlinear ordinary differential equations and are provided in Equation 4 and Equation 5 utilizing drag coefficient (C_d), air density (ρ_a), and density of the slurry mixture (ρ_l). The dot accent above directional variables refers to the time derivative of that variable.

$$\ddot{x} = -C_d \frac{\rho_a}{2D_h \rho_l} \dot{x} \sqrt{\dot{x}^2 + \dot{y}^2}, \quad (4)$$

$$\ddot{y} = -C_d \frac{\rho_a}{2D_h \rho_l} \dot{y} \sqrt{\dot{x}^2 + \dot{y}^2} - g, \quad (5)$$

where

$\ddot{x}$ = second derivative with respect to time of the horizontal distance (horizontal acceleration),

C_d = drag coefficient,

ρ_a = air density,

ρ_l = slurry mixture density,

- $\dot{x}$ = first derivative with respect to time of the horizontal distance (horizontal velocity),
- $\dot{y}$ = first derivative with respect to time of the vertical distance (vertical velocity), and
- $\ddot{y}$ = second derivative with respect to time of the vertical distance (vertical acceleration).

Equation 4 and Equation 5, which are second-order equations, can be broken into a set of four, first-order equations. This allows for numerical integration with respect to time. An Adams-Bashforth method of time integration would be chosen because it is an explicit integration method and can be implemented easily while also retaining an order of accuracy of two with respect to the time-step (Peinado et al. 2010). This time integrator is a type of linear multistep algorithm. The time-step size is another parameter that the user can control through the Advanced Controls menu. The stopping condition for the integration is the y -value reaching a negative value. The x -value at this final time is taken as the throw distance measured from the pipe center.

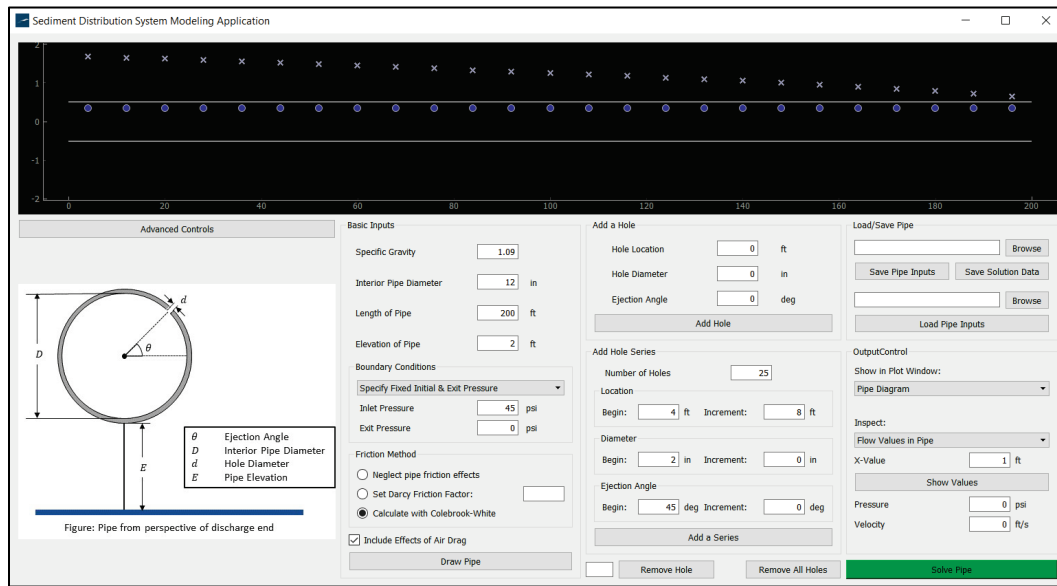
As of the current implementation, there is no recommendation for appropriate values for the modeling constants of ξ , C_d , and κ . These values must be calibrated by additional field tests, physical modeling, and computational experimentation. The calibrated values for these constants determined in the field application of this report may provide a first order approximation for future projects until additional guidance is provided. Future research will include more robust experimental and computational studies that will yield insight to the formulations given here and the values of modeling coefficients (Beardsley et al. 2022).

6.3 Modeling Application Overview

The application is designed to allow users to generate an arbitrary pipe design within the interface, specify necessary inputs, and calculate a prediction of flow through the pipe and throw distance through each of the holes. A diagram is included in the interface so users can reference input parameters and ensure consistent definition of input variables. The interface also contains a graphics window that will update as the user designs their pipe, modifies a design, generates a solution, or alters the output control settings. The application features can be grouped into four

main categories: (1) basic inputs; (2) hole placement; (3) solution and output control; and (4) a file storage method (Figure 15).

Figure 15. User interface for the sediment distribution pipe modeling application (SDPMA) (Beardsley et al. 2022; Image reproduced with permission from the Western Dredging Association.)



The user begins by specifying the basic inputs pertaining to their pipe design, along with several modeling options available. In addition to these basic inputs, the user may specify more numerical and model controls through an Advance Controls pop-up menu. The user then places their holes using the dedicated modules, with the options to place a single hole at a time, or to place a series of holes that vary incrementally in size, distance, or angular position along the cross section. Having done this, the user has now specified every input necessary to define their pipe design, geometry, and flow conditions. A representation of the pipe and holes are updated continually in the graphics window.

The user then must select the Solve Pipe button to generate a solution. This will update the graphics window containing the pipe diagram to include positions of the sediment placement for each hole. The user can also choose to replace this pipe diagram with a plot of the pressure or velocity as a function of the length along the pipe. The user can finally then save the setup of their problem to a comma-separated values (CSV) file, which can be read in and modified later, and the user can also save the solution data along the pipe in CSV file format for plotting or manipulating in another program of their choice. Another use for these setup files is for

the rapid generation of a pipe design using another code or program with the ability to load in and solve the pipe with SDPMA.

6.4 Modeling Application Conclusion

The SDPMA is a novel application that shows the potential for a rapid prediction tool for modeling SDPs. These systems allow substantial reductions to operation costs for several different dredging operations including wetland nourishment. The development of such an application is necessary for designing systems with minimal risk of system failure and anticipating the effects of adjustments made to designs in the field. The current state of the system is limited in that its models are not validated, the modeling coefficients are not calibrated, and it does not consider certain aspects of the system such as dredge pump performance characteristics, sediment deposition within the pipe, and air-water interfaces within the pipe flow. Despite these limitations, initial feedback from users has indicated that this is a helpful and easy-to-use tool with the potential to improve dredge placement operation and lower operation costs.

There are many potential areas of improvement upon the current application. The most notable is the need for validation of current models. Moving forward, additional empirical data will be collected, and computational fluid dynamics simulations will be used to further improve the models and understand the flow through the SDP more thoroughly. The modeling improvements must also include the consideration of sediment properties, as well as scour and deposition within the pipe, to accurately model the system. Another point of modeling improvement is in the ability to model pipe flows with the pipe not being entirely filled with the slurry mixture, which is often the case in SDP systems as noticed by field engineers.

7 Results and Discussion

This section describes the results of the field data collection. The characteristics of the slurry for each dredging event are presented, as well as the thickness and characteristics of the DM. The variation of the slurry velocity, density, composition along the distribution pipe, and resulting topography were also analyzed.

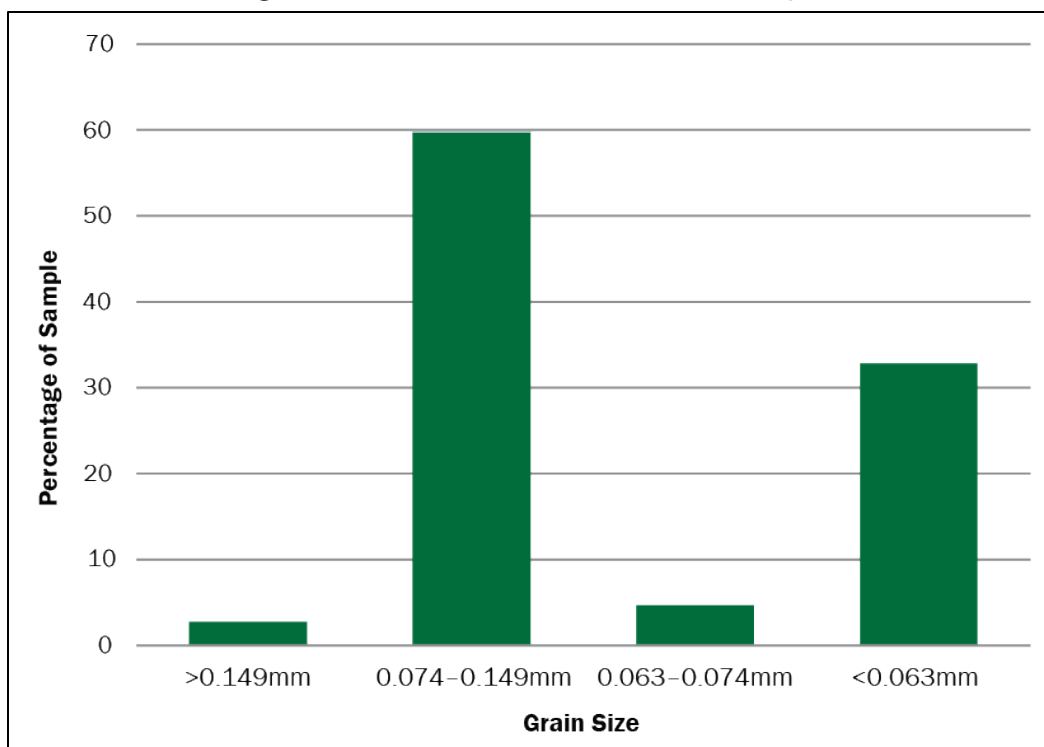
7.1 Slurry Composition

NAP and US Army Engineer Research and Development Center (ERDC) collected NJIWW sediment samples on 3 March 2020. These samples were used to determine which in situ material possessed high sand content that could be dredged to test the feasibility of the SDP to nourish Sturgeon Island.

According to the Unified System of Soil Classification, soils are considered fine-grained (referred to as fines) if 50% or more pass through the No. 200 ASTM sieve. For this analysis, particles less than 0.075 mm were considered fines, and particles greater than 0.075 mm were considered coarse. In total, 15 samples were collected from the NJIWW and had an average fines content of 53.8%.

During the spring 2020 placement, the majority of material was dredged in the vicinity of sample core S-5, for which a grain size distribution is shown in Figure 16. This channel section was chosen because it balanced a shorter pipeline distance with a high-sand concentration and shows a potential bimodal distribution of fines and fine sands. The D_{50} for the sample is 0.088 mm.

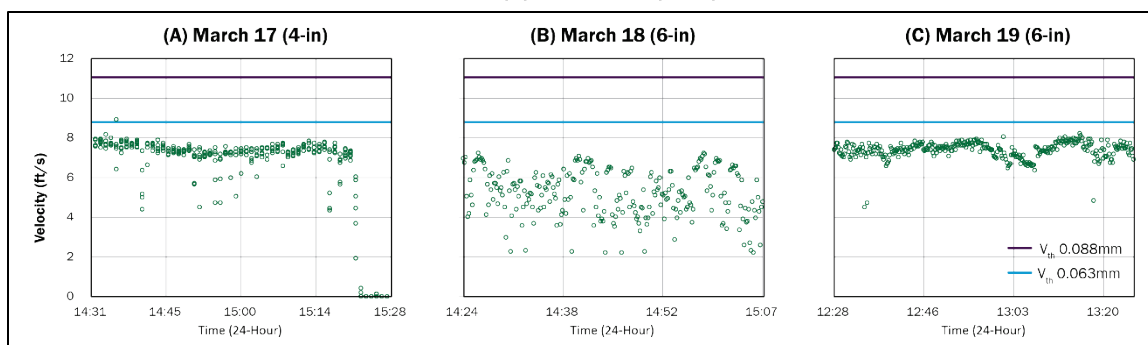
Figure 16. Grain size distribution of S-5 core sample.



7.1.1 Phase 1: Spring 2020

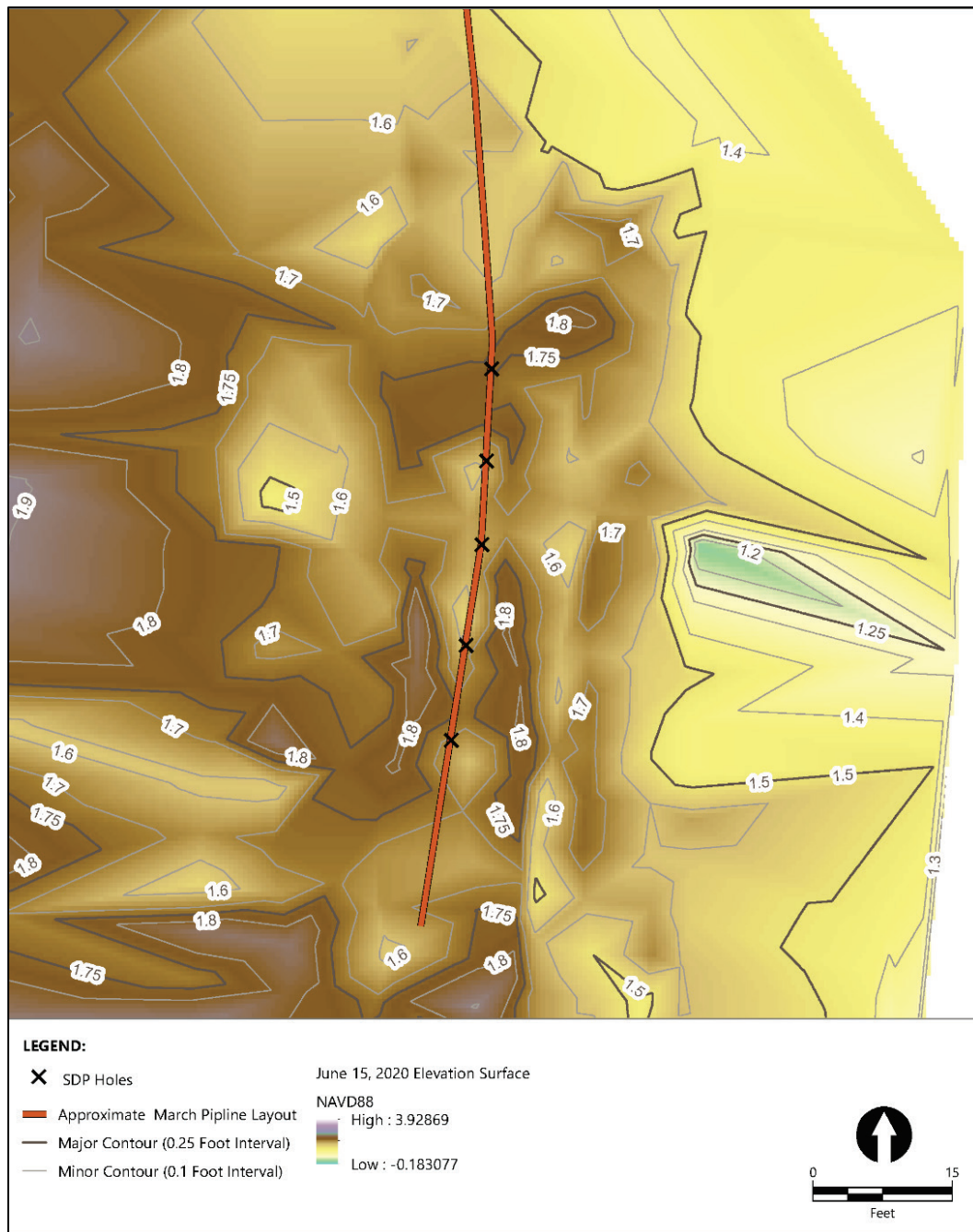
The Phase 1 placement included a wye-valve configuration with an elevated SDP with five holes. A subsample of the slurry velocity measurements taken during the Phase 1 dredging event is shown in Figure 17. Because the grain size distribution for the in situ sediment is bimodal, the slurry regime analysis was conducted with respect to each of the main constituent grain sizes (the lower limit tested for 0.063 mm and 0.088 mm). For the fine and coarse components of the flow, the flow regime is expected to transition from heterogeneous to pseudohomogeneous at 8.8 ft/s and 11.1 ft/s for 0.063 mm and 0.088 mm, respectively. During the sampling events, the velocity remains within the heterogeneous regime for both grain sizes.

Figure 17. Phase 1 Slurry velocity measurements: (A) March 17 (4 in.), (B) March 18 (6 in.), and (C) March 19 (6 in.)



The SDP appeared to form a low-relief levee structure, which was somewhat offset to the longitudinal axis of the SDP. The offset may be due to net transport of the DM occurring from west to east across the site, with sand particles depositing to form the berm while finer particles remained in suspension. Visual observations of the discharge from the western segment of the pipeline diverted at the wye-valve showed that the discharge (both spreader plate and spray nozzle) flowing from west to east was diverted north and south of the levee structure formed by the SDP. Unfortunately, the levee feature does not show on the 15 June 2020 postdredge topographic survey (Figure 18); however, this may be due to the spacing of the survey points. In future studies, a denser survey is recommended to more accurately establish the formation of features generated during DM placement.

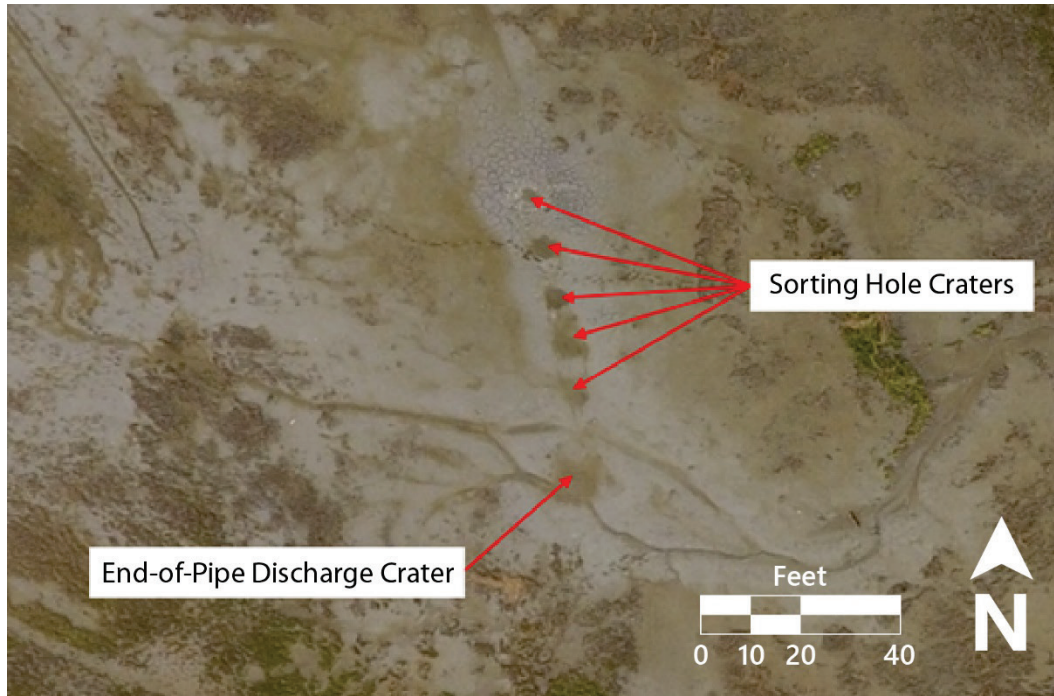
Figure 18. After-dredge topographic survey (in feet) of placed sediment in near vicinity of the SDP.



Directly below the holes placed in the SDP, scour holes were formed due to high-energy discharge causing erosion of the marsh. Coarse particles were observed to be deposited immediately adjacent to the holes due to the reduction in slurry velocity post impact with the wetland. This deposition pattern can be seen in the aerial photograph in Figure 19 that was collected on 3 May 2020. During future uses, diffusion plates could

be considered below the SDP to redirect the high-energy discharge and avoid scouring the marsh.

Figure 19. After-dredge photograph of a drone overflight collected 3 May 2020, showing crater-shaped deposition patterns of sandier sediment around locations where slurry initially contacts wetland.



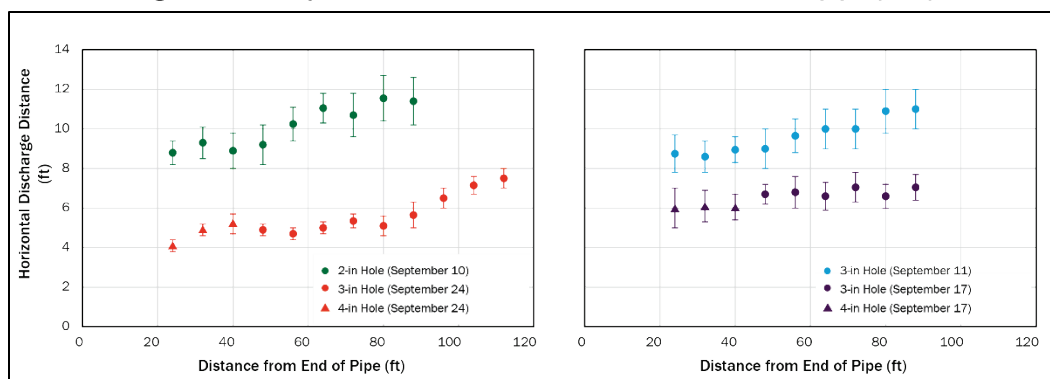
7.1.2 Phase 2: September 2020

The Phase 2 placement included application of the SDP directly on the marsh surface with 12 holes at a 45° angle upwards from the horizontal axis (Figure 23A).

7.1.2.1 Throw Distances

To understand the slurry throw distance, the throw distance was measured with different hole sizes (Table 1). The mean velocity varied slightly during each test, but it was approximately 11 ft/s, which is approximately the transition velocity for 0.088 mm sand from heterogeneous to pseudohomogeneous. The measured slurry throw distances for the different hole configurations are shown in Figure 20.

Figure 20. Slurry throw distance versus distance from end of pipe (EOP).



The throw distance slightly decreased farther downstream due to a loss of energy at each hole in the SDP; however, throw distances leveled for the last 40 ft to 50 ft. The 2 in. hole configuration and 3 in. hole configuration performed similarly with the farthest throw distance. This may be due to higher exit velocities generated by constricting flow through relatively smaller holes than the 4 in. hole cases. The minimum, maximum, and average throw distance for the 2 in. and 3 in. hole configuration was 8.6 ft, 11.6 ft, and 9.8 ft, respectively. The minimum, maximum, and average throw distance for the combination of 3 in. and 4 in. hole configuration was 4.1 ft, 7.5 ft, and 5.9 ft, respectively. Further studies could be conducted to determine the direct relationship between the design of the holes and their correlating throw distances, or the throw distances for varying configurations can be rapidly approximated with the SDPMA.

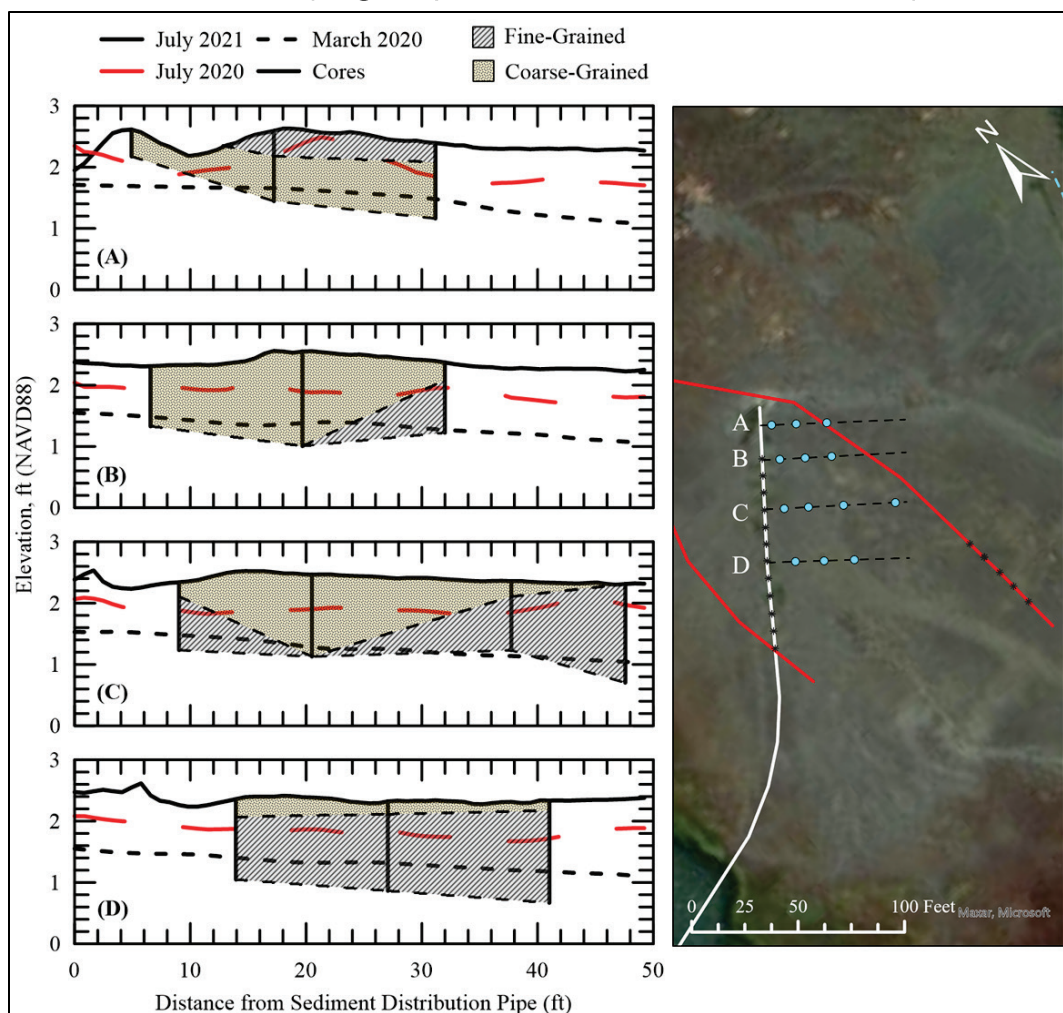
7.1.2.2 Sediment Distribution

The available sediment data for the Phase 2 dredging event were collected in July 2021, which included sediment from both Phases 1 and 2 dredging activities. Deposited sediment from the phases were indistinguishable from each other. The percentage of fines (particles with grain size $\leq 75 \mu\text{m}$) and sands (particles with grain size $> 75 \mu\text{m}$) were determined with depth from the core samples collected in July 2021, within the vicinity of the SDP.

Figure 21 shows the sediment composition of the surface samples decreases in sand concentration along the downstream direction of the SDP, as well as moving away from the pipe. This suggests that the sands may have been discharged in higher concentrations at the upstream holes and that the sands were being deposited in the marsh closer to the pipe than the fines which remained in suspension and were carried farther from the SDP as the slurry was transported from west to east.

To investigate these results in the context of the two dredging events, Figure 21 highlights four transects of wetland surface elevation at varying times (i.e., March 2020, preplacement; July 2020, in between placements; and July 2021, postplacement), as well as the depth and sediment type from the core samples. For readability, sediment type of a sample is shown as fines if more than half of the particles are fines, and the sediment type is shown as coarse if more than half of the particles are coarse. As evident from Figure 21, elevation gain was measured in the areas nourished by the SDP. Localized indentions in the wetland surface were noted 6 ft to 10 ft from the SDP, which corresponded to the measured throw distances from the SDP. On Transect A, a 0.5 ft sand lens was measured 5 ft from the outfall, but farther from the SDP, the sand was overlain by fine-grained sediment. This differed from the other transects and was most likely attributed to this transect being closer to the EOP than the holed section of the SDP. A 1 ft thick sand layer was recorded across Transect B from 6 ft to 20 ft away from the SDP and decreased to a thickness of 0.3 ft at 32 ft from the SDP. Transect C was nearly in the center of the SDP holes and exhibited the most pronounced sand bulb with a thinner 0.3 ft layer of sand at 9 ft that increased to a maximum thickness of 0.5 ft at 21 ft but then decreased back to 0.3 ft at 38 ft before transitioning to all fine-grained material at 48 ft. Last, Transect D exhibited the lowest amount of coarse-grained material compared to the other transects with a maximum thickness of 0.3 ft at 14 ft that stayed relatively consistent as distance from the SDP increased. It is possible the coarse-grained layer may be thicker closer to the SDP outfall (i.e., EOP), but a closer core was not collected.

Figure 21. Transects of sediment type and elevation profiles moving downstream of the SDP outfall. (Image adapted from Maxar Microsoft. Public domain.)



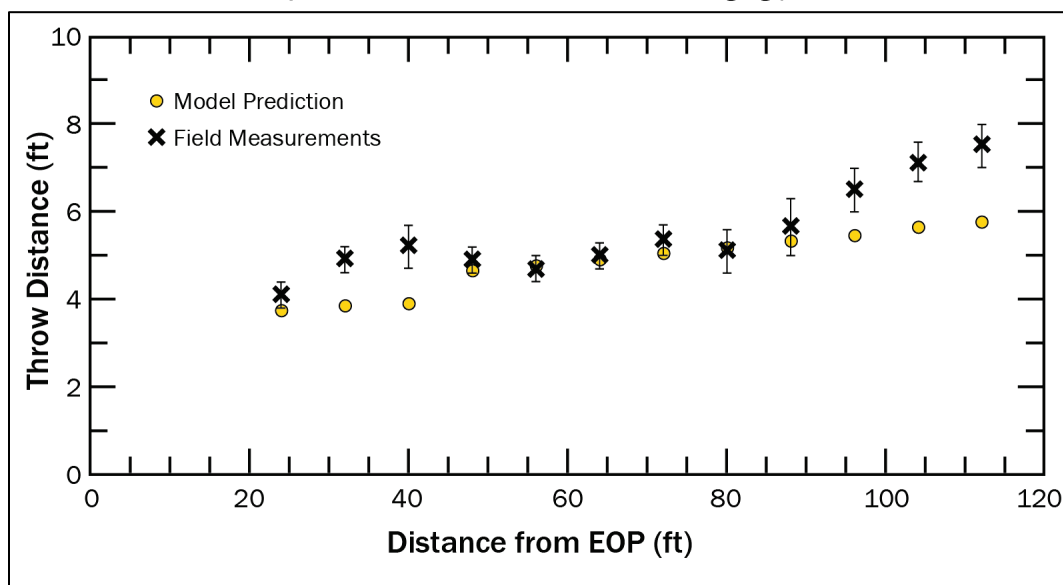
A plausible explanation for observing sands in the top samples and fines in the bottom samples could be that the sample locations are farther from the Spring SDP layout (Figure 21), so fines that ran off from the slurry discharge would have settled in these locations. During the fall placement event, when the SDP layout was closer to these locations (Figure 21), sands from the discharge may have been deposited here. The observed decrease of sands in top samples moving away from the SDP could be the result of denser sand particles falling closer from the slurry thrown out of the holes on the side of the SDP. However, note that the surveys and sampling did not immediately commence following the dredging activities and other factors could have influenced the soil stratigraphy. For example, these locations are below 2.6 ft NAVD88 and the closest tide gauges (NOAA) (i.e., Cape May and Atlantic City, New Jersey) frequently record high tides

of more than 3 ft. Hence, these locations could have experienced tidal inundation that affected the soil stratigraphy.

7.2 Application of SDPMA

The SDP throw distance measurements were used to calibrate the ejection and in-pipe resistance coefficients to minimize the mean squared error in the numerical throw distance predictions in the SDPMA as compared to the field measurements (Beardsley et al. 2022). Based on this calibration analysis, the optimal discharge coefficient (ξ) was determined to be 0.12, and the in-pipe resistance coefficient (κ) was determined to be 0.86 for this field case scenario. When the calibrated SDPMA throw distance predictions are plotted alongside the average field measurements with bars that show the minimum and maximum distances of the impact area for each of the holes, the model yields reasonable results with an average error for the throw distances being 0.6 ft (Beardsley et al. 2022; Figure 22).

Figure 22. Plot comparing the 24 September field measured throw distances for each hole to the SDPMA predictions after calibration. (Beardsley et al. 2022). (Image reproduced with permission from *WEDA Journal of Dredging*.)



Further field studies are encouraged to refine the SDPMA with the goal of providing field engineers and construction contractors the opportunity to plan and improve placement operations using the SDP.

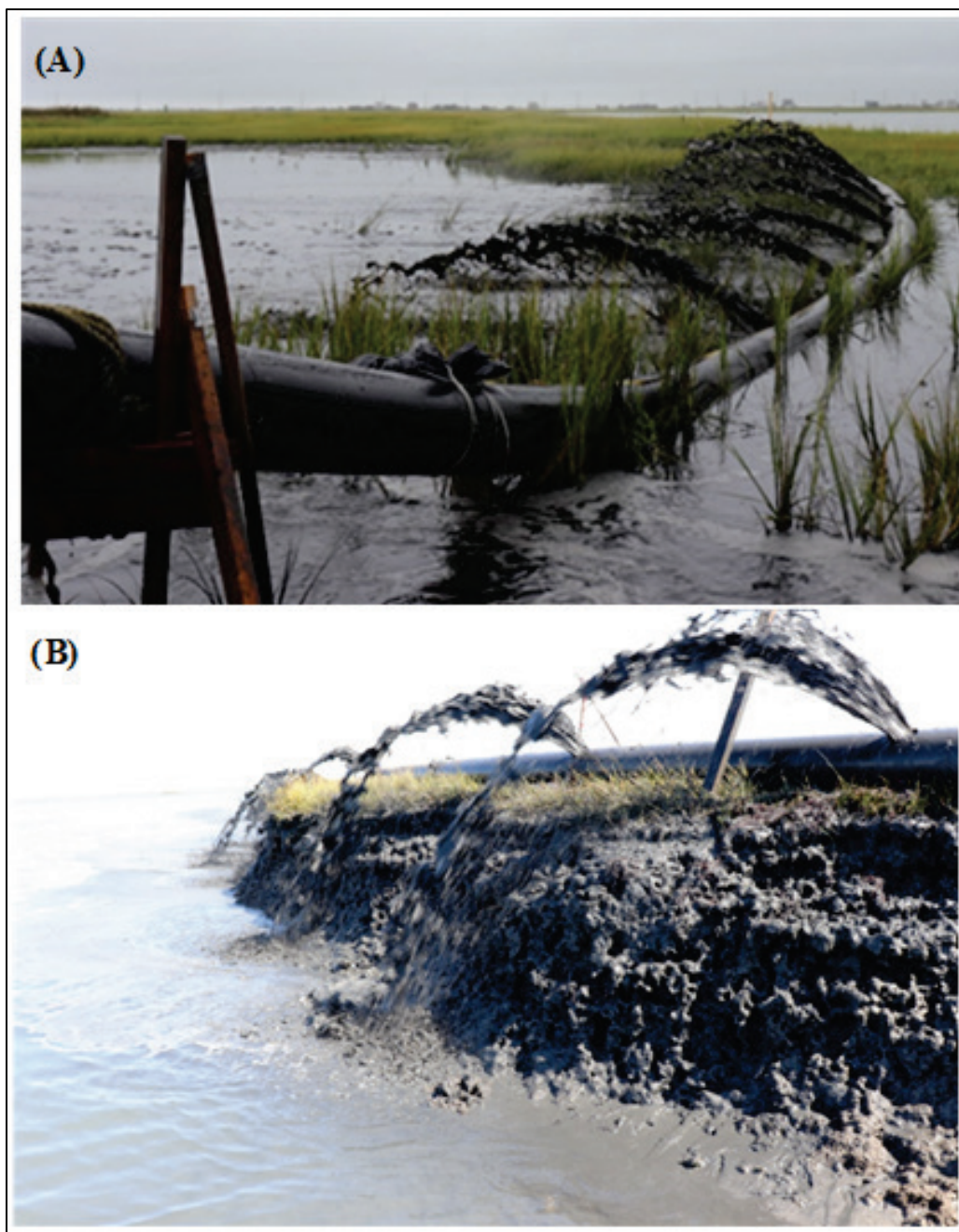
8 Additional Applications

During Phase 2 of the field application, two additional applications of the SDP were investigated: using the SDP itself as lateral containment during placement and creating marsh edge protection (Figure 23).

A 14 in. water-filled pipe was used as lateral containment along the eastern edge of Sturgeon Island during Phase 1 and 2 of the field application, indicating that the SDP could be used for containment. By acting as its own containment, the SDP could potentially provide reduced project costs by eliminating the need for a separate containment structure as well as limiting impacts to the marsh by reducing the level of construction or set-up needed to create confinement for the placed dredged material. This configuration was tested during the fall 2020 (Figure 23A); however, this was not optimized for containment as the holes were too close to the end of the pipe.

Based on observations from Phase 1, the SDP proved successful in distributing sediment laterally. Therefore, during Phase 2, the SDP was briefly positioned along the northwestern edge of the island for 2 days with drainage ports facing off the island to test placing sediment on the marsh edge to nourish the tidal flat protecting the marsh edge (Figure 23B). Visual inspections documented an accumulation of sandy sediment on the mudflat.

Figure 23. (A) On-ground (lateral confinement) testing setup of the SDP system and (B) discharge pipeline along the northwestern edge, testing placement of sediment on the marsh edge and nourishing a tidal flat.



9 Summary and Recommendations

9.1 Summary

NAP, State of New Jersey, TWI, and ERDC have teamed up to develop an innovative means to beneficially use DM to nourish wetlands with less wetland impacts than traditional placement of DM. In the field proof-of-concept study, the team used this pragmatic SDP approach of sediment nourishment to address a several-year decline in habitat suitability and availability at Sturgeon Island in the New Jersey Great Sound. The main objective of this proof-of-concept study was to evaluate the ability of the SDP for the following aspects:

- Distribute sediment efficiently.
- Optimize pipeline moves.
- Minimize the marsh surface disturbance.
- Develop a numerical model to simulate SDP.

Qualitatively, it is anticipated that the SDP distributes sediment more efficiently than traditional open-pipe discharge as the SDP can have many discharge points throughout the length of the pipeline as opposed to a single-point discharge. Unfortunately, the limited size of the site, as well as having multiple dredge events in the same area, make it difficult to determine the exact extent that material was distributed by the SDP. To assess this performance metric, future SDP field studies are warranted. The future field studies should have a significantly larger placement area than Sturgeon Island; there should be extensive topographic surveys of the sample area before and after placement; and influence of multiple placement events should be limited.

The two different SDP layouts associated with the spring and fall 2020 placements successfully nourished approximately 4 acres of Sturgeon Island and no pipeline moves were needed; however, this was attributed more to the size of the placement as opposed to the SDP's performance. SDP field tests conducted on a significantly larger project site would be helpful to analyze the ability to achieve a targeted elevation gain over a more widespread surface. The number of SDP pipeline moves on a larger project should be compared to traditional placement techniques to quantify differences between the two methodologies.

This field proof of concept illustrates the SDP's ability to distribute sediment with minimal marsh surface disturbance. The SDP configurations required little to no heavy machinery and supporting infrastructure. No marsh surface disturbances were identified during the SDP field demonstrations except for the crater formations underneath the SDP during the Phase 1 placement. Crater formation could be mitigated in future field tests with diffuser plates. Additional field demonstrations on larger project sites are recommended to analyze SDP capabilities with no heavy machinery, invasive infrastructure, and minimal SDP moves.

One of the objectives of the SDP field demonstration project was to inform the development of an SDP model application for prediction of placement behavior. When the model was calibrated to the field conditions, the model was able to predict the throw distances to within 1 ft of accuracy. This can provide contractors and engineers a way to design the SDP to fit their project needs. More field investigations are recommended to further evaluate the ability of the SDPMA to accurately predict the discharge of dredged slurry from the SDP. The accuracy of the SDPMA could be increased by adjusting the fluid dynamics model by evaluating and including turbulence modeling used in commercial mixing and diffuser models such as CORMIX.

An interesting finding that came from the SDP field deployment was how the additional exit points resulted in a lower exit velocity. During traditional beneficial use of DM events, the single discharge point can cause significant scour and will eventually develop a preferential path for the DM to flow. This preferential path reduces the residence time for the sediment to fall out of suspension and can cause undermining of containment. The lower exit velocities reduce development of preferential flow paths resulting in more placid flow conditions. Future work is recommended on monitoring field flow conditions from the SDP as this can allow dredgers to operate at higher dredging rates while limiting adverse impacts on the placement site.

9.2 Recommendations: Future Design Modifications

During future studies, the following modifications could be evaluated:

- Install a wheel-mounted scaffolding system so that if the SDP needs to be moved, it will disturb only the marsh surface associated with the wheel path.
- Determine viability of the SDP being used as containment during placements.
- Install diffuser plates beneath discharge holes to avoid local scour of the marsh.
- Explore commercial mixing and diffuser models that adequately represent the effects of turbulence, velocity and pressure drop, slurry deposition within the pipeline, and material displacement into the ambient environment.

The work presented in this report serves as a proof of concept of the SDP. Future SDP research should include additional field studies, improved numerical modeling to include computational fluid modeling of the slurry in the pipe, and physical model studies that identify and refine conditions suited for sediment sorting and creation of features. The ultimate goal of SDP research is to develop guidance for application of the SDP in TLP projects.

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Abbreviations

BU	Beneficial use
CSV	Comma-separated values
DM	Dredged material
DOER	Dredging Operations and Environmental Research
EOP	End of pipe
ERDC	US Army Engineer Research and Development Center
EWN®	Engineering With Nature®
i.d.	Inner-diameter
NAP	Philadelphia District
NAVD 88	North American Vertical Datum of 1988
NJIWW	New Jersey Intracoastal Waterway
NWR	National Wildlife Refuge
PDFM	Portable doppler flow meter
RTK-GPS	Real Time Kinematic–Global Positioning System
SDP	Sediment distribution pipe
SDPMA	Sediment distribution pipe modeling application
SMIIL	Seven Mile Island Innovation Laboratory
TLC	Thin-layer cover
TLP	Thin-layer placement
TWI	The Wetlands Institute
USACE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
USFWS	US Fish and Wildlife Service

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