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GUIDELINES FOR HOW TO APPROACH THIN-LAYER PLACEMENT PROJECTS

Candice Piercy and Timothy Welp
U.S. Army Engineer Research and Development Center

Ram Mohan
Texas A&M University

Guidelines for How to Approach Thin-Layer Placement Projects

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This document was kicked off with the aid of a technical workshop whose attendees are listed in Appendix C. A list of external peer reviewers, who provided valuable suggestions during the final assembly of this document, is included as Appendix D.

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In Memoriam: Timothy Lee Welp (1957–2021)

Long-time researcher Tim Welp, who contributed in many ways to the dredging, coastal, and marine industry, passed away on June 18, 2021. Tim served in the U.S. Navy and earned engineering degrees from the University of Wisconsin and the Florida Institute of Technology. Since 1990 he worked as a research hydraulic engineer at the U.S. Army Engineer Research and Development Center, where he contributed to many programs, including Dredging Operations Technical Support, Dredging Operations and Environmental Research, and Engineering With Nature®.

Tim was one of the world's leading experts in innovative dredging practices and sediment management. He had exceptional enthusiasm for dredges and dredging equipment and was passionate about his work. More important, his spirit and kindness made him a wonderful colleague, mentor, and friend to everyone who worked with him. Tim was also a loving husband and father and an avid scuba diver, metal detector, and fisherman. And he was a third-degree black belt. To honor Tim and his many contributions to the dredging industry, we dedicate this document in his memory.

Foreword

A Toolkit for Wetland Restoration

It is undisputed that our coastal wetlands play a vital role in the earth's ability to combat the effects of climate change, as well as provide valuable nursery habitat for several benthic species, and also filter the effects of many anthropogenic pollutants that would otherwise make their way into our waterbodies. Wetlands have been constantly eroding or degrading due to a variety of reasons that include sea level rise, subsidence, and the continuous effects of physical forcing events, such as waves, tidal flows, vessel wakes, and storm impacts. Recognizing the accelerating trends in coastal wetland loss, several federal, state, local resource agencies, and nongovernmental organizations (NGOs) have made it part of their mission to try and restore this valuable habitat loss.

The U.S. Army Engineer Research and Development Center (ERDC) is pleased to present these engineering guidelines on a technique to restore coastal wetlands—the thin-layer placement (TLP) of dredged sediments. Not only does this facilitate the beneficial use of sediments dredged from our navigation channels and waterways, but it also facilitates a "nature-based solution" that works well within the context of ERDC's Engineering With Nature® (EWN®) program that the U.S. Army Corps of Engineers is promoting nationally as a sustainable way to solve our many pressing challenges and needs along the coastal and inland waterways and shorelines. This document provides specific recommendations spanning all aspects of implementation of TLP, including early project planning and data collection, engineering design, construction, and monitoring and adaptive management. Additionally, it includes technical "to-do" steps as well as several recommendations that are generated from reviews of case studies and lessons learned from the practice in the recent years.

These TLP guidelines are the result of a multiyear collaboration amongst several agencies—federal, state, and local—the marine construction industry, practitioners, NGOs, and others. It is hoped that this document will be widely accepted as an EWN tool to help promote more sustainable use of sediments across the nation.

Dr. Jeffrey K. King
National Lead and Program Manager
U.S. Army Engineer Research and Development Center Engineering With Nature®

Millimeters to Miles

Creating the conditions for resilient coasts and communities is a matter of millimeters and miles. The inexorable millimeter-by-millimeter creep of sea level rise poses significant flood risks that will increase substantially over time. Millions of acres of coastal wetlands and other landscapes throughout the United States (and in other countries) play a vital role in reducing those risks. Matching the millimeter-by-millimeter rise in sea level by supporting and supplementing the natural sedimentary processes that create, nourish, and sustain coastal landscapes is one key to achieving comprehensive resilience. In addition to reducing flood risks, coastal nature-based solutions can provide valuable habitat, support biodiversity, absorb nutrient loads, and contribute to the health and wellbeing of our coastal communities.

Delivering these benefits depends on many factors. Although the rise in vertical elevation is measured in millimeters to meters, the need to address that rise across the horizontal scale of the landscape is measured in miles upon miles. Integrated solutions that combine nature based, structural, and nonstructural measures must scale to the processes, drivers, hazards, and scope of the problem, which is significant. A substantial amount of translation is also needed—and not just between the metric and imperial systems I have been mixing here. Engineers, ecologists, economists, and others need to come together, communicate across their disciplines, and translate actions into new technical means to deliver comprehensive solutions and resilience.

Our coastal landscapes and infrastructure are subject to a variety of natural and human forces in addition to sea level rise, among them land development, subsidence, waves, tidal flows, vessel wakes, and storms. A large and growing network of federal, state, and local agencies; nongovernmental organizations; and private sector entities recognize the important role natural and nature-based features play in coastal resilience. Coordinated intervention by these organizations will be necessary to sustain these systems and the vital ecosystem services they provide.

This document will not only facilitate the beneficial use of sediments dredged from our navigation channels and waterways, but also support nature-based solutions that embody the principles of EWN. In addition to its technical steps, the guidelines provides several recommendations, all supported by case studies and lessons learned from projects and practices in the field. The recommendations span the gamut of TLP implementation, including early project planning and data collection, engineering design, construction, and monitoring and adaptive management. Essayons!

Dr. Todd S. Bridges
Professor of Practice in Resilient and Sustainable Systems
University of Georgia

Former National Lead
U.S. Army Engineer Research and Development Center Engineering With Nature®

Introduction

Thin-layer placement (TLP) is the "purposeful placement of thin layers of sediment (e.g., dredged material) in an environmentally acceptable manner to achieve a target elevation or thickness" (Berkowitz et al. 2019, 6). TLP is used for a variety of purposes, such as sediment management, the beneficial use (BU) of dredged material (DM), and ecological enhancement (Wilber, Clarke, and Rees 2007; Mohan et al. 2016; Smith and Niles 2016; Berkowitz, VanZomeren, and Piercy 2017). The word *thin* is used to distinguish TLP from traditional sediment placement, where the primary objective is to maximize storage while minimizing surface area. In those cases, sediment layers are often several meters thick. In this document, *DM placement* refers to the discharge of sediment in a location and manner where no BU is attained, whereas with TLP, the sediment is used to benefit society and the environment. TLP of sediment has displayed advantages over thicker sediment applications in environments where thicker layers pose potential challenges to natural resources, infrastructure, navigation, or other assets (Berkowitz et al. 2019).

Although most TLP projects have been conducted in intertidal and shallow-water environments, there are open-water applications for TLP as well. Because TLP is relatively early in its development, there is a dearth of design and construction information and guidance available to its practitioners.

This document provides a history of TLP's evolution and presents guidelines on TLP projects in wetlands and open-water environments. It is based on how TLP projects are currently designed and constructed and is intended for engineers, scientists, and other practitioners tasked with planning, designing, constructing, and managing TLP projects. This document is organized into eight chapters that cover the history of TLP, how to conceptualize the project area, setting goals and objectives, project design steps, construction considerations, monitoring and adaptive management aspects, knowledge gaps, and future research and development needs. Several case studies are presented as examples of how such applications have been implemented and highlight lessons learned, particularly on best-management practices.

Development of this document consisted of a literature search and a field survey of (primarily) the design and construction aspects of TLP projects. The field-survey phase involved direct and indirect interaction with federal and state governments, nonprofit organizations, private industry, and academic personnel involved in TLP projects. Most direct interaction occurred during a June 2018 workshop to discuss TLP state of the practice with those who have been directly involved in such projects. (See Appendix C for a list of workshop attendees.) These guidelines were preliminarily formulated and subsequently refined through further interactions with these TLP practitioners.

Thin-Layer Placement Spray in Progress

Source: ERDC

Chapter 1. Defining TLP and Contexts for Application

Throughout history, sediment has been excavated from one location and placed in another location to achieve particular benefits. This document presents guidelines on one specific type of sediment placement: TLP of DM. Increasingly, projects are using this methodology because TLP provides ecological and resiliency benefits over more traditional, thicker sediment placement applications.

The adopted definition of TLP is intentionally broad so it can be applied to placement in a variety of habitats and for a variety of purposes, including wetlands, open water, and capping. TLP projects may include efforts to support infrastructure and to create, maintain, enhance, or restore ecological functions.

Recent interest in TLP has centered mostly on applications in coastal wetlands. Figure 1.1 shows a cutterhead dredge conducting wetland TLP via high-pressure spray. Various reports document the benefits of wetland TLP, including increased marsh elevation (to offset sea-level rise and subsidence), improved soil stability, and enhanced wetland functions while maintaining characteristic plant communities (DeLaune et al. 1990; Mendelssohn and

Kuhn 2003; Mohan et al. 2016). Several studies document the benefits of TLP applications to marsh vegetation, with common wetland plants (e.g., *Sporobolus alterniflorus*) displaying the capacity for recovery following the deposition of a 0- to 1-foot (ft; 0 to 30.48 centimeter [cm]) thick layer of sediment (Ray 2007; Mohan et al. 2016; VanZomeren and Piercy 2020).

TLP Definition

The “purposeful placement of thin layers of sediment (e.g., dredged material) in an environmentally acceptable manner to achieve a target elevation or thickness” (Berkowitz et al. 2019, 6).

Figure 1.1. *High-Pressure TLP of DM on Wetlands*

Source: Bob Blama, USACE (retired)

In this report, marsh nourishment is considered a subcategory of TLP. The Louisiana Coastal Protection and Restoration Authority (CPRA) referenced LaPeyre, Piazza, and Gossman’s (2006) definition of marsh nourishment as “a restoration technique that can refer to either the direct placement of a thin layer of sediment through spray or hydraulic dredging or from the ‘spilling’ of a thin layer of sediment over marsh that is adjacent to an uncontained restoration project” (CPRA 2008, 11). At the time, it was reported that “marsh nourishment is a relatively new restoration strategy that provides an opportunity for further research”

(CPRA 2008, 11), and a marsh nourishment component had been included in several marsh creation projects constructed in coastal Louisiana and funded under the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA). Marsh nourishment is currently defined by CPRA as "typically accomplished by the placement of hydraulically dredged material into unconfined or confined vegetated marsh area(s), to the elevation (typically lower than MC [marsh creation]) required to achieve the project intertidal marsh objectives for the project design life" (CPRA 2017d, 40).

Open-water TLP has been used as a sediment management tool to maintain littoral sediment supply in coastal and estuarine settings. Examples include placement in shallow water—10 ft (3 meters [m]) deep—to reduce impacts to the benthic communities in the Mississippi Sound by placing a 0.5-ft (15.24 cm) thick layer of DM (Wilber, Clarke, and Rees 2007) and to maintain sediment supplies in the Mobile Bay system while enhancing benthic communities with a 1-ft (30.48 cm) thick sediment layer (Parson et al. 2015). Figure 1.2 shows a spill barge placing DM from a cutterhead dredge during a 2012 TLP project in Mobile Bay. A deeper open-water TLP project in Oregon at the mouth of the Columbia River (40 to 55 ft [12.2 to 16.8 m]) provided supplementary sediment to support existing infrastructure to address littoral sediment needs. By placing sediments with a hopper dredge, scour was reduced along jetties and potential negative impacts were avoided, including impacts to navigation safety due to mound elevations and the smothering of biological resources such as fish and crabs (Norton et al. 2015).

Figure 1.2. *Spill Barge Placing Thin Layers of DM in Mobile Bay*

Source: U.S. Army Corps of Engineers (USACE)–Mobile District

Thin-layer capping or covers (TLC), a modified TLP approach, has been used to restore environmentally degraded sediments at, for example, legacy contaminated sites. Merritt et al. (2010) present a summary of case studies of open-water TLC, and Mohan et al. (2021) present a summary of considerations for the first successful field-scale pilot TLC application to restore a legacy contaminated wetland site in Brunswick, Georgia (see Figure 1.3). Regardless of the method of application or the ecosystem uplift goal, similar principles apply for successfully planning, designing, and implementing TLC and TLP projects.

Figure 1.3. *Marsh Recovery Following TLC in Brunswick Estuary, Georgia*


6 months: 9/26/2018
12 months: 3/28/2019
18 months: 11/6/2019
24 months: 9/26/2020

Note: Six-month photo shows two of the four test plots, while others show measurement quadrats.

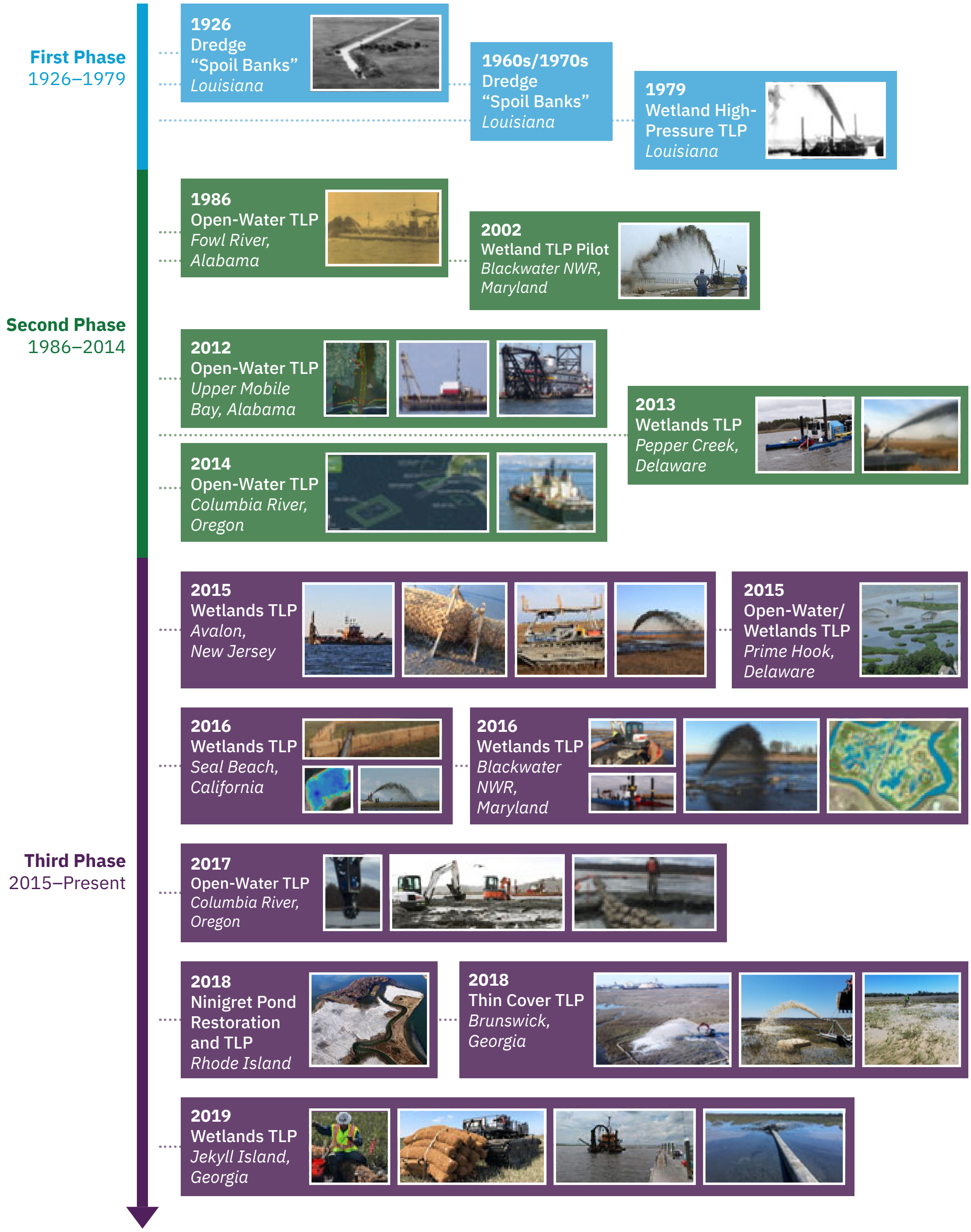
Source: Mohan et al. (2021)

The Dredging Operations and Environmental Research (DOER) program and U.S. Army Engineer Research and Development Center (ERDC) Dredging Operations Technical Support (DOTS) program have developed a website highlighting TLP concepts, case studies of pilot- and full-scale projects, and associated literature (ERDC 2021a). Although this website includes information on capping contaminated sediments with a relatively thin layer of clean DM, this guidelines document does not address this form of TLP. Appendix A presents a summary list of select wetland and open-water TLP projects retrieved from the USACE TLP website and identified in the literature search.

1.1 History and Types of TLP

An increasing number of TLP projects are being designed and constructed because of the method's advantages over more traditional, thicker sediment placement applications in certain situations. This section presents the history of wetland and open-water TLP and describes project- and equipment-specific aspects to accentuate significant stages of its evolution. (See Figure 1.4 for a chronology of TLP projects.)

Figure 1.4. *Chronology of TLP—A Historical Summary of Pivotal TLP Project Events*



Note: This figure presents a chronology of different wetland and open-water TLP project events to illustrate how the method has evolved from its beginning in the Louisiana wetlands to its current state of practice. There are three distinct phases in the evolution of TLP. The first phase (1926 to 1979) represents the shift from traditional placement methods in which DM was disposed of in the most convenient location (i.e., immediately adjacent to the channel) to a more mindful placement that avoided the creation of DM banks. The second phase (1986 to 2014) represents a shift from open-water disposal to purposeful open-water placement. The third phase (2015–present) represents a renewed interest in TLP to restore wetlands and promote resilience to storms and sea-level rise.

Abbreviation: NWR—National Wildlife Refuge

Source: Timothy Welp, ERDC

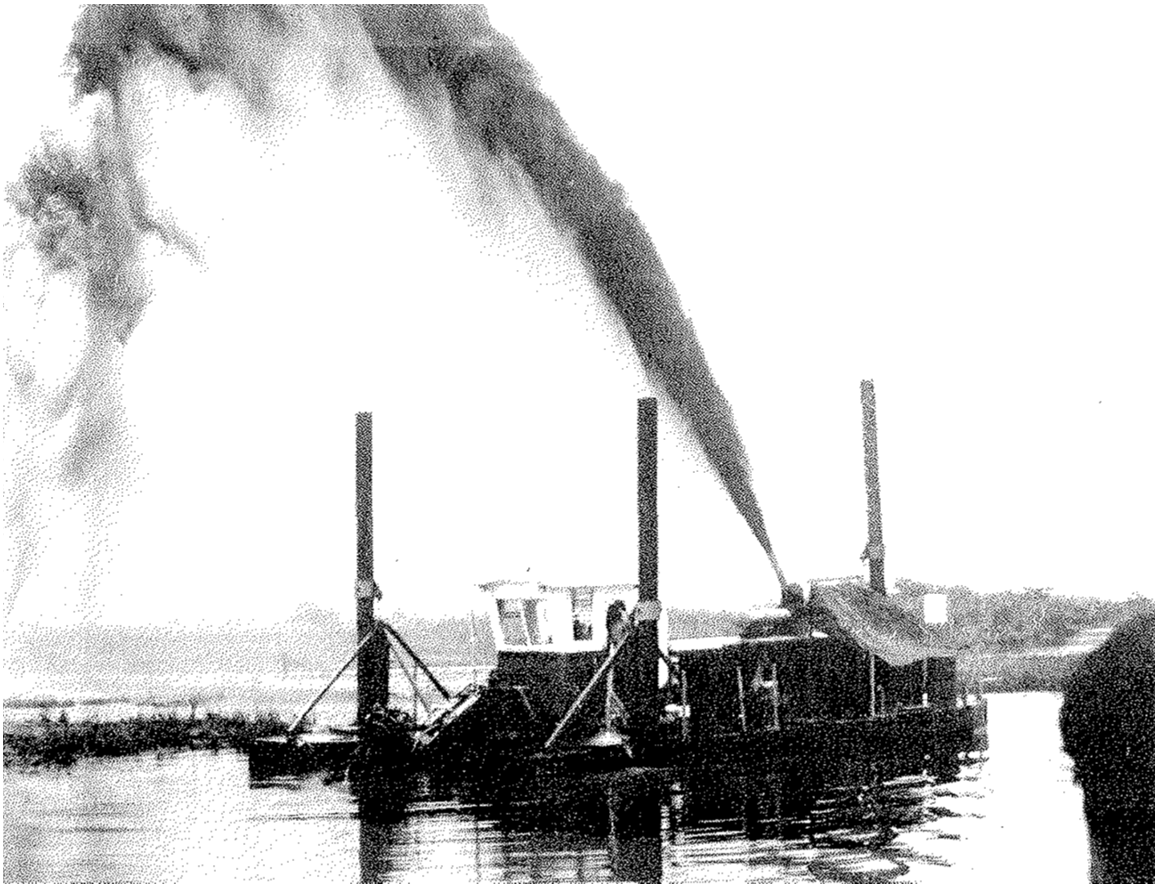
1.1.1 TLP in Wetlands

The first documented TLP in the United States was in the Louisiana wetlands in the late 1970s. The earliest canals were dug by European settlers to give trappers' pirogues access to the marsh. Later, drainage and logging canals were dug to further exploit Louisiana's natural resources. The discovery and exploitation of oil resulted in the massive system of petroleum canals that crisscross the state's wetlands today. Initially, board roads were built to provide a stable platform for heavy oil-drilling equipment to penetrate deep into the Louisiana marshes, but it was the first successful use of a submersible drilling barge, in 1934, that marked the start of expanded drilling (Davis 1976). To fully capitalize on this technology required the dredging of petroleum canals to float the drilling barges into the wetlands. Theriot (2014) quotes the claim of McGhee and Hoot (1963) that, in 1938, a barge-mounted dragline excavated "the first drilling site ever prepared by floating equipment," but Davis (1976, 237) reports that "the oldest petroleum-related canal was built 12 years earlier at Venice."

Mechanical (bucket) dredges were initially used, but these early dredges were limited in the distance they could cast excavated material to the side. Mechanical dredges were not normally used to transport DM to the placement area, so the material was deposited on the canal bank immediately adjacent to the dredging area. The resulting DM banks would sometimes cause the canal banks to collapse, and sediment would slide back into the waterway. The 1930s and 1940s saw the use of hydraulic dredges, which are characterized by the use of a centrifugal pump to transport dredged sediment in slurry form to the discharge area. These dredges had a hydraulic low- pressure discharge (Cahoon and Cowan 1987) that consisted of an open-ended discharge pipe generally equipped with a diffuser (or spreader plate); the diffuser slowed the velocity of the slurry to provide better control over its placement and to reduce impacts to wetland surfaces or the water column. The bucket dredges created DM banks approximately 3 ft (91.44 cm) high, while the hydraulic dredges generated DM banks approximately 1 ft (30.48 cm) high. After improvements in the 1950s and 1960s, mechanical dredges dominated petroleum canal construction. But in the late 1960s and early 1970s, “the research community began to suggest that the traditional method of banking [DM] in the Louisiana coastal zone might be associated with adverse environmental and ecological impacts, and the need to minimize these impacts became a regulatory and environmental concern” (Cahoon and Cowan 1987, 3). Part of the concern was that erosion and dredging caused wetland loss by directly disrupting the substrate that results in either open-water or upland habitat (Cahoon et al. 1986).

Hydraulic “high-pressure spray disposal” (Cahoon and Cowan 1987, 2) was developed in response to the need for minimizing impacts to the state’s wetlands related to dredging petroleum canals. This technology uses a contraction section at the pipeline discharge (typically a nozzle) that increases the slurry’s exit velocity to propel the slurry in an arc shaped pattern (similar to hopper dredge rainbowing; see Figure 1.5). Cahoon and Cowan (1987, 3) report that hydraulic dredges equipped with the high-pressure discharge technology were first used in south Louisiana in 1979. The technology was viewed favorably by the regulatory agencies because it appeared to have the potential for “not significantly altering desirable marsh habitats; . . . not drastically altering local hydrologic patterns; . . . and not enhancing wetland loss to the same degree as conventional spoil [DM] banking methods” (Cahoon and Cowan 1988, 348). Swinging ladder hydraulic cutterhead dredges sucked sediment, vegetation, and water into a pump equipped with a cutting knife (where the material was further broken down) before spraying the material out of a nozzle as much as 250 ft (76.2 m) over the marsh to a depth of “only a few inches” (Cahoon and Cowan 1987, 3). This capability to spread DM a few inches deep over a wider area (compared to mechanical dredges side-casting or low-pressure discharge of hydraulic dredges) was the primary distinction between these different placement technologies. At first, this new technology was used for maintenance dredging of existing channels, but in 1983 it was improved so it could be used to dredge new canals through a marsh (Cahoon and Cowan 1988).

Figure 1.5. *High-Pressure Discharge from a Swinging Ladder Cutterhead Dredge in Louisiana*



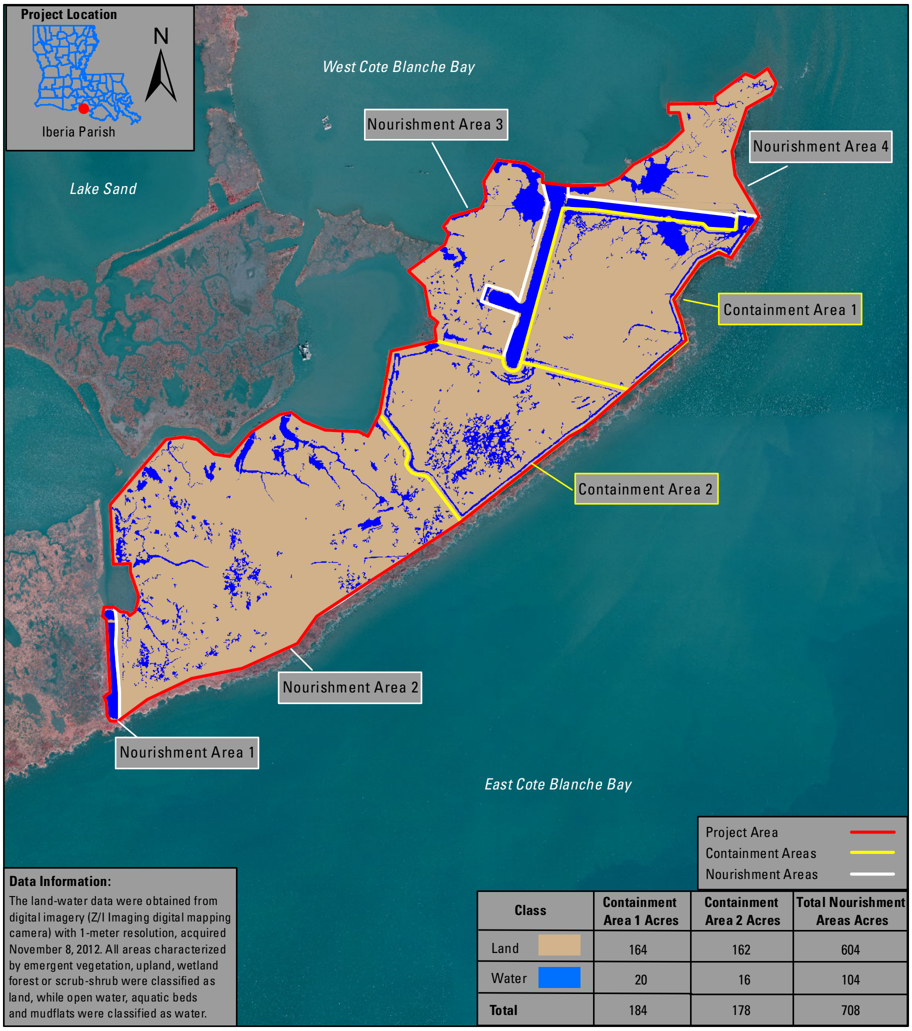
Source: Cahoon and Cowan (1987)

Cahoon and Cowan (1988, 342) noted that, although regulatory agencies immediately recognized the potential for high-pressure spray discharges to reduce DM bank impacts—and some had "already developed in-house policies for using this newly emerging resource management tool"—the potential impacts of this technology had not been examined, so its value as a management tool was never verified. Cahoon and Cowan (1988) did, however, provide qualitative field assessments of the effectiveness of four Louisiana high-pressure discharge TLP projects in minimizing DM placement impacts, and they recommended improvements in policies, frameworks, site investigations, and long-term monitoring to improve the database of TLP case studies.

East Marsh Island Marsh Habitat Creation (Louisiana)

One of the Louisiana marsh nourishment projects is the East Marsh Island Marsh Creation (see Figure 1.6). In addition to marsh creation, this project's objectives included the use of marsh nourishment that "was designed to deposit new sediments into uncontained marsh areas in the project and provide an influx of nutrients, as well as the benefits of increased elevation" (CPRA 2018, 1–2).

Figure 1.6. *East Marsh Island Marsh Creation Map and 2012 Land Water Classification*



Data Information:
The land-water data were obtained from digital imagery (Z/I Imaging digital mapping camera) with 1-meter resolution, acquired November 8, 2012. All areas characterized by emergent vegetation, upland, wetland forest or scrub-shrub were classified as land, while open water, aquatic beds and mudflats were classified as water.

Class	Containment Area 1 Acres	Containment Area 2 Acres	Total Nourishment Areas Acres
Land 🟫	164	162	604
Water 🟦	20	16	104
Total	184	178	708

Source: USGS-NWRC and CPRA (2013)

Starting in March 2010, 3,836,000 cubic yards (yd^3; 2,932,832.4 cubic meters [m^3]) of fine-grained sediment was dredged by a 30 inch (in; 76.2 cm) cutterhead dredge with a booster pump from a borrow location in East Cote Blanche Bay directly east of the project area. A total of 362 acres (ac; 146.5 hectares [ha]) of emergent marsh was created within 14,000 linear feet (4,267.2 m) of earthen containment levees. An additional 797 ac (323.5 ha) of created or nourished marsh outside of the contained areas was completed on November 4, 2010 (CPRA 2018).

Initial wetland TLP projects were conducted to achieve navigation while mitigating impacts from petroleum canal DM banks, but subsequent projects were more focused on ecological and flood risk reduction. The State of Louisiana and its federal partners, including USACE, have been designing and constructing successful marsh creation projects for decades. The East Marsh Island Marsh Creation project is one of these projects that included more traditional marsh restoration and creation as well as marsh nourishment (see the "East Marsh Island Marsh Habitat Creation" box).

Wetland TLP projects constructed in the early twenty-first century have been implemented primarily to address wetland resilience and sustainability under sea-level rise, climate change, and disrupted sediment supplies. After Hurricane Sandy, there was an influx of funding for coastal restoration and coastal protection work along the mid-Atlantic coast, particularly in New Jersey. Similar funding increases followed hurricanes and the Deepwater Horizon oil spill along the Gulf Coast. This influx led to additional local restoration funds, including national restoration grants from the National Fish and Wildlife Foundation (NFWF). Using the post-Sandy restoration funds, several wetland TLP projects were implemented in the mid-Atlantic and northeastern United States. In 2013, the Delaware Department of Natural Resources and Environmental Control (DNREC) placed approximately 6,000 yd^3 (4,587.33 m^3) of fine-grained DM over roughly 47 ac (19 ha) to increase the marsh platform elevation of a wetland site on Pepper Creek in the Assawoman Wildlife Area near Dagsboro. USACE–Philadelphia District partnered with the New Jersey Division of Fish and Wildlife, The Nature Conservancy (TNC), and the Green Trust Alliance under a $3.4 million NFWF grant from the Hurricane Sandy Response Fund to restore 14 ac (5.67 ha) of fragmented marsh near Avalon, New Jersey, with TLP of sediment from the New Jersey Intracoastal Waterway (see Figure 1.7). Another example of marsh enhancement through TLP is the Ninigret Pond Salt Marsh in Rhode Island (see Figure 1.8). The Rhode Island Coastal Resources Management Council placed approximately 30,000 yd^3 (22,936.65 m^3) of dredged sediments in layers 6 to 12 in (15.24 to 30.48 cm) thick over 25 ac (10.12 ha) of marsh in 2016, followed by planting (postplacement).

Figure 1.7. *TLP by Conventional Cutterhead with a Crib-Mounted High-Pressure Nozzle in Avalon, New Jersey*

Source: New Jersey Department of Transportation (NJDOT), Office of Maritime Resources (OMR)

Figure 1.8. *Salt Marsh Restoration by Hydraulic Dredging and Conventional Earth-Moving Equipment in Ninigret Pond, Rhode Island*

Source: J.F. Brennan Company

1.1.2 TLP in Open Water

DM has been applied by TLP in open waters using different types of dredging methodologies. The first known documented purposeful TLP project in open water was in Mobile Bay, Alabama, in 1986. Since the early 1800s, most of the material dredged from the Mobile Bay channel was cast alongside the channel by mechanical dredges. Hydraulic cutterhead dredges replaced the mechanical dredges in the late 1800s, but the DM from side-casting and open-water placement accumulated in mounds in the shallow water just outside and parallel to the channel limits. In the 1980s, opposition to this practice in shallow estuarine waters increased primarily because of three concerns: (1) creation of these DM mounds, (2) short- and long-term impacts to biological resources, and (3) water quality (Nester and Rees 1988).

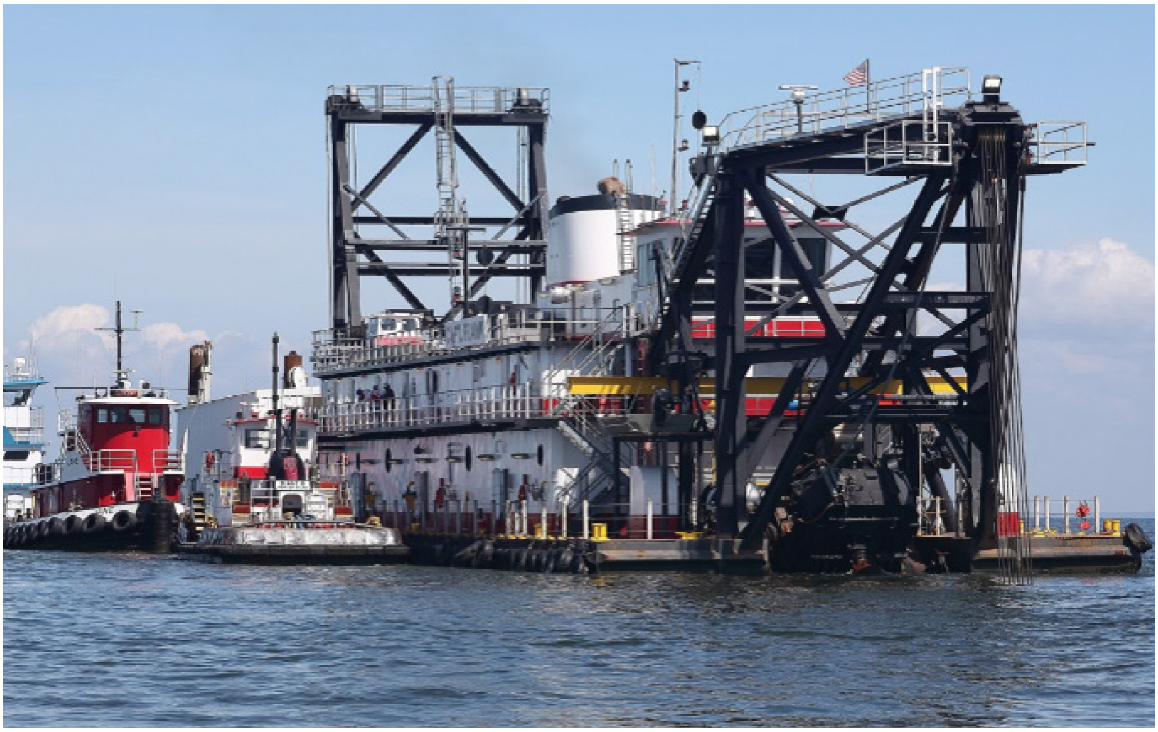
In response, USACE–Mobile District designed a project to place thin layers of DM in the open water of Mobile Bay near the Fowl River channel. The plan was designed to limit the thickness of the DM to approximately 6 in (15.24 cm). A monitoring plan was also designed; it called for data collection before, during, and after dredging. Data collection before and after dredging included hydrographic surveying, benthic sampling, trawling, and vertical sediment profiling. Data collection during dredging focused on sampling to generate water quality data.

Preliminary analyses of the monitoring data permitted the following generalizations (Nester and Rees 1988):

- The hydrographic surveying showed that the thin-layer deposition ranged from 0.5 to 2.0 ft (15.24 to 60.96 cm) within the designated placement area and from 0 to 1.0 ft (30.48 cm) in the fringe areas.
- No significant impacts to water quality were detected, with the exception of total suspended solids during placement.
- No differences were detected in the macrofauna community, and a broad recolonization occurred over the study area three weeks after placement.
- The fisheries data did not show significant variability, ether spatially or temporally, that could be linked to the thin overburden of DM.

As positioning technology advanced and overall environmental awareness rose, cutterhead dredges (Figure 1.9) were able to avoid mounding by more accurately controlling placement location and lift thickness, at a placement cost of approximately \$2 per yd^3 (approximately \$2.5 per m^3; Parson et al. 2015). The practice was discontinued in 1986 after passage of the Water Resources Development Act banned in bay placement and required the material be transported to the open ocean instead. In bay TLP was approved for emergency dredging in 2012, but the Mobile Harbor Interagency Working Group had concerns about DM's behavior after placement. A monitoring and modeling program to evaluate short- and long-term dispersion and the fate of in-bay TLP (Parson et al. 2015) was conducted by ERDC and leveraged by the Engineering With Nature® (EWN®) and the Regional Sediment Management programs.

Figure 1.9. *Thirty-Inch (76.2 cm) Cutterhead Dredge Used in the 2012 Mobile Bay TLP Project*



Source: USACE–Mobile District

Based on monitoring and modeling data, which showed minimal environmental effects, long-term in bay, TLP was approved for the site in 2014, and 1 million yd^3 (764,554.86 m^3) of sediment was placed by low-pressure discharge from a spill barge outfitted with winches and a continuous Global Positioning System (GPS) tracking system that constantly moved the barge to maximize attainment of the design lift thickness of 12 in (30.48 cm). In-bay TLP (sometimes referred to locally as *thin-layer disposal*) is now used regularly to help maintain the sediment budget in Mobile Bay and to provide a more economical DM placement alternative.

Section 5.9.2 includes a case study of a project at the mouth of the Columbia River in Oregon that used a hopper dredge for open-ocean TLP (see Figure 1.4) to provide supplementary sediment in support of existing infrastructure to address littoral sediment needs.

TLP has also been used in various estuarine systems to provide edge protection to eroding islands or to restore eroding islands. Although this involves additional techniques such as living shorelines (for lateral containment purposes), TLP can be an effective way to gradually build up elevations lost to ongoing erosion, subsidence, or other environmental factors such as sea-level rise. The principles that apply to such projects are similar to those that apply to regular TLP projects but with additional consideration given to turbidity controls and lateral containment.

1.2 Framework for TLP Projects

This section lays out a framework for initiating, planning, designing, constructing, monitoring, and managing a TLP project (Figure 1.10). This process is not linear, and one-size-fits-all procedures do not always apply. The order of the process may change from project to project, requiring iterations between steps. The duration of each step may vary depending on the particularities of the project; however, each element of the process should be addressed in some fashion. Developing a TLP project’s concept ideally should begin with a consideration of ecological aspects and system function, as discussed in VanZomeren et al. (2019). TLP applies to a wide range of DM management projects, including coastal marsh enhancement as well as subaquatic placement. Although this document primarily covers TLP for marsh-enhancement applications, similar principles also apply to other types of TLP projects.

Planning, designing, implementing, and adaptively managing TLP projects have much in common with wetland- and aquatic-restoration projects and with dredging projects (Figure 1.10). That TLP projects are complex is due not only to the difficulty of designing for the creation, maintenance, enhancement, or restoration of ecological function but also to the regulations that govern wetlands and open-water areas. The need to identify and acquire a suitable sediment source within the project time line can add additional complexity. Diligence in the planning and initial design phases to address logistical issues can mitigate project delays.

Figure 1.10. *Process Flowchart for TLP Projects*

Planning

Conceptualize system and identify possible sites
Determine site needs and success criteria
Engage stakeholders
Set goals, quantify objectives, identify constraints
Conduct preliminary evaluation of sediment sources
Evaluate funding options

Adaptive Management

Baseline monitoring
Define success criteria and triggers for corrective action
Management responsibilities
Project performance monitoring
Future management actions

Design

Assess baseline and reference conditions
Prepare preliminary design
Evaluate sediment source in detail
Detailed design and permitting
Prepare final design
Develop specifications

Implementation

Bidding and contractor selection
Means and methods
Specialty equipment/requirements
Construction monitoring
Construction quality assurance
Long-term monitoring

Project planning requires significant engagement with key stakeholders and should focus on team building and consensus development on important project aspects, such as goals and objectives, constraints, and success criteria. Because TLP projects frequently involve groups with distinct (and sometimes different) goals, ensuring clear communication among all parties at project outset is critical. To be successful, TLP projects require the balancing or harmonization of all stakeholder perspectives, as well as continual management of expectations, to achieve a win-win situation. Harmonization is facilitated when all sides have a “clear and common understanding of the overall project goals” (TNC and NJDEP 2021), and it often requires a flexible approach so goals and objectives can be reviewed and refined throughout the project time line (MDNR 2021).

Adaptive management should be used throughout the planning, design, construction, and postconstruction phases. This guidelines document's definition of adaptive management is slightly modified from the *International Guidelines on Natural and Nature-Based Features for Flood Risk Management* (Bridges et al. 2021) and Craig and Ruhl (2014), to wit:

> *Adaptive management is a structured decision-making method, the core of which is a multistep, iterative process for adjusting management actions to changing circumstances or new information about the effectiveness of [prior TLP] projects or the system being managed.*

How TLP will achieve project objectives should be established during the planning of each TLP project. TLP is one technique and should be clearly distinguished from traditional DM placement methods. The primary purpose of TLP is not DM placement but rather the achievement of a specific target elevation or depth, often for an ecological purpose. If a site requires sediment to improve the ecological health of the system, then TLP can be considered to restore the site. But TLP should be considered only if those charged with improving the ecological health of a site fully agree that the site would benefit from TLP. The choice to use TLP should be considered carefully, because there are limitations and trade-offs to the technique (see Table 1.1). Most TLP projects have addressed degradation in the landscape, such as loss of wetland elevation or coastal erosion, but some projects are designed simply to keep sediment within the coastal or riverine system while minimizing potential negative ecological and navigational impacts.

Table 1.1. *Summary of TLP Benefits and Drawbacks*

Benefits	Drawbacks
Enables reestablishment of vegetation in degraded wetland areas	Can cause short-term impacts to benthic organisms and wetland vegetation
Generally, provides a clean surface layer, which promotes the reestablishment of benthic organisms	Not a viable option if DM is contaminated
Enhances natural sedimentation processes and, in some cases, allows a wetland to keep pace with sea level rise	Elevation change due to material placement may negatively affect hydrodynamic or hydrologic conditions
Placed sediment may provide nutrients to habitat	Limited equipment and methodology choices owing to limitations of wetland and open water environments
Enables reclamation or restoration of lost or open water intertidal wetlands	Dramatic change in elevation may encourage establishment of invasive species

Table 1.1 *(cont). Summary of TLP Benefits and Drawbacks*

Benefits	Drawbacks
Eliminates the need for upland containment facilities for DM	Decomposition of organic material may lead to hypoxic conditions not conducive to plant growth in poorly drained soils
Minimizes adverse impacts from traditional thick DM placement	Possible changes in geochemical and biogeochemical activity, particularly in sulfidic sediments

Note: Benefits and drawbacks are not ranked and may not apply to all projects.

A major consideration for TLP projects is the alignment of sediment acquisition and sediment placement. Sediment must be acquired and placed in a way that does not damage unnecessarily the receiving and surrounding habitats; the placement design must be compatible with not only the sediment type but also the source location, quantity, and method of conveyance. Because the sediment properties drive many aspects of the design, the sediment source should be identified early. Often a nearby dredging project will be the source.

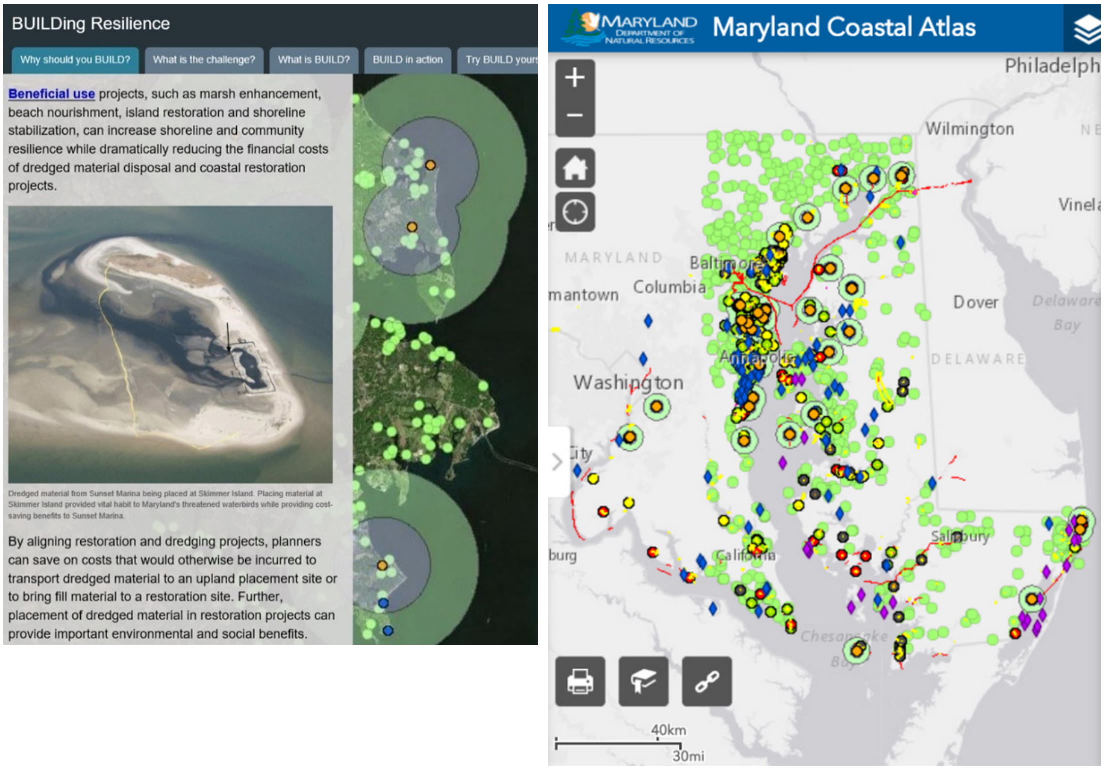
One or more sediment sources can be identified in both the planning and design phases, depending on the project's primary purpose. When TLP is part of a navigational dredging project, the sediment source is readily apparent. But for other projects, identifying feasible sediment sources or borrow sites will require investigation. If TLP is to be paired with navigational dredging, multiple possible placement locations (e.g., other TLP sites, other restoration sites, or acceptable placement areas) should be identified, because alternative placement locations may be required to ensure all sediment is removed from the channel to meet navigation requirements on schedule and within budget.

Matching a sediment source with a potential TLP site, is complex; so, the most practical approach is to rely on regional documents and assessments that identify potential TLP sites separate from project initiation (see the Natural Infrastructure Opportunities Tool [NIOT] by ERDC [n.d.; 2021b] and the Coastal Resiliency Evaluation and Siting Tool [CREST] by NFWF [n.d.]). The Louisiana CPRA Master Plan and DM management plans, the Maryland Department of Natural Resources' Beneficial Use – Identifying Locations for Dredge (BUILD) tool (see the "Beneficial Use Planning Tool" box), and TNC's Marsh Explorer and Restoration Explorer (Coastal Resilience 2021) are examples of these resources. These efforts are not exhaustive, however, and coordination with local nongovernmental organizations (NGOs) and federal and state agencies is recommended before embarking on a project. More detailed examinations of aspects of TLP design can be found in Chapter 4 of this guidelines document.

Beneficial Use Planning Tool

The Maryland Department of Natural Resources' new tool, called BUILD (see Figure 1.11), identifies opportunities for the BU of clean dredged sediments. The mapping tool was developed to "assist governmental and nongovernmental entities to synchronize the use of DM from navigation channels with projects that reduce flooding and storm risk impacts" (MDNR 2019). BUILD is a set of layers within the state's existing mapping portal and provides access to various dredging and restoration data sets that include navigational channel depth surveys, potential restoration sites, upcoming navigational improvement projects, and Maryland's Wetlands and Waterways permit database.

Figure 1.11. *BUILD Tool for Beneficial Use*



Beneficial use projects, such as marsh enhancement, beach nourishment, island restoration and shoreline stabilization, can increase shoreline and community resilience while dramatically reducing the financial costs of dredged material disposal and coastal restoration projects.

Dredged material from Sunset Marina being placed at Skimmer Island. Placing material at Skimmer Island provided vital habit to Maryland's threatened waterbirds while providing cost-saving benefits to Sunset Marina.

By aligning restoration and dredging projects, planners can save on costs that would otherwise be incurred to transport dredged material to an upland placement site or to bring fill material to a restoration site. Further, placement of dredged material in restoration projects can provide important environmental and social benefits.

Source: MDNR (2019); MDNR, n.d.

The implementation phase of TLP projects includes active construction and any additional postconstruction work, such as planting or containment removal or grading. Implementation can take a few days or multiple years, depending on a site's complexity and staging. Documentation of the completed project is key for future reference and is usually done via as-built surveys. Implementation considerations are detailed in Chapter 4.

Although adaptive management should be applied at the beginning of a project and during implementation, its benefits are especially derived after construction. The success of a TLP project is not assessed until this phase and then through routine monitoring and management. Some TLP projects are designed as one-off projects, but others are designed to receive sediment routinely because of dispersive hydrodynamic conditions, subsidence, or rising sea levels. Adaptive management of such sites is critical to optimize subsequent design and operations, such as when to begin planning the next TLP event. CPRA (2017a) provides a good summary of best-management practices for adaptive management for wetland-restoration projects. Also, see Chapter 5 for further guidelines on adaptive management of TLP projects.

The scope of wetland TLP can range from a relatively small-scale project involving a single wetland, a single site owner, and a single TLP application to a systematic implementation of TLP on a much larger scale, such as the large coastal marshes being restored by CPRA.

Restoration via State Legislation

The 1990 federal CWPPRA was designed to identify, prepare, and fund construction of Louisiana coastal wetlands restoration projects. In addition to creating wetlands under the act, the state practices marsh nourishment. The Louisiana CPRA was created after Hurricanes Katrina and Rita in 2005 to develop, implement, and enforce a comprehensive coastal protection and restoration coastal master plan. The plan, which is updated every five years, is a statement of priorities describing how the state can best use its resources to reduce coastal flood risk and build and maintain coastal wetlands. The 2017 coastal master plan includes 124 projects estimated to reduce flood damage by $150 billion by creating a projected 802 square miles (64.75 square kilometers [km^2]) of restored wetlands (CPRA 2017c).

Sediment Distribution Pipe for Wetland Restoration
Source: ERDC

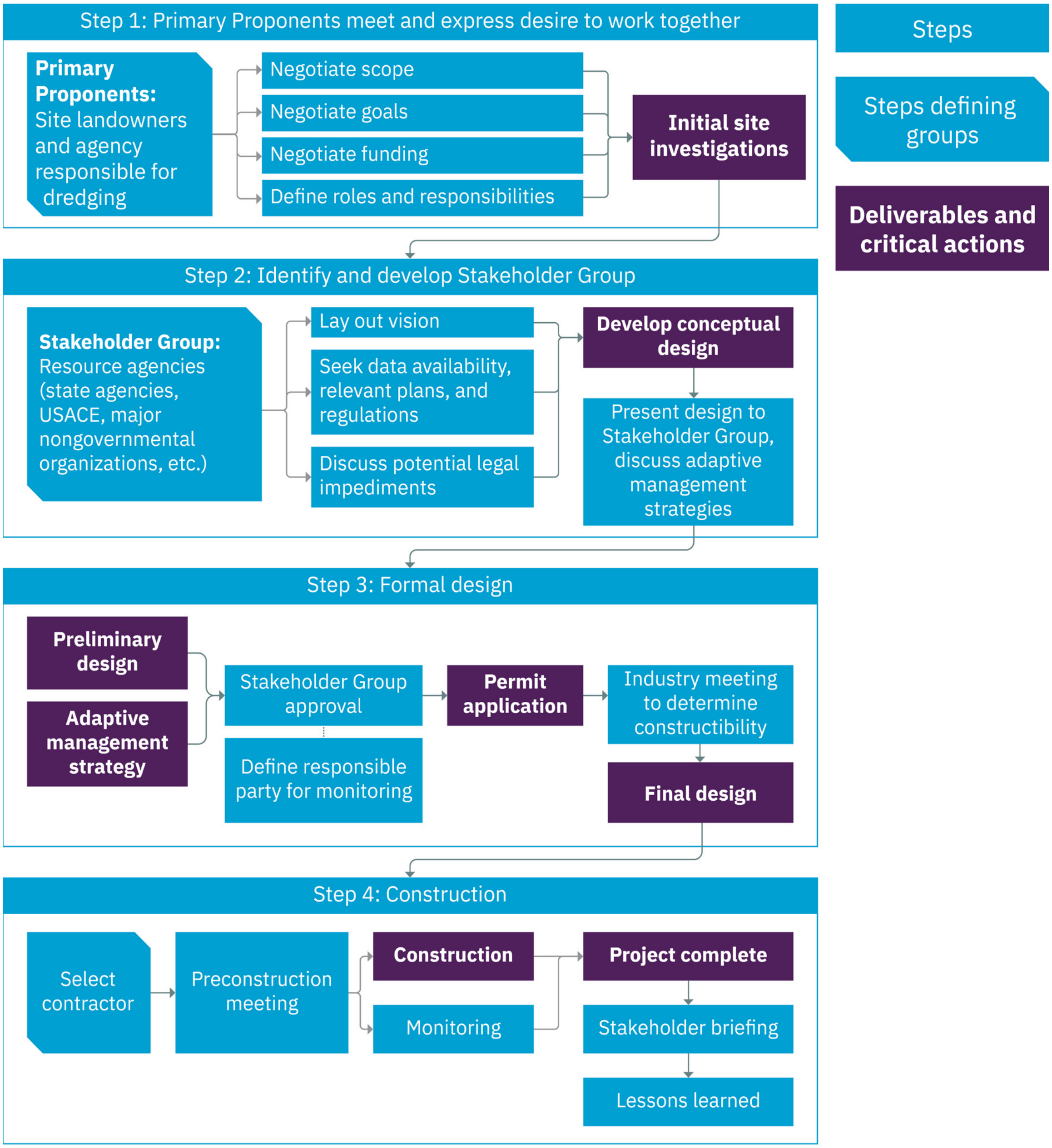
Chapter 2. Planning

2.1 Stakeholder Engagement

TLP projects often bring together many disparate groups, so stakeholder engagement should begin at project outset (see Figure 2.1 for the engagement process and Table 2.1 for some examples). A project's stakeholder group should include the project lead and representatives of groups or universities that may be involved in project monitoring and goal or objective setting; regional restoration programs; federal, state, and local government agencies, including regulators; regional or local groups interested in conservation or waterway management; the landowner and nearby residents; and multidisciplinary team consisting of engineers, scientists, construction experts.

Early stakeholder engagement often informs the project goals and objectives, so key stakeholders should be approached before the project goals and objectives are formalized. Early stakeholder group formation also enables relationships and trust to develop over time. But not all potential stakeholders must be assembled immediately; some stakeholders may not be immediately apparent at the outset of the TLP project, and more peripheral stakeholders may be better engaged once the project enters the design phase. Understanding a project's social and regulatory context (Section 2.2) will help identify key stakeholders and provide guidance on when they should be engaged. Reviewing funding options and engagement with project sponsors is also recommended.

Figure 2.1. *Stakeholder Engagement Plan for TLP Projects*



Source: Scott Douglas, NJDOT OMR

Table 2.1. *Examples of Stakeholder Groups Essential to TLP Project Success*

Mobile Bay Interagency Working Group

- Alabama State Port Authority
- USACE–Mobile District
- ERDC
- Alabama Department of Conservation and Natural Resources (ADCNR), State Lands Division
- ADCNR, Marine Resources Division
- ADCNR, Wildlife and Freshwater Fisheries Division
- Alabama Department of Environmental Management
- Geological Survey of Alabama
- U.S. Fish and Wildlife Service (USFWS)
- National Marine Fisheries Service Habitat Conservation
- Mobile Bay National Estuary Program
- U.S. Environmental Protection Agency (EPA)
- Dauphin Island Sea Lab
- TNC
- Mobile County Environmental Department
- Mobile Bay Keeper

Lower Columbia Solutions Group

- National Oceanic and Atmosphere Administration
- EPA
- Office of the Governor, Oregon
- Office of the Governor, Washington
- Washington Department of Ecology
- Columbia River Crab Fishers Association
- Washington Department of Natural Resources
- Oregon Department of Land Conservation and Development
- Oregon Sea Grant
- Portland State University
- Oregon State University
- Oregon Health Sciences University
- National Policy Consensus Center
- Oregon Department of Environmental Quality
- Port of Astoria
- Port of Ilwaco
- Port of Chinook
- Pacific County, Washington
- Clatsop County, Oregon
- Oregon Department of State Lands
- USFWS
- Oregon Department of Fish and Wildlife
- Washington Department of Fish and Wildlife
- Lower Columbia Solutions Group
- Institute for Natural Resources
- Center for Public Service

Note: These groups may also include environmental organizations, NGOs, citizen groups, and Tribal governments and Indigenous nations.

Regulators should be engaged early in the planning stages, ideally soon after a project is conceptualized. Regulators' engagement does not need to be time consuming or formal at this point, but introducing key TLP concepts to regulators early on can help identify critical constraints and stakeholders. Early engagement with key regulators can help ensure a TLP project addresses important regulatory concerns that could cause delays later in the process.

If habitats and species of special concern are involved, or if a novel placement strategy will be attempted, more-active stakeholder and regulatory groups will be required. The Mouth of the Columbia River (MCR) project, which is discussed in more detail in Section 5.9.2, is a case in point. USACE–Portland District proposed using enhanced hopper-dredge TLP methods to create nearshore DM sites that would feed sediment to areas experiencing erosion. The emplaced sediment would come from the federal navigation channel at the river mouth, which USACE maintains. Although USACE sought to minimize other impacts with its proposal, the multitude of singularly focused interests in the channel area meant no single solution to the sediment erosion problem could also meet the needs of the more than two dozen channel stakeholders. Among their concerns were potential wave amplification due to the depth of the DM deposition leading to safety issues for the fishing fleet and the potential impacts of material placement on commercially important sensitive species such as the Dungeness crab. Faced with the prospect of being unable to move forward with its proposed project because of such concerns, USACE–Portland District eventually convened a science-based stakeholder working group to inform a method of DM placement that would have the greatest benefit to the region.

USACE–Portland District first engaged with the National Policy Consensus Center at Portland State University to bring all interested parties together. The Lower Columbia Solutions Group (LCSG) was subsequently created in 2004 to give all parties a voice and to streamline the environmental permitting process by including state and federal regulators (Norton et al. 2015). That the LCSG was able to work through the stakeholders' concerns and pave the way for a DM placement pilot project in September 2005 clearly shows the value of early stakeholder engagement. Seven years after the pilot, Portland District's TLP project went operational.

2.2 Conceptual System Understanding

Before a TLP project—or any project with habitat restoration or management components—begins, the project team should have a good understanding of existing wetland functions and how TLP may alter those functions. Even if a site is not degraded, evidence that it may become degraded in the future (because of sea-level rise or other factors) should be part of the conceptual system evaluation. Timescale should be evaluated for each system's no-action alternative because not acting may lead to severe loss of habitat or function that would require immediate TLP to mitigate. In the early phases of a TLP project, the team should work with local experts to examine the region of interest and obtain a rough conceptual understanding of how that system functions, including its sediment and biota and how its water moves.

Wetlands and nearshore open-water habitats function at the intersection of a number of systems:

- **Physical—**Geomorphic setting, water levels, riverine flows, currents, tides, and sediment transport
- **Chemical—**pH, salinity, sulfide composition, organic content, and other nutrients
- **Ecological—**Feedback between vegetation and inundation, faunal use (especially benthic fauna), wildlife and fisheries, and invasive species
- **Socioeconomic—**Goods and services to communities, regarding coastal resiliency for both natural and human communities
- **Engineered—**Alterations in hydrodynamics from structures or stormwater inflows from adjacent developed lands' diking and ditching
- **Cultural—**Historic features, land-use practices, heritage, and cultural resources
- **Regulatory—**Special laws, regulations, and policies for wetlands and in aquatic habitats

Consequently, any prospective TLP project must examine the function of the wetland or open-water environment in relation to these systems, especially if the project may significantly alter these functions. This examination should identify any degradation of the system as a whole and what the causes of that degradation may be. In some cases the physical, chemical, and ecological systems may be degraded but the engineered and socioeconomic systems may be fairly robust, especially in heavily developed areas of the coast. Other areas that are not heavily developed, however, may not be physically degraded but may be ecologically degraded (because of invasive species, marsh platform subsidence, or shoreline erosion). Each wetland and nearshore open-water area requires unique evaluations and considerations, including assessments of the potential for natural migration over time compared to active restoration practices.

2.2.1 Site Selection

Sites that show a pattern of degradation attributed primarily to surface-elevation loss or sediment loss are ideal candidates for TLP. Sea-level rise and subsidence can accelerate natural processes, leading to marsh degradation over time. Ideally, TLP should be used to provide elevational enhancement to existing wetlands so that natural recolonization of the vegetation occurs over time (which means not placing more than 6 to 12 in [15.24 to 30.48 cm] of material at one time). Optimal TLP sites have limited potential for natural sediment resupply—or have undergone engineered changes that have altered their hydrology—and a dredging project nearby that can provide material suitable for beneficial reuse. If a site is degraded for multiple reasons, TLP should be conducted when those reasons are addressed, because leaving those other causes unaddressed may render TLP ineffective. Although TLP is often used for wetlands because adding sediment is the most efficient way to increase wetland elevation, marsh-edge erosion can often be addressed by other techniques, such as living shorelines or offshore (underwater) berms or reefs. Thus, other options for coastal-zone enhancement (such as beach nourishment, island creation or restoration, or nearshore placement) should also be considered during alternatives evaluation when considering a TLP project. When traditional nearshore placement techniques can lead to adverse outcomes for benthic invertebrates, TLP is selected to minimize those impacts and still provide the benefits of nearshore placement. As discussed in Chapter 4, however, during design of TLP projects, details for material placement, slurry (lateral) containment, and effluent quality should be carefully evaluated. BU projects, such as TLP, conserve valuable placement capacity and provide a more resilient shoreline and resulting habitat. TLP can also be used as part of a BU program resulting from dredging, and sites could be considered as repeat candidates for TLP applications over time if additional elevational uplift is desired.

2.2.2 Physical System

The physical system comprises the morphology of a site and the surrounding area in addition to the hydrodynamic and meteorological forces that shape the system’s form and function. A site’s morphology includes its topography, bathymetry, and surrounding area as well as its proximity to uplands, deeper water, inlets, rivers, etc. Site topography includes channels, flow paths and directions, local low and high points, and slopes. The relative uniformity of its shoreline, the curvature of its marsh, and the slope of its mudflat can indicate whether a site is an erosive or depositional environment, which has implications for the relative importance of hydrodynamic forces on the site’s function (Friedrichs and Perry 2001). Changes in site morphology should be examined through historical images, local estimates of shoreline change, and local sea-level-rise rates.

Hydrodynamic forces of interest include waves, water levels, tides, and currents. Closely associated with those forces are sediment erosion, transport, deposition, and accretion patterns, as well as the availability of sediments from adjacent areas such as uplands, deep water, or rivers. Meteorological forces of interest include seasonal wind directions, temperatures (which dictate growing season length and the potential for ice rafting), and, for emergent sites, precipitation patterns (and the potential for drought) and storm patterns. Climate change and its effects are also a large-scale driver of physical systems.

Physical drivers are useful to understand because they influence the site function, the recovery time after TLP, and the longevity of the site enhancements. Also of interest are the sediment type, bottom substrate, and the presence and proximity of engineered structures—especially those that may alter site hydrodynamics.

The project team should also understand the site's role in modifying waves, currents, or erosion in adjacent areas, so any impacts TLP has on these functions are also understood. This was particularly important in the MCR open-water TLP project because the navigation channel and nearby waters are important for commercial fishing and fishermen transit through the channel and the placement sites (Norton et al. 2015). USACE specified mound-height targets for TLP, noting that sediment mounding that increases wave heights by more than 10% above baseline may be unacceptable (USACE 2003).

2.2.3 Ecological System

TLP projects frequently occur in vegetated tidal wetlands and in shallow, open-water environments, and the ecological system in each depends on the dominant vegetative cover. Understanding the ecological system, which includes the physical environment as previously described, is required so the potential benefits or adverse impacts of TLP can be identified and quantified, if necessary.

2.2.3.1 Wetlands

Although TLP is often used in coastal wetland freshwater environments, hyposaline and freshwater marshes are more sensitive to sediment placement, so TLP generally is limited to coastal wetlands such as salt and brackish marshes (Ray 2007). No case studies of TLP in mangrove wetlands are known, but the characterization of mangroves would be similar to that of coastal marshes because mangroves, like salt marshes, are adapted to the higher deposition rates in marine and estuarine environments. VanZomeren et al. (2019) lay out a framework for assessing salt marsh condition and determining which restoration techniques should be considered, including TLP.

Ecological understanding of wetland systems includes understanding the vegetation communities present, the condition and distribution of the vegetation, the biotic communities that use the wetland, and the roles plants and biota play in supporting the wetland soils and substrates. Salt marsh (and mangrove) vegetation is a critical component of the biophysical feedback that enables wetlands to adjust to changing sea levels through sediment accumulation and carbon mineralization (called *accretion*). Vegetation communities zone by the duration, not only of inundation and salinity, but also of root zone saturation. Wetland areas devoid of vegetation are indicative of physical or biogeochemical conditions that are not conducive to the establishment and persistence of plants; therefore, the underlying factors that should be corrected before TLP is considered should be evaluated carefully. Note also that some of these are natural features, such as salt pans, which may provide an inherent function to the wetland system, which should be carefully assessed.

Use of wetlands by biota, whether benthic invertebrates, mammals, or birds, is a function of the physical characteristics, water levels, and vegetation structure. For example, nekton use wetland creeks, ponds, and portions of the low marsh adjacent to this open water, whereas some birds prefer to nest in the upper extent of the salt marsh so their nests will not be flooded under normal tidal conditions. Wetland vegetation and biota, especially microbes, play an important role in soil formation and biogeochemical cycling in wetland systems, controlling the cycling and transport of nutrients such as nitrogen and phosphorus, cycling and sequestering carbon, and processing excess sulfides from salt water that can be phytotoxic at high concentrations. Although not every aspect of the wetland ecological system needs to be quantified, it is necessary to understand and monitor the system's key processes so the TLP project's success can be evaluated and communicated. Such knowledge should also be incorporated into adaptive management protocols.

2.2.3.2 Benthic Habitats

Although wetlands and open water have comparable ecological value, wetlands are generally seen as having greater social and recreational values. Understanding the ecological function of open-water environments, however, is just as important as understanding the ecological function of wetlands. Open-water environments may have muddy or sandy substrates and may be habitat for submerged aquatic vegetation (SAV), macroalgae, and the animals and fish that depend on them. SAV and macroalgae communities can be ephemeral, so understanding their persistence before a TLP project begins is necessary to determine the project's long-term impacts. The ecological condition of shallow-water environments is also driven by dissolved oxygen, temperature, and turbidity, which is related to concentrations of suspended sediment, plankton, and other material. Physical processes generally control open-water environments more than wetland environments. That is because fewer open-water biota—including sessile invertebrates, such as chelates, and bivalves and mobile burrowing invertebrates, such as crabs—can modify their environment to the same degree as wetland plants. Reef-building biota are an exception, however, and TLP projects near extensive reefs of any kind will need more planning and monitoring to minimize any adverse impacts.

2.2.4 Engineered System

The engineered and built environments in which many TLP projects are conducted are intricately tied to physical, ecological, and social systems. In many coastal environments, engineered elements modify the physical system and may directly or indirectly affect the ecological system. Engineered elements may facilitate access to the site by people or provide critical services, such as utilities, to surrounding communities. But the typical infrastructure of jetties, seawalls, culverts, dams, roads, navigation channels, utilities, pipelines, piers, etc. are not the only engineered elements considered in TLP projects. The engineered system also includes sediment management and the operation and management of impoundments, inlets, reservoirs, dams, and other features. Dredging considerations, as the nature of a dredging project and the typical cycles for maintenance dredging, are also part of the engineered system.

Local navigation channels, confined disposal facilities (CDFs) or placement areas, and all other possible sources of sediment should be identified for TLP projects that will use navigational DM. The type and size of dredging equipment to be used is also a critical consideration because it will not only influence how sediment will be moved to the wetland or shallow open-water TLP site but also determine the production rate and physical state of the sediment delivered to the placement site. Some TLP projects, like the Sachuest Point National Wildlife Refuge (NWR) Marsh Restoration in Rhode Island, have used sediment trucked from land-based sources. But the TLP projects in this report used sediment dredged by hydraulic dredges and distributed through a network of pipelines for placement.

Primer on Dredging Terms and Equipment

There are two types of navigation dredging projects: new work and maintenance. New work is dredging in an area that has not been dredged before and often includes more-consolidated or higher-density sediment. Maintenance dredging involves the cyclical dredging of a constructed project to remove recurring sedimentation. A CDF is a diked area built to contain DM. A borrow area is a location where material is excavated and transported by a dredge for use at another location; therefore, the term *dedicated dredging* is used to differentiate it from dredging for navigational purposes.

Hydraulic dredges use an excavating device (cutter or auger) to excavate the sediment and make it available at the suction inlet to a pump that pumps and transports the slurry (sediment-water mixture) through a pipeline to the desired placement location. Hydraulic dredges, in the context of TLP applications, come in two general types: hopper dredges and cutterhead dredges (see Figure 2.2). With a hopper dredge, one or two drag heads at the end the suction pipe are lowered to the channel bottom to entrain the sediment, and the slurry is pumped into a hopper; once the dredge is filled, it stops pumping, raises the drag head, and sails to the placement area, where it deposits its sediment load on the ocean floor through bottom doors or opening of a split hull. Some hopper dredges also have a hydraulic system that can pump the slurry ashore through a separate pipeline in the hopper for beach nourishment and loading of barges for transport to an open-water placement site. A hopper dredge is sized by the carrying capacity of its hopper. The USACE dredge *ESSAYONS*, for example, has a 6,423-yd^3 (4910.74 m^3) hopper.

Figure 2.2. *Example Hydraulic Dredges*

Hopper dredge

Cutterhead dredge

Source: John Henriksen, Manson Construction

A hydraulic cutterhead dredge pumps slurry though a pipeline. The size of a cutterhead dredge is determined by the dredge pump's discharge diameter. In wetland TLP projects, the end of the discharge pipeline is usually open ended or fitted with a nozzle or spreader plate (see Chapter 4). In open-water TLP projects, the discharge pipe is mounted on an anchor barge that can be repositioned in some manner to achieve the target elevation or thickness. A diffuser may be used to increase placement efficiency.

As pipeline length and hydraulic friction increase, more pump power is required. The addition of a nozzle to use high-pressure discharge also increases hydraulic resistance that requires additional pump power. Once the maximum available pump power is reached, booster pumps are required to avoid slurry velocity reductions that may risk plugging the pipe and maintain efficient production rates. Booster pumps significantly increase dredging and transportation costs. For more detailed information on dredges and dredging project management, see USACE's Engineer Manual, *Dredging and Dredged Material Management* (USACE 2015).

2.2.5 Physical and Ecological System

Physical and ecological systems provide numerous benefits to the people living near wetlands and open water, including reduced risks of erosion and flooding; the removal and transformation of waterborne constituents (such as nutrients, organic compounds, metals, and suspended sediment); spawning areas for fish and shellfish; opportunities for recreation; and aesthetic values. These goods and services, however, a re provided regardless of the value the local physical and ecological system places on them.

The opinions, preferences, and social values of the communities, especially underserved communities, that use these natural resources should be considered in early planning and stakeholder engagement so conflict can be avoided (such as peak tourism seasons) and managed through engagement with the local community and special interests. The key is to keep interested parties informed about the need for the TLP project and when major milestones can be expected and to manage expectations about site conditions. As described in Section 2.1, the early formation of a stakeholder working group is a significant part of ensuring a successful TLP project with minimal public concern.

Funding sources should be identified early in the project. Sometimes funding is initiated before a project is identified. Sometimes one or more sites are identified and then funding mechanisms are sought. A well-established stakeholder group may be able to leverage multiple lines of funding to achieve project goals and requirements, not only for the design and implementation stages but also for the adaptive management stage. In some cases, local environmental groups can be tapped to assist with project monitoring.

As discussed earlier, TLP projects are also applied in open-water settings along some regions of the country. In the two Mobile Bay open-water TLP projects discussed later, the formation of a stakeholder group was essential to the ultimate success of the projects. USACE–Mobile District's Mobile Bay Regional Sediment Management—Watershed Management Study recommended establishing an interagency working group to develop a sediment-management strategy. After the Mobile Bay Interagency Working Group was organized, the following goals were set:

- Develop short- and long-term in-bay placement strategies.
- Use environmentally accepted alternatives for beneficial uses of DM.
- Identify, evaluate, and use new and existing engineering techniques and management models and tools to evaluate alternative management options.

The Mobile Bay Interagency Working Group's initial meeting was in February 2012. The in bay TLP project was allowed to proceed approximately two years later, and other beneficial uses of DM, such as filling in a depression in the bay and restoring wetlands, were also implemented (Parson et al. 2015).

2.2.6 Regulatory Context

TLP project sites typically must adhere to federal, state, and local regulations. Wetlands and open-water areas require special permits and certifications in addition to those of a typical construction project. USACE and other federally funded TLP projects are required to comply with the National Environmental Policy Act of 1969 (NEPA; Public Law 91–190, 83 Stat.852, enacted 1 January 1970, 42 U.S.C. §§ 4321–47) whether they are part of navigation maintenance dredging, an ecosystem restoration project, or an effort to mitigate wetland impacts.

In general, regulatory agencies require TLP project applicants to provide documentation of anticipated changes in habitat type and site degradation; details of the design and construction plans, including plans to handle damages from construction; and a monitoring and adaptive management plan. Project sponsors or applicants other than USACE must obtain regulatory approval from USACE and a host of other entities. Although USACE does not issue permits for its own projects, USACE should provide the level of information and documentation that its permitting regulations require from other entities.

NEPA requires regulatory approvals or concurrence from the U.S. Environmental Protection Agency (EPA) or its state designee and from the National Oceanic and Atmospheric Administration (NOAA) Fisheries, the U.S. Fish and Wildlife Service (USFWS), relevant state agencies, and local governments. Which other agencies get involved depends on the project's location (e.g., state or federal departments of transportation for projects near highways or roads and local mosquito-control boards for wetland projects). State and local permitting varies in terms of the regulations, permit needs, and agencies, but many states require permits to discharge fill into wetland areas and permits to protect natural and cultural resources and water quality. In many locations, state permitting for projects is done concurrently with federal permitting to reduce the regulatory burden and to ensure consistency across permitting agencies. States may have additional requirements for actions on state-owned lands. This is particularly pertinent to TLP projects because in many states coastal areas below mean-high-tide or mean-low-tide elevation are owned by the state. As follows are some of the federal laws that pertain to TLP projects:

- **Coastal Zone Management Act (CZMA)—**The CZMA of 1972 (Public Law 92 583, 86 Stat. 1280, 16 U.S.C. §§ 1451–64, Chapter 33) was established in recognition of the importance of and challenges to continued growth in the coastal zone. From this act, the Coastal Zone Management Program administered by NOAA's Office of Ocean and Coastal Resource Management was created. The program aims to protect, restore, and responsibly develop the nation's coastal zones to ensure the oceans and coasts remain healthy and thriving environments. Consistency with the CZMA and associated permitting is administered by states, and requirements should be determined according to the state-specific implementation of the CZMA. A list of federal consistency by state is available online at https://coast.noaa.gov/czm/consistency/states/.
- **Endangered Species Act (ESA)—**The ESA of 1973 (Public Law 93 205, 87Stat. 884,16 U.S.C. §§ 1531–44 and 15 Code of Federal Regulations, Part 930) requires federal agencies to ensure that any action they authorize, fund, or conduct is not likely to jeopardize the continued existence of any threatened or endangered species and will not destroy or adversely modify critical habitat. Such projects may require consultation with the USFWS and NOAA Fisheries under Section 7 of ESA. Many states also regulate threatened and endangered species according to their own threatened and endangered species lists.
- **Magnuson-Stevens Fishery Conservation and Management Act (MSA)—**The MSA of 1976 (Public Law 94 265, 90 Stat. 331,16 U.S.C. §§ 1801–84) governs marine fisheries management. One component of this management is the determination of Essential Fish Habitat (EFH). The act defines EFH as "those waters and substrates necessary to fish for spawning, breeding, feeding, or growing to maturity" (P.L. 94 265, at 7 [1976]) as determined by NOAA Fisheries or regional fishery management councils.

- **Marine Mammal Protection Act (MMPA)—**The MMPA of 1972 (Public Law 92 522, 86 Stat. 1027, 16 U.S.C. §§ 1361–62, 1371–89, 1401–07, 1411–18, 1421–21h, 1423–23h), provides several species of marine mammals with protections from take, including harassment, hunting, capturing, collecting, or killing in United States waters. TLP projects that are anticipated to result in a take of marine mammals require permitting.
- **Rivers and Harbors Act of 1899 (RHA) Section 10 Permit—**The RHA (33 U.S.C. §§ 401–26p) includes a provision, at Section 10 (33 U.S.C. §§ 403, 30 Stat. 1151), that any work in or affecting commercially navigable waters of the United States requires a permit from USACE. Such work includes dredging, channelization, excavation, filling, and construction of piers, breakwaters, bulkheads, revetments, power transmission lines, aids to navigation, and sewer outfalls over commercially navigable waters. Depending on state regulations, the Section 10 permit application may be completed as part of state permit submittals.
- **Clean Water Act (CWA) Section 404 Permit—**The CWA (Public Law 92 500, 86 Stat. 816, 33 U.S.C. §§ 1251–1387) includes a provision, at Section 404 (33 U.S.C. §§ 1344), that states the discharge of dredged or fill material into waters of the United States requires authorization. Several types of permits are available to authorize the discharge of dredged or fill material into waters of the United States, including wetlands and navigable waters. In general, proposed projects may be authorized under three types of permits: Nationwide Permits (NWPs), Regional General Permits, or Individual Permits. In general, NWPs provide a streamlined authorization mechanism for minor projects that are anticipated to have minimal adverse effects on the aquatic environment. TLP projects may fall under NWP 27 (Aquatic Habitat Restoration, Enhancement, and Establishment Activities) or NWP 54 (Living Shorelines) depending on the project details and potential impacts.
- **CWA Section 401 Certification—**Under Section 401 of the CWA (33 U.S.C. §§ 1341), any federal action that includes discharges to wetlands or waters under federal jurisdiction must obtain state certification of compliance with state water quality standards. Section 401 authorizes states to review and approve, set conditions on, or deny all federal permits or licenses that have the potential to result in a discharge to state waters, including wetlands. Generally, the state or an authorized Tribal government is responsible for issuing Section 401 water quality certifications (WQCs) where a discharge would originate. A 401 WQC is required for any federally permitted or licensed activity that may result in a discharge to waters of the United States.
- **NEPA—**Projects that use federal funding and projects that require a federal CWA Section 404 Individual Permit must also complete NEPA documentation, such as a categorical exclusion, environmental assessment, or environmental impact statement. These documents analyze the potential environmental impacts of a proposed TLP project. Some states, including California and Washington, have their own environmental policy act that may require additional or concurrent environmental analysis and review.

- **National Historic Preservation Act and Other Cultural Resources Permitting—**Under Section 106 (16 U.S.C. §§ 470f) of the National Historic Preservation Act of 1966 (Public Law 89-665, 16 U.S.C. §§ 470a to x-6), a federal project sponsor is charged with providing the State Historic Preservation Officer (SHPO) and applicable Tribal Historic Preservation Officer (THPO) opportunities to comment on the effects of a proposed project on historic properties listed or eligible for inclusion on the National Register of Historic Places. The SHPO and THPO have the responsibility to determine those effects and consult to avoid, minimize, or mitigate the adverse effects. In some states, actions undertaken by the state or on state land are also subject to permitting and consultation requirements to protect cultural resources. Nonfederal applicants may be designated responsibility for Section 106 permitting if other federal permits are required, but those requirements are sometimes undertaken by the permitting agency.

Almost every state regulates activities in wetlands or waterways to some degree, and wetlands may also be regulated by local jurisdictions. Some states, such as Maryland, have been granted a general programmatic permit approval by USACE to review minor activities in wetlands on behalf of USACE. Other states have a process for issuing state and federal wetland permits jointly.

Raposa et al. (2020) provide a general step-by-step guide for permitting wetland TLP projects that consists of the seven steps (see the “Step-by-Step Guide for Permitting Wetland TLP” box). The authors emphasize that, while their guidance is by no means exhaustive, “the ultimate goal is to ensure that when TLP projects are considered, the permit hurdles are identified early on” (Raposa et al. 2020, 22). As the planning process evolves, regional regulatory agency offices should be contacted, and the authors provide examples of links in a permitting table in their document. Involving regulatory agencies early and often throughout the design process is highly advisable.

Step-by-Step Guide for Permitting Wetland TLP

Step 1: Determine which permits are needed.
Step 2: Clarify project goals.
Step 3: Develop a clear picture of existing conditions.
Step 4: Design project and determine construction sequencing.
Step 5: Outline potential impacts.
Step 6: Explore different mitigation measures.
Step 7: Establish a compliance monitoring plan.

Source: Raposa et al. (2020)

2.3 Objectives, Constraints, and Performance

After assembling the project stakeholder group, the most critical step in planning a TLP project is developing project goals and objectives and identifying the related constraints and success criteria. The goals and objectives should relate directly to performance metrics that will determine project success. Considering during the planning stage how to measure project performance, both immediately after implementation and in subsequent years, is helpful when the project moves into the design phase, where performance metrics can help dictate design criteria. Clearly defining project constraints helps the project team limit the array of project solutions and prevents the team from adopting unattainable objectives. The following sections detail considerations related to goals.

2.3.1 Goals and Objectives

Initial goals for TLP projects may be broad and general; however, they should evolve to become more specific and well defined as the project itself becomes more defined. Specific, clearly defined objectives are critical to ensure that the ensuing design and construction processes result in a project that meets the project goals.

Specific goals and objectives are critical communication tools; successful wetland and open-water TLP project teams may be large and members' backgrounds diverse. Having clear objectives helps ensure the project moves through the planning, design, construction, and monitoring and management phases with a definite end in mind. But it is also important to balance the restoration objective with the need to find a placement site (for a dredging project), noting in particular that some projects may not be a good match. Thus, project goals need to be flexible and reasonable according to the current state of the larger aquatic system. In addition, expectations of various stakeholders will also need to be considered and managed. For example, a project goal may be the restoration of a degraded marsh so it will provide nesting and foraging habitat for migratory birds. The specific objectives for the project, then, may be to produce a system with 75% high marsh and less than 10% open water according to the optimal habitat for a targeted nesting bird species. But this goal may not be reasonable if other marshes in the estuarine system consist of wetlands dominated by low marsh. Goals and objectives should be refined until they are consistent with local conditions and, therefore, have a greater chance of success. For example, the project team may determine TLP alone is insufficient to meet restoration goals; in that case, pairing TLP with other restoration measures, such as edge protection or invasive species control, may be necessary.

By their nature, TLP projects involve a number of stakeholders with their own motivations, missions, and authorities. The goals and objectives of these projects, then, will reflect those of the stakeholder group involved. To ensure that conflicting objectives do not hinder project success, the objectives should be prioritized (Mitsch and Gosselink 2015). For example, if an agency or a landowner wants to restore a degraded salt marsh with navigational DM, the project must balance that goal with the goals of the dredging project that will supply the DM. The wetland restoration will need to achieve the target elevation across as much of the degraded marsh as possible, and the navigation project will need to clear the channel in an efficient, economic, and environmentally acceptable manner. Similarly, engineering requirements sometimes conflict with ecological or dredging (sediment management) goals.

Goals and objectives may come from outside the project team in some cases. Projects may be funded by programs that impose certain goals and objectives, and some locations may be covered by planning guidelines that define regional goals and objectives that local projects must adopt. In some of these cases, performance and the associated metrics may also be externally defined, although the project team should still ensure such goals, objectives, and associated performance requirements are applicable to the project site. If the project cannot meet the requirements, the project site should be reassessed.

2.3.2 Project Constraints

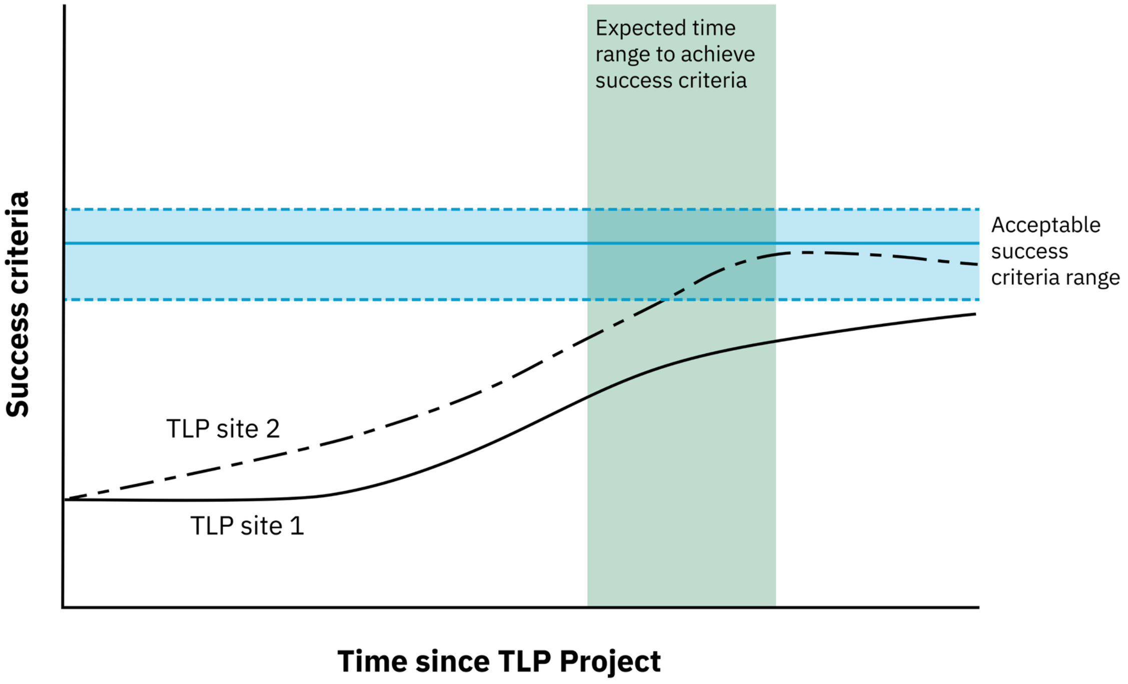
Identifying project constraints may be just as critical as identifying project objectives. Constraints may be dictated by the project objectives or may be externally imposed through, for example, funding limitations or regulatory requirements. Constraints can be useful in limiting the array of feasible project solutions. For instance, the maximum sediment transport distance can limit the number of possible placement sites. Regulatory constraints may include limitations on the timing or rate of both dredging and placement. The project objectives can also impose constraints. If one of the goals is to minimize mortality to benthic organisms, the burial tolerance of the organisms serves as a default placement depth constraint.

Project objectives and constraints can also conflict. If a TLP project uses navigational DM, the placement objectives and constraints may not align with the dredging project's objectives and constraints such as timing, sediment volumes, transport distance, equipment availability, and production requirements. For example, a wetland TLP project may be able to accept up to an average of 15 cm of sediment across the site, but the anticipated dredge volume is significantly greater. In such cases, the navigation project may need to find an alternate placement site for either the excess volume or the entire volume (i.e., not place sediment within the wetland site at all).

2.3.3 Success Criteria and Performance Metrics

Success criteria and performance metrics should be specified at the outset of a project, ideally in collaboration with all stakeholders. Project objectives should be tied to defined success criteria assessable not only immediately after construction and also in subsequent years. Success criteria are aspects of a TLP project that will determine whether the project has met the goals and objectives defined by the project team. Success criteria should be quantifiable using a defined performance metric bound by a clear range of values that are achieved over a defined period (see Figure 2.3 for an example). These success criteria and associated performance metrics will become the foundation for the monitoring and adaptive management of the site after construction. Ideally, objectives should be structured so that success criteria can be examined at multiple points in the project lifespan, not just at fully developed ecological end points that may not be possible to achieve for years. This requires that the team identify short-term (on the order of months to a couple of years), mid-term (on the order of five years), and long-term (on the order of decades) success criteria that are measured using defined performance metrics that can be assessed as needed.

Figure 2.3. *Conceptual Diagram of Critical Success Criteria for a TLP Project*



Note: If a project achieves the acceptable success criteria range within the expected time, the critical success criterion is met (area of intersection of the two shaded zones). In this example, TLP site 1 does not meet the critical success criterion, but TLP site 2 does.

2.4 Sediment Source Identification

If a TLP project location has been identified but its sediment source has not, all possible sources—including area navigation channels, available borrow sites, and CDFs—should be identified during project planning, and the potential for material variability should be noted and must be closely evaluated. Most sediment sources for TLP wetland restorations have been either from a navigation project or a borrow site. Although most sediment sources for wetland nourishment projects in Louisiana have been from borrow areas, most TLP projects have involved navigation projects. Mining CDFs for clean sediment has also been proposed in multiple locations; however, not many projects have been implemented from such sources.

Some basic information should be gathered on the sediment properties, such as grain size distribution and whether the sediment is acceptable from a chemical (contaminant) perspective. Although chemicals in low concentrations but below local standards may be acceptable in some cases, contaminated sediment is generally not compatible with TLP methods. A rough estimate of sediment grain size may be all that is available during the planning stage until more detailed sediment sampling can be done. An approximate sediment texture assessment can also help the project team determine whether the project objectives and constraints are compatible with the sediment available. Very thin, uniform placement depths can be challenging to achieve with sandy sediments, and thicker placements in areas subject to strong currents or waves are not well suited for fine-grained sediments. Finally, it is often desirable for borrow-area sediments to be of similar type and consistency as placement-area sediments.


Mushroom-Style Placement Nozzle for TLP
Source: Sevenson Environmental Services

Chapter 3. Baseline and Data Needs

3.1 Assessing Baseline Conditions

For TLP projects, understanding baseline conditions at the proposed site and a relevant reference site (if a reference approach is employed) is necessary before developing a design. Wetlands and shallow-water environments are dynamic systems, and their ecological function is intricately linked to their environmental conditions. Generally, conditions can be grouped into six categories:

1. Geomorphology
2. Hydrodynamics
3. Soils and geotechnical characteristics
4. Vegetation and macroalgae
5. Biogeochemistry
6. Faunal use

Although every applicable category of conditions should be addressed, conditions related to the critical success criteria defined in the planning stages should be analyzed most closely. In the planning phase, potential no-go issues, such as the potential for contaminated sediments or property issues, should also be addressed. Examination of baseline conditions typically occurs in two phases: the first occurs in the planning phase and may be broad with qualitative and limited quantitative analysis focusing on preexisting data whenever possible, and the second occurs in parallel with the initial stages of the design phase when quantitative, site-specific data are required.

3.1.1 Planning Phase Site Investigation

During the planning phase of a project, site investigation may be limited to desktop analysis of the six categories of conditions. Generally, desktop analyses use existing information and analyses of the TLP site. Table 3.1 lists some of the common sources of data to support these analyses. For wetland TLP, delineation of low or degraded marsh areas using a combination of elevation data and aerial photography, especially in the near-infrared bands, can provide order-of-magnitude estimates of DM needs and capacities at the site, which are critical when determining sediment and dredging needs. Similarly, available estuarine and marine-bottom bathymetry, substrate type, and shoreline change data can be used to identify areas of erosion and deposition. Habitat quality can be assessed by historical trend analysis focusing on vegetative loss, edge erosion, and the presence of pools and pannes and by forecasting the potential for future losses. National databases such as the National Wetlands Inventory (fws.gov 2021) and the National Estuarine Research Reserves (NOAA OCM, n.d.) may also provide useful information. A site visit may be warranted before proceeding with further analysis or design if data are insufficient to determine the site's viability. But detailed data collection is best done when a project is likely to move forward to avoid potentially expensive efforts at sites that are unsuitable.

Table 3.1. *Planning Phase Site Investigation Resources*

Resource	Description and link
ERDC TLP Database	Information and case studies on various TLP projects around the United States https://tlp.el.erdc.dren.mil/case-studies-by-location/
ERDC NIOT	Database for nature-based solutions User's Guide: https://ewn.erdc.dren.mil/wp-content/uploads/2021/02/NIOT-UsersGuide.pdf Web Application: https://www.arcgis.com/apps/MapSeries/index.html?appid=18079f5b628b4a7bb52acbe089d80886#

Table 3.1 *(cont.). Planning Phase Site Investigation Resources*

Resource	**Description and link**
Louisiana Sand Resource Database (LASARD)	This database is used to manage, archive, and maintain geological, geophysical, geotechnical, and other related data pertaining to the exploration of sand and sediment in various environments. https://coastal.la.gov/project/louisiana-sand-resource-database-lasard/
Coastal Resilience Website by TNC	National database on case studies of natural shoreline infrastructure https://coastalresilience.org/nature-based-solutions-and-the-fema-community-rating-system/
NFWF CREST	Siting tool for resiliency projects https://resilientcoasts.org/#Home
NOAA Green Infrastructure Effectiveness Database	Compilation of literature resources documenting the effectiveness of using green infrastructure to reduce impacts from coastal hazards https://S/gisearch/#/search
Strategic Online Natural Resource Information System (SONRIS)	State of Louisiana's online mineral resource database, which gives information on oil, gas, and injection-well information; state land leasing; groundwater information; and more https://www.sonris.com/
CPRA Coastal Information Management System (CIMS)	Central access point for information on CPRA's protection and restoration projects, and ongoing initiatives https://cims.coastal.la.gov/
USACE–Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) database	USACE coastal mapping and charting database https://www.sam.usace.army.mil/Missions/Spatial-Data-Branch/JALBTCX/
USACE Sediment Analysis and Geo-App (SAGA) web mapper and database	USACE navigation sediment database https://navigation.usace.army.mil/SEM/Analysis

Table 3.1 *(cont.). Planning Phase Site Investigation Resources*

Resource	Description and Link
U.S. Geological Survey (USGS) usSEABED data	Database on U.S. seabed Overview: https://www.usgs.gov/programs/cmhrp/science/usseabed Web application: https://cmgds.marine.usgs.gov/usseabed/
Maryland Department of Natural Resources BUILD	Mapping tool developed to assist governmental and nongovernmental entities to synchronize the use of DM from navigation channels with projects that reduce flooding and storm risk impacts. Planning Process: https://dnr.maryland.gov/ccs/Documents/BU-PlanningProcess.pdf Web Application: https://maryland.maps.arcgis.com/apps/MapSeries/index.html?appid=d0c99b4a4b564a6a9e8d6ff665c7b2d1
NOAA Nautical Charts	National bathymetry data set https://nauticalcharts.noaa.gov/
Historic Aerials	Historic aerial database https://www.historicaerials.com/

Understanding some basic information about the sediment source is also critical in the planning and early design phases. Some sediment sources may be well understood, such as routinely dredged navigation channels. In those cases, relying on the characteristics of previously dredged sediment may be sufficient. The Sediment Analysis and Geo-App (SAGA) web mapper and database (USACE, n.d.), part of the USACE Sediment and Ecosystem Management portion of the Navigation Data Portal, provides locations and physical, chemical, and biological results from past sediment sampling. For state or locally maintained channels or marinas, agency headquarters or area offices may have to be contacted. In the case of infrequently dredged channels or borrow sources, some sediment samples may be necessary to characterize the sediment before moving forward with the project. Greater concern about contamination will warrant a more thorough investigation prior to the design phase, when there is still time to investigate alternative sources of material. The Maryland Department of the Environment's innovative sediment reuse guidance offers advice on using dredged sediments in a beneficial manner (MDE 2017).

Thoroughly investigating such data and information sources can help optimize resources and determine which kinds of data and how much additional data will be required. The following sections describe aspects of data collection as they relate to project design criteria. Both planning and design phase data needs are addressed.

3.1.2 Defining Existing Geomorphology and Topography

Geomorphology is the shape, configuration, size, and position of the TLP site on the landscape. For wetland sites, geomorphology also describes the drainage network (i.e., tidal channels in salt marshes or distributary networks in riverine floodplain wetlands) as well as the size, location, and distribution of topographic features such as high spots and pools. For open-water sites, geomorphology describes the size, location, and relative relief of the existing bottom and the location of the TLP site relative to existing infrastructure, uplands, and deep water.

The geomorphology of a site and the characteristics of the native sediment help define the shape of the TLP site after construction; often, sediment placement does not completely reshape the landscape. Fine-grained sediment slurries frequently used in TLP projects produce uniformly sloped surfaces and result in thicker sediment deposits in lower areas of the landscape and relatively thinner sediment placement deposits in higher areas. This effectively results in soft, low-strength ground or bottom surface unless coarse-grained sediment (sand) is used (which tends to mound near the point of discharge) or containment structures (discussed later in this document) are used to control finer-grained sediment.

Some sediment loss and redistribution are to be expected and may even be desirable in shallow open-water sites and areas in the lower intertidal zone, where waves and currents can move freshly deposited sediment. Examining historical wetland geomorphology can reveal the density and planform of natural channels and pools at sites that may have been hydrologically altered by the construction of ditches for drainage or mosquito control. Similarly, examinations of historical bathymetry can help determine the location of old channels and persistent shoals or deep areas. And if a reference site is used, characterizations of the geomorphology can be used to determine what the final geomorphology of the TLP site may ideally look like after construction.

Vegetative, hydraulic, and terrain surveys of nearby reference marshes are a good starting point to gauge the site conditions to which the restored mash may naturally return over the long term. In the planning phase, topographic investigation of the site relies on existing data. For areas above sea level, current digital elevation models (DEMs) are typically available from several federal agencies. Although a DEM resolution of 1.64 to 3.28 ft (0.5 to 1 m) is usually acceptable for the planning phase, more detailed surveys are required during project design. Some states collect their own topographic data and may have more up-to-date information than national agencies.

Modern DEMs typically rely on lidar, a remote-sensing method that uses a pulsed laser to measure ranges; however, when using lidar, the metadata should be reviewed to determine the laser type and postprocessing assumptions used in coastal areas. Coastal wetlands, intertidal areas, and some shallow subtidal areas are typically covered by the National Coastal Mapping Program or several NOAA- or USGS-initiated mapping efforts. For shallow-water areas and wetlands in the intertidal zone, lidar may be helpful. Both the National Coastal Mapping Program and NOAA provide some topographic bathymetric lidar measurements made with a green laser capable of penetrating clear, shallow water. For sites that are partially or completely inundated some or most of the time, having some idea of shallow-water depths may reduce uncertainty before field surveys can be conducted. Traditional bathymetric data collected by hydrographic surveying are required in open-water areas below the limits of topographic bathymetric lidar. NOAA's National Centers for Environmental Information maintain a bathymetric data viewer that includes NOAA National Ocean Service Hydrographic Data surveys in DEM format and raw, single- and multibeam survey data. Other sources of bathymetric data are navigational charts and, possibly, state data.

Equally important is an investigation of historical elevation and bathymetry data and imagery to determine the magnitude of any changes in the wetland or bottom surface. The earliest historical data will likely be low-resolution, black-and-white images or relatively coarse sounding data, but manual delineations of shorelines and open-water areas in wetlands and along water edges may be available. Despite the well-documented issues with lidar accuracy and bias in wetlands and shallow water (Medlock, McKenna, and Callahan 2018), simple calculations within a geographic information system (GIS) framework considering typical lidar error can give an order-of-magnitude estimate of the range of a TLP site's sediment capacity and how it is spatially distributed. This exercise can also help screen potential sediment sources by estimating how much sediment they can provide compared to how much the receiving site can take. The precision and accuracy of topographic and bathymetric data should be documented in the metadata with the reported error carried through any capacity calculations. Sediment volumes resulting from navigational dredge projects are often large and may exceed the capacity of a single TLP project. It can be useful to construct multiple TLP projects in close proximity simultaneously to take advantage of the navigational dredge project volume, preferably under a single permit application. Multiple permit applications complicate projects and increase planning costs, potentially to the point of making them infeasible.

Once a project enters the design phase, surveys that are more accurate and precise are necessary for both the placement site and any reference sites. The accuracy and precision requirements for the wetland topographic data are a function of the elevation and inundation requirements of the target wetland plant communities. In salt marshes, these vegetation community zones scale roughly with the tide range. For sites with high-tide ranges (higher end of mesotidal to macrotidal settings), lower-elevation accuracy and precision may be acceptable. For microtidal sites, greater precision is necessary. At sites with very small tide ranges, wind-driven events can also affect long-term water level dynamics, so tide range alone may not be enough for estimating vegetation-community elevation ranges. Where vegetation is very sparse, clear-water aerial topographic bathymetric lidar surveys may be sufficient, but for most sites, traditional survey methods that use an on-the-ground team will be required. Real-time kinematic (RTK) GPS systems are used predominantly (and to a lesser extent Total Station and leveling) to conduct these surveys. CPRA's *Marsh Creation Design Guidelines* (CPRA 2017d) presents a contractor's guide to standards of practice for performing topographical, construction, and monitoring surveys in the Louisiana coastal zone. Although specifically written for CPRA contractors working in Louisiana, these standards of practice provide valuable guidance for surveying in wetlands. Recommended transect and point density varies widely depending on site size and heterogeneity—recommended transect spacing ranges from 100 to 500 ft (30.48 to 152.4 m) with points measured every 25 ft (7.62 m) or where elevation changes more than 0.5 ft (0.15 m)—yet this type of information can serve as a starting point for subsequent discussion and refinement to site-specific conditions (S. Douglas, NJDOT OMR, pers. comm., June 2017).

Some wetlands may be instrumented with surface elevation tables (SETs) to measure subsidence and accretion processes (Lynch, Hensel, and Cahoon 2015). SET sites can be a valuable source of data to determine the elevation dynamics of the wetland. SETs should also be augmented by surveys, when available. Additional site-specific geotechnical data, including index properties and bearing-capacity calculations, can be used to determine how surface and subsurface layers may respond differently to additional loading from TLP sediment and equipment.

The survey precision requirements may be more relaxed for open-water TLP projects because, unlike land applications, there are no tight tidal-range-elevation tolerances to be dealt with in open water for vegetation reestablishment—unless SAV is present and may require good characterization. Bottom elevation is more dynamic absent the stabilizing effects of vegetation and macroalgae, however, s o dedicated bathymetric surveys are advised unless the existing bathymetric data are very recent and no significant storm events occurred between the time of data collection and the project. Recommended guidance, quality control and quality assurance (QA/QC), and standards for hydrographic surveys are available in the USACE *Hydrographic Surveying* Engineer Manual (EM 1110-2-1003; USACE 2013a). In very shallow areas such as wetland pools, pannes, or mudflats, neither land-based nor bathymetric survey techniques or platforms may be ideally suited. In these cases, creative solutions to obtain sufficient bathymetry may be required, such as manual soundings taken with a lead line or survey rod or a portable echo-sounding system deployed from a shallow-draft watercraft (e.g., kayak or airboat) to provide more accurate measurements. Portable unmanned surface vehicles have recently been used more for hydrographic surveying, but they have had problems operating in high winds. Conducting such surveys around spring high tide or daily high tides may provide better access to sites in tidal systems.

In areas of shallow open water and in wetland systems adjacent to open water, knowledge of the nearshore bathymetry is also useful. In wetland areas (pools, pannes, etc.) that may be filled with sediments, current bathymetry is critical for determining the capacity of the site. At the wetland edge, the nearshore topography and bathymetry may be critical to establish pipeline corridors and access routes for equipment and personnel and to determine the feasibility of containment structures if the wetland extent is expanded beyond the current footprint.

The effect that a soft bottom will have on measuring accurate and repeatable depths should be considered when selecting a survey system for use in waterbodies with an unconsolidated bottom (i.e., fluid mud). When the upper sediment layer is not well consolidated, the three major depth measurement methods used (sounding pole, lead line, and acoustic echo sounding) will generally not correlate with one another and my not give consistent readings from one time to the next when the same type of instrument or technique is used (EM 1110-2-1003; USACE 2013a). Depth measurements by manual methods (sounding pole or lead line) may vary depending on probe weight, probe surface area, and insertion velocity, whereas the accuracy of acoustics methods primarily depend on the echosounder sensitivity setting and the acoustic transducer frequency. Higher frequencies (+200 kilohertz [kHz]) will generally reflect off lower-density mud (e.g., lutocline [water–muddy water interface]), while lower frequencies (approximately 24 kHz) will penetrate deeper into the mud.

3.1.3 Characterizing Existing Sediments and Substrate

In the planning stages of projects at sites above mean sea level and subaqueous sites that have been included in the latest coastal soils mapping efforts, consulting the U.S. Department of Agriculture soil survey (USDA, n.d.) may be sufficient to describe the expected soil conditions. The soil survey provides an expected range for soil grain size, organic content, salinity, and bulk density and an engineering assessment of the site's suitability for a variety of uses. If there may be a potential nutrient or contamination issue, further analysis in the planning stages may be warranted. The soil survey can also indicate changes in the soil at deeper depths, which may indicate how the wetland will respond to the additional load of the placed sediment.

A few sources of sediment data for subtidal areas are available. NOAA has created benthic habitat maps of critical ecological resources and benthic substrate types for some areas (NOAA NCCOS, n.d.). Historical sediment coring data collected by USACE and contractors are stored in the Flood Decision Support Toolbox (USGS 2021). USGS usSEABED data (USGS 2020) are available for many coastal and major estuarine areas and include sand distributions; grain-size variations; mud, sand, and rock distributions; and estimates of erodibility of sediments. The USGS East Coast Sediment Texture Database further classifies marine sediment textures (USGS 2014). Most USGS sites are in deeper water, so local data should take precedence.

In the design phase, sediment coring in the placement area and in the sediment source area is considered prudent. Typical sediment properties of interest are the grain-size distribution, organic content, salinity, moisture content, and bulk density The number of cores and samples required to characterize a site varies with site size and heterogeneity. If a site is significantly heterogeneous, stratified sampling may be warranted to characterize the full range of variability. One concern often raised in TLP projects is the need to address iron sulfide (FeS) and associated low pH issues when placing marine sediments in an aerobic zone. Data from a marsh creation site in Chesapeake Bay and laboratory studies indicate the importance of maintaining tidal hydraulic connectivity in restored wetland sites that are prone to FeS development, facilitating the removal of sulfuric acid and moderation of redox conditions until the site self-mitigates over time (Berkowitz et al. 2021; Cornwell et al. 2020). At wetland sites, samples should be taken from the soil surface layers, where many plant roots occur, and from deeper cores if consolidation modeling will be conducted. Although not every wetland TLP project has included a consolidation analysis, it is a recommended analysis for wetland-creation and marsh-nourishment projects The magnitude of consolidation will be a function of the thickness (and type) of placed materials as well as the nature of substrate soils and underlying stratigraphy. For some sites, consolidation could exceed several feet over time, and, hence, such settlement effects should be considered in overall project planning.

Some settling and consolidation analyses may also be required if potential erosion of material, either intentional or not, is of concern. Some TLP placements are intentionally dissipative; others may intend for the sediment to remain in place. The settling and consolidation processes will affect the overall erodibility of the material after placement and should be coupled with analysis of the site hydrodynamics to determine the material's fate and transport over time under different conditions.

Soil and sediment sampling procedures may be predetermined at some sites, but at others it will be up to the project team to determine an acceptable sampling scheme. Communication with regulatory agencies before committing to a sampling scheme is advisable to prevent having to repeat or increase soil and sediment sampling at a later date. For chemical analyses, composite sampling may be acceptable and can reduce testing costs. In soils with high organic content, larger organic particles may be classified as sands. In these cases, it may be helpful to conduct the grain-size analysis after the loss-on-ignition testing procedure used to quantify the organic content. This can reduce the likelihood that the grain-size distribution will be biased toward sand particles and give a better representation of the true grain size of the mineral fraction of the soil.

To ensure compliance with the antidegradation standards of CWA Section 401, some states require a like-on-like assessment for mildly contaminated sites (where the TLP placement area and the sediment are mildly contaminated but do not violate EPA or state standards) or for sites where the sediments are sufficiently different from the wetland soil or bottom substrate. When like-on-like criteria apply, the sampling scheme for the soil and source sediments should ensure that enough samples are taken at each location to permit statistical comparisons. It should be expected that the DM will likely have less organic content and may have a different grain-size distribution than the native sediments at placement sites, especially in wetlands. A range of sediment grain sizes have been used in TLP projects, even in wetland environments, and does not seem to affect the long-term trajectory of the project. Indeed, if the environmental conditions at a site change because of natural or human alteration (e.g., becoming more energetic from navigation projects or from erosion of surrounding shorelines), a coarser grain size than the in situ soil or substrate may be preferable.

Geotechnical testing including water content, index properties (Atterberg limits, grain size), bulk density, and strength is critical not only for placement design but also for estimates of long-term surface elevation changes that may result from consolidation. Details on specific measurements related to the geotechnical properties of wetland restoration sites are available in CPRA's *Geotechnical Standards for Marsh Creation and Coastal Restoration Projects* (CPRA 2017b), which provides recommendations on tests and sampling densities for various types of coastal restoration projects. That guidance addresses subsurface investigations, soil boring layout, sampling techniques, laboratory testing requirements, earthen containment dike geometry, slope stability design, and estimated consolidated settlement design.

Soil strength and bearing capacity are important considerations because of the additional loading from added sediment and for equipment and personnel access. Each project team should decide how best to determine whether the soil in a wetland TLP project is strong enough to support low-ground-pressure equipment such as marsh buggies. Ground pressure is the force exerted on the ground by the tires or tracks of a piece of equipment; it is calculated by dividing the equipment's weight by the total area of its tires or tracks in contact with the ground. Low-ground-pressure equipment distributes its weight over a larger area to reduce ground pressure. On some TLP sites, surface impacts from equipment (such as marsh buggy tracks) may take over three years to slowly recover (Harris et al. 2021).

Many wetlands derive a certain measure of soil strength from their network of plant roots, so any direct measures should be conducted in situ rather than from laboratory cores, especially if the soil material is separated from the root matrix. Some TLP projects have not addressed soil strength at all, and others have left it to the construction contractor to determine.

In some cases, a general description of the site heterogeneity and response to foot traffic may be adequate. Poindexter-Rollings (1990, 4) quotes James Walker's (former USACE) rule of thumb, as follows:

> *A very simple test can easily be conducted to give a rough indication of the soil support to be expected from the material in its present condition: a person can attempt to walk on the [DM] surface. A rule of thumb is that if a person can walk on the [DM] surface, then low-ground-pressure equipment can work on it.*[1]

To be more quantitative, calculations can be made to gauge which pieces of equipment can or cannot operate on the TLP site surface or newly placed DM. To determine an individual's ground-contact pressure, divide the weight of someone who walked on the DM surface by the contact area of the sole of one shoe.

Thus, knowing the individuals' weight, the equivalent foot-pressure, and the ground pressure can be computed (see Rush and Rula 1967), which can then be compared to the manufacturer's specifications for various equipment. Any vehicle with an equal or lower ground-contact pressure can probably be used for a single-pass operation in the placement area. Driving multiple times across the same area, accelerating or slowing down, or turning too quickly can destabilize the ground.

This empirical approach gives only a very rough indication of site conditions and thus of potential vehicle mobility, but it should not be used to determine when to initiate operations at a site or to select specific pieces of equipment. This approach only gives tentative guidance about conditions where and when the individual walked and when to conduct an equipment evaluation.

If quantitative data about a site's geotechnical properties are required or desired, there are multiple ways to acquire them, including using standard geotechnical investigative tools such as vane shear tests, pocket penetrometers, and strength testing. Although written for the timber industry, the European Union's *Operations Protocol for Eco-efficient Wood Harvesting on Sensitive Sites* (Owende, Lyons, and Ward 2002) is another source of information about equipment access and potential damage to sensitive soils. Many of the same issues covered also apply to wetland sites. Regardless of how the issue of soil strength is handled, some description of site heterogeneity should be included in contract specifications because wetland substrate characteristics may be highly variable across the site.

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[1] *As quoted per James E. Walker, July 1988, Operations Division, USACE—Mobile District, Alabama.*

Three large manufacturers of marsh equipment (MBI Marsh Equipment, Wetland Equipment Company, and Wilson Marsh Equipment) were contacted to determine whether current practices, protocols, or laboratory tests were used to assess the operability of low-ground-pressure equipment on wetlands. Table 3.2 summarizes their input. Note that the summary does not constitute a recommendation by the U.S. government or the authors.

Table 3.2. *Considerations for the Use of Low-Ground-Pressure Equipment*

Manufacturer and contact	Comments
MBI Marsh Equipment Belle Chasse, Louisiana www.marshbuggies.com Contact: Gary Rodriguez Phone: 504-394-5050	• Mentioned operator experience is critical for safely and efficiently operating low-ground-pressure equipment in open water and on wetlands. • Agreed in concept with the "person walking" rule of thumb.
Wetland Equipment Company Thibodaux, Louisiana www.wetlandequipment.com Contact: Jodi Simoneaux Phone: 985-447-0354	• Mentioned the need for sediment characterization to assess equipment operability on wetlands. • Empirical "person walking" rule of thumb is a good approximation. • Experience is critical to the safe operation of marsh buggies on wetlands. (Note: marsh buggies are amphibious, but swamp buggies are not.) • Operational procedures (such as minimizing turns or using same track in and out) help minimize impacts. • Canada does not allow low-ground-pressure equipment over 2.75 pounds per square in (17.74 pound per square cm) on their wetlands. • Recommended that, for more efficient and safer contracting of these types of equipment, the size of the pontoon should be specified.
Wilson Marsh Equipment Westwego, Louisiana www.wilsonmarshequipment.com Contact: John Wilson Phone: 337-412-2142	• Unaware of any projects that required prior sediment characterization. • Agreed with the applicability of the empirical "person walking" rule of thumb as a general statement but stressed the operator's experience should be applied to site-specific conditions.

Note: Represents three select manufacturers offering low-ground-pressure equipment. For a more comprehensive listing of vendors refer to Hale (2022).

3.1.4 Determining Existing Hydrodynamic Conditions

During the planning of a TLP project, some assessment of site hydrology and hydrodynamics is required. For wetland sites, the components of a general water budget (including tide ranges, velocity regimes, and inundation and drainage patterns, if applicable) should be identified and their relative importance assessed so the most critical contributors to site hydrology and hydrodynamics can be determined. Drainage patterns are particularly important if slurry runoff is a concern that must be mitigated by containment. Wetland sites near the toe of a slope into higher elevation uplands may also experience significant groundwater interactions and freshwater inflows. These interactions will be less likely in wetlands far from upland areas but may be significant in association with barrier islands or other geomorphic features. Tides, water levels, and currents are generally the predominant types of hydrodynamic data required for open-water sites, but wave data may be collected if wave interaction with the bed is determined to be a significant mode of sediment transport. A reference site analysis should be included where applicable and is a must for all wetland restoration sites.

Sources of hydrological data should be determined, including nearby tide gauges, surface and groundwater monitoring sites, and wave gauges. The scientific literature should be searched for any studies conducted at or near the site of interest. The NOAA website "Tides and Currents" (NOAA CO-OPS, n.d.-a) provides access to local water levels, tide and current predictions, and other oceanographic and meteorological data collected at gauge sites. For an estimate of tide range at a site, the NOAA tide-prediction stations provide time and height offsets to the instrumented harmonic gauge sites. NOAA's VDatum software (NOAA, n.d.) can be used to estimate important tidal data, such as mean lower low water, mean sea level, and mean higher high water, at sites that lack gauges. Some site water levels may be a function of not only tides but also riverine discharge or wind. USGS and some states operate networks of water-level gauges in estuarine and riverine environments that may be more representative of the actual water level observed on a wetland site (USGS 2023). Care should be taken when using tidal data sets to ensure that local variants, such as sea-level rise, are also factored into the analysis.

Although water levels control the inundation duration and frequency in intertidal areas, waves and currents affect sediment transport dynamics, especially at shallow depths, wetland edges, and near creek networks. In initial stages, a simple measurement of the maximum fetch length and direction may be all that is required to determine whether wave conditions are severe enough to significantly affect sediment movement during and after placement. In some cases, wave conditions may be energetic enough to consider temporary protective structures for recently placed sediments as they undergo settling and consolidation, and, in some cases, more permanent protective structures may be incorporated into the design.

Direct measurements of hydrodynamic conditions are generally desired in the design phase, although additional data may not be required for small or relatively simple projects or for well-understood sites. For example, if a wetland site has well-understood hydrological conditions and a well-characterized reference site, the elevation range occupied by the desired community may be used as a proxy for hydrological data collection, because wetland vegetation communities reliably zone by inundation time.

Water levels in intertidal areas are not uniform during a tide cycle. The hydraulic gradient in wetlands may follow the creek network or the wetland edge, depending on the marsh elevation and tide range. If a site is small or relatively uniform, one gauging site may be enough, but large and complex sites may require several gauges to characterize water levels. Water-level logger sampling should be frequent enough to capture the site's predominate hydroperiod. (For example, every six minutes is standard for a dynamic semidiurnal tidal site; hourly may be sufficient for a diurnal system.) In sites exposed to significant waves, the placement of wave gauges may be desired. For areas with vegetation or macroalgae, multiple wave gages may be deployed within and at the edges of the vegetation or macroalgae to capture any wave attenuation. If groundwater interactions are of interest, the installation of groundwater wells or piezometers may be warranted. Precipitation data can be collected at sites subject to significant precipitation or sites that may be susceptible to drought, or they may be taken from the nearest weather station. Data collection and modeling may be necessary if open-water TLP is expected to alter waves, currents, or sediment transport patterns or to affect protected ecological resources such as oysters or SAV.

Hydrodynamic modeling may be required for sites that have been hydrologically altered and whose drainage patterns are changing. Enough baseline data should be collected to parameterize models and produce reliable validation and verification data. Clearly understanding the hydrodynamics will also help minimize potential delays due to adaptive management changes required midproject.

3.1.5 Characterizing Existing Ecological Conditions

Characterizing the ecological conditions within and around a TLP area is critical for the project's design, capturing its potential impacts and benefits and informing the postconstruction monitoring and adaptive management. Several recent publications discuss ecological condition assessment of potential coastal wetland sites (VanZomeren et al. 2019 and references therein; Raposa et al. 2020). A representative baseline survey is essential, but the frequency and intensity of postconstruction sampling will depend on the site conditions and project objectives. Specific parameters evaluated will depend on the current condition and the anticipated future condition. A reference location or control site is highly desirable, if available. Care should be taken to capture the full range of each parameter's variability throughout the site under both pre- and postconstruction conditions.

3.1.5.1 Vegetation and Macroalgae

In the planning phase, desktop analyses of vegetation and macroalgae conditions will be limited. Qualitative assessments of historical vegetation cover at a site can be determined using historical black-and-white and true-color images, but near-infrared imagery is optimal for determining vegetation vigor and cover for emergent vegetation. The National Wetlands Inventory may provide some indication of inundation frequency and general conditions expected at the wetland of interest, but often these data are coarse and not routinely updated for site conditions. Vegetation indices derived from near-infrared imagery, such as the normalized difference vegetation index (NDVI) or the enhanced vegetation index, can be used to make comparisons among wetland sites, but these measures may be sensitive to the tide cycle at the time of image capture. A relevant geospatial metric for marshes is the unvegetated-vegetated ratio defined by Ganju et al. (2015), which can give an idea of vegetation cover at a site and is correlated with the net sediment budget on salt marshes. For wetlands dominated by mangroves, general vegetation indices such as the NDVI are also used (Valderrama-Landeros et al. 2018), but mangrove-specific geospatial metrics have also been developed that use satellite imagery to assess mangrove condition (Manna and Raychaudhuri 2018).

If applicable to the project, it is also critical to identify areas of possible SAV, not all of which are mapped. In areas with relatively clear water, possible SAV beds can be identified from aerial imagery. Some locations may have additional sources of SAV data collected through routine surveys or aerial or satellite imagery (e.g., Virginia Institute of Marine Science SAV Monitoring and Restoration Program [VIMS 2023]) but if such data are not available, water clarity does not permit mapping via aerial or satellite imagery, or permitting requirements dictate, a physical survey will likely be required. If SAV is identified in the immediate area of the placement or the dredging area, special measures to prevent sedimentation and increased turbidity, such as the use of silt curtains, will be required, and project boundaries may be relocated to prevent impacts to SAV.

Depending on the project goals, assessments of the distribution of dominant vegetation and macroalgae species cover may be acceptable, but more quantitative assessments of vegetation may be warranted for some sites, especially during the postconstruction phase. Species composition and distribution at the current site should be linked to the elevation and hydrodynamic conditions because those environmental controls will affect species composition and distribution after the restoration. Specific metrics to include in assessments will depend on the site of interest as well as the project objectives. In the design phase of a project, more detailed vegetation and macroalgae surveys are required. It is good practice to conduct vegetation surveys at the same time as topographic and bathymetric surveys so critical vegetation community transitions can be identified. This practice is most useful at sites that use a lower density of survey points, where critical transition zones may be missed using a standard grid or transect spacing. Critical elevations and locations of the transition points from unvegetated to vegetated areas and, in wetlands, the transition from wetland species to upland species or, in some cases, invasive species such as common reed (*Phragmites australis*) can be used to determine design criteria and elevation tolerances. Aboveground biomass is commonly sampled or estimated from other metrics (such as basal area) at restoration sites and is often a success metric for wetland TLP sites. But, belowground biomass may be a more reliable predictor of long-term vegetation vigor at wetland sites.

3.1.5.2 Fauna

Most wetlands and aquatic habitats are critical for a variety of fauna, and state and federal wildlife agencies, such as USFWS, are mandated to manage habitats for certain species or groups of species. These requirements may affect not only a project's goals but also its design, permissible construction techniques, and timing. Restrictions on the timing of proposed in-water and wetland construction activities can greatly affect overall schedules, so time-of-year dredge and placement restrictions should be explored early and often during the planning phase. Although no comprehensive geospatial tools exist to assess faunal use, NOAA provides benthic habitat mapping for some areas (NOAA OCM, n.d.; NOAA NCCOS, n.d.). More comprehensive maps of threatened and endangered species habitats may be available from USFWS and NOAA Fisheries. A desktop assessment of EFH and of federal and state threatened and endangered species, marine mammals, migratory birds, and other unique habitats is also recommended. NOAA's Environmental Sensitivity Index (NOAA OR&R 2023) identifies some sensitive habitat types along shorelines for a variety of species types, including birds and large mammals. Many state marine resources or land and wildlife management agencies also maintain geospatial databases of critical habitat areas.

Many placement sites managed by wildlife organizations will require some quantitative assessment of faunal use. Bird survey protocols are commonly prescribed, but specific methodologies are typically prescribed by the responsible organization or permitting agency and reflect the types and species of birds of interest. Nekton surveys are also common for wetland and open-water placement sites. Nekton usage in wetlands indicate whether the open-water areas adjacent to and within the wetland are well connected and whether the wetland provides the required habitat characteristics. Nekton surveys within open-water placement areas may not be as useful unless the open-water placement was designed to provide a habitat characteristic for a specific type or species of nekton. Again, nekton survey protocols vary and may be prescribed by the land manager or permitting agency. Benthic organisms are directly affected by dredging and placement activities and cannot readily move in response to construction activities (Bolam 2011; Wilber, Clarke, and Rees 2007). Benthic surveys can be useful indicators of site function, as many benthic organisms are food sources for birds and fish, contribute to soil organic matter decomposition, and, in wetlands, are indicators of overall condition (Tong et al. 2013). While traditional benthic sampling protocols can be expensive and time consuming to implement, implementation of underwater camera systems to map and monitor the benthos has been used in conjunction with TLP projects in the past (Norton et al. 2015), and new technologies, such as environmental DNA metabarcoding, promise a more complete picture of benthic ecosystems with increased efficiency (Pawlowski et al. 2022).

3.1.6 Determining Availability and Characterization of Sediments

Characterizing the sediments to be used in a TLP project is crucial. Depending on prior knowledge of a sediment source, it may be prudent to fully analyze sediments before beginning a design-level analysis of the TLP project itself. As mentioned previously, the characteristics of sediment in routinely dredged navigation channels may be well known, and historical data may be sufficient to proceed with analyses of other aspects of the project, but sites that will use sediment from infrequently dredged navigation channels, borrow areas, or CDFs may be best served by a preliminary or full sediment analysis up front. Several wetland TLP projects, including Seal Beach in California and Fortescue in New Jersey, unexpectedly encountered unanticipated conditions in the sediment as it was being placed on the wetlands (Thorne et al. 2019; TNC and NJDEP 2021). Although these situations were adaptively managed, avoiding unexpected conditions during construction is generally preferred. Therefore, if surveys are more than five years old or if environmental conditions have changed (e.g., as the result of a major storm), additional investigations are warranted. If sediment from the borrow source may be contaminated, sediment testing is critical and should be conducted in the preliminary site-assessment stage because contaminated sediment could make the borrow source unusable.

Key sediment characteristics are grain-size distribution, wet and dry density, organic content, pore-water salinity, and constituent analysis required for dredging in a specific area. The presence of significant debris in targeted sediments can complicate dredging and affect construction operations and time lines. If the sediment source is a navigation channel, the volume of sediment that must be dredged can affect the overall feasibility of the project. Given the relative precision required for wetland and open-water TLP projects, the dredge discharge rate may need to be restricted.

Many East Coast wetland TLP jobs were completed by environmental dredging contractors using dredges, on the order of 8 to 14 in (20.32 to 35.56 cm) for the inside diameter of the discharge pipe. Much larger dredges are often used in many major waterways. In Louisiana, where dredges 26 to 32 in (66.04 to 81.28 cm) are usually used, wetland-creation projects are designed to handle large volumes of sediment placed at relatively high flow rates. High discharge rates may not be realistic for smaller sites, and some sediment rehandling may be required to make the project logistically and financially feasible.

The location of the sediment source is often used to match TLP projects with sediment sources. Detailed analysis of potential transportation options—including distance and typical currents during all phases of the tide cycle that may require pipeline management—is required as a project enters the design phase. Increasing DM transport distances increases pumping costs. Typical types of dredges used in the area will inform the analysis of transport routes. Cutterhead hydraulic dredges have been most commonly used in TLP projects, so pipelines were routed from the sediment source to the wetland. But sediment can also be reslurried and pumped off from hopper barges or hopper dredges to the wetland site. Trucks may be used when sediments come from an upland or sediment storage site, but access considerations such as temporary roads can raise concerns (see Sachuest Point NWR TLP project at the USACE TLP website [ERDC 2021a]).

Dredging or environmental windows are periods of the year when dredging and placement activities are allowed because regulators have determined the adverse impacts of these activities can be kept below critical thresholds. Potential windows need to be identified early in the planning process to ensure a project can be completed in the available time. In some cases, overlapping or consecutive windows at the dredging and placement sites will result in a very limited construction season, and construction over multiple seasons may be necessary to meet project objectives. Communicating this issue to the stakeholder group early is prudent because multiple construction seasons may have a greater impact on a sensitive resource than a single season. This situation may provide room to negotiate a project window that will allow more efficient construction. Confounding this issue is the relative scarcity of qualified contractors and specialty equipment that some wetland-nourishment projects require. Together, these limitations can result in lead times on the order of years from project conception to design to implementation.

3.1.7 Other Investigations

Cultural resources, land rights (easements, rights of way, etc.), and infrastructure (pipelines, cables, etc.) are also of interest. Historical and archeological resources should be investigated in a phased survey, overseen ideally by a registered professional archeologist qualified to undertake such studies. A comprehensive archeological and cultural assessment (CARA) survey should follow desktop evaluations of the history of the site and the potential to find such resources there. Other investigations (such as bathymetry, magnetometer, side-scan sonar, and sub-bottom profiler) may be used to aid CARA evaluations. Depending on the evaluations' results, site-specific test digs and observations by a registered CARA professional may be necessary during project implementation.

Land ownership and easement information can be obtained from property searches and surveys at the county level or from the local tax assessor's office or similar. Following the initial assessment, prompt notification of landowners is required to alert them to project-related activities and to seek access, if appropriate. Easements (such as utility corridors) or sensitive habitats (such as oyster or essential fish habitats) should also be mapped as part of this process. Once ownership of the project site and environs is determined, negotiations to obtain site access and storage, if needed, can begin.

Equipment, such as side-scan sonar or magnetometers, can help identify pipelines, cables, utilities, etc. Utility company maps and coordinates of buried lines and structures can be used to locate specific site features. Gas pipelines in the dredging area pose a particular threat to cutterhead dredges, which have ruptured gas pipelines in the past several decades. In one instance, there was loss of life, and the dredges were severely damaged or sunk. Focused site investigations may also be undertaken if there are suspect features along certain sites or areas.

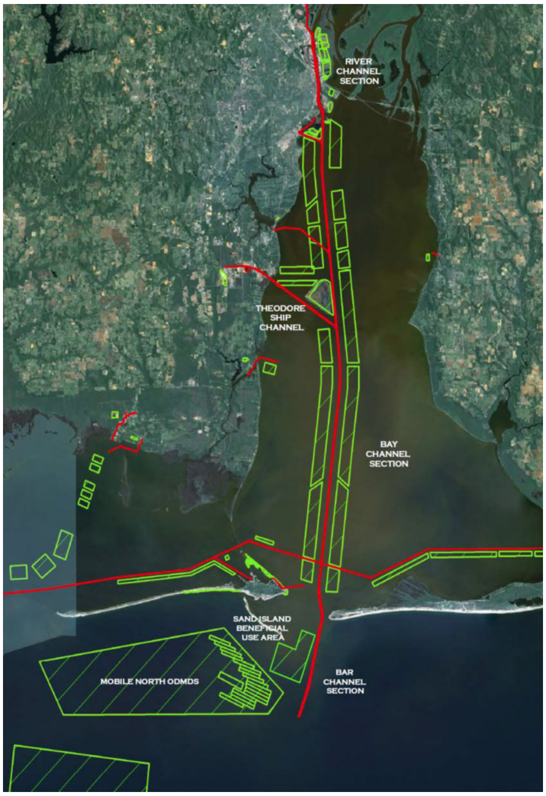
3.2 Project Footprint and Area of Influence

The footprints of TLP projects are broader than the footprints of traditional construction and restoration projects. The TLP project footprint is not only the area on which the sediment is applied but also the adjacent areas that may receive overflow from the placement area, the receiving waters, the intertidal and subtidal areas that may receive the outflows from dewatering, the immediate and adjacent areas around the sediment source, and the larger aquatic system that may be affected by the project. Restoring a severely degraded or former marsh, for example, may alter hydrodynamic conditions and sediment transport pathways in the marsh. It may also affect conditions in the immediate upland areas, potentially changing water levels during floods. Similarly, TLP footprint and area of influence in shallow, open water will be determined by initial design placement area, as well as the range of typical tidal currents and the wave conditions necessary to resuspend bed sediments, and the nature (quantity and direction) of nearshore sediment transport. Any sensitive areas (such as SAV s or oyster beds) downdrift of the placement area should also be considered as part of the area of influence and any adverse effects qualified. CPRA (2017d, 40) refers to this collective larger area that receives ancillary benefits from TLP as “nourishment areas.”

Although the entire area of influence may not require quantification, acknowledging a site’s role in the dynamics of the estuarine or riverine system could be critical to calculations of the site’s benefits and analyses of its long-term sustainability and resiliency. In this regard, a regional sediment budget with sufficient scale to determine the net fluxes and direction of sediment movement before a TLP project is initiated is especially helpful. Louisiana’s 2017 coastal master plan, for example, takes a regional-scale approach to coastal risk reduction and restoration by relying on wetland restoration, including TLP, to achieve systems-level goals. The area of influence of any project that is part of the master plan, consequently, extends far beyond the project’s footprint.

Open-Water TLP Application

Figure 3.1. *Mobile Bay Historic Open-Water Placement Areas*



Source: USACE–Mobile District

The environmental consequences of not adequately characterizing the area of influence of a DM placement strategy, including TLP, may take years to manifest. For example, the Water Resources Development Act completely changed the dredging and material-placement practices in Alabama's Mobile Bay by requiring all material dredged from the bay channel to be placed in the open ocean south of Dauphin Island (see Figure 3.1), as much as 40 miles (64.37 kilometers [km]) from the north end of the bay (USACE 2013b). This meant maintenance dredging would be conducted exclusively by hopper dredges, at a cost of about \$6 per yd^{3} (\$7.80 per m^{3}). Each year since 1986, approximately 4 million yd^{3} (approximately 3 million m^{3}) of maintenance material have been removed from the bay channel and placed in the ocean (Parson et al. 2015). The effect of this sediment loss could be seen in the recession of wetlands and SAV beds in the north and west portions of the bay (Byrnes, Berlinghoff, and Griffee 2013). In-bay TLP was once again permitted, in 2012, after the long-term consequences of neglecting the project's area of influence became evident.

Lateral TLP Spray being Tested via the Sediment Distribution Pipe
Source: ERDC

Chapter 4.
Engineering Design

The structure of this chapter generally follows the phases of the engineering design process. Although the process is presented as a linear progression from concept to final design, the exact order of tasks will depend on the project's goals and requirements. Some design steps may proceed concurrently while others must wait on the completion of prior steps; preliminary analysis of the baseline project conditions can proceed concurrently during the conceptual design phase, for example, but intermediate and final design phases can only proceed once critical data needs are addressed. Regardless of the order in which the design proceeds, there are key design aspects that should be considered during the process. These considerations are discussed here, and a checklist is provided in Appendix B.

4.1 Design Stages

Once a project team decides to proceed with a TLP project, the development schedule should be determined. This will include not only the design schedule and placement time frame but also the expected total recovery time frame of the wetland or subaqueous bottom following placement. Once the schedule is known, the restoration needs can be matched with existing and future DM sourced from nearby projects, or another sediment source can be identified. Either way, early identification of the sediment source is critical to the project schedule. Although the design process for TLP projects is similar to that for other earthwork projects, TLP projects that rely on DM for sediment are essentially two projects: a TLP project and a dredging project. The engineering phases for dredging and the placement should align as much as possible so that both projects are ready for implementation at the same time. This design process requires a multidisciplinary approach that can involve a wide variety of professionals, including a variety of science and engineering specialties, all working to design documents (including technical specifications, engineering drawings, cost estimates, measurement and payment clauses) that will enable the contractors to bid and construct the project.

The following are the typical phases of engineering design for TLP projects:

- **Conceptual (10%–15%) Design—**This is mostly equivalent to the development of a master plan to implement the project, focusing on overall design goals and success criteria and the path to get there. Key conceptual project features are developed; a conceptual-level cost estimate is also often developed. These design documents are used to evaluate the technical and cost feasibility of different alternatives and potential funding sources for the project if they have not already been secured.
- **Preliminary (30%) Design—**At this stage, site-specific data are incorporated into the engineering analysis and the design is further developed. A data gap analysis is conducted to identify any critical data that may be missing so they can be collected in the field. Preliminary plans and a list of technical specifications are also developed. An updated construction cost estimate, which should indicate a reduced contingency factor, is developed.
- **Intermediate (60%) Design—**This is an optional design stage in which the plans and specifications are advanced much further with associated level of engineering design. Typically, this is also when processes, such as value engineering (to identify high-cost items with a view to reducing costs) and a constructability review (to identify costly or infeasible construction elements that can then be optimized), are implemented. This stage also aids early engagement with the industry not only to obtain feedback on data and design but also to let the industry know about the design concepts and, more importantly, the construction time line for the project. Project permit applications are usually submitted at either the preliminary or the intermediate design stage of a project, depending on agency criteria and preference, and on the level of design details that are requested. Any early regulatory or agency input is also incorporated into the design during this phase.

- **Prefinal and Final (90% and 100%) Design—**At this stage, design reviews are obtained from senior managers at multiple agencies and from stakeholders to finalize the engineering design. Any permit conditions stipulated by the agencies are also incorporated into the design at this stage. Final estimated quantities; design specifications, such as pipeline corridors and marsh access; staging areas; restoration plan; and other relevant details are developed during this phase of design. Contingencies at this stage should be minimal and should reflect uncertainties such as market factors and material variability in the field. Project certifications and permits are required for both dredging and placement, and prefinal design drawings are typically required to obtain these documents. Once the regulatory reviews are complete, the revised version of the prefinal design becomes the final design. Plans and specifications are also final and stamped or sealed at this time.

Note that the conceptual, preliminary, or intermediate design stages may be combined for some projects, depending on the level of site knowledge, available design and equipment details, regulatory and owner preferences, and funding constraints.

4.1.1 Developing Conceptual Designs

Conceptual design development for TLP projects is not a discrete event. Although included in the “Design Stages” section of this document, the conceptual design begins as soon as the project goals and objectives are determined and may be considered part of the planning process. A project goal can be a description of a destination, while an objective is a measure of the progress required to get to that destination. Some refinement of project objectives may be required at this stage, but routinely revisiting the project goals should be discouraged.

4.1.1.1 Criteria and Constraints

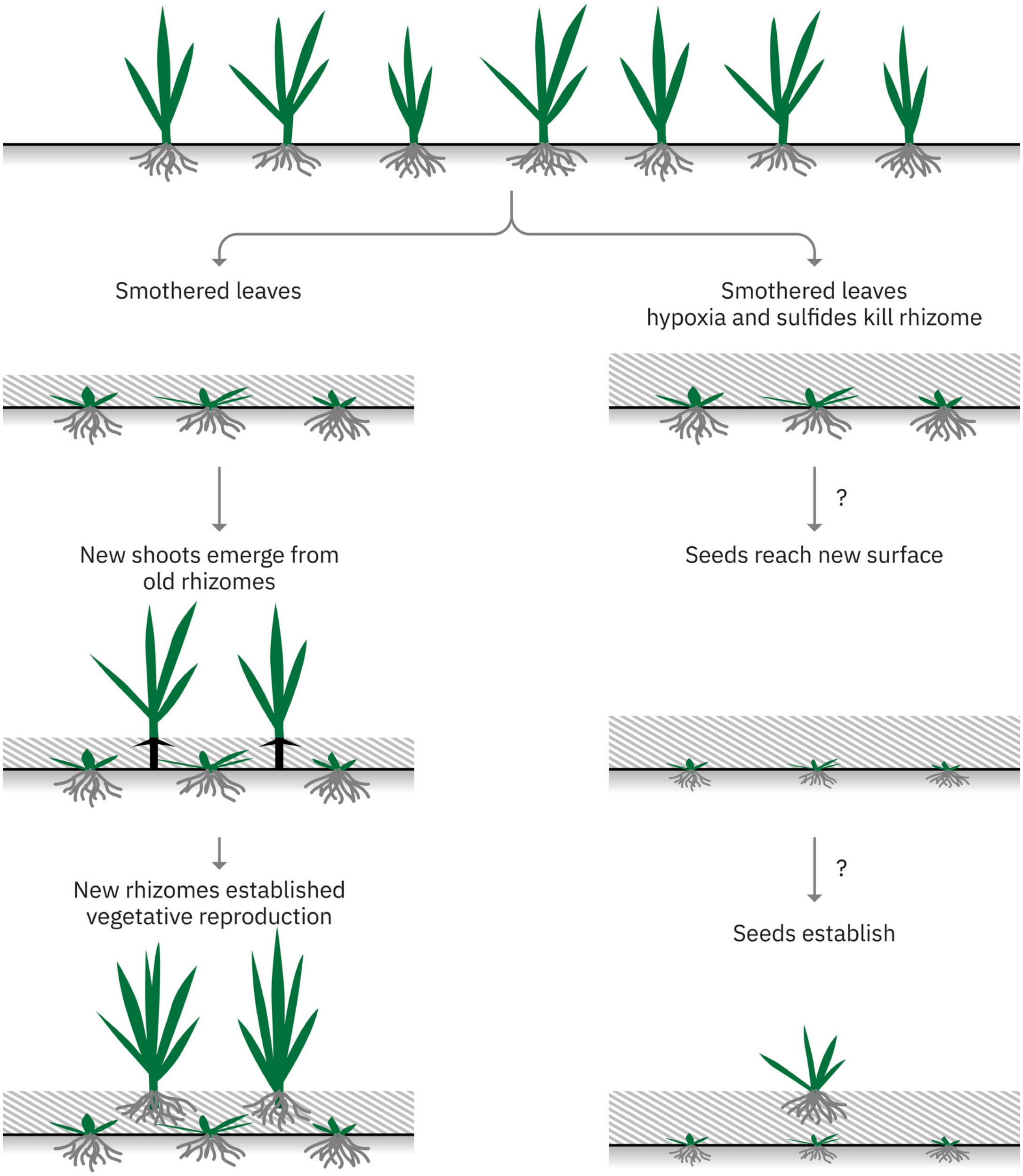
During the initial stages of the design phase, the project team should use the goals, objectives, constraints, and success criteria to define the project design criteria and the constraints. Given the diversity of TLP project teams, this process may not be intuitive and should be conducted as a team. Project objectives are frequently expressed as desired ecological end points; design criteria and constraints are required to translate the qualities of the ecologically desired state into quantifiable designed and as-built, on-site conditions that can be specified and measured. Funding options are also discussed at this stage if funding is not already confirmed.

Consider the following hypothetical wetland TLP project as an example. The project objectives are a mix of wetland communities and open-water areas to achieve a mosaic of habitat types consisting of 50% low marsh, 35% high marsh, 10% tidal creek, and 5% marsh pool. The design criteria need to quantitatively describe the qualities of high marsh, low marsh, tidal creeks, and marsh pools (e.g., elevations and minimum and maximum areas); the spatial and temporal distribution of those features; and the relationship of those features to each other. Similarly, an objective of a hypothetical open-water TLP project is to retain sediment in the system to reduce the deleterious effects of erosion or to facilitate formation of SAV. The design criteria need to describe the desired increase in sediment concentration, volume, or elevation in the project area and in the surrounding area under a set of environmental conditions.

Many design criteria and constraints are driven by biologic and vegetation requirements. For TLP projects, the primary design criterion related to biotic requirements is the target DM placement thickness or target elevation. Although specific cases will differ, open-water TLP projects typically will be defined by a target thickness determined by biotic requirements or resultant water depth, and wetland TLP projects may use either a target elevation to be consistent with the desired marsh community or a target thickness that will allow vegetation to grow through. Figure 4.1 shows how biotic constraints may affect marsh TLP design. At greater thicknesses, vegetation establishment largely relies on seeds, recolonization, and planting, so if vegetation survival is a project objective, the design is limited to thicknesses that do not smother existing vegetation.

The conceptual design should also identify ecological resources or infrastructure that may need to be protected during construction or that may constrain construction operations in some way. These may include SAV, oysters, or mussels in the nearby open water; roads; cultural resources; culverts; power lines; and navigation channels. Anything that may become a design constraint in the future should be identified so its impact can be assessed at later design stages.

Figure 4.1. ***Schematic Illustration of Wetland Recovery Following TLP in a*** *Sporobolus alterniflorus* ***Dominated Marsh***



Source: Mohan et al. (2016), modified from Wilber and Engler (1993)

Although *target* implies a single number, target elevations and target thicknesses should be expressed as a range of desired placed-material thicknesses and elevations and any maximum values that should not be exceeded. Constraints may also prohibit thicknesses or elevations that may alter habitat type (e.g., conversion of a low marsh to a high marsh, or vice versa, or the filling of pools and pannes). Sediment type, equipment capabilities, and site-specific conditions affect achievable DM placement accuracy and precision. Target elevations should also consider current and future trends in site-specific factors such as land subsidence, environmental and wave impacts, and sea-level rise. Predictions of future conditions should take a reasonable, middle-ground approach and should be limited to 50 years out, after which the level of uncertainty increases significantly. Final ecological target elevations for habitat establishment should also be considered in settlement and consolidation calculations. These factors will constrain the range of target elevations, thicknesses, and acceptable tolerances above and below the target. Although equipment is not typically specified during the initial design stages, if at all, a project team should understand the capabilities of the equipment typically used so the design elevations and thicknesses are achievable within the specified tolerances.

In general, performance-based specifications are preferable for TLP projects because they offer the most flexibility for innovation and optimization during construction. Therefore, it is often best not to over-engineer the site design. Some key considerations during design include DM placement tolerances, initial and final design elevations, pipeline discharge locations, inflow sequencing, and planting time frame (if specified) The time frame for planting and the final elevations are related and will, of course, depend on material types, lift thickness, and time to achieve a near-final (>90%) degree of consolidation so that future elevation changes are minimal.

4.1.1.2 Developing Design Concepts

Conceptual designs should identify specific areas of the TLP sites suitable for sediments and the range of elevations and sediment thicknesses required in those areas to meet the project goals. The desired range of elevations and thicknesses and the areas can be combined to determine the general order of magnitude of sediment needed. Although existing elevation data may not be precise enough to calculate sediment capacity to great precision, initial calculations can still be used to coarsely compare available versus needed volume. If a sediment source, such as a navigational dredging project, has been identified, this initial calculation can indicate whether the TLP site has the potential to accept all DM or whether several TLP locations or alternate placement areas need to be identified.

The project team should balance ecologically informed ideal locations of habitat types with the practical realities of DM placement and physical processes. Defining the initial boundaries of the placement areas will help estimate not only the required sediment volume (or available capacity) but also, in part, construction requirements such as pipeline length and access areas. From an implementation perspective, larger areas are typically preferable to smaller areas. But if large areas of benthic fauna or vegetation die off, natural recolonization may take significant time. For intertidal areas, placement should be relatively hydrologically isolated (i.e., not immediately adjacent to main-stem wetland channels or edges) so the sediment slurry has as much distance as possible to flow along and deposit sediment before entering open water. For subtidal shallow open-water areas, placement areas that are relatively quiescent and not immediately adjacent to sensitive ecological resources (such as shellfish, SAV, or macroalgae) are preferred, as are areas away from navigation channels or other infrastructure, such as culverts, to minimize the potential for the sediment to easily erode and fill in channels. Large areas are preferable for wetland and subtidal placement because they permit greater slurry flow rates during construction, limiting the impact of the placement process on the dredging project. Designers should use any topographic high points, catchment boundaries, or other natural barriers to sediment (slurry) movement around or within the placement area to manage sediment movement during placement.

When developing design concepts, it is useful to remember that TLP does not result in a flat, uniform surface or a uniformly thick layer, and the elevation immediately following construction is not the expected final elevation of the TLP placement. Although DM is typically applied in a slurry that is 80% to 90% water by volume, the processes of dewatering, settling, and consolidation result essentially in a dampened version of the surface prior to placement unless coarse-grained sediment (sand) is used or containment structures are used for finer-grained sediment.

The volume of fine-grained sediment immediately after pumping can be two to four times greater than the in situ volume, though sand will not bulk or settle much. Dewatering, settling, and consolidation generally occur over days to months following placement and are largely related to the sediment grain size. Sandy material settles and consolidates less than silt-clay mixtures, hence the different capacity requirements for various sediment types. Table 4.1 presents a rule of thumb for sediment type and placement volume developed by USACE–Baltimore District by correlating in situ volumes of sediment removed from navigation channels with their respective upland-placed volumes.

Table 4.1. *Baltimore District "Blama" Rule of Thumb for Estimating Site Sediment Capacity*

Sediment type	Footprint volume (yd^3/ac ft)
Silt	800
Mixed	1,000
Sand	1,200

Note: Bob Blama, former member of the USACE Baltimore staff, suggested these rules based on his extensive ecosystem restoration work in Chesapeake Bay.

Observations from wetland TLP sites indicate that elevation shrinks from 10% to 40% during the first 10 days after placement. Generally, the magnitude of DM consolidation, assuming a constant substrate settlement rate, is greatest for fine-grained DM placed at thicknesses on the order of 6 to 12 in (15.24 to 30.48 cm) or more. Depending on the design requirements, designers may need to fill a TLP site to a higher elevation or thickness than ultimately desired to account for settling and consolidation. Given the data on natural recolonization of marsh vegetation following placement, however, it is ideal to keep the wetland TLP lifts on vegetated marshes to no more than 12 in (30.48 cm). Note that this guidance on thickness is for optimal natural regrowth of vegetation postplacement, with no replanting. If there are deeper pools that require restoration or filling or if the site plan calls for replanting following placement, thicker placement thicknesses are acceptable. Therefore, some TLP projects may require multiple lifts spaced over time to achieve the final desired elevations.

For design concepts that use elevation as the design criteria, two ranges may be considered: a construction target-elevation range; and a biological target-elevation range. Each should consist of a typical elevation and the minimum and maximum optimal elevations. The constructed marsh-fill elevation is designated as the top of the marsh fill upon completion of material placement. In some projects, the maximum of this range may be referred to as a not-to-exceed elevation and is usually the most critical elevation constraint. The biological target elevation range is the elevation of the sediment surface at a specified time (e.g., in a year or two) after sediment placement and is the elevation of the new soil or bottom surface as the vegetation or benthos begins to recover.

Another consideration for the conceptual design phase is the role of adaptive management and the project team's risk tolerance. Understanding the risks and consequences of failing to meet design criteria, such as elevation ranges, will help designers determine how much data collection and analysis are required in the design phase and how tightly the design specifications should be prescribed. The risk tolerance will also, in part, dictate which aspects of the project are specified, which are left for the contractor to determine, and how adaptive management can be used to manage risk during and after implementation. Managing risks through adaptive management can reduce implementation costs, but risk management is dependent on project funding, land ownership, project goals, regulatory requirements, and any number of other constraints. If future sources of sediment are likely to be available frequently, the site is relatively large, and conditions permit a more flexible range of construction target elevations, then the design can also be more flexible, relying on adaptive management to meet goals over a longer time period. In general, performance based specifications are better because they provide construction flexibility to achieve project goals. This consideration requires an accurate assessment of the project team members' acceptance of risk in the design and construction phases of the project.

Example of a Structured Decision-Making Approach to Select Placement Locations in a Salt Marsh

During the conceptual design phase, it is common for stakeholder priorities to conflict. In these cases, an examination of the goals and objectives of each party involved in the project is helpful. For example, a landowner may be concerned with wildlife management, while the agency responsible for the dredging may be concerned with maintaining a navigable waterway. Each regulatory agency involved has its own purview and requirements to maintain or improve some aspect of the aquatic or built system. Sometimes, acknowledging the design team's various points of view will be sufficient for developing a realistic conceptual design but, for more complex projects with many parts, structured methods may be more helpful in determining placement locations that serve multiple competing interests. Table 4.2 demonstrates the use of a structured approach to select placement locations in a salt marsh. The NWR selected multiple marsh units for marsh nourishment. Subareas of the units were selected and ranked using vegetation cover, elevation, and overall vulnerability as the criteria for prioritizing restoration. These were balanced with the requirement of the partnering agency to economically place DM; the subareas were ranked according to the subarea compactness, the average DM fill depth (lift thickness) to reach the minimum design elevation, and the overall area of the subarea. The ranks were combined to identify the subareas that best met both partners' requirements. Subareas that were low priority for restoration and difficult to construct were dropped from consideration; the areas that were suboptimal for restoration or construction were used as alternate locations to meet DM capacity requirements.

Table 4.2. *Example of a Structured Decision-Making Approach*

Cell	Area	Wildlife scores	Engineering score	Combined rank
BRB-1	21.27	1.00	1.00	1.00
BRB-2	10.29	1.00	0.85	0.85
BRB-3	17.6	1.00	0.85	0.85
BRB-4	0.99	0.55	0.25	0.14
BRB-5	9.44	1.00	1.00	1.00
BRB-6	1.02	0.10	0.25	0.03
BRB-7	2.31	1.00	0.25	0.25
BRB-8	7.13	1.00	0.55	0.55
GLP-1	5.63	1.00	0.70	0.70

Table 4.2 *(cont.). Example of a Structured Decision-Making Approach*

Cell	Area	Wildlife scores	Engineering score	Combined rank
GLP-2	4.74	1.00	0.55	0.55
GLP-3	3.14	1.00	0.40	0.40
GLP-4	2.52	0.55	0.25	0.14

In the conceptual design phase for navigation projects, a variety of TLP placement areas should be identified because not all sites are easily constructible. If the objective is to restore a single TLP site, then multiple dredging locations should be considered to ensure material compatibility. When projects use navigational DM, the potential capacity of the TLP area and other suitable placement locations should exceed the required dredging volume so the design can be adjusted if an area is unsuitable or if initial estimates of required dredging volumes are wrong. Generally, large TLP areas requiring very thin lifts are the most difficult to construct. Very small areas are also difficult to construct because they fill quickly and handling the dredge's discharge can be challenging. Sites with limited water access are also difficult because many TLP projects rely on dredges (hydraulic pipeline or pump out from mechanical barges), which require minimal draft to navigate the waterway.

4.1.2 Preliminary Design

After site-specific data are collected, the conceptual design can evolve into a more specific preliminary design that considers access to the site from land or water; currents; tides; the location of protected and limited access areas (e.g., instrumentation, critical habitats, and cultural resources); infrastructure such as roads, bridges, pipelines, and culverts; the site's bearing capacity; and other factors.

The preliminary design should also identify ecological resources or infrastructure that may require protection during construction or that may constrain construction operations in some way. These may include tidal creeks, SAV, oysters or mussels in nearby open water, roads, cultural resources, culverts, power lines, or navigation channels. Potential design constraints should be identified so their future impact can be assessed at later stages in the design.

4.1.2.1 Design Elements

The preliminary design should assess which elements are required to finalize the project design. Common key design elements are listed in Table 4.3. Not every project's design will need all these elements.

Table 4.3. *Common Key Design Elements for Wetland and Open-Water TLP Projects*

- Access corridors for pipelines and vehicles
- Buffer zones
- Channel or borrow DM volumes versus placement capacity
- Construction access and staging areas
- Containment structures (if any)
- Desired DM composition (grain size)
- DM elevation (consolidation, settling, etc.)
- Environmental aspects (including flow, waves, ice)
- Equipment type
- Erosion and sediment control
- Flood and scour protection
- Long-term monitoring for vegetation and biota
- Measurement and payment methods
- Permit conditions
- Placement area layout
- Placement area topography and bathymetry
- Placement tolerances
- Planting and restoration
- Project area (limits of work)
- Real estate considerations
- Sediment biogeochemistry (i.e., nutrients, sulfides)
- Sediment transport (during and after TLP)
- Sequence of work
- Source material for TLP (dredge site)
- Target elevations and depths

Depending on the project, other design elements may be required. Not every design element will require the same level of detail for a successful project; the project team should determine the appropriate level of detail according to the project objectives and the regulatory environment. Projects that involve or are near especially sensitive habitats or protected ecological resources, such as shellfish, may require a greater level of design detail than projects in or near degraded habitats.

4.1.2.2 Design Tools

Part of the preliminary design process is determining what, if any, modeling is needed as the design concepts evolve. Although a number of geospatial tools were mentioned in the sections on site characterization and conceptual design, specific tools can be used in the preliminary and intermediate design phases to better visualize the site and predict the environmental response to sediment placement. Some of the tools are commonly used in engineering design, but others are more specialized and may require additional time or training to use the ERDC DOTS webpage has additional information on available tools and available guidance (DOER 2023).

Tools like ArcGIS and Autodesk Civil 3D that can visualize DEMs, using either rasterized elevation data or triangular irregular networks, are useful for calculating surface areas and fill volumes. Such specialized tools also enable engineers to combine different types of aerial and land-based lidar data, bathymetric data, and survey data to produce a complete model of a site's elevation. Such data can be used in the hydrologic and hydraulic designs of a site and in the layout of hydraulic pipelines used during construction.

Procedures have been developed to estimate the physical characteristics of placed DM over time. These models and supporting laboratory evaluation methods were originally developed and verified to simulate the bulking, settling, and consolidation of DM in a CDF. If containment is required to keep fine-grained sediment on site, tools developed to design CDFs can be used. A wetland containment structure similar to a CDF should be designed and operated to hold as much of the DM solids as practical during active filling.

Calculations of the initial storage volume must consider the DM bulking factor. The bulking factor is the ratio of the volume of DM placed in a containment area immediately after dredging to the volume occupied by the same amount of soil in the channel or borrow area. The bulking factor is affected by soil material, mass, and behavior characteristics as well as different types of dredges and dredging techniques. Granular (sand-sized) materials may increase or decrease in volume depending on their initial density (loose or compact) and final deposition manner. Cohesive soils tend to increase in volume upon removal. Hydraulic dredges usually bulk up sediment more than mechanical dredges because of water entrainment, and new-work material tends to have higher initial bulking in the placement area than maintenance material because it is usually more consolidated in situ. A general rule of thumb is the larger the grain size, the lower the bulking factor (sand 1.0 to 1.2, silt 1.2 to 1.8, and clay 1.5 to 3.0; USACE 2015).

Slurry Flow-Rate Considerations

The flow rate of DM slurry should relate to the capacity of the placement area, with smaller placement areas requiring lower flow rates. If the slurry flow rate is too high in comparison with the placement area capacity, the slurry can overwhelm the placement area. Table 4.4 presents very general dredge slurry (instantaneous) flow rates by sediment and water for the smaller hydraulic cutterhead dredges typically used in East and West Coast wetland TLP projects. For example, a 14-in (35.56 cm) dredge pumps fine-grained slurry at 20 ft (6.096 m) per second, resulting in 228 yd^3 (174.32 m^3) of sediment and 2,621 yd^3 (2,003.9 m^3) of water placed per hour. If a 5-acre (217,500 square foot [ft^2; 20,206.41 square meter]) placement area is designed to receive an average lift thickness of 0.5 ft (15.24 cm)—108,750 cubic feet or 4,027 yd^3 (3,078.86 m^3)—and the containment structure is only 0.5 ft (15.24 cm) high, the containment area will fill with slurry in approximately 1.4 hours, after which the water and the fine-grained solids remaining in suspension will overflow the containment structure. Because silt with a diameter of 0.0004 in (0.01 millimeter [mm]) takes approximately 30 minutes to settle (assuming a Stokes settling rate of 0.00285 foot per second [ft/s; 0.0087 cm/s]), the overflowing slurry would have a relatively high percentage of solids.

Table 4.4. *Hydraulic Dredge Production Rules of Thumb*

Discharge pipe diameter in (cm)	**Flow velocity** ft/s (m/s)	**Flow volume** ft^3/s (m^3/s)	**Flow volume** GPM (m^3/min)	**Flow volume** yd^3/hr (m^3/hr)	**Water volume** yd^3/hr (m^3/hr)	**Sediment volume*** yd^3/hr (m^3/hr)	**Sediment volume*** yd^3/hr (m^3/hr)
8 (20.32)	10 (3.05)	3.5 (0.10)	1,566 (5.93)	465 (356.8)	428 (327.2)	37 (28.3)	0.6 (0.46)
8 (20.32)	15 (4.57)	5.2 (0.15)	2,349 (8.89)	698 (530.1)	642 (533.7)	56 (42.8)	0.9 (0.69)
8 (20.32)	20 (6.10)	7.0 (0.20)	3,132 (11.86)	930 (713.6)	856 (711.0)	74 (56.6)	1.2 (0.92)
8 (20.32)	25 (7.62)	8.7 (0.25)	3,915 (14.82)	1,163 (886.9)	1,070 (818.1)	93 (71.1)	1.6 (1.22)
10 (25.40)	10 (3.05)	5.5 (0.16)	2,447 (9.26)	727 (560.7)	669 (511.5)	58 (44.3)	1.0 (0.76)
10 (25.40)	15 (4.57)	8.2 (0.23)	3,670 (13.89)	1,090 (835.9)	1,003 (766.8)	87 (66.5)	1.5 (1.15)
10 (25.40)	20 (6.10)	10.9 (0.31)	4,893 (18.52)	1,454 (1111.2)	1,337 (1022.2)	116 (88.7)	1.9 (1.45)
10 (25.40)	25 (7.62)	13.6 (0.39)	6,117 (23.16)	1,817 (1386.4)	1,672 (1278.3)	145 (110.9)	2.4 (1.83)
12 (30.48)	10 (3.05)	7.9 (0.22)	3,523 (13.34)	1,047 (805.3)	963 (736.3)	84 (64.2)	1.4 (1.07)
12 (30.48)	15 (4.57)	11.8 (0.33)	5,285 (20.01)	1,570 (1202.9)	1,444 (1104.0)	126 (96.3)	2.1 (1.61)
12 (30.48)	20 (6.10)	15.7 (0.44)	7,047 (26.68)	2,093 (1600.5)	1,926 (1472.5)	167 (127.7)	2.8 (2.14)
12 (30.48)	25 (7.62)	19.6 (0.56)	8,808 (33.34)	2,617 (1998)	2,407 (1840.3)	209 (159.8)	3.5 (2.68)
14 (35.56)	10 (3.05)	10.7 (0.30)	4,796 (18.15)	1,425 (1090.8)	1,311 (1002.3)	114 (87.2)	1.9 (1.45)
14 (35.56)	15 (4.57)	16.0 (0.45)	7,193 (27.23)	2,137 (1631.1)	1,966 (1503.1)	171 (130.7)	2.8 (2.14)
14 (35.56)	20 (6.10)	21.4 (0.61)	9,591 (36.31)	2,849 (2181.5)	2,621 (2003.9)	228 (174.3)	3.8 (2.91)
14 (35.56)	25 (7.62)	26.7 (0.76)	11,989 (45.38)	3,562 (2721.8)	3,277 (2505.4)	285 (217.9)	4.7 (3.59)
16 (40.64)	10 (3.05)	14.0 (0.40)	6,264 (23.71)	1,861 (1427.2)	1,712 (1308.9)	149 (113.9)	2.5 (1.91)
16 (40.64)	15 (4.57)	20.9 (0.59)	9,396 (35.57)	2,791 (2130.6)	2,568 (1963.4)	223 (170.5)	3.7 (2.83)
16 (40.64)	20 (6.10)	27.9 (0.79)	12,527 (47.42)	3,721 (2844.1)	3,424 (2617.8)	298 (227.8)	5.0 (3.82)
16 (40.64)	25 (7.62)	34.9 (0.99)	15,659 (59.28)	4,652 (3557.7)	4,280 (3272.3)	372 (284.4)	6.2 (4.74)

Note: *Assuming 8% solids concentration by volume

Abbreviations:

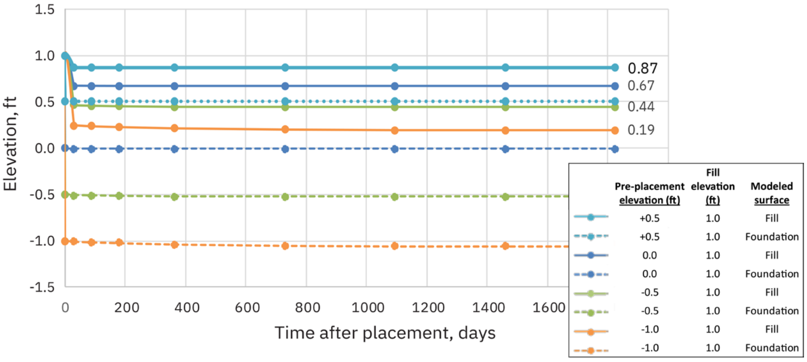
GPM—gallon per minute
ft^3/s—cubic foot per second
m/s—meter per second
m^3/hr—cubic meter per hour
m^3/min—cubic meter per minute
m^3/s—cubic meter per second
yd^3/hr—cubic yard per hour
yd^3/min—cubic yard per minute

The SETTLE model used to evaluate this initial sediment behavior during placement and dewatering can also be used to design CDF storage and to evaluate effluent water quality. Compression settling data, derived from laboratory column settling tests, are a primary input to the model (USACE 2015).

The Primary Consolidation, Secondary Compression and Desiccation of Dredged Fill (PSDDF) model (Stark 2014) simulates longer-term consolidation of DM placed in a CDF. This model considers the geotechnical characteristics of the foundation and the placement materials, including consolidation behavior typically determined through laboratory tests. The model outputs the consolidated surface elevation at a user-specified time in the future (USACE 2015). Additional discussion on estimating settlement of DM can be found in Stark, Choi, and Schroeder (2005a, 2005b) and Jafari, Harris, and Stark (2019).

The combination of the SETTLE and PSDDF models provides a holistic approach to estimate placement volume and elevation over a range of time scales from days to multiple years (Figure 4.2). Although a marsh environment is not the same as a CDF, these models can be used to predict elevation changes associated with TLP settling and consolidation (Bailey, Tyler, and Welp 2017). SETTLE can be used to predict the bulking factor of the DM initially placed on the wetland. PSDDF can be used to predict how the TLP surface elevation will change in the days, months, and years following placement. Combined with detailed surface elevation data, PSDDF can be used to refine capacity estimates for the site and to identify the construction target-elevation range appropriate for the desired biological target-elevation range defined during the conceptual design stage. An alternate approach is to use adaptive management via close (weekly) monitoring of the DM surface and adjusting inflow locations and volume, as appropriate.

Figure 4.2. *Example of PSDDF Output for a Proposed Wetland TLP Site at Good Luck Point, New Jersey*



Note: Consolidation of material placed to +1 ft (+30 cm) elevation. The dotted lines represent the consolidation of the compressible foundation.

Source: Bailey, Tyler, and Welp (2017)

CPRA (2017b) provides information on other design tools that can be used to calculate foundation loading and DM placement behavior that will affect the wetland's elevation over time.

Hydrodynamic modeling may be necessary to ensure proper hydraulic and hydrologic functioning of TLP sites or to determine the hydrodynamic forces the site will be subject to after placement. The required level of monitoring effort is a function of the complexity of the site hydraulics; tools range from simple 1D approaches to more advanced 2D and 3D models. Simple 1D models are sufficient to simulate changes in the tidal prism or flows through hydraulic structures such as culverts and weirs. More advanced approaches may use 2D or 3D hydrodynamic models to analyze changes in flow patterns caused by the TLP project. Models can also be used to capture the interactions between a wetland platform and the open water, as well as the hydrodynamics in wetland channels due to a proposed TLP project. This level of effort is warranted if multiple ditches or drainages are to be plugged or filled, or if the change in tidal prism caused by the sediment placement or an alteration to the site hydraulics is large in proportion to the total tidal prism of the original site. The site design may change the flow direction of marsh and mudflats, or erosion, waterlogging, or other issues related to site hydraulics. Examples of 2D hydrodynamic modeling in marsh restoration are found in Roman and Burdick (2012).

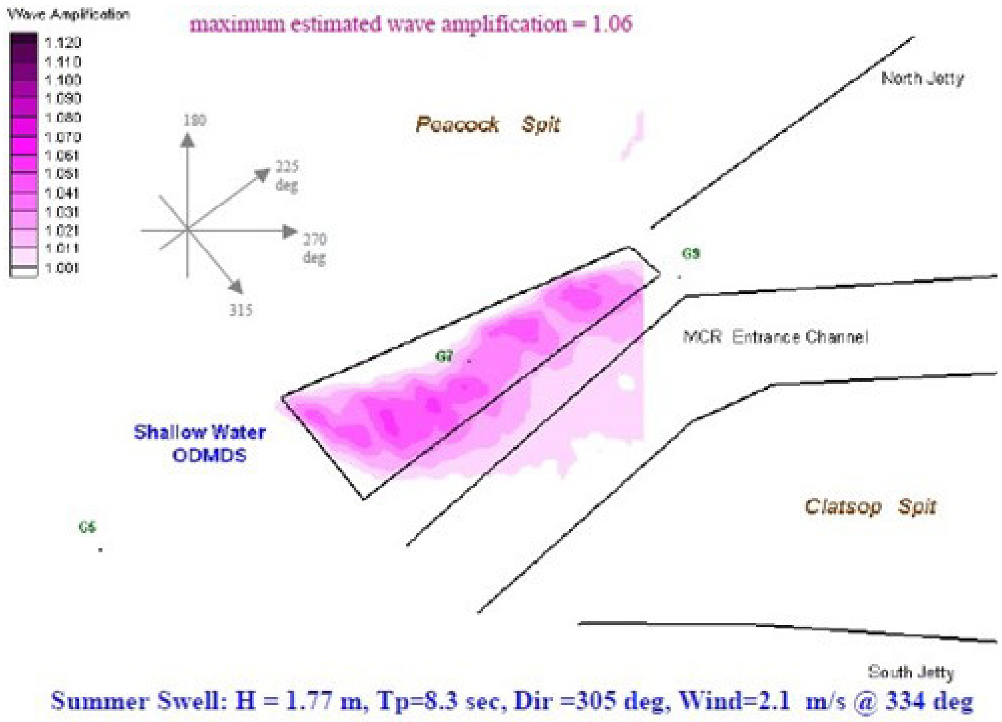
Hydrodynamic model outputs can be coupled with sediment transport models to determine whether the sediment will be retained or dispersed and, if it is resuspended and distributed, what its fate and transport pathways will be. In these cases, a 3D hydrodynamic model that has sufficient resolution at the sediment bed is often required, and it must be coupled with a sediment transport model that can simulate the sediment transport processes of interest (cohesive or noncohesive). In the case of fine-grained cohesive sediments, further analysis should be conducted to determine how the material is being transported—as discrete grains or as flocs or aggregates—because the transport and fate will depend heavily on the sediment properties. The Long-Term Fate of DM Model (LTFATE), a cohesive sediment transport model designed to determine the stability of DM mounds, has been used to simulate the fate of TLP in Mobile Bay (Parson et al. 2015). The model can help answer questions about the erodibility of TLP material after placement and the potential interaction of any eroded sediment with ecological resources of concern, such as oyster reefs or SAV beds.

Wave models may be warranted if a site's wave energy is high enough to erode the DM (whether by design or not) or if waves may be altered by the TLP project. Waves may erode freshly placed DM at wetland TLP sites where extensive edge erosion has been documented and where water levels are routinely greater than the wetland surface. In open water, waves may be an important driver of sediment resuspension at shallow depths, where the wave interacts with the sediment surface. Wave modeling was conducted as part of the MCR open-water TLP project to determine whether the placement would lead to wave amplification that could exacerbate erosion along the beach and jetties (USACE 2013b; Norton et al. 2015).

Assessment of Potential Wave-Related Impacts

Continued use of an open-water TLP site at the MCR is important for maintaining the federal entrance channel and for delaying the need for repairs to the north jetty. There are two competing objectives for this site: (1) maximize the site's use to retain as much DM (sand) as possible in the nearshore littoral system, and (2) minimize any exacerbation of the already hazardous wave climate at MCR. To assist EPA in developing the designation proposal and a site management and monitoring plan for any new sites, USACE conducted wave modeling (Figure 4.3) to evaluate how best to meet both objectives (USACE 2003).

Figure 4.3. *Model Output for the MCR Shallow-Water Placement Site Simulation*



Models can also be used to estimate a marsh's long-term response to a wetlands TLP project. NOAA's Marsh Analysis and Planning Tool Incorporating Tides and Elevations (MAPTITE; available on the "Tides and Currents" website at tidesandcurrents.noaa.gov/maptite.html [NOAA CO-OPs, n.d.-b]) can be used during project design to predict which species may be expected at a site according to the tide and elevation range and to set biological target-elevation ranges according to the desired mix of wetland community types. Although existing site conditions and reference sites can provide insights on the range of optimal elevations for plant communities of interest, these elevations will change as sea levels rise.

Biophysical modeling tools developed for use in wetlands that link inundation patterns with vegetation response include the Marsh Equilibrium Model (MEM; MARISA, n.d.) and the related 2D hydroMEM, which couples MEM with the Advanced Circulation Model (ADCIRC; UNC-Chapel Hill, n.d.). MEM is a zeroth-order model of salt marsh elevation response to sea-level rise based on environmental conditions such as the suspended-sediment concentration of incoming water, tide range, vegetation parameters such as distribution patterns, trapping efficiency, and growth rate.

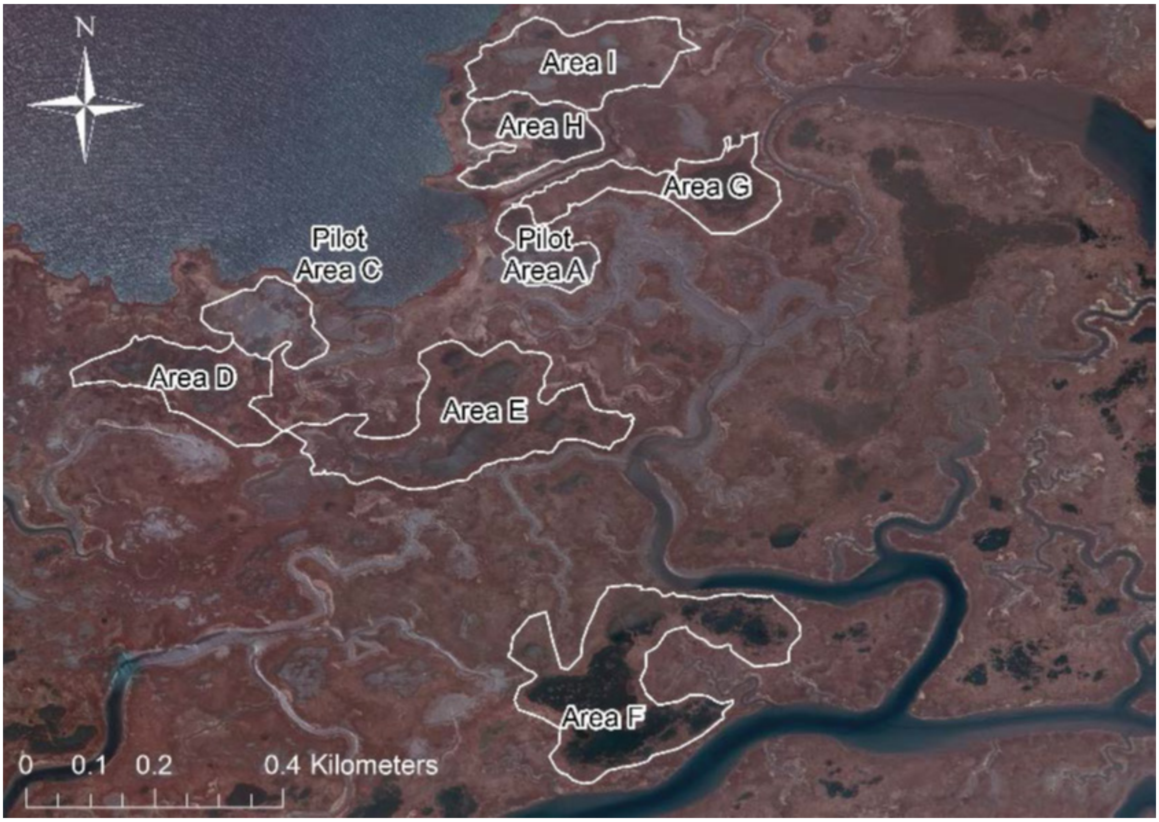
The Marsh Equilibrium Model—Thin-Layer Placement (MEM-TLP) can simulate a wetland's long-term response to TLP. Users specify the depth of sediment deposition at a given time and interval and the estimated vegetation recovery time to simulate how the marsh elevation, biomass, and carbon sequestration will change over a century. The model can also be used to test TLP scenarios during the design phase of a wetland TLP project. Specifying a slightly higher biological target elevation may provide a longer-lasting lift in the marsh elevation of wetland systems where the rate of sea-level rise is high—especially if fine-grained materials were used or the systems have compressible subsurface layers. Other tools include USGS's Wetland Accretion Rate Model of Ecosystem Resilience (WARMER) model (Swanson et al. 2013), which simulates how inundation patterns and sea-level rise influence vegetation and faunal wetland habitats (Buffington et al. 2021; Thorne et al. 2018).

4.1.2.3 Placement Area Delineation

Geospatial tools are invaluable for visualizing site topography and bathymetry and for creating accurate site elevation models at the preliminary design phase. Combined with water-level data, these high-accuracy elevation maps can be used to determine the current depth range and inundation patterns to help refine the biological target-elevation or depth range. The accuracy and precision of both the horizontal and vertical locations of the data must be considered when developing elevation maps. As noted previously, lidar data typically are positively biased for coastal wetland sites and may have larger errors in shallow open water. But when lidar data are combined with accurate survey data collected at a site, these errors can be reduced and the higher point density associated with lidar data retained, allowing for the production of an accurate, high-resolution model of the site. For more details on how to improve lidar accuracy with additional data, including survey data, see Fernandez-Nunez, Burningham, and Ojeda Zujar (2017).

High-precision, accurate elevation data can be used with the hydrology, hydraulics, and watershed tools available in geospatial tools such as ArcGIS and Autodesk Civil 3D to delineate flow paths, subwatersheds or catchments within a site, or hydrologic sinks. These flow paths and catchments can help delineate low areas of the site. Large sinks or parts of a site with long flow paths and small flow accumulations may be conducive to retaining sediment. Conversely, areas with short flow paths and large flow accumulations, especially areas near to marsh edges or delineated tidal creek networks, may require additional retention structures to prevent sediment from short-circuiting and flowing immediately off the site. Figure 4.4 shows the delineation of placement areas at the Avalon, New Jersey, wetland TLP site.

Figure 4.4. *Placement Areas Delineated Using Natural Topography in Avalon, New Jersey*



Source: USACE–Philadelphia District

This process was used at Pepper Creek, where designers capitalized on the topography, vegetation, and other physical conditions so that the only containment used was hay bales in tidal creeks. Postconstruction removal of containment systems, such as hay bales, can be challenging, however, especially if there are access restrictions.

Site specific data and information, such as topography, bathymetry, land ownership, and access, can also be used to optimize design of the pipeline discharge configuration, including the type of pipe, discharge locations, equipment (e.g., multiple discharges with Y valves, jetting nozzles, and spreader bars), pumping schedule, and containment options.

Small areas are difficult to construct because they fill quickly, and handling the dredge's discharge can be difficult, particularly if containment is used. In projects like Avalon, Fortescue, and Seal Beach, containment was used to the extent that it functioned like a CDF. These small placement areas quickly filled with sediment slurry and caused unexpected containment breaching or required the end of the pipeline to be moved frequently, necessitating a pause in dredging operations.

Although geospatial tools can help identify potential placement areas, they should not be used to define their edges. The boundaries of a highly irregular and complicated placement area often are extremely difficult to recognize during implementation. Describing a buffer around the placement area is desirable. A buffer lets some sediment slurry overflow the placement area, and the reduced hydraulic forces at the placement area's margins allow more sediment to settle out—dramatically decreasing the amount of sediment leaving the placement area—before the flow reaches adjacent areas where water quality standards may apply. Having a buffer area also provides flexibility during construction, which may decrease associated time and costs.

Field Rules of Thumb

TLP Field Observations

New shoots can penetrate 3- to 9-in-thick (7.6 to 23 cm thick) sediment layers.

- Generally, 6 to 12 in (15 to 30 cm) of placement is the maximum thickness for natural vegetative recovery, in a two- to five-year time frame.
- Larger sites will generally take longer to recolonize than smaller sites because wetland species generally colonize via rhizomes along edges.

The design team should strive for as simple a design as possible to achieve project goals, minimizing as much as possible the number of placement areas, containment structures, and discharge points. Add complexity only as required by site or resource constraints.

4.1.2.4 Biological and Construction Target-Elevation Ranges

Once site characterization is complete, the sediment source should be well described, and the available volumes of sediment known. Paired with site survey data, a more complete accounting of site capacity and available volumes enables engineers to determine more precisely the placement areas that can be used according to the biological elevation ranges desired. It should also be known at this point how the designed target elevation should vary across the placement area. Precise boundaries between biological target elevations are not recommended because current TLP construction techniques are generally not accurate or precise enough to allow very precise sediment grading, but the zones where higher and lower target elevations are desired should be clearly defined. *Case Study: Improving Marsh Resilience through the Hurricane Sandy Coastal Resilience Program*, which included evaluations of the Ninigret Pond Salt Marsh, Blackwater, Avalon, Fortescue, and Rhode Island TLP projects, reported that although target elevations were reached, adaptive management should be built into project time lines because "the deposition of sediment was sometimes uneven and project leads moved dredge sediment or added more sediment to some locations" (Abt Associates 2019, 8). Another good case study is the Seal Beach restoration project (Borgnis Sloane et al. 2021).

Note on Realistic Elevation Tolerances and Construction Abilities

A conservative estimate of TLP elevation placement accuracy is ±6 in (±15 cm); however, higher accuracy and precision are possible, especially if the DM is primarily fine grained and placed with a high- or low-pressure discharge that is easily moved or adjusted. Higher accuracy and precision elevation criteria will increase the cost to place sediments because personnel are required to monitor the placement closely and pump shut down will occur relatively frequently in comparison with thicker lifts.

At this stage, the design team should also determine which channels, ditches, and pools should be filled and to what extent to achieve the desired ratio of habitat types. As mentioned previously, sediment accumulates in deeper areas, but deeper areas are also subject to a greater degree of consolidation, so the difference in elevation immediately after construction and one to two years later is greater than in areas with thinner sediment layers. Although some channels and pools are desired ecologically, preventing any sediment from entering these low areas in a placement area may not be feasible. Likewise, filling these areas to an elevation equivalent to the surrounding area may not be feasible unless sandy DM is available. The available options, therefore, are either to leave them at a lower elevation or build them up with multiple lifts (layers) followed by planting to achieve a desired higher elevation—which will depend on site-specific factors, such as overall habitat goals. Elevation in channels can be manipulated during and after construction by the use of planned removal of containment structures or by placing the pipeline discharge to optimize coarse-grained material deposition (by hydraulic sorting) in these areas (discussed later in this section). Channels should also be protected during infilling so that they do not constrict or transport sediments to downstream sources.

Large TLP placement areas that require very thin lifts are generally the most difficult (ergo, expensive) to construct because vertical and horizontal control of sediment placement is accomplished primarily by moving the pipeline discharge and the resulting slope of placed sediment depends largely on grain size distribution. For example, the design of the placement areas for the Edwin B. Forsythe NWR set minimum size requirements of 5 ac (2 ha) and sediment lifts of at least 6 in (15.24 cm). Depending on the pipeline discharge configuration, such requirements can require frequent pausing of dredging to reposition the pipelines, which also increases costs. (For a more detailed discussion of sediment placement equipment and operational methodology, see Section 5.2).

4.1.3 Intermediate and Final Design and Contract Specifications

In the intermediate and final design phases, the preliminary design is further refined, and the best available topography and bathymetry data are used to calculate the best estimates of construction and biological target elevations and associated tolerances. This information can be used to estimate sediment volumes required to meet those goals. Although the conceptual and preliminary design steps focus more on how a TLP design meets project objectives, the intermediate and final design phase must consider how the project is implemented. Consequently, these later design phases include more details on how to manage sediment during and after construction to meet project objectives.

Typically, during these phases of design, the project details are advanced to a level that is sufficient for bidding and construction purposes. The following activities are normally included as part of these phases of design:

- Engineering analysis, including quantity takeoffs for dredging, placement site construction features (containment berms), and any other cut and fill aspects
- Dredge plans and cross sections for the dredge (or borrow source) site
- Material transport and management plan
- Placement site design, including containment dikes, effluent management, and final site restoration and development, if applicable
- Measurement and payment specifications for construction contractor, including overrun and underrun criteria

- Requirements for third-party or owner-contracted surveying
- Incorporation of performance-based specifications to the extent feasible
- Contractor work plan requirements to set project expectations for key contractor activities
- Incorporation of past experience and performance requirements in bid documents, as allowable

Intermediate and final designs should leave enough flexibility for field engineering and changes during implementation, if warranted. This means designing and permitting limits of the work area or areas larger than the project footprint and designing more capacity than may be required. This is especially prudent in the case of navigational dredging when clearing the channel to a required depth may require removing more sediment than there is capacity to manage at the site. Also, if material bulks more than predicted or material properties are different than anticipated, additional capacity may be necessary to provide options for managing that DM. Therefore, it is prudent to obtain permits for alternative placement locations if site conditions (or project uncertainties) warrant such considerations.

4.2 Design Considerations

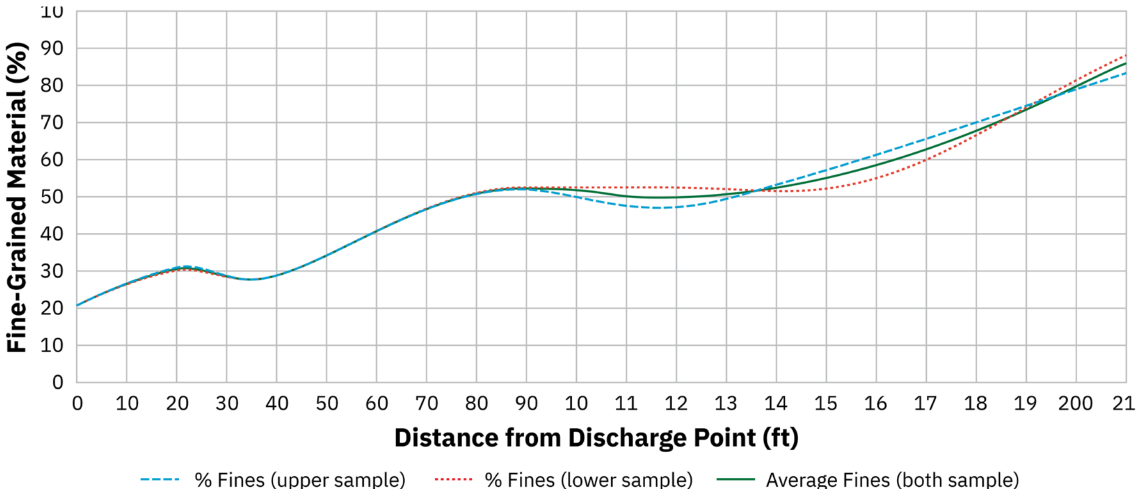
4.2.1 Use of Hydraulic Sorting for Placement Design Optimization

When TLP projects use hydraulic placement techniques, designers should take advantage of the DM source material's engineering properties and the placement area's topography and bathymetry to achieve project objectives. As previously discussed, a good understanding of the spatial distribution of in situ sediment physical characteristics can enable a designer to tailor the placement strategy (i.e., placing coarser-grained sediment where optimal by selective dredging and placement sequencing. Discharge pipe placement location and orientation should also consider site geometry so the end of the pipe is not too close to the placement area boundary and the drainage direction of the slurry is considered. As with a CDF, baffles (earthen berms, hay bales, etc.) can be used to redirect the slurry as needed to achieve project objectives.

Because DM is transported during hydraulic placement in a slurry that is 80% to 90% water by volume, the hydraulic sorting of sediment particles that occurs when the slurry leaves the pipe should also be considered. Hydraulic sorting is based on the principle that different-sized sediment particles of different or similar density have different settling velocities in a fluid (water) medium. During slurry placement, the different settling velocities, in addition to the water velocity and direction, result in particle segregation by size and type according to distance from the discharge point.

The results of field sampling at the Avalon TLP project to investigate this hydraulic sorting process from a single-station, low-pressure discharge are shown in Figure 4.5. Coarse-grained (sand-sized) particles settle near the discharge, and finer particles settle further from the discharge. Consequently, coarser-grained material tends to mound quickly and may require frequent movement of the pipeline discharge point and closer spacing between the discharge locations. Fine-grained sediments dewater more slowly. Therefore, smaller subareas within the placement area should be designed to allow excess water and solids to easily drain into buffer areas, or additional discharge points should be considered so the flow can be switched easily between multiple areas. In general, fine-grained material is preferred for thinner lifts and coarser sandy materials for thicker lifts because fine-grained material flows farther and more evenly. The grain size of the material does not seem to correlate with its suitability for marsh vegetation in wetland environments, so the need to match the sediment grain size at the placement site with the source material is not critical to the overall success rate (Berkowitz, VanZomeren, and Piercy 2017).

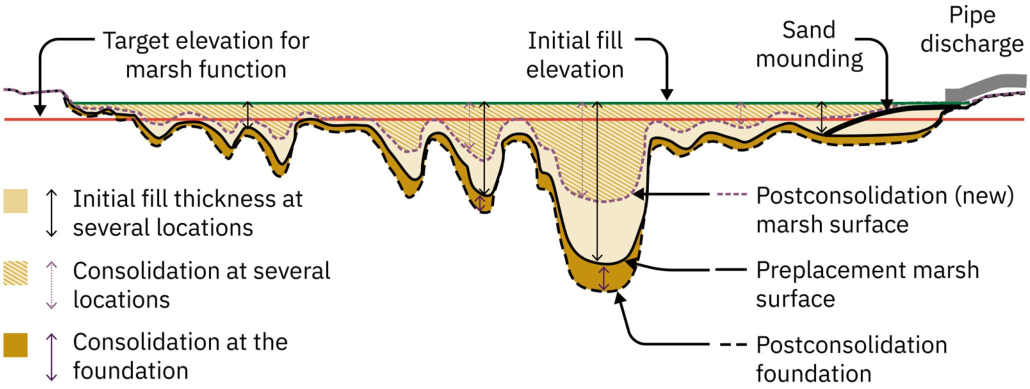
Figure 4.5. *Hydraulic Settling Characteristics of Fine-Grained Sediments*



Source: ERDC

After initial dewatering of the placed DM, its elevation changes over time varies with the material's type and thickness and the foundation's properties (Figure 4.6). The heterogeneity of DM in the channel or borrow site and the hydraulic sorting behavior mentioned previously should be considered to optimize sediment placement. Sandier sediments consolidate less, so they are desirable in areas like pools and holes that require thicker lifts, provided the substrate consolidation is considered. Likewise, areas requiring thinner lifts can be located far from the discharge where primarily fine-grained material will settle, resulting in a thinner lift. Note that the weight of the added sediment may also cause consolidation of the existing foundation soils and sediments, which can reduce the final elevation. A detailed discussion of sediment placement equipment and operational methodology is presented in Section 5.2.

Figure 4.6. *Changes in Marsh Topography Due to DM Placement and Consolidation*



Source: Bailey, Tyler, and Welp (2017)

As mentioned in Section 4.1.2.2, the PSDDF and SETTLE models can be used to predict DM behavior upon placement; however, PSDDF may not be required for all TLP projects. PSDDF modeling can be forgone depending on the design team's tolerance for variation in the final elevation design, and the construction elevation range can be set to the biological target-elevation range with the understanding that the final elevation may be lower than ideal. The lower limit of the target elevation range can be increased to account for some inevitable consolidation, but this method ensures the elevation will not exceed the maximum acceptable biological target elevation, which is typically most critical. Projects that would benefit most from PSDDF data are (1) those that use fine-grained sediments, especially at placement thicknesses of approximately 12 in (30.48 cm) or more; (2) sites that have highly compressible foundations dominated by soft peats and fine-grained sediments; and (3) sites that are at higher risk for ecological damage if design elevations are not achieved or maintained. Sites that have the potential for multiple placements, even if they are years apart, also tend to have more tolerance for surface elevation variations.

4.2.2 Hydrodynamic Design Considerations

Large wetland TLP projects that cross multiple tidal creeks or other drainages require explicit consideration of the project's effects on these features and the effect of the drainage features on the TLP project. Previous projects have taken a variety of approaches, from completely or partially excluding tidal channels from placement to completely filling all channels. There is no consensus on the best approach, and how approaches are considered depend on the site, stakeholder, and regulatory considerations. Raising the wetland platform without subsequently raising the tidal channel elevation may reduce their connectivity, interfering with tidal exchange. But very large tidal channels may be very deep, and relative changes in elevation between the marsh platform and the channel bottom may not be significant. Keep in mind that if channels are part of the hydrologic functioning of the site, then new channels will likely form as the site stabilizes after placement. Overengineering channels or protecting existing drainage pathways, therefore, may not be desirable or necessary. A combination of approaches may be used across a site to best suit the project objectives. If tidal channels are to be filled, in-channel containment structures will be required. Previous projects have used simple straw bales and coir logs or temporary weirs; soft measures, such as straw bales and coir logs, only work in very small channels (less than or equal to 6 in [15.24 cm] deep) with very low maximum velocities during placement. More information on containment structures is presented in Section 4.2.3. Restoration of ditched and drained wetland sites frequently calls for the use of clay ditch plugs, which are designed to remain in place.

Mobile Bay Native Bed Erosion Versus TLP Erosion

LTFATE was used to identify transport patterns in Mobile Bay as a function of natural forcing, including river discharge, tidal flows, local wind-driven currents, waves, and storm surge. The model was also used to quantify changes in transport patterns produced by DM TLP in Mobile Bay. Parson et al. (2015) indicate TLP placement in Mobile Bay had the following impacts:

- TLP did not significantly change the bathymetry in Mobile Bay.
- TLP sediments were similarly or less erodible than native sediments (especially so in the northern third of Mobile Bay).
- TLP materials may hinder mobilization of underlying native sediment.
- TLP did not significantly influence total suspended sediments near ecological resources in Mobile Bay, according to a comparison of native bed and TLP sediment transport modeling scenarios.

The modeling also indicated that TLP in Mobile Bay will have negligible impacts on navigation channel infilling, total suspended sediments, and Mobile Bay bottom morphology.

At sites with sufficient tidal energy, tidal creeks will reform quickly after construction if the sediment is sufficiently erodible. Sands and new work DM may be less mobile than fine-grained maintenance DM. At microtidal sites, however, tidal currents have limited ability to mobilize sediments, so care should be taken to prevent channels from infilling, or channels should be cleared after DM placement. In some cases, new drainage pathways may need to be constructed once the site stabilizes to facilitate proper hydrology.

Open-water TLP projects are typically concerned with DM mobility during and after placement. Designs should minimize loss of sediment to the water column during placement to minimize the impact of construction and ensure placed sediment reaches the desired depth or elevation.

4.2.3 Containment Structures and Slurry Distribution

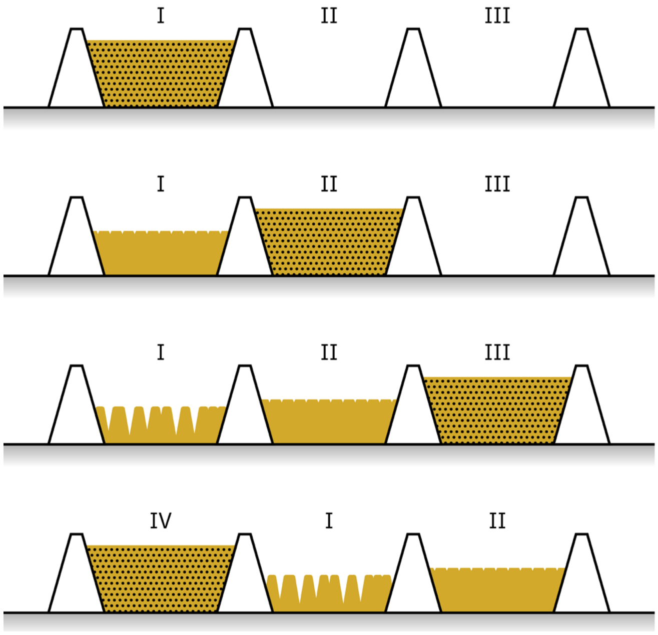
Containment refers to any TLP project component designed to prevent the movement of sediment from the designated placement area. Because sediments are most mobile during and immediately after placement, containment structures, or cells, are often designed to limit the movement of solids while settling and consolidation occur. Containment may be total confinement of the placement area or optimal placement of structures (coir logs, hay bales, berms, etc.) around the site (partial containment). Containment may also be implemented in an adaptive manner, by trying to manage the inflow initially so the slurry settles on-site, and then adding containment features as necessary during construction—however, that would require some containment structures be stored on-site, as contingency. Any type of containment structure will also require close evaluation to understand and manage the risk of potential failure of containment. For wetlands, containment generally should be minimized because the materials and labor to build it are expensive, and installation and removal usually requires the operation of amphibious or low-ground-bearing-pressure equipment that can damage the marsh. Containment can also inhibit proper exchange of water within the placement area after construction and affect project success (TNC and NJDEP 2021).

Containment can be provided by natural features, such as existing site topographic and bathymetric relief and vegetation, or by fabricated structures. Containment structures may be either temporary—designed to be removed after placement—or permanent. Although design plans may not need to prescribe a type of containment (and associated details such as the required height, length, and configuration of a containment structure), it is often a good practice to do so, to ensure that the desired solids retention is achieved. If the decision on containment is left to the contractor, the designer should carefully assess the proposed means and methods of containment prior to construction to ensure that the design intent is met. Also note that for some sites, redistribution of placed sediments is desired, and a transmissible containment structure design can help facilitate this redistribution. Additionally, the containment structure for TLP does not need the same level of robust design and analysis as would be required for CDFs.

Sedimentation efficiency in a wetland cell depends on the available surface area relative to the inflow rate (a function of the dredge size), operational conditions (e.g., slurry pipeline velocity), physical properties of the sediment, and salinity of the dredging environment. Containment cells that are too small result in frequent pipeline movements or pumping stoppages and, consequently, may increase project construction time and costs.

The design and use of a slurry distribution system in conjunction with multiple cells on the project site can provide the capability to efficiently sequence DM placement into different containment cells at different times. The slurry distribution system consists of all the equipment used to transport and place the water and sediment mixture on site, including pipeline, intermediate fittings (Y valves, etc.), discharge attachments (nozzle, spreader plate, etc.), and repositioning equipment (such as marsh buggies, barges). The sequential placement process is illustrated in Figure 4.7, where different containment cells are used for separate filling operations. After the first cell is filled in its initial placement, the slurry discharge is redirected into the next cell while the first cell dewaters. The longer that the first cell is allowed to settle and dewater (depending on the pipeline distribution system, number of available containment cells, and dredging production and schedule), the more holding capacity it will have for the secondary placement. Figure 4.8 shows an engineering drawing of the slurry distribution system and sequential placement configuration used at the Fortescue TLP project.

Figure 4.7. *The Sequential Containment Cell Placement Process*



I Initial placement

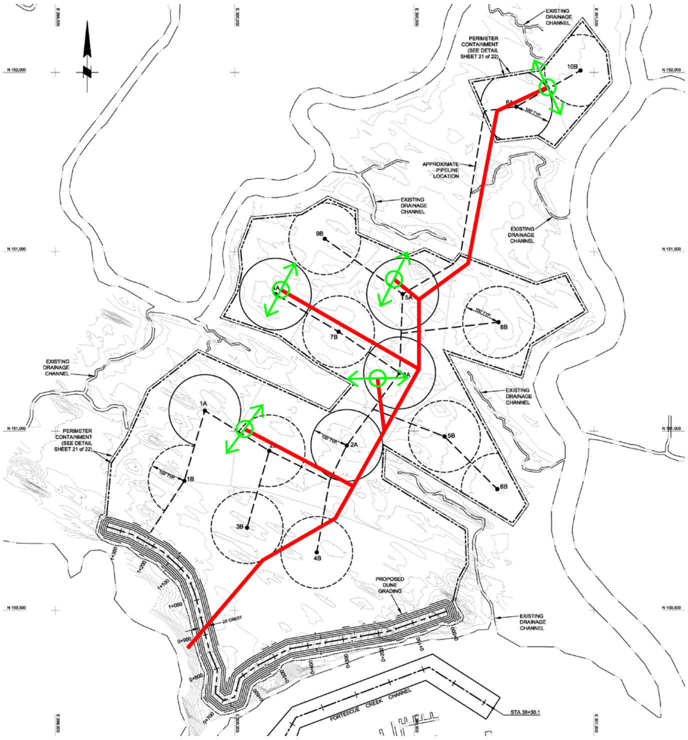
I Dewatering initiated
I Initial placement

I Relatively dewatered
II Dewatering initiated
III Initial placement

IV Secondary placement
I Relatively dewatered
II Dewatering initiated

Source: Modified from USACE (2015)

Figure 4.8. *Sequential Containment Cell Placement at the TLP Project Site*



Source: Scott Douglas, NJDOT OMR

Lateral containment may be total containment of the placement area or partial containment. Partial containment may be effective in many cases and may also provide a cost-effective way to control effluent discharge from the site. Partial containment may also be used at wetland TLP sites to do the following: (1) retain sediment to achieve the required elevation or thickness, (2) minimize sediment flowing into undesired locations, and (3) redirect sediment and water to slow the flow along concentrated flow paths or to prevent short-circuiting. Containment design and construction will be determined by the following: (1) which of the three aforementioned objectives apply, (2) the external loads that must be resisted to achieve confinement requirements (e.g., loads induced by the slurry or by tides), and (3) site-specific conditions such as the existence of vegetation and condition of the site foundation. Hay and straw bales, degradable semipermeable coconut fiber (coir) logs, filter socks, clam and oyster bags, lumber, earthen containment dikes built from sediment on-site, and silt curtains have all be used for containment.

Figure 4.9 shows containment structures made of various materials used to retain sediment in wetland TLP projects to achieve the required elevation or thickness. Figure 4.10 shows examples of effluent control using containment structures to minimize sediment flow into undesired locations.

Figure 4.9. *Containment Materials Used for Various Wetland TLP Projects to Retain Sediment for Achieving Required Elevation or Thickness*

a. Coir Logs, Jekyll Island, Georgia
Source: Clay McCoy, DNREC

b. Hay bales, Blackwater NWR
Source: Bob Blama, USACE (retired)

c. Filter Soxx, Fortescue, New Jersey
Source: NJDOT

d. Clam and oyster shell bags, John H. Chafee NWR
Source: TNC

e. Earthen containment dike, Gaillard Island, Alabama
Source: Nate Lovelace

f. Straw bales, silt curtain, and earthen containment dike, Ring Island, New Jersey
Source: Timothy Welp, ERDC

Figure 4.10. *Examples of Effluent Control Using Containment Structures to Minimize Sediment Flow into Undesired Locations*

a. Coir mat filled with sand, Blackwater NWR
Source: Albert McCollough, Sustainable Science

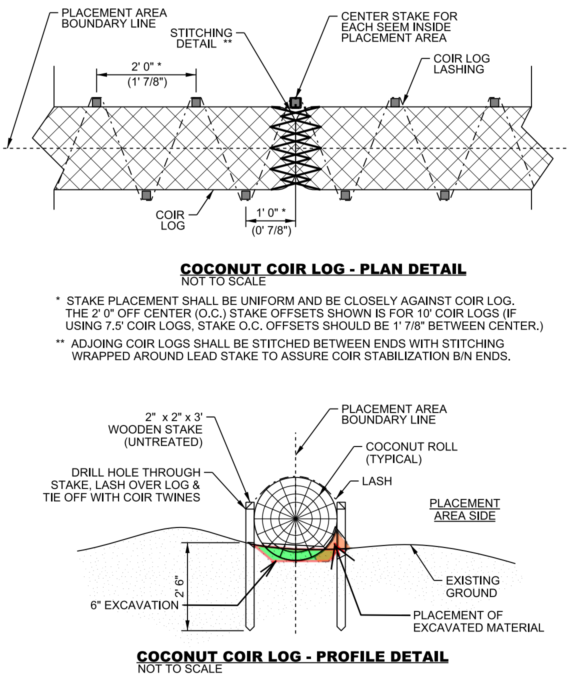
b. Dredge pipeline, Sturgeon Island, New Jersey
Source: Timothy Welp, ERDC

c. Coir logs, Avalon, New Jersey
Source: Timothy Welp, ERDC

Jekyll Island Coir Log Design and Specifications

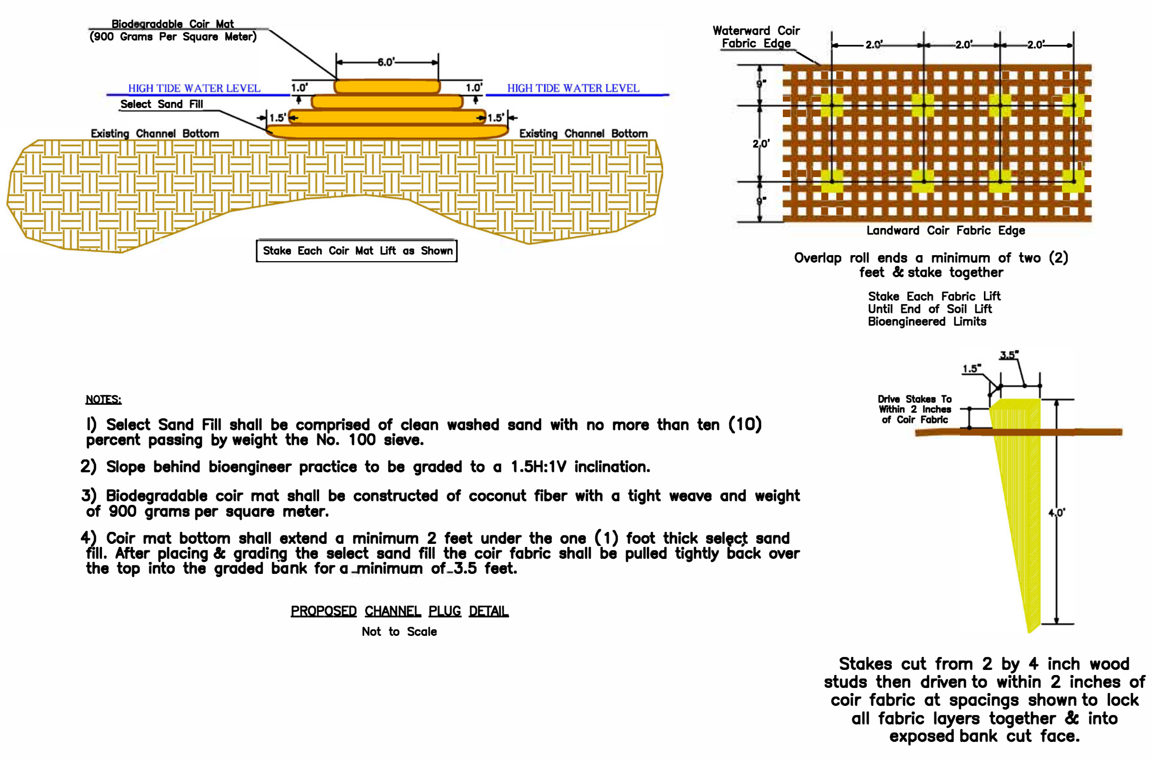
Coir logs are designed to contact the soil, so any stumps or potential obstructions should be removed. As much as practicable, dig a small trench no greater than 6 in (15.24 cm) deep where the coir logs need to be placed (see Figure 4.11). Place the coir logs in the trench and backfill with soil within the placement area boundary. Adjacent coir logs should be positioned so the ends fit tightly against each other. Ends should be joined or secured together with 100% biodegradable coir twine. Excess coir fiber may be used to fill spaces between log ends. Anchor the coir logs into position using untreated stakes and lashing according to plan details. Indoor or outdoor storage of coir logs prior to placement should be limited because the nets begin to degrade immediately.

Figure 4.11. *Example Coir Log Design*



The box above presents an example of the technical specifications of the Jekyll Island project coir log containment design. In this project, USACE–Jacksonville District was able to use Jekyll Island's topography to advange in that 16-in (40.64 cm) diameter coir logs could be used on the high side of the island, while 20-in (50.8 cm) diameter coir logs were required in the lower-lying areas. Figure 4.12 presents the contract design of the channel plug used in the Blackwater NWR Marsh Resiliency Thin Layering Project. The constructed containment structure is shown in previous Figure 4.10*a*.

Figure 4.12. *Channel Plug Design Used in the Blackwater NWR Marsh Resiliency TLP Project*



NOTES:

1) Select Sand Fill shall be comprised of clean washed sand with no more than ten (10) percent passing by weight the No. 100 sieve.

2) Slope behind bioengineer practice to be graded to a 1.5H:1V inclination.

3) Biodegradable coir mat shall be constructed of coconut fiber with a tight weave and weight of 900 grams per square meter.

4) Coir mat bottom shall extend a minimum 2 feet under the one (1) foot thick select sand fill. After placing & grading the select sand fill the coir fabric shall be pulled tightly back over the top into the graded bank for a minimum of 3.5 feet.

Stakes cut from 2 by 4 inch wood studs then driven to within 2 inches of coir fabric at spacings shown to lock all fabric layers together & into exposed bank cut face.

Source: Albert McCullough, Sustainable Science

Easily removed materials are generally preferred at sites where the containment structure is designed to be removed immediately or soon after construction. Biodegradable materials are preferred for the entire structure including attachments (e.g., lashing twine instead of wire) if the containment structure is designed to be left in place. Containment materials capable of absorbing water (e.g., coir logs and straw bales) become very heavy after inundation. As part of the Avalon project's adaptive management plan to encourage more drainage, long, continuous sections of the coir log containment in nonpriority areas were perforated either by cutting loose portions and removing them from the wetlands or by cutting the logs open and spreading the biodegradable coconut stuffing over the marsh (TNC and NJDEP 2021).

In the Seven Mile Island Innovation Lab TLP project on Sturgeon Island, the dredge's own high-density polyethylene (HDPE) pipeline was used in two ways to manage slurry with temporary containment. In the first, the pipeline corridor was designed so the dredge's active discharge pipeline would retain sediment on the wetlands (see Figure 4.13*a*). In the second, a disconnected length of air-filled pipe was floated into the wetland on the tide and placed as a temporary containment feature (see Figure 4.13*b*). The pipe was then pumped full of water so the added weight would help form a better seal between the pipeline and the vegetated wetland surface. Still, DM seeped beneath the pipe during placement, resulting in some DM in the areas beyond the water-filled pipe.

Figure 4.13. *Temporary Containment to Retain Sediment on Seven Mile Island Innovation Lab TLP Project*

a. Use of dredge's HDPE active discharge pipeline

b. Section of disconnected water-filled pipe

Source: ERDC

In wetland areas with tidal currents and waves strong enough to mobilize sediments, containment in channels can be removed immediately after construction to allow currents to naturally distribute the excess sediment. But the effect of sediment dispersion on the surrounding aquatic habitats should be evaluated. If some sediment retention in channels is desired, channel containment can be removed weeks to months after placement to allow some mobilization to occur. If tidal creeks are filled and are intended to reform, any containment structures should be removed before the DM is fully consolidated. Although there is no universal recommendation on the time frame for removing containment structures, one rule of thumb is to breach containment structures when the DM is 50% consolidated (A. McCullough, Sustainable Science, pers. comm., 2018). If sensitive ecological resources such as SAV or oysters are nearby, controlled removal may be planned to regulate the volume of sediment released during ebb tide.

At sites with relatively thick placements, on the order of 12 in (30.48 cm) or more, of fine-grained materials, sediment may be excavated from the placement area and mounded to create earthen containment dikes to contain the DM slurry. The TLP sediments then fill the placement area and the containment mound borrow area. This technique can be used for both intertidal and subtidal placements and is a more permanent type of containment. It has been used for marsh construction in Galveston Bay and coastal Louisiana, where most DM is fine-grained silts and clays. CPRA Geotechnical Standards (2017b) provide guidance on earthen containment dike design.

If placement is occurring in or immediately adjacent to sensitive aquatic habitats, silt curtains or other floating barriers may be required to trap sediments. Innovative silt curtain designs using biodegradable burlap have been implemented in wetland construction projects at the Gaillard Island Disposal Facility in Alabama (Lovelace 2013; see Figure 4.14). The material is left in place to help retain the relatively mobile, recently placed sediments until settling and consolidation occur over the subsequent months and years.

Figure 4.14. *Biodegradable Burlap Silt Curtain at the Gaillard Island Disposal Facility*

Biodegradable turbidity curtain

- Burlap anchor tube
- Burlap curtain and flotation

Source: Nate Lovelace

Any disturbed areas, such as pipeline corridors, equipment access and staging areas, and transport routes, will need to be restored and replanted with appropriate vegetation at the completion of the TLP project. Depending on the degree of soil compaction, techniques to loosen the soil (such as tilling) may also need to be used prior to replanting.

4.3 Cost Estimate

The final construction cost estimate should be based on plan quantities and pricing estimates once the design nears finalization, detailing the critical construction steps depicted in the bid sheet and project schedule. Typical elements for wetland TLP projects include mobilization and demobilization, surveys (including material costs [e.g., grade stakes or settlement plates]); access and staging areas; containment structures; dredging (if applicable); transport; placement; site restoration; and temporary warning signs. Vegetative plantings may be added according to landowner preference and risk tolerance related to concerns with recolonization of the existing vegetation or seed stock or as a contingency measure. As noted by CPRA, the engineer's estimate of probable construction cost plays a critical role in marsh creation projects that includes marsh nourishment because "it is utilized to manage project funding, manage project resources, and minimize project uncertainty" (CPRA 2017d, Appendix E, 1). Although focused on marsh creation and nourishment projects in Louisiana, CPRA (2017d) presents more detailed information on general construction cost-estimating techniques, project design phases, construction cost estimate contingencies, and cost-estimate deliverables. The document also presents measurement and payment examples.

It is important to provide uncertainties and appropriate contingency factors for each phase of the engineering design, as depicted in Table 4.5.

Table 4.5. *Typical Marsh Creation Project Design Phases*

Design phase	Construction cost-estimate description	Level of contingency*
Planning and Conceptual Design (<15%)	• Feasibility-level project cost estimate • Construction cost estimate meant to be conceptual and basic in nature • Estimated unit rates based on past data may be inaccurate • Magnitudes of quantities and costs understood to lack accuracy	30% to 40%
Preliminary Design (30%)	• Estimate generated near or at completion of data collection • Estimate produced to accompany preliminary design deliverables • Level of accuracy understood to be moderate	20% to 30%

Table 4.5 *(cont.). Typical Marsh Creation Project Design Phases*

Design phase	Construction cost-estimate description	Level of contingency*
Intermediate Design (60%)	• Estimate advanced to significant level of detail • Magnitudes of quantities, unit rates, and costs estimated with low uncertainty • Level of accuracy understood to be high	15% to 20%
Final Design (95%)	• Magnitudes of estimated quantities, units, and costs understood to have little uncertainty and are incorporated into construction bid schedule • Excluding change orders, construction coast estimate should be highly accurate with respect to final construction cost	10% to 15%

Note: *The level of contingency is shown for informational purposes and does not replace the judgment of the design professional.

In a dredging project, the type and size of dredge used, and the dredging project costs, depend on the following general parameters (modified after EM 1110-2-5025 [USACE 2015]):

- Physical characteristics of the material to be dredged
- Quantities and physical layout of the material to be dredged
- Dredging depth
- Distance and features between the dredging and placement sites
- Physical environment of and between the dredging and placement areas
- Production required
- Types of dredges available
- Placement site design
- Environmental considerations

To illustrate the magnitude and range of wetland TLP projects, construction costs (excluding monitoring when possible) for selected TLP projects are summarized in Table 4.6. Although these costs were compiled from the available literature, their relative comparability is unknown because of uncertainty about what each project's reported total cost includes (e.g., mobilization and demobilization, engineering costs, contract inspection costs, containment, or other components). A more detailed cost analysis and comparison between the Ring Island, Avalon, and Fortescue projects is presented in TNC and NJDOT (2021).

Table 4.6. *Engineering and Construction Cost of Selected Wetland TLP Projects*

Project name and location	Volume (yd^3)	TLP area (ac)	Total cost ($)	Unit cost (cost/yd^3)	Unit cost ($/ac)
Ninigret Pond Salt Marsh, Rhode Island	68,000	20	1,519,565	22.35	75,978
Seal Beach, California	13,500	10	236,000	17.48	23,600
Pepper Creek, Delaware	9,000	25	5,000	n.d.	200
Prime Hook, Delaware	600,000	4,000	9,500	n.d.	2.375
Ring Island, New Jersey	7,000	2	470,400	67.20	235,200
Fortescue, New Jersey	32,100	10.5	4,391,200	136.80	418,210
Avalon, New Jersey	55,300	45	2,063,100	37.31	45,846

Note: n.d.—no data available.

The 2012 and 2014 open-water TLP in Mobile Bay realized significant savings in dredging costs. For the 2014 TLP effort, cost savings were $4 per yd^3 over conventional disposal, which amounted to a total project cost reduction of $4 million (USACE 2020). Monitoring and modeling concluded that the placed DM is less erodible than the native bay bottom sediment because of its fine-grained cohesive properties (Parson et al. 2015). In addition, material placed in thin layers is not transported along the bottom as a slug of sediment; rather, it is remobilized into the water column by waves and currents and returned to the bay's natural sediment transport system and so does not affect other natural resources in the bay (Parson et al. 2015). Monitoring in 2012 indicated that the material consolidated rapidly, and the benthic community recovered quickly (Gailani et al. 2019).

4.3.1 Other Considerations

To provide flexibility during construction, the permitted project footprint should extend beyond the targeted placement areas so that small amounts of slurry can flow beyond the placement areas without concern. In some cases, this may eliminate the need for regulatory permit approval of impacts to costly containment structures.

As mentioned previously, dredging and placement may be subject to different regulatory timing constraints (environmental windows). If a TLP project uses navigation channel DM, both sets of environmental windows apply, which may substantially limit the time of year when the project can occur. For projects with short construction windows, dredge availability and production rates can be critical to implementation.

Production is best estimated using a from-the-ground-up approach. By considering the estimated volume of material to be placed and the lift thicknesses required to achieve elevations across the site, the rate of transport required to meet the project construction window can be determined. This can then be compared with experience from prior projects, which can be used as generic guidance. A primary component of cost estimating is determining dredge production given the dredge type and size, channel site-specific conditions, transport distance, and placement requirements. Parameters that affect dredge productivity are discussed in more detail in USACE's *Dredging and Dredged Material Management* Engineer Manual (USACE 2015). The specific contracting aspects (solicitation, payment basis, bid selection, quality assurance, etc.) employed will depend on factors such as (1) involved stakeholders (federal, state, and private) and their respective roles, (2) funding sources and their respective fiscal requirements, (3) sediment source (navigation channel or borrow area), and (4) local market conditions, including qualified contractors and their availability.

Most, if not all, TLP projects are design-bid-build projects in which the engineering design documents are prepared by either the owner or an engineer under contract. The contractor is selected through a bidding process, and the selected contractor enters into a contract with the owner. Developing contracting specifications for TLP projects that use navigational DM is similar to developing specifications for any other navigational dredging project. But because TLP projects require close coordination with and cooperation between the owner, stakeholders, and contractor, the contract specifications and engineering drawings must be sufficiently detailed for the contractor to clearly understand the project objectives, and the contract documentation must reinforce this cooperation and coordination between all the parties involved. The required level of detail in contract plans and specifications varies by project, state, and stakeholders. TLP projects in areas of greater ecological concern may require more detail than others. Care should be taken to avoid overengineering the project, which may stifle contractor creativity and adaptive management. A well written adaptive management plan is probably more important to project success than the design process itself.

Best-practice guidelines for developing TLP specifications are similar to those for any other project. Specifications should be written in clear, concise language stating what the contractor shall or shall not do with no ambiguity. Project success should be clearly described with measurable metrics to determine whether the project meets specifications. The methods, responsible parties, and period of performance that determine project success must be clearly stated. As mentioned previously, the proportion of the area allowed to be out of specification should also be clearly stated so any required remedial actions can be taken quickly.

Prescriptive versus Performance Specifications

"Prescriptive specifications are recipes: do this, then do this, then do this, etc. Performance specifications aren't recipes. They don't tell the contractor how to do the work. What they tell the contractor is what [the Owner] wants" (Lowe 2022).

There are different types of specifications the design engineer can select to encourage competition while maximizing contract quality by not inhibiting the contractor's innovation. Preexisting specification formats usually exist for larger federal or state agencies, and they can be advantageous for dredging contractors because they may be more familiar with these formats (and with the agency's dredging contract process). But even these preexisting specifications must find a balance between prescriptive (or descriptive) specifications and performance- (or function-) based specifications.

Although the owner (or engineer) exercises more control over the work with prescriptive specifications, the owner assumes more risk because the contractor is not responsible for the end product's performance. (Common observations from the TLP workshop participants were that "over engineered" prescriptive specifications could lead to higher costs.)

Alternatively, performance specifications tell the contractor what the owner wants but not how to do it; therefore, the contractor assumes more risk but is also encouraged to be more innovative to reduce costs that, in turn, can lead to a reduced contract cost. Performance specifications must include criteria by which the product's performance is evaluated and must explain how those performance criteria can be verified.

Specifications should also clearly state what the contractor should not do, especially with regard to environmental requirements or ecological considerations.

If allowed, prequalification of contractors can ensure the contractor has the experience required to deliver a successful TLP project. Even in public projects, certain criteria can be enforced as necessary to ensure qualified contractors. As follows are some examples:

- Experience with three to five projects of similar scope and magnitude in the past five years
- Proof of no violations or citations from any regulatory or enforcing authority
- Certificate of training for operators and a statement that operators (once proposed) cannot be changed without the contracting officer's written approval


Placing Sand in the Nearshore Zone for Marsh Restoration
Source: Scott Douglas, NJDOT OMR

Chapter 5. Construction Considerations, Equipment, and Methods

Construction considerations, equipment, and methods for dredging and placing DM are discussed in USACE's *Dredging and Dredged Material Management* Engineer Manual (USACE 2015) and CPRA engineering guidance pertaining to marsh creation and wetland nourishment projects (CPRA 2017d). Lessons from implementing the Ring Island, Avalon, and Fortescue TLP projects are presented in TNC and NJDOT (2021). This chapter presents additional information on construction considerations, equipment, and methods specific to wetland and open-water TLP projects to emphasize or augment the information in those three references.

5.1 Safety Considerations

Although safety has always been a concern in dredging (an industry that uses heavy equipment on both water and land), there has been significant improvement during the past decade or so with an industry-led shift toward more emphasis on safety. Safety and health requirements for all USACE activities and operations are provided in USACE's *Safety and Health Requirements* Engineer Manual (USACE 2014), and compliance with this manual is a USACE contract requirement. The following safety considerations from past wetland TLP projects presented here to further enhance safety and allow workers to "leave the worksite the way they entered it" should be included in the appropriate accident prevention plan and activity hazard analysis.

Although preplacement topographic surveying can present personnel hazards in areas of unconsolidated sediment, topographic and hydrographic surveying in pannes, pools, and water-filled ditches in conjunction with unconsolidated bottoms can significantly increase risks to personnel. Alternative survey methods are presented in Section 3.1.2.

After fine-grained sediment is placed on wetlands (particularly over pannes, pools, and ditches), the loose, unconsolidated material can present a hazard to personnel transiting, working, and operating equipment on the site. After placement, access to the (preplacement) deeper areas should be restricted; if access is required, safe transit corridors should be plainly marked.

Construction activities in wetlands, often in remote locations, can present environmental hazards that must be mitigated through safety measures, including first aid kits and training, potable water, emergency plans (including escape procedures and routes) in case of an emergency (accident, severe weather, lightning, etc.), effective means of emergency communications, and personal protective and safety equipment.

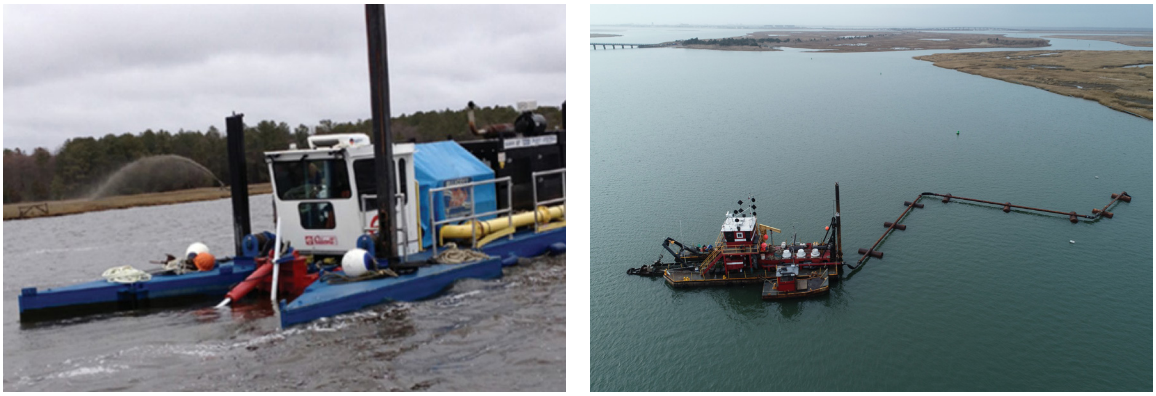
Most East Coast wetland TLP projects dredge and place DM only during daylight. Sometimes, to accelerate production or make up lost time, additional work windows, including 24-7 operations, may be instituted. If nighttime dredging and placement are conducted, the appropriate health and safety requirements apply, including adequate lighting, personal protective and safety equipment, an appropriate communications plan and equipment, and implementation of a buddy system. Additional protective measures and safety protocols should be developed and implemented for extremely cold or hot weather.

5.2 Equipment and Methods

Larger cutterhead and hopper dredges (see "Primer on Dredging Terms and Equipment" box in Section 2.2.4) may be used for open-water TLP of sediment from navigation channels. A 30-in (76.2 cm) cutterhead dredge placing sediment in a target layer thickness of 1 ft (30.48 cm) in Mobile Bay is described in Section 1.1, and a case study on the use of a 20-in (50.8 cm) cutterhead dredge to deposit sediment at a target thickness of 0.5 ft (15.24 cm) at the Fowl River in Alabama is presented in Section 5.9.1. Section 5.9.2 includes a case study that provides additional information on the MCR TLP project, where the 6,423-yd^3 (4,910.74 m^3) hopper dredge *ESSAYONS* placed sediment at target layer thickness ranging from 0.3 to 2.3 ft (9.14 to 70.1 cm), depending on the placement subarea.

Cutterhead dredges are the most common type used to excavate sediment from a navigation channel or borrow area and transport it, via a short or long pipeline, to the wetland TLP sites. Figure 5.1 presents photographs of several cutterhead dredges used in TLP projects to show the variety of placement configurations available.

Figure 5.1. *Cutterhead Dredges of Various Sizes Used in Wetland TLP Projects*



a. Pepper Creek, Delaware 10-in (25.4 cm) swinging ladder cutterhead dredge

Source: ERDC

b. Avalon, New Jersey 14-in (35.56 cm) cutterhead dredge

Source: Stephen Rochette, USACE, and Barnegat Bay Dredging Company

Figure 5.1 *(cont). Cutterhead Dredges of Various Sizes Used in Wetland TLP Projects*

c. Prime Hook, Delaware 12-in (30.48 cm) swinging ladder cutterhead dredge

Source: Samuel Robinson, Dredge America, and Bart Wilson, USFWS

d. Mobile Bay, Louisiana 30-in (76.2 cm) swinging ladder cutterhead

Source: Travis D. Dyess, USACE

Most Atlantic Coast and Pacific Coast wetland TLP projects use smaller cutterhead dredges with discharge pipelines ranging from 10- to 14-in inside (25 to 35.56 cm inside) in diameter (see Figures 5.1*a* and 5.1*b*, respectively) to place the slurry on the wetland (see an example of the end of a pipe in the background of Figure 5.1*a*). Several TLP projects have used these smaller cutterhead dredges with the end of pipe located on the dredge's stern and equipped with a nozzle to produce the rainbow shaped spray pattern shown in Figure 5.1*c*. Two 8-in (20.32 cm) swinging ladder dredges were used at the Ninigret Pond in Rhode Island. Larger cutterhead dredges, like the 30-in (76.2 cm) inside-diameter discharge shown in Figure 5.1*d*, typically operate in the larger-scale marsh-creation and marsh-nourishment projects conducted in Louisiana.

Other dredge types, such as horizontal auger dredges and mechanical dredges combined with a fluidization or pump hopper system, or a submersible pump, can achieve similar objectives. Submersible centrifugal pumps are typically single-stage, vertical pumps, with discharge diameters ranging from 4 to 12 in (10.16 to 30.48 cm) inside; they differ from conventional dredges in that the submersible pump is placed directly behind the excavator (cutterhead or auger head). The excavator is submerged in the material to be removed. A submersible pump with a cutting module can also be attached to the stick of a hydraulic excavator, as shown in Figure 5.2.

Figure 5.2. *Submersible Pump with Cutterhead Attached to a Hydraulic Excavator*

Source: Andrew Timmis, J.F. Brennan Company

Different attachments can be connected to the end of a pipeline to modify slurry deposition patterns. The discharge generated by the attachments that have been used in TLP projects can be categorized as one of the following:

- Low-pressure discharges—from either an open-ended pipe without any attachment, or a pipe equipped with a spreader plate to slow the discharged slurry so it can be directed with better control over the placement point and reduce impacts to the wetland surfaces or the water column (Cahoon and Cowan 1987).
- High-pressure discharges—from a contraction section (typically a nozzle) at the end of the pipe to increase the slurry's exit velocity so the resultant jetting action propels the slurry in an arc-shaped pattern (Cahoon and Cowan 1987). If this method is used, due consideration should be given to ensure that any localized scour from the discharge pipe is within acceptable limits.

Figure 5.3 shows the variety of low- and high-pressure discharges used in wetland TLP projects.

Figure 5.3. *Examples of Low- and High-Pressure Discharges in Wetland TLP*

a. John H. Chafee NWR, Rhode Island low-pressure (naked) discharge

Source: USFWS

b. Sturgeon Island, New Jersey low-pressure (spreader plate) discharge

Source: USACE–Philadelphia District

c. Blackwater NWR, Maryland high-pressure (ground-mounted nozzle) discharge

Source: Albert McCollough, Sustainable Science

d. Pepper Creek, Delaware high-pressure (barge-mounted nozzle) discharge

Source: DNREC

The type of pipeline discharge and how it is repositioned have a crucial impact on achieving target elevations (or thicknesses) and on optimizing the engineering characteristics of placed sediment while maintaining dredge production that is as efficient as possible. A primary distinction between high- and low-pressure discharges is the deposition pattern (Cahoon and Cowan 1987).

Low-Pressure Discharge Observations

Cahoon and Cowan (1987) report that low-pressure discharges used in early Louisiana canal TLP projects could, depending on sediment type, deposit slurry over an area up to 75 ft (22.86 m) wide at a minimal thickness of 1 ft (30.48 cm). The slurry could be place discontinuously around the canal, but the deposition pattern depended on a fixed-terrain pipeline that had to be repositioned frequently to prevent high sediment accumulation. The water and sediment mixture were described as “macerated and liquefied, but not slurried” (Cahoon and Cowan 1987, 7).

During the Avalon project, hydraulic sorting of the coarse-grained sediment immediately around the discharge was apparent because this deposited sediment could be walked on, unlike the increasingly finer-grained material that was more easily walked through farther from the pipe’s discharge. A field sampling exercise conducted to investigate this hydraulic sorting process quantified this observation (see Figure 4.2).

TNC and NJDOT (2021) describe how, during Avalon Phase II, the pipe discharge would be positioned near the edge of a large pool inside each confined placement cell and how, after pumping until the DM was overtopping the containment in its vicinity and this overtopping could not be stopped, the pipe discharge would be moved. Two or three discharge locations were usually needed in each cell to achieve the target elevation across the full extent of that cell (see Figure 5.4). In most cases, the target elevations were achieved near the discharge before they were achieved farther away. The pool-panne complexes were described as “bathtubs” (i.e., areas of lower elevation) because during pumping they would retain slurry and prevent it from dispersing, but once the “bathtubs” were full, the slurry would spill out from their lowest point (TNC and NJDEP 2021, 84).

The lowest point was either predicable—for example, an existing drainage path off the marsh—or unpredictable, with the slurry flowing along the path of least resistance created around placed mounds of DM. Usually the drainage path led directly to the surrounding containment and caused overtopping, which could have been resolved by moving the pipe outlet more frequently (TNC and NJDEP 2021).

Figure 5.4. *Avalon (New Jersey) Phase II DM Placement with a Low-Pressure (Spreader Plate) Discharge*

Note: Photo shows the discharge at the end of the pipeline, with the perimeter protected by coir logs.

Source: TNC

High-Pressure Discharge Observations

Cahoon and Cowan (1987, 3) report that in the early Louisiana TLP projects (see dredge in Figure 1.5 where the nozzle is relatively easily repositioned) the slurry "can be spread as much as 250 ft across the marsh to a depth of only a few inches," and because the high-pressure spray nozzle can be aimed in any direction, the slurry not need be deposited continuously in the marsh and "small natural drainage streams can be avoided completely." The deposited slurry was described as "a liquefied, unsegregated slurry" (Cahoon and Cowan 1988, 359).

Whitbeck et al. (2019, 15) report that during the Blackwater NWR project (see discharge used in Figure 5.3*c*) "the dredge material was observed to flow approximately 150 ft [45.72 m] radially beyond the discharge point," and after grade was achieved, "the nozzle was repositioned 300 ft (91.44 m) from its previous location. This placement sequence resulted in circular material placement patterns with sandier centers gradually grading to finer grained sediments outward."

"In general, coarser material tended to stack up close to the point of discharge and declined to flatter slopes towards the periphery" (Whitbeck et al. 2019, 19).

High-pressure discharge is usually used only in small dredge applications (8 to 12 in [20.32 to 30.48 cm]) because of the back force created in the pipe by the nozzle contraction. During the Pepper Creek project, the nozzle was clogged by debris (including shells), and dredge production was significantly reduced because of delays to clear debris as well as the reduced slurry pipeline flow (D. Brower, pers. comm.).

Various sources have observed that higher-velocity winds can also affect the deposition pattern of a high-pressure discharge (Cahoon and Cowan 1987).

TNC and NJDOT (2021) describe the placement phenomenon that results in the formation of a scour hole (shown in Figure 5.5). With enough sand in the slurry and a lengthy-enough deposition at high or low pressure, a scour hole can occur and significantly affect project efficiency. Sometimes the sand can also mound near the discharge pipe, and a scour hole may form within the sand mound, with the slurry eventually breaking through and funneling the flow in one direction, thereby limiting its dispersion. In such cases, frequently moving the discharge pipe, or using dozers or front end loaders to move the material, can mitigate these issues. Therefore, an adaptive process is often required during construction (see below), thus reemphasizing the need for close tracking and oversight during construction.

Figure 5.5. *Scour Hole at the Base of a Dredge Pipeline Discharge*

Source: New Jersey Department of Environmental Protection (NJDEP) and TNC

Given these deposition characteristics, the following should be considered when selecting or operating a high- or low-pressure discharge (or discharges):

- Location and geometry (shape and dimensions) of placement areas
- Where the sediment is wanted (and not wanted)
- Composition of DM (grain-size distribution, presence of debris, etc.)
- Target elevation or layer thickness values and tolerances
- Placement area's DM volume storage capacity
- Confined versus unconfined placement
- Dredge production parameters (slurry density, slurry velocity, pump characteristics)
- Discharge repositioning methodology
- Placement area conditions (topography, hydrography, ground-bearing strengths, etc.)

These aspects also influence the decision to design and operate valves in the slurry distribution system if the project design includes elements such as multiple containment cells for sequential placement (Section 4.2.3) or various unconfined placement areas. Figure 5.6 shows photographs of the slurry distribution system of the Sturgeon Island, New Jersey, project, part of the Seven Mile Island Innovation Lab that emphasizes demonstrations and evaluations of innovative technologies. This Y valve consisted of an HDPE connector section (shaped like a Y) with two individual gate valves mounted downstream of the bifurcation. The Y valve was operated in the conventional manner (one gate valve open and the other closed) to direct slurry flow down either of the downstream pipeline segments. It was used to optimize dredging efficiency in placing slurry in different areas in conjunction with the use of low-pressure discharges (both open end and spreader plate) and high-pressure (nozzle) discharges. An innovative proof of concept that was successfully demonstrated during this project consisted of partially opening both gate valves to split the slurry feed from the 14-in (35.56-cm) cutterhead dredge (see dredge in Figure 5.1*b*) between both downstream pipelines to reduce slurry volume and energy to enhance sediment deposition on the wetland.

Figure 5.5 also shows that, similar to more recent East Coast and West Coast TLP projects, the Sturgeon Island project used an HDPE plastic discharge pipeline. HDPE has about one-eighth the density of steel pipe and is lighter than water, so it can be towed in long lengths to the dredge site. This reduced weight can translate into less construction-related damage to the wetlands because pipe can be handled with lighter equipment. The flexibility of HDPE pipe allows it to be bent to radii approximately 25 times the pipe diameter, minimizing the need for mechanical connectors (USACE 1986) and allowing greater flexibility in repositioning. HDPE pipe sections are bonded by heat fusion that makes connections as strong as the pipe itself.

Figure 5.6. *Sturgeon Island Project Slurry Distribution System Components*

a. Viewing upstream of Y valve between valve and dredge (in background)

b. Downstream of Y valve between valve and placement areas

Source: Timothy Welp, ERDC

These capabilities can be advantageous in the design, mobilization, construction, and demobilization phases, especially if adaptive management requires significant changes during construction. Different slurry distribution system operational methodologies can also be optimized in response to field conditions (e.g., placing sediment as pipe is added while advancing into a wetland [relative to the access water body] or placing sediment as pipe is removed while retreating out of a wetland).

The determination that DM has been placed to the target elevation (or within the designated tolerance) is usually based on visual observation of the deposited DM's elevation relative to grade stakes installed at various locations in the placement area. Because wetland site conditions can affect the ability to accurately read conventional grade stakes, different types have been devised and used to enhance observability. Use of binoculars or spotting scopes may also help resolve this issue. Figure 5.7 shows modified grade stakes employed at the first Blackwater NWR TLP project to enhance the ability to observe the attainment of grade at a longer distance.

Figure 5.7. *Modified Grade Stakes Used to Ascertain Attainment of DM Grade at First Blackwater NWR TLP Project*

Source: Bob Blama, USACE (retired)

In the second Blackwater NWR TLP project, “witness boards” were used not only to measure attainment of grade but also to predict consolidation of DM (see Figure 5.8). The witness boards “consisted of two vertical wooden stakes driven into the marsh with two horizontal cross boards attached. The elevation of the horizontal boards was surveyed with construction-grade laser level. The upper horizontal board was set to indicate the maximum elevation of dredge material placement, and the lower board indicated predicted settlement height that would be achieved two weeks after material placement” (Whitbeck et al. 2019, 14).

Figure 5.8. *Blackwater NWR TLP Project Witness Board*

Source: Middleton Evans, USFWS

Corridor selection and access are critical for pipelines, particularly because a project's footprint should be minimized to avoid construction-related impacts. In Louisiana, pipeline corridors are typically 60 to 100 ft (18.29 to 30.48 m) for land-based pipe (shore pipe) and 100 to 300 ft (30.48 to 91.44 m) for offshore corridors (CPRA 2017d). The sensitivity of wetlands to damage from construction, even when low-ground-pressure equipment is used (described in Section 3.1.3), is emphasized by numerous sources (e.g., Cahoon and Cowan 1987; TNC and NJDOT 2021; CPRA 2017d; Whitbeck et al. 2019). Figure 5.9 presents a sequence of photographs from the Fortescue TLP project that illustrates its wetlands' sensitivity to the marsh-buggy construction activities conducted there. In general, corridors are best linked to placement areas so that the damage is repaired as sediment is added. Of course, this is not always possible given marsh platforms' lack of stability in degraded areas.

Figure 5.9. *Time Series of Recovery from Damage to Fortescue, New Jersey, Wetland Caused by Low-Ground-Pressure Marsh Buggy Construction Activities*

2016

2017

2018

2019

Source: NJDEP and NJDOT

As previously described, TLP ideally should be implemented by experienced contractors who are aware of the sensitive nature of the marsh environment. The soft nature of the substrate alone can be quite challenging to work on and around. Construction activities to transporting personnel and material, installing (and, if necessary, removing) containment structures, mobilizing and demobilizing the pipeline, and repositioning the pipeline discharge to achieve grade will all affect the wetland. Figure 5.10 presents examples of amphibious and low-ground-pressure equipment that has been used in marsh restoration projects. Figure 5.11 provides an illustration of side-cast (open-water) TLP operations, and Figure 5.12 shows a cutterhead dredge and tailpipe for open-water TLP applications.

Figure 5.10. *Amphibious and Low-Ground-Pressure Equipment Uses in Marsh Restoration Projects*

Source: Anchor QEA

Source: Andrew Timmis, J.F. Brennan Company

Source: Anchor QEA

Source: Tim Donegan, Sevenson Environmental Services

Figure 5.11. *Side-Cast (Open-Water) TLP Discharge*

Source: William Wetta, II, DSC Dredge

Figure 5.12. *Cutterhead Dredge and Tailpipe for Open-Water TLP*

Source: Weeks Marine

Mat-based roadways are preferred since they are relatively easier to restore if the underlying strata are not excessively consolidated. But if the underlying strata are consolidated, it can take several years for vegetation to reestablish itself unless surface tilling or other methods to loosen the surficial consolidated dense sediments are employed.

These construction activities require skilled operators to run the equipment safely and efficiently. The following panel contains the requirements for utility operators working under USACE contracts. Appendix B includes operational best-management practices to guide engineers and personnel working in marsh environments in avoiding and reducing ecological impacts during construction.

Utility Vehicle Operator Requirements

Utility vehicle operators shall be trained.

a. They must be familiar with the use of all controls and understand proper moving, stopping, turning, and other operating characteristics of the vehicle.

b. Operators must review all training materials provided by the manufacturer for the specific vehicles, and training should be in accordance with appropriate manufacturer recommendations. At a minimum, training shall be documented and shall address:

    1. Basic riding tips from the manufacturer's published literature for each vehicle
    2. Reading terrain
    3. Climbing hilly terrain
    4. Descending a hill
    5. Traversing a slope
    6. Riding through water
    7. Cargo carriers and accessories
    8. Loading and unloading
    9. Troubleshooting
    10. Proper preventative maintenance (i.e., oil levels, tire pressure requirements, and scheduled maintenance requirements according to the manufacturer's guidelines).

c. A copy of the operator's manual shall be kept on the vehicle at all times and protected from the elements.

d. Amphibious excavators will only be operated in accordance with the manufacturer's operating instructions.

e. A copy of the operator's manual will be readily available on the equipment.

Source: Adapted from USACE (2014)

For equipment access, mat-based roadways are ideal as they can be restored following completion of the placement part of the project. Care should be taken not to overload the marsh, because if consolidation is induced in the underlying strata, natural recovery is inhibited, potentially requiring replanting.

5.3 Construction Schedule

Construction schedules initially should be based on the proposed scope of work, site-specific and logistical constraints, production rates and efficiencies from past dredging and TLP projects, and professional experience and judgment. All the relevant construction steps should be presented, including notice to proceed, required submittals, preconstruction meetings, regulatory time-of year restrictions, preconstruction (and interim) surveys, mobilization, dredging and TLP schedule, restoration, and demobilization. Calendar days are often used. The contractor should provide its own schedule prior to construction and interim makeup schedules as necessary.

5.4 Construction Work Plan

The construction work plan (CWP) should include, at a minimum, the following information:

- **Project organization—**Details on project management structure, including contractor project manager, principal, superintendent, and other key positions
- **Health and safety plan—**Provided either as part of the CWP or as a separate deliverable; includes all relevant details for safe execution of work, including operation in wetlands, soft sediment considerations (for personnel and equipment), and considerations for working around tides, as well as night shifts, if applicable
- **Mobilization and demobilization—**Plan to stage equipment and facilities on-site and to remove them
- **Construction equipment—**Specifications for land and marine equipment, access plan, and staging
  - Dredge details, such as type, horsepower, and discharge diameter
  - Details for TLP equipment, including spray nozzle type and operation and project controls for accurate placement
  - Pipeline type, diameter, thickness, length, layout, maintenance, and removal
  - Boosters, if required
  - Backup equipment to be used in case of unforeseen delays due to breakdown, weather, or other causes given the extremely tight dredging windows required by TLP permits
- **Borrow source—**Plan and schedule for borrow area dredging
- **Pipeline corridor—**Details of dredge pipe (type, diameter, thickness, and length), plan and schedule for layout, operation, maintenance, and final removal and restoration of the corridor
- **Staging areas—**Locations for upland processing of equipment or slurries and for support areas (trailers, etc.)

- **Environmental controls—**Plan to minimize on- and off-site impacts from construction; include lateral containment features, if applicable
- **Permit compliance—**Plan for complying with all permit requirements
- **Submittals—**List of anticipated submittals and review schedule to finalize them
- **Schedule of work—**Details on workdays, shifts, hours of work, and contingency plans
- **Construction QC verification—**Include methodologies and software for survey data collection, processing, and calculations and for ancillary methods such as grade stakes or coring; the construction quality control plan (CQCP) can be submitted either as part of the CWP or as a separate deliverable
- **Site restoration—**Final plan to restore the affected site areas that need prompt restoration

5.5 Construction Quality Assurance Plan

The owner-generated construction quality assurance plan (CQAP) outlines the activities and measurements to be undertaken by the owner's representative to confirm that the contractor is implementing work in compliance with the project plans and specifications. The CQAP is often a companion to the CQCP prepared by the contractor. The plans can be implemented in tandem to maximize efficiency, with the owner's representative and contractor's quality control team working in close collaboration.

5.6 Measurement and Payment

It is important to define clearly how the work will be measured for compliance and payment purposes. Multiple methods are often used, so the hierarchy of measurements should be established. This is particularly useful in cases of conflicting data. Also specify who will perform the measurements and, if duplicate data will be collected, how potential differences will be resolved.

5.7 Contingent Disposal or Borrow Sites

Contingency plans are a good idea when a TLP project is implemented in collaboration with a dredging project. Such plans can identify alternative borrow and dredge sites, and alternative disposal sites, in case the project schedules do not align, unanticipated conditions prevent dredging at the primary borrow source, or issues with the placement of material at the TLP site arise. Ideally, the contingent site will be near the TLP site to minimize additional transport costs.

TLP can also be implemented with material from a virgin borrow source or from a CDF. Again, the closer the alternate borrow source is to the TLP site, the more cost efficient it would be to use.

5.8 Contractor Submittals

Although contractor submittals vary by the project owner, engineer, and contracting entity, as well as by project type and other factors, a generic list is provided in Table5.1 for reference purposes.

Table 5.1. *Example Contract Submittal List*

Submittal	Submittal time frame
Schedule of values	Within 10 days after notice to proceed (NTP)
Certificates of insurance	Within 10 days after NTP
Performance and payment bonds	Within 10 days after NTP
Preliminary progress schedule	5 days prior to preconstruction meeting
Daily activity report template	5 days prior to preconstruction meeting
CWP; contractor's CWP includes the following: • Organization chart and project directory • Health and safety plan • Preconstruction survey • Dredging and TLP plan • CQCP • Site restoration plan • Lighting and signage • Vessel management procedures • Laboratory qualifications and certifications	14 days prior to start of construction
Ancillary submittals, including the following: • Environmental protection plan • Spill prevention plan • Survey plan	14 days prior to start of construction
Notice to mariners	At least 3 days prior to start of construction

5.9 Selected Case Studies of TLP Approaches

Appendix A summarizes some TLP projects implemented throughout the United States. The summaries include relevant factors and lessons learned from those projects. The following selected case studies of TLP applications in marine settings illustrate further the use of TLP in a much broader context.

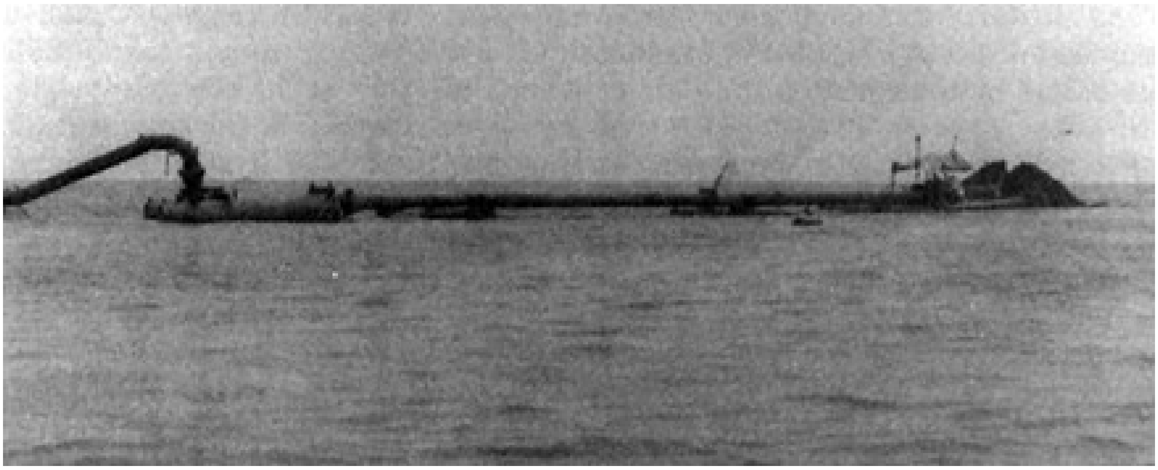
5.9.1 Fowl River Project

Since the early 1800s, most material mechanically dredged from the Mobile Bay channel was side cast alongside the channel. In the late 1800s, hydraulic cutterhead dredges replaced the mechanical dredges, but the DM from side-casting and open-water hydraulic placement formed mounds in the shallow water just outside and parallel to the channel limits. Opposition to using this placement method in shallow estuarine waters increased during the 1980s, primarily because of the creation of the DM mounds and the short- and long-term impacts to biological resources and water quality (Nester and Rees 1988).

In response, USACE–Mobile District designed a project to place thin layers of DM in the open water of Mobile Bay near areas adjacent to the Fowl River channel. The operational plan limited the DM thickness to approximately 6 in (15.24 cm), and the monitoring plan called for data collection before, during, and after dredging. Before- and after-dredging data collection included hydrographic surveying, benthic sampling, trawling, and vertical sediment profiling; the during-dredging sampling focused on collecting water quality data.

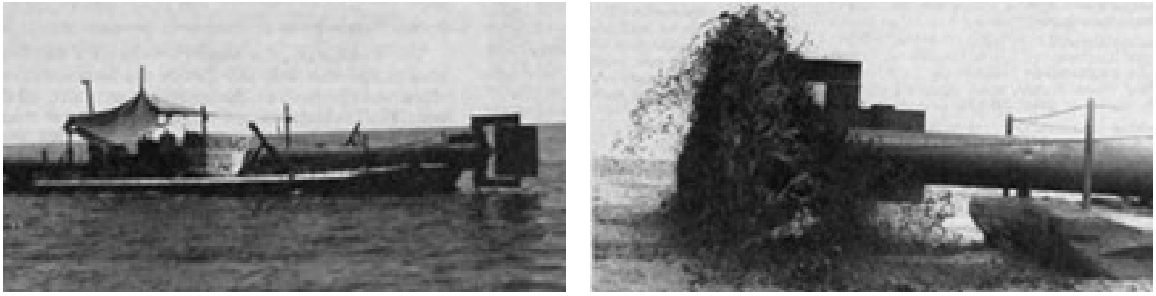
A cutterhead dredge with a 20-in (50.8 cm) discharge pipe was used to pump a slurry of 40% sand, 50% silt, and 10% sandy clay through a 4,400-ft (1,341.12 m) pipeline to a placement site approximately 1,050 ft (320 m) south of the channel. The pipeline was fitted with two steel vertical swivel ball joints that enabled the pipeline to spread sediment across the bay bottom. The discharge pipe was mounted on a barge and fitted with a wing-mounted baffle plate to spread the slurry. Figure 5.13 shows one of the vertical swivel ball joints and discharge barge configuration; Figure 5.14*a* gives a close-up of the baffle plate, and Figure 5.14*b* shows the plate in operation. Note that the horizontal wing-mounted baffle plate was mounted to a swivel, and the discharge against the angled or adjustable plate moved the discharge barge left and right to attain the TLP.

Figure 5.13. *Fowl River TLP Discharge Pipeline with Vertical Swivel Ball Joint and Barge*



Source: Nester and Rees (1988)

Figure 5.14. *Fowl River TLP Project*



a. TLP barge

b. Baffle plates at the end of pipeline

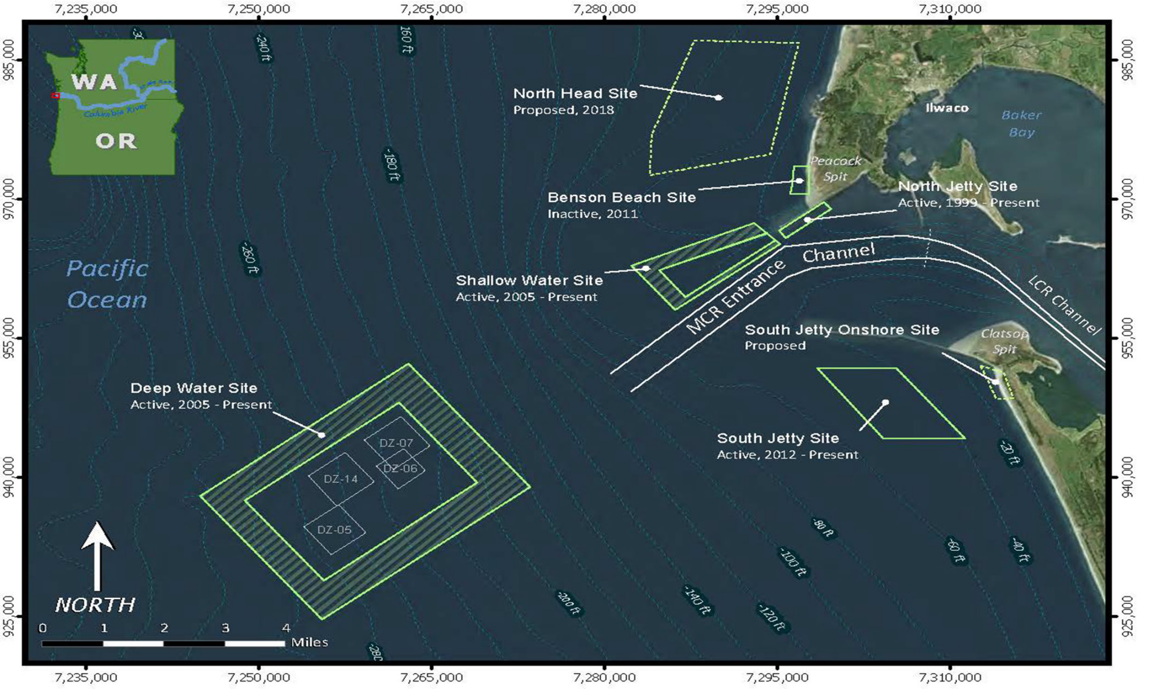
Source: Nester and Rees (1988)

The hydrographic survey showed the thin-layer deposition ranged from 0.5 to 2 ft (15.24 to 60.96 cm) in the designated placement area and from 0 to 1 ft (0 to 30.48 cm) in the fringe areas. No significant water quality impacts were detected except to total suspended solids during placement. No differences were detected in the macrofauna community; a broad recolonization occurred over the study area three weeks after placement. The fisheries data did not show significant variability, either spatially or temporally, that could be linked to the presence of the thin DM overburden (Nester and Rees 1988).

5.9.2 Mouth of the Columbia River

USACE–Portland District conducts dredging at the MCR (see Figure 5.15) to support the Columbia and Snake River Navigation System. Shortly following construction, large amounts of sediment accreted on the MCR's north and south coastal margins, but over time this accretion slowed and then reversed until now the areas (particularly on the Oregon side) are receding. This recession threatens the stability of the navigation channel and the South Jetty (Norton et al. 2015). Wanting to minimize the sediment loss, USACE–Portland District evaluated the possibility of feeding those eroding sites with sediment dredged from the navigation channel and placed in nearshore locations. In coordination with the LCSG and with the assistance of the Oregon governor's office, USACE–Portland District designated the South Jetty Site for the test placement (Roegner and Fields 2014).

Figure 5.15. *Entrance Channel and DM Placement Sites at the Mouth of the Columbia River*



Source: USACE–Portland District

The project was designed to evaluate the feasibility of using enhanced hopper dredge TLP techniques to keep the DM placement thicknesses to between 2 and 4 in (5 to 10 cm). Over a 2-day period in September 2005, the USACE hopper dredge *ESSAYONS* (Figure 5.16) dredged 35,314.67 yd^3 (27,000 m^3) of sand from the navigation channel and placed it in six 1,800 by 15 m lanes previously prescribed as part of a nearshore area south of the South Jetty. Measurements from a sediment profile imaging camera indicated that a layer thickness of 5 cm or less was achieved (SAIC 2006). This placement accuracy was achieved by coordinating the vessel's speed and the sequencing of which hopper doors were opened. A sediment tracer study in 2008 validated the hypothesis that nearshore TLP could be used to feed the sediment-starved areas (Norton et al. 2015).

Figure 5.16. *USACE Hopper Dredge ESSAYONS*

Source: USACE–Portland District

5.9.3 Brunswick Estuary Thin Cover Placement

The innovative use of TLP to restore historically degraded wetlands in Georgia's Brunswick Estuary serves as a national case study in the application of thin-cover techniques for sediment remediation (Mohan et al. 2021). The project site is a mix of tidal creeks, marshes, a brackish estuary, and an adjacent upland area that was affected by historical industrial operations. A pilot project that placed 6 to 9 in (15.24 to 22.86 cm) of material in a .67-acre (0.27 ha) marsh was completed in 2018 to demonstrate the thin-cover concept. Two material types—sand and higher-organic-content fines—were tested. The pilot tested cover placement methodology and remedy performance before the full-scale thin-cover remedy was implemented in larger areas throughout the site.

The contractor identified the appropriate equipment, means, and methods to hydraulically convey and place the thin-cover material in the pilot area in accordance with stated performance objectives. A mat-based access road enabled equipment to move the pipeline and spray nozzle-controlled placement in the pilot marsh area. (The access road initially experienced some settlement due to loading and required restoration following project completion.) The thin-cover placement in the field ranged from 6 to 12 in (15.24 to 22.86 cm) thick; the design thickness called for 6 to 9 in (15.24 to 22.86 cm). A 30- to 45-degree spray yielded the best distribution of materials for the equipment used. Sandy material was placed faster and more uniformly than fines because of its enhanced settling characteristics and ease of distribution. A modified mix of topsoil and fines and the use of a baffle plate on the discharge pipe permitted optimal placement of fines while maintaining the target organic content.

Turbidity in the water discharged from the treatment area was minimized by environmental controls (e.g., perimeter hay bales) installed by the contractor. Physical, chemical, and vegetative monitoring conducted in six month increments over a two-year period indicated strong natural recolonization of the vegetation and the reestablishment of benthic species (see Figure 1.3).

Some of the key takeaways from the pilot cover installation are as follows:

- Portions of the marsh could not support a low-ground-pressure pontoon excavator. Detailed geotechnical studies with potentially tighter data collection density than typical should be performed as part of the remedial design to evaluate not only the load-bearing capacity of key marsh locations but also variability within the system. The remedial design should consider alternate approaches to minimize equipment requiring marsh access or to distribute machine loads, such as the HDPE mat roadway used during the pilot study.
- Low-density sources of total organic carbon (TOC) were difficult to place effectively because they tended to float and to be carried away from the cover area by surface water from the slurry. Alternate sources of TOC should be considered, if necessary.
- Debris in the cover materials (primarily root matter in the TOC-containing materials) severely affected production because they frequently plugged the slurry pipelines, and the plugs were time consuming to locate and clear. Ideal thin-cover source material is loose, friable, and free of root matter, debris, and other deleterious materials. A shaker screen before the slurry tank may be necessary to remove large pieces of debris.
- Increasing the dispersion of the slurry as it exited the pipeline improved the effectiveness of the cover material placement. For the slurry sled, angling the two slurry nozzles at a 45 degree angle so the slurry streams crossed increased dispersion of the spray and yielded gentler, more even placement. For mushroom-style placement, adding a steel plate reduced the energy of the slurry and prevented it from displacing previously placed cover materials.

5.9.4 Pepper Creek

A wetland TLP project conducted in 2012–2013 on Pepper Creek in Dagsboro, Delaware, used a swinging ladder cutterhead dredge with a 10-in (25.4 cm) diameter pipeline discharging from a barge-mounted adjustable spray (see Figure 1.4). “The thin-layer application of fine sediments was intended to replenish native sediments to emergent wetlands, boost the elevation platform, and reduce interior marsh breakup, ultimately to prevent conversion to open water as water levels rise faster than natural accretion rates” (DNREC 2014). Given the site topography, hay bales were the only containment structures used to control sediment movement—in the tidal creeks. DNREC continues to monitor biological and chemical conditions to determine whether the project’s objectives are being achieved.

5.9.5 Avalon

In the aftermath of Hurricane Sandy, which struck northern New Jersey in October 2012, critical shoals that were impeding navigation on the New Jersey Intracoastal Waterway needed to be removed while adjacent environmental resources required repair. The Avalon marsh showed indications of stress such as low elevation, standing water, increasing open-water areas (pools and pannes), and eroding edges. Navigation managers from USACE–Philadelphia District quickly partnered with ERDC, NJDEP, and nonprofit environmental contractors to execute a natural and nature-based features (NNBF) strategy to use DM to enhance wetlands and build system resilience to reduce flooding. NNBFs are landscape features used to help manage flood risks while producing additional economic, environmental, and social benefits. NNBF features include salt marshes, beaches and dunes, coral and oyster reefs, barrier islands, and vegetated environments, such as maritime forests, freshwater wetlands and fluvial flood plains, and seagrass beds (ERDC 2023).

Target elevations ranging between 2.4 and 3 ft (0.73 to 0.91 m) North American Vertical Datum of 1988 (NAVD 88) were assigned to each placement area according to tidal and biological reference elevations. Two design DM placement thicknesses (or target thicknesses) were selected; less than 6 in (15.24 cm) directly on the marsh surface and approximately 1.5 ft (0.46 m) within selected pools and pannes to allay ongoing pool expansion.

The Avalon TLP project dredging was conducted in two phases. In Phase I (the pilot project, which ran from December 29, 2014, to January 7, 2015) a 10-in (25.4 cm) cutterhead dredge excavated sediment from the New Jersey Intracoastal Waterway shoals and piped approximately 5,000 yd^3 (3,822.78 m^3) of fine-grained DM up to approximately 3,500 ft (1,066.8 m) into the Avalon wetlands. There, thin layers were placed with a single-point, high-pressure discharge nozzle (as shown in Figure 1.7) on a combined area 6 ac (2.43 ha) of Areas A and C (see Figure 4.5). Biodegradable coir (coconut husk) logs were used in conjunction with site topography for sediment containment.

Lessons from the Phase I dredging and placement area design and management were incorporated into Phase II, which was conducted from November 24, 2015, to February 19, 2016. In Phase II, a 14-in (35.56 cm) cutterhead dredge excavated and transported sediment into the Avalon wetlands through pipeline up to 7,000 ft (2,133.6 m) long. In addition to the spray nozzle, a spreader attached to the end of the pipe was used to deposit coarse-grained sediment more efficiently in pools and pannes or to pump plain water to redistribute sandier sediment and influence subsequent slurry flow and deposition. Phase II sediment containment consisted of coir logs of varying diameters that were tailored for used with the site topography. Approximately 45,000 yd^3 (34,404.97 m^3) of DM were placed on 35 ac (14.16 ha) during Phase II. The project partners continue to monitor the site's response and recovery.

TLP projects are monitored during and immediately after construction to determine whether the construction activities meet specifications and comply with regulatory requirements. Baseline and postconstruction monitoring are designed to evaluate site recovery and enhancement after TLP. Monitoring plans should focus primarily on metrics that are easily measured and actionable from an adaptive management standpoint for wetland TLP sites. Collecting a wealth of "nice-to-know" metrics with no clear plan for how to use the data to manage the TLP site can raise project costs without increasing benefits. Instead, monitoring a few thoughtfully selected metrics is recommended; additional metrics can be added if the site does not function as expected. This caution does not apply to biological resource use monitoring, which should track more with ongoing resource management plans. Raposa et al. (2020) provide a good overview of planning objectives and monitoring for wetland TLP sites.

Monitoring during construction typically includes some measurement of the placement depth or elevation throughout the TLP site, either by using simple grade stakes to visually assess the elevation or depth of slurry or by conducting hydrographic surveys. Some dredges are equipped with flow meters that can determine the volume of slurry moved to the site and density gauges that can be used to provide information to estimate how much sediment has been placed there.

Other monitoring during construction is designed to assess whether the construction is affecting ecological resources in the area. Turbidity is frequently monitored near TLP sites to determine whether sediments are quickly leaving the site or moving into ecologically sensitive areas. No hard-and-fast rules exist for what turbidity levels are permissible near a TLP site; allowed levels vary from project to project and state to state. But previous work indicates turbidity originating from TLP sites decreases rapidly with distance, especially if the site is in relatively shallow water (DNREC 2014; TNC and NJDEP 2021; Mohan et al. 2021). Photographs and video of TLP projects have also been used to assess ecological impacts qualitatively and quantitatively. The MCR TLP project used a benthic sled mounted with video cameras to document benthic marine species in the TLP area before and after placement. Benthic video was coupled with acoustic tagging of Dungeness crabs to assess the mortality and mobility of crabs in the placement area.

Once construction is complete, the conditions should be documented through a detailed as-built survey. Subsequently, monitoring plans shift focus to site recovery and function. The monitoring plan postconstruction should have been informed by the TLP project objectives and developed as part of the adaptive management plan. Consequently, no standardized array of recommended monitoring metrics will work for every TLP project. For example, TLP projects designed for marsh restoration will use a very different set of monitoring metrics than projects designed to disperse sediment into the nearshore environment. Instead, the project team should use best practices to develop a monitoring plan that is compatible with the project objectives and budget.

Monitoring plans should be designed to inform site management, and metrics ideally should be tied to prospective site management decisions and adaptive actions. Metrics for TLP projects typically fall into one of four categories: (1) placement site geometry, (2) hydrodynamic function, (3) sediment and soil properties, and (4) ecological properties. Placement site geometry includes the topography and bathymetry of the site and the planform size and shape. It is commonly monitored in some way for all TLP projects. Typical site survey methods are used to monitor site geometry; depending on the site characteristics and required resolution, land surveying techniques—such as total station or RTK GPS, bathymetric surveys using side-scan or multibeam sonar, or remote sensing techniques using lidar or structure-from-motion photogrammetry—may be used. When sediment is meant to be dispersed, repeated surveys can determine how quickly it is being removed from the site. When the sediment is meant to be retained, repeat surveys can be used to ensure sediment is not being lost or to determine consolidation rates. Surveys repeated over many years can be used to determine site erosion or accretion rates, which may be especially important for wetland TLP projects. Finer-scale measurements of accretion and elevation change may require the use of marker horizons, settling plates, or surface-elevation tables.

Hydrodynamic monitoring is not required for all TLP projects, and hydrodynamic metrics will depend on project characteristics. Hydrodynamic metrics relevant to wetland TLP projects can include water level and inundation duration on the wetland platform, waves over the wetland platform or at the wetland edge, and tidal currents in creeks. Currents, waves, and water levels may all be appropriate for open-water TLP projects, depending on project purpose and concerns surrounding placement. For example, MCR project stakeholders were concerned that nearshore placement could cause wave amplification, so waves were monitored following placement to ensure their height remained the same. Bottom currents were monitored in the Mobile Bay TLP area to determine the conditions under which they were strong enough to mobilize the sediment.

Sediment and soil properties should be monitored if the stakeholders are concerned with consolidation or soil-development processes. Typically, sediment and soil properties are monitored for fine or mixed sediments only during site recovery because sandy sediments consolidate very little and are unlikely to show much change in biochemical properties.

Metrics such as bulk density can determine how the sediment is self-compacting. For projects with mixed grain size, additional sediment grain-size sampling may help determine the degree of hydraulic sorting that occurred during placement and identify areas that are likely to consolidate more than others. Soil development metrics typically focus on biochemical properties.

For wetland TLP sites, sediment salinity will often rise immediately after placement as sediments dewater and evaporation concentrates salts in the pore space. Monitoring salinity after placement can help determine when planting can occur without salt-induced plant mortality. Other biochemical properties that may be useful to monitor if ecological function fails to increase as quickly as expected are pH, soil carbon, and nutrients. Screening for acid volatile sulfides may be indicated if soil conditions appear to inhibit ecological recovery. Note that it is not unusual for some sites to show cyclical patterns in soil chemistry, so it is advisable to wait until long-term trends are confirmed before embarking on intrusive actions to mitigate field conditions.

Ecological metrics are frequently monitored for TLP projects. Wetland projects often focus on vegetation monitoring, using a range of vegetation techniques from simple percent-cover estimates to quantification of belowground biomass and species diversity. Other ecological metrics relevant to wetland TLP sites are invasive species; bird usage, such as number of nests; and benthic macroinvertebrates. An abundance of fiddler crab burrows noticed in the years following placement at Avalon, New Jersey, was responsible for widespread bioturbation of the freshly placed sediments prior to vegetation recovery. Common ecological metrics for open-water TLP typically consider benthic macroinvertebrate abundance and use. But if the site is near other ecological resources of concern, such as SAV or shellfish, additional monitoring may be required to determine the long-term benefits or to assess whether the placement caused any long-term impacts.

Monitoring timing and frequency should reflect the expected timing of the change in the metric of interest. For example, if vegetation recovery is expected to take between three and five years, annual vegetation measurements, beginning in year zero or year one , are not recommended unless needed to trigger planting in an adaptive management plan. Conversely, consolidation occurs quickly following placement, so monitoring to capture the initial rate of consolidation should occur in the initial weeks and months following placement. Monitoring events can also be initiated after storms or other energetic events that may move or redistribute TLP sediments. If a TLP site is expected to persist or will be used for multiple placements, basic site monitoring may continue throughout the lifetime of the project. Some projects, however, may only require monitoring until the site meets the predefined success criteria. Site recovery time must be reasonably predictable and, when TLP sites are part of a longer-term DM management plan, the overall restoration plan must be compatible with the dredging time line and available placement volume.

A summary of potential considerations for various monitoring criteria is provided in Table 5.2. Monitoring can also serve a larger purpose to ascertain how multiple TLP sites fare in the long term and to determine whether design and construction practices influence the site's functioning. Although TLP has been used in marshes for decades, primarily in the Gulf Coast region, the exact response of an individual marsh to the placement of DM is not yet clear. Consequently, comprehensive monitoring is needed to determine how sites will respond physically and ecologically in the long term, especially when multiple placements are possible. Coordinated development of standard monitoring plans may be required in these cases, but recommending specific monitoring practices is beyond the scope of this guidelines document. See the Conservation Gateway (Yepsen, Moody, and Schuster 2016) for monitoring plan recommendations.

Table 5.2. *Examples of Potential TLP Monitoring Metrics, Methods, and Purposes*

Metric type	Metric	Method	Purpose
Geometry	Elevation	• RTK ground-penetrating radar (GPR) field survey • Ground-based or aerial lidar • SET	Determine elevation change after TLP
Hydrodynamic properties	Wave conditions	• Wave gages	Determine whether wave conditions have changed because of TLP
	Water levels	• Water-level loggers	Determine whether duration of marsh surface inundation has decreased
Sediment and soil properties	Salinity	• Conductivity probe • Soil samples, refractometer	Determine whether pore-water salinity allows planting
	Bulk density	• Soil cores	Determine whether sediment has consolidated enough to support plant roots (alternatively also to confirm that planting can be done before the substrate gets too dense for the roots to penetrate) and stabilized elevation
	pH	• pH/EC probe of soil and sediment slurry	Detect reduction in porewater pH from acid sulfide production

Table 5.2 *(cont.). Examples of Potential TLP Monitoring Metrics, Methods, and Purposes*

Metric type	Metric	Method	Purpose
Ecological properties	Vegetation	• Percent cover • Aboveground biomass • Belowground biomass	Determine whether vegetation recovery is occurring; determine whether planting is necessary
	Macro -invertebrates	• Benthic invertebrate sampling • Acoustic tagging	Determine whether TLP caused invertebrate mortality Determine whether benthic community is recovering
	Invasive species	• Vegetative surveys	Determine whether invasives are present, document type for site management plan
	Birds	• Abundance • Diversity	Determine whether TLP affected number of birds using area Determine whether types of birds using TLP area has changed
	Nekton	• Abundance • Biomass	Determine whether TLP caused nekton mortality, shifts in use patterns


Blackwater NWR TLP Dredge Spray Pilot Project
Source: Albert McCollough, Sustainable Science and USFWS

Chapter 6. Gaps and Future Directions

In recent years, the TLP science and knowledge base has improved significantly, largely because of USACE's focus on the EWN program, on documenting case studies and lessons learned on the ERDC website (ERDC 2021a) and on the outreach efforts discussed in this document. Several states and nonprofit organizations have embarked on similar initiatives, and numerous TLP work groups have been formed and held around the country in the past five years. Further investigations and studies to answer the following questions would help advance the state of the science of TLP:

- What is the best way to evaluate baseline conditions of coastal marshes?
- Are there advanced survey protocols to improve the accuracy of vertical and horizontal measurements in marshes?
- How long does it take a marsh to degrade absent TLP?
- Are there long-term negative impacts of TLP?
- Is there a need for new or improved TLP methods, including greater pumping distances?
- Are there enough long-term data on marsh function and use following TLP?
- Can or should new methods for quantifying the economic benefits of TLP be developed?

TLP should be considered as one of the available tools for sustainable management of DM. Recognizing TLP may often have a limited application thickness (and hence capacity); where applicable, repeat applications of TLP could be considered to continue to restore the habitat and improve overall resiliency of the system. Although this document does not focus specifically on compatibility of sites for TLP, such a consideration is a critical component in the project development process. TLP should never be viewed exclusively as a DM placement technique but rather as a method that may create, maintain, enhance, or restore ecological function while supporting channel infrastructure and providing flood risk management benefits. Wetland evaluation is discussed in the Ecosystem Management and Restoration Research Program (EMRRP) document *Maintaining Salt Marshes in the Face of Sea Level Rise—Review of Literature and Techniques* (VanZomeren et al 2019), which outlines a framework for deciding which type of wetland restoration effort, including TLP, is appropriate given the mode of wetland degradation. The decision to apply TLP is not formalized, but documents describing TLP projects in open-water environments are referenced throughout this document and should be consulted for more information on how TLP was selected. This document is intended to augment, not replace, the professional judgment of the practitioner.

References

Abt Associates. 2019. *Case Study: Improving Marsh Resilience through the Hurricane Sandy Coastal Resilience Program*. Prepared for the National Fish and Wildlife Foundation and U.S. Department of Interior. Rockville, MD: Abt Associates. https://www.nfwf.org/sites/default/files/hurricanesandy/Documents/hurricane-sandy-marsh-restoration-case-study.pdf.

Bailey, S., Z. Tyler, and T. Welp. 2017. "Application of Laboratory and Modeling Tools to Design Thin Layer Placement Projects for Marsh Nourishment." PowerPoint presented at the Western Dredging Association Dredging Summit and Expo, Vancouver, Canada, June 2017. https://www.westerndredging.org/index.php/information/category/272-session-2a-beneficial-reuse-of-dredged-sediments?download=1472:2a-3-application-of-laboratory-and-modeling-tools-to-design-thin-layer-placement-projects-for-marsh-nourishment.

Berkowitz, J. F., N. R. Beane, K. D. Philley, N. R. Hurst, and J. F. Jung. 2021. *An Assessment of Long-Term, Multipurpose Ecosystem Functions and Engineering Benefits Derived from Historical Dredged Sediment Beneficial Use Projects*. ERDC/EL TR-21-4. Vicksburg, MS: ERDC-EL. https://apps.dtic.mil/sti/pdfs/AD1144436.pdf.

Berkowitz, J. F., C. M. VanZomeren, and C. Piercy. 2017. "Marsh Restoration Using Thin Layer Sediment Addition: Initial Soil Evaluation." *Wetland Science and Practice* 34 (1): 15–19. https://issuu.com/societyofwetlandscientists/docs/march_2017_wsp.

Berkowitz, J. F., C. Piercy, T. Welp, and C. VanZomeren. 2019. *Thin Layer Placement: Technical Definition for U.S. Army Corps of Engineers Applications*. ERDC TN-19-1. Vicksburg, MS: ERDC. https://apps.dtic.mil/sti/pdfs/AD1067526.pdf.

Bolam, S. G. 2011. "Burial Survival of Benthic Macrofauna Following Deposition of Simulated Dredged Material." *Environmental Monitoring and Assessment* 181 (1): 13–27. https://dx.doi.org/10.1007/s10661-010-1809-5.

Borgnis Sloane, E., K. Thorne, C. Whitcraft, and V. Touchstone. 2021. "Enhancing Marsh Elevation Using Sediment Augmentation: A Case Study From Southern California, USA." *Shore and Beach* 89 (4): 21–32. https://doi.org/10.34237/1008943.

Bridges, T. S., J. K. King, J. D. Simm, M. W. Beck, G. Collins, Q. Lodder, and R. K. Mohan, eds. 2021. *International Guidelines on Natural and Nature-Based Features for Flood Risk Management*. ERDC SR-21-6. Vicksburg, MS: ERDC. https://hdl.handle.net/11681/41946.

Buffington, K. J., C. N. Janousek, B. D. Dugger, J. C. Callaway, L. M. Schile-Beers, E. Borgnis Sloane, and K. M. Thorne. 2021. “Incorporation of Uncertainty to Improve Projections of Tidal Wetland Elevation and Carbon Accumulation with Sea-Level Rise.” *PLoS ONE* 16 (10): e0256707. https://doi.org/10.1371/journal.pone.0256707.

Byrnes, M. R., J. L. Berlinghoff, and S. F. Griffee. 2013. *Sediment Dynamics in Mobile Bay, Alabama: Development of an Operational Sediment Budget*. Final Report. Prepared for Mobile Bay National Estuary Program. Mashpee, MA: Applied Coastal Research and Engineering.

Cahoon, D. R., and J. H. Cowan Jr. 1987. *Spray Disposal of Dredged Material in Coastal Louisiana: Habitat Impacts and Regulatory Policy Implications*. Baton Rouge, LA: Louisiana Sea Grant College Program, Center for Wetland Resources, Louisiana State University. https://nsgl.gso.uri.edu/lsu/lsut87006.pdf.

Cahoon, D. R., and J. H. Cowan Jr. 1988. “Environmental Impacts and Regulatory Policy Implications of Spray Disposal of Dredged Material in Louisiana Wetlands.” *Coastal Management* 16 (4): 341–62. https://doi.org/10.1080/08920758809362067.

Cahoon, D. R., J. Donley, S. Hamilton, and R. E. Turner. 1986. *Prototype Handbook for Evaluating Drilling Site Access in Wetlands via Canals*. Final Report. Prepared for U.S. Environmental Protection Agency. Santa Fe, NM: Lee Wilson and Associates.

Coastal Resilience. 2021. What is the Restoration Explorer App? *Restoration Explorer*. Web page. https://coastalresilience.org/project/restoration-explorer/.

Cornwell, J. C., M. S. Owens, L. W. Staver, and J. Stevenson. 2020. “Tidal Marsh Restoration at Poplar Island I: Transformation of Estuarine Sediments into Marsh Soils.” *Wetlands* 40 (6): 1673–86. https://doi.org/10.1007/s13157-020-01294-5.

CPRA (Louisiana Coastal Protection and Restoration Authority). 2008. *Ecological Review: East Marsh Island Marsh Creation*. CWPPRA Priority List 14, State No. TV-21. Baton Rouge, LA: Coastal Protection and Restoration Authority, Planning and Project Management Division. https://lacoast.gov/reports/project/3890553~1.pdf.

CPRA. 2017a. *2017 Coastal Master Plan—Appendix F: Adaptive Management Plan*. Version Final. Baton Rouge: LA: Coastal Protection and Restoration Authority. https://coastal.la.gov/wp-content/uploads/2017/04/Appendix-F_FINAL_04.04.2017.pdf.

CPRA. 2017b. *Geotechnical Standards: Marsh Creation and Coastal Restoration Projects*. Report: Version 1.0. Baton Rouge: LA: Coastal Protection and Restoration Authority. https://coastal.la.gov/wp-content/uploads/2015/07/Appendix-B-CPRA-Geotechnical-Standards_12.21.17.pdf.

CPRA. 2017c. *Louisiana's Comprehensive Master Plan for a Sustainable Coast*. Baton Rouge: LA: Coastal Protection and Restoration Authority. https://coastal.la.gov/wp-content/uploads/2017/04/2017-Coastal-Master-Plan_Web-Book_CFinal-with-Effective-Date-06092017.pdf.

CPRA. 2017d. *Marsh Creation Design Guidelines: Marsh Creation Projects*. MCDG1.0. Baton Rouge: LA: Coastal Protection and Restoration Authority. https://cims.coastal.louisiana.gov/RecordDetail.aspx?Root=0&sid=21477#.

CPRA. 2018. *2018 Operations, Maintenance, and Monitoring Report for East Marsh Island Marsh Creation*. State Project Number TV-21, Priority Project List 14. Lafayette, LA: Coastal Protection and Restoration Authority of Louisiana. https://www.lacoast.gov/reports/project/TV-21_2018_OM_M_Final.pdf.

Craig, R. K., and J. B. Ruhl. 2014. "Designing Administrative Law for Adaptive Management." *Vanderbilt Law Review* 67 (1): 1–87. https://scholarship.law.vanderbilt.edu/faculty-publications/463.

Davis, D. W. 1976. "Changes in Marsh Environments through Canalization." Paper presented at the Proceedings of Time-Stressed Coastal Environments: Assessment and Future Action, New Orleans, LA, November 1976. https://nsgl.gso.uri.edu/tcs/tcsw76001/tcsw76001i.pdf.

DeLaune, R. D., S. R. Pezeshki, J. H. Pardue, J. H. Whitcomb, and W. H. Patrick. 1990. "Some Influences of Sediment Addition to a Deteriorating Salt Marsh in the Mississippi River Deltaic Plain: A Pilot Study." *Journal of Coastal Research* 6 (1): 181–88. https://journals.flvc.org/jcr/article/view/78015/75443.

DNREC (Delaware Department of Natural Resources and Environmental Control). 2014. *Annual Monitoring Report: Pepper Creek Beneficial Reuse Project*. Technical Report. Dover, DE: Delaware Department of Natural Resources and Environmental Control.

DOER (Dredging Operations and Environmental Research). 2023. Tools. *Dredging Operations and Environmental Research*: *U.S. Army Corps of Engineers*. Web page. https://doer.el.erdc.dren.mil/tools.html.

ERDC (U.S. Army Engineer Research and Design Center). 2021a. Thin-Layer Placement. *Thin-Layer Placement of Dredged Material*. Web page. https://tlp.el.erdc.dren.mil/.

ERDC. 2021b. *Using the Natural Infrastructure Opportunities Tool (NIOT): User's Guide*. Vicksburg, MS: ERDC. https://ewn.erdc.dren.mil/wp-content/uploads/2021/02/NIOT-UsersGuide.pdf.

ERDC. 2023. What is a Natural and Nature Based Feature? *Engineering With Nature: Natural and Nature-Based Features*. Web page. https://ewn.erdc.dren.mil/natural-nature-based-features/.

ERDC. n.d. *Natural Infrastructure Opportunities Tool*. Web map application. Esri ArcGIS. Vicksburg, MS: ERDC. https://www.arcgis.com/apps/MapSeries/index.html?appid=18079f5b628b4a7bb52acbe089d80886#.

Fernandez-Nunez, M., H. Burningham, and J. Ojeda Zujar. 2017. “Improving Accuracy of Lidar-Derived Digital Terrain Models for Saltmarsh Management.” *Journal of Coastal Conservation* 21: 209–22. https://doi.org/10.1007/s11852-016-0492-2.

Friedrichs, C. T., and J. E. Perry. 2001. “Tidal Salt Marsh Morphodynamics: A Synthesis.” *Journal of Coastal Research* 27: 7–37. https://www.jstor.org/stable/25736162.

Gailani, J., K. E. Brutsche, E. Godsey, P. Wang, and M. A. Hartman. 2019. *Strategic Placement for Beneficial Use of Dredged Material*. ERDC/CHL SR-19-3. Vicksburg, MS: ERDC-CHL. https://hdl.handle.net/11681/33169.

Ganju, N. K., M. L. Kirwan, P. J. Dickhudt, G. R. Guntenspergen, D. R. Cahoon, and K. D. Kroeger. 2015. “Sediment Transport-Based Metrics of Wetland Stability.” *Geophysical Research Letters* 42 (19): 7992–8000. https://doi.org/10.1002/2015GL065980.

Hale, E., ed. 2022. *2022 Heavy Construction Costs Book with RSMeans Data*. 36th Annual Edition. Greenville, SC: The Gordian Group.

Harris, B. D., D. J. Day, J. A. Cadigan, N. H. Jafari, S. E. Bailey, and Z. J. Tyler. 2021. “Establishment of Soil Strength in a Nourished Wetland Using Thin Layer Placement of Dredged Sediment.” *PLoS ONE* 16 (5): e0251420. https://doi.org/10.1371/journal.pone.0251420.

Jafari, N., B. Harris, and T. Stark. 2019. “Settlement of the Caminada Headlands Beach and Dune Nourishment in Coastal Louisiana.” *Journal of Geotechnical and Geoenvironmental Engineering* 145 (12): 05019. https://doi.org/10.1061/(ASCE)GT.1943-5606.0002170.

LaPeyre, M., B. Piazza, and B. Gossman. 2006. *Short and Long-Term Effects of Thin Layer Deposition of Dredged Material on Marsh Health*. 1434-05HQRU1561, RWO No. 77. NMFS–USGS Interagency Agreement No. HC-119. Year 1 Report. National Marine Fisheries Service, Office of Habitat Restoration.

Lovelace, N. 2013. “Gaillard Island Bio-Degradable Geotextile Test Project.” Paper presented at the 33rd PIANC International Navigation Congress, San Francisco, CA, June 2014.

Lowe, S. 2022. “Prescriptive vs. Performance Specifications in Construction.” Web page. Philadelphia, PA: Trauner Consulting Services. https://www.traunerconsulting.com/prescriptive-vs-performance-specifications-in-construction/.

Lynch, J. C., P. Hensel, and D. R. Cahoon. 2015. *The Surface Elevation Table and Marker Horizon Technique: A Protocol for Monitoring Wetland Elevation Dynamics*. Natural Resource Report NPS/NCBN/NRR—2015/1078. Fort Collins, CO: National Park Service.

Manna, S., and B. Raychaudhuri. 2018. “Mapping Distribution of Sundarban Mangroves Using Sentinel-2 Data and New Spectral Metric for Detecting Their Health Condition.” *Geocarto International* 35 (4): 434–52. https://doi.org/10.1080/10106049.2018.1520923.

MARISA (Mid-Atlantic Regional Integrated Sciences and Assessments). n.d. MEM: Marsh Equilibrium Model. *MARISA: A NOAA Mid-Atlantic RISA Team*. Web page. https://www.midatlanticrisa.org/data-tools/water-model-tool/items/mem.html.

McGhee, E., and C. Hoot. 1963. “Mighty Dredgers, Little-Known Work Horses of Coastal Drilling, Producing, Pipelining, Now 25 Years Old.” *Oil and Gas Journal* 61: 150–52.

MDE (Maryland Department of the Environment). 2017. *Innovative Reuse and Beneficial Use of Dredged Material: Guidance Document*. Baltimore, MD: Maryland Department of the Environment. https://mde.maryland.gov/programs/Marylander/Documents/Dredging/FINAL_IBR_GUIDANCE_8.30.2017_MDE.pdf.

MDNR (Maryland Department of Natural Resources). 2019. Maryland Introduces Tool for Beneficial Use of Dredged Materials. *Maryland Department of Natural Resources*. https://news.maryland.gov/dnr/2019/10/29/maryland-introduces-tool-for-beneficial-use-of-dredged-materials/.

MDNR. 2021. *Beneficial Use of Dredged Material Planning Process*. Annapolis, MD: Maryland Department of Natural Resources. https://dnr.maryland.gov/ccs/Documents/BU-PlanningProcess.pdf.

MDNR. n.d. Maryland Coastal Atlas. *Maryland Department of Natural Resources*. Web map application. Esri ArcGIS. Annapolis, MD: MDNR. https://gisapps.dnr.state.md.us/coastalatlas/WAB2/.

Medlock, C. L., T. E. McKenna, and J. A. Callahan. 2018. “Lidar Vertical Bias Assessment and Digital Elevation Model Correction in Delaware’s Tidal Salt Marshes.” Paper presented at the American Geophysical Union, Fall Meeting, December 2018.

Mendelssohn, I., and N.L. Kuhn. 2003. “Sediment Subsidy: Effects on Soil-Plant Responses in a Rapidly Submerging Coastal Salt Marsh.” *Ecological Engineering* 21 (2-3): 115–28. https://doi.org/10.1016/j.ecoleng.2003.09.006.

Merritt, K. A., J. Conder, V. Kirtay, D. B. Chadwick, and V. Magar. 2010. "Review of Thin Layer Placement Applications to Enhance Natural Recovery of Contaminated Sediment." *Integrated Environmental Assessment and Management* 6 (4): 749–60. https://doi.org/10.1002/ieam.76.

Mitsch, W. J., and J. G. Gosselink. 2015. *Wetlands*. 5th ed. Hoboken, NJ: John Wiley and Sons.

Mohan, R., K. Goldberg, T. Pratt, A. Rizzo, M. McHugh, W. Mears, and L. Bray. 2016. "Improving Coastal Resiliency Along America's Shorelines: One Wetland at a Time." PowerPoint presented at the Proceedings of the World Dredging Congress (WODCON XXI), Miami, FL, June 2016.

Mohan, R., C. Piercy, and T. Welp. 2021. "Thin Layer Placement for Marsh Enhancement: Planning, Design, Construction, and Monitoring Considerations." *Shore and Beach* 89 (4): 4–12. http://doi.org/10.34237/1008941.

Mohan, R., M. Reemts, P. Gupta, R. Galloway, T. Johnson, R. Brown, and T. Donegan. 2021. "Restoration of Estuarine Wetlands Using Thin Cover Placement: A Pilot Application in Brunswick, Georgia." *Shore and Beach* 89 (4): 62–72. http://doi.org/10.34237/1008947.

Nester, R. D., and S. I. Rees. 1988. "Thin-Layer Dredged Material Disposal—Fowl River, Alabama, Test Case." In *Environmental Effects of Dredging*. Vol D-88-4:1–6. Information Exchange Bulletin. Vicksburg, MS: ERDC-WES. http://hdl.handle.net/11681/4271.

NFWF (National Fish and Wildlife Foundation). n.d. Coastal Resilience Evaluation and Siting Tool (CREST). *NFWF*. Web map application. https://resilientcoasts.org/#Home.

NOAA (National Oceanic and Atmospheric Administration). n.d. Welcome to VDatum! *Vertical Datum Transformation*. Web page. https://vdatum.noaa.gov/.

NOAA CO-OPS (NOAA's Center for Operational Oceanographic Products and Services). n.d.-a. *NOAA: Tides and Currents*. Wep map application. https://tidesandcurrents.noaa.gov/.

NOAA CO-OPS. n.d.-b. Marsh Analysis and Planning Tool Incorporating Tides and Elevations (MAPTITE). *NOAA: Tides and Currents*. Web page. https://tidesandcurrents.noaa.gov/maptite.html.

NOAA NCCOS (NOAA's National Centers for Coastal Ocean Science). n.d. Benthic Habitat Mapping. *NCCOS Data Collections*. Web page. https://products.coastalscience.noaa.gov/collections/benthic/default.aspx.

NOAA OCM (NOAA's Office of Coastal Management). n.d. About National Estuarine Research Reserves. *Office of Coastal Management: National Estuarine Research Reserves.* Web page. https://coast.noaa.gov/nerrs/.

NOAA OR&R (NOAA's Office of Response and Restoration). 2023. Environmental Sensitivity Index (ESI) Maps and Data. *NOAA: Office of Response and Restoration*. https://response.restoration.noaa.gov/resources/environmental-sensitivity-index-esi-maps.

Norton, J., R. Moritz, M. Ott, W. Briner, C. Roegner. 2015. "Balancing Benefits and Impacts when Using a Nearshore Dredged Material Placement Site at the Mouth of the Columbia River." *Proceedings of Coastal Sediments* 2015. https://doi.org/10.1142/9789814689977_0147.

Owende, P.M.O., J. Lyons, and S.M. Ward. 2002. *Operations Protocol for Eco-Efficient Wood Harvesting on Sensitive Sites*. Developed by the Ecowood Partnership. December 2002.

Parson, L., N. Lovelace, E. Godsey, K. Reine, and J. Gailani. 2015. *Regional Sediment Management (RSM) Strategy for Mobile Bay, Alabama*. ERDC/CHL CHETN-XIV-41. Vicksburg, MS: ERDC-CHL. https://hdl.handle.net/11681/5009. https://erdc-library.erdc.dren.mil/jspui/bitstream/11681/5009/1/ERDC-CHL-CHETN-XIV-41.pdf.

Pawlowski, J., K. Bruce, K. Panksep, F. I. Aguirre, S. Amalfitano, L. Apothéloz-Perret-Gentil, T. Baussant, et al. 2022. "Environmental DNA Metabarcoding for Benthic Monitoring: A Review of Sediment Sampling and DNA Extraction Methods." *Science of The Total Environment* 818: 151783. https://doi.org/10.1016/j.scitotenv.2021.151783.

Poindexter-Rollings, M. E. 1990. *Selecting Equipment for Use in Dredged Material Containment Areas*. Technical Note EEDP-90-5. Vicksburg, MS: ERDC-WES. http://hdl.handle.net/11681/4659. https://apps.dtic.mil/sti/pdfs/ADA292707.pdf.

Raposa, K., K. Wasson, J. Nelson, M. Fountain, J. West, C. Endris, and A. Woolfolk. 2020. *Guidance for Thin-Layer Sediment Placement as a Strategy to Enhance Tidal Marsh Resilience to Sea-Level Rise*. Published in collaboration with the National Estuarine Research Reserve System Science Collaborative. https://nerrssciencecollaborative.org/media/resources/TLP-Guidance-for-Thin-Layer-Placement-20200217-HRes.pdf.

Ray, G.L. 2007. *Thin Layer Placement of Dredged Material on Coastal Wetlands: A Review of the Technical and Scientific Literature*. ERDC/EL TN-07-1. Vicksburg, MS: ERDC-EL. https://apps.dtic.mil/sti/pdfs/ADA475811.pdf.

Roegner, G. C., and S. A. Fields. 2014. *Mouth of the Columbia River Beneficial Sediment Deposition Project: Benthic Impact Study 2014*. Seattle, WA: National Marine Fisheries Service–Northwest Fisheries Science Center.

Roman, C., and D. Burdick, eds. 2012. T*idal Marsh Restoration: A Synthesis of Science and Management*. Washington, D.C.: Island Press.

Rush, E. S., and A. A. Rula. 1967. *A Limited Study of Effects of Soil Strength on Walking Speed*. Miscellaneous Paper 4-950. Vicksburg, MS: ERDC-WES.

SAIC (Science Applications International Corporation). 2006. *Final Report: Pilot Project Survey Results for the Nearshore Beneficial Use of Dredged Material at the South Jetty of the Mouth of the Columbia River (MCR)*. Bothell, WA: Science Applications International Corporation.

Smith, J., and L. Niles. 2016. "Are Salt Marsh Pools Suitable Sites for Restoration?" *Wetland Science and Practice* 33 (4): 101–109. https://members.sws.org/wetland-science-and-practice/Details/december-2016-wetland-science-practice-46857.

Stark, T. D. 2014. *Program Documentation and User's Guide: PSDDF—Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill—Microsoft Windows*. Instruction Report No. EL-14-XX. Vicksburg, MS: ERDC-WES. http://tstark.net/wp-content/uploads/2015/08/CP0111.pdf.

Stark, T. D., H. Choi, and P. R. Schroeder. 2005a. "Settlement of Dredged and Contaminated Material Placement Areas. I: Theory and Use of Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill." *Journal of Waterway, Port, Coastal, and Ocean Engineering* 131 (2): 43–51. https://doi.org/10.1061/(ASCE)0733-950X(2005)131:2(43).

Stark, T. D., H. Choi, and P. R. Schroeder. 2005b. "Settlement of Dredged and Contaminated Material Placement Areas. II: Primary Consolidation, Secondary Compression, and Desiccation of Dredged Fill Input Parameters." *Journal of Waterway, Port, Coastal, and Ocean Engineering* 131 (2): 52–61. https://doi.org/10.1061/(ASCE)0733-950X(2005)131:2(52).

Swanson, K. M., J. Z. Drexler, D. H. Schoellhamer, K. M. Thorne, M. L. Casazza, C. T. Overton, J. C. Callaway, et al. 2013. "Wetland Accretion Rate Model of Ecosystem Resilience (Warmer) and Its Application to Habitat Sustainability for Endangered Species in the San Francisco Estuary." *Estuaries and Coasts* 37: 476–92. https://doi.org/10.1007/s12237-013-9694-0.

Theriot, J.P. 2014. *American Energy, Imperiled Coast: Oil and Gas Development in Louisiana's Wetlands*. Baton Rouge, LA: Louisiana State University Press.

Thorne, K. M., C. M. Freeman, J. A. Rosencranz, N. K. Ganju, and G. R. Guntenspergen. 2019. "Thin-layer Sediment Addition to an Existing Salt Marsh to Combat Sea-Level Rise and Improve Endangered Species Habitat in California, USA." *Ecological Engineering* 136: 197–208. https://doi.org/10.1016/j.ecoleng.2019.05.011.

Thorne, K. M., G. MacDonald, G. Guntenspergen, R. Ambrose, K. Buffington, B. Dugger, C. Freeman, et al. 2018. "U.S. Pacific Coastal Wetland Resilience and Vulnerability to Sea-Level Rise." *Science Advances* 4 (2): eaao3270. https://www.science.org/doi/10.1126/sciadv.aao3270.

TNC (The Nature Conservancy) and NJDEP (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*. National Fish and Wildlife Foundation Grant #43095. https://www.nj.gov/dep/dsr/wetlands/beneficial-use-dredged-material-project-summary-lessons-learned.pdf.

Tong, C., J. J. Baustian, S. A. Graham, and I. A. Mendelssohn. 2013. "Salt Marsh Restoration with Sediment-Slurry Application: Effects on Benthic Macroinvertebrates and Associated Soil-Plant Variables." *Ecological Engineering* 51: 151–60. https://doi.org/10.1016/j.ecoleng.2012.12.010.

UNC-Chapel Hill (The University of North Carolina at Chapel Hill). n.d. ADCIRC. *The University of North Carolina at Chapel Hill*. Web page. https://adcirc.org.

USACE (U.S. Army Corps of Engineers). 1986. *Field Applications of Polyethylene Pipe in Dredging*. ETL 1110-2-530. Washington, DC: U.S. Army Corps of Engineers. https://plasticpipe.org/common/Uploaded%20files/1-PPI/Divisions/Municipal%20and%20Industrial/a403256.pdf.

USACE. 2003. *Mouth of the Columbia River Shallow Water Ocean Dredged Material Disposal Site Supplemental Evaluation of Optimized Site Utilization and Assessment of Potential Wave-Related Impacts*. CENWP-EC-HY Final Report. Prepared for Environmental Protection Agency, Region 10, Seattle, WA. Portland, OR: U.S. Army Corps of Engineers.

USACE. 2013a. *Hydrographic Surveying*. Engineer Manual. EM 1110-2-1003. Washington, DC: U.S. Army Corps of Engineers. https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-1003.pdf?ver=-VR9ILCMojaogWSxI5AILA%3d%3d.

USACE. 2013b. *O&M Sediment Management Strategy for Mobile Bay: Mobile Harbor Operations and Maintenance, Mobile County, Alabama*. Regional Sediment Management Program. Mobile, AL: U.S. Army Corps of Engineers–Mobile District.

USACE. 2014. *Safety and Health Requirements*. Engineer Manual. EM 385-1-1. Washington, DC: U.S. Army Corps of Engineers. https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_385-1-1.pdf.

USACE. 2015. D*redged and Dredged Material Management*. Engineer Manual. EM 1110-2-5025. Washington, DC: U.S. Army Corps of Engineers. https://www.publications.usace.army.mil/portals/76/publications/engineermanuals/em_1110-2-5025.pdf.

USACE. 2020. *2020 South Atlantic Division Regional Sediment Management Optimization Update*. U.S. Army Corps of Engineers–South Atlantic Division. https://www.sad.usace.army.mil/Portals/60/siteimages/SACS/2020%20RSM%20OPTIMIZATION%20UPDATE%20FINAL-508.pdf?ver=2020-02-26-105945-033.

USACE. n.d. Sediment Analysis and Geo-App. *Sediment and Ecosystem Management*. Web page. https://navigation.usace.army.mil/SEM/Analysis.

USDA (U.S. Department of Agriculture). n.d. Coastal Zone Soil Survey. *USDA: Natural Resources Conservation Service*. Web page. https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/soil/coastal-zone-soil-survey.

USFWS (U.S. Fish and Wildlife Service). n.d. National Wetland Inventory. *U.S. Fish and Wildlife Service*. Web page. https://www.fws.gov/wetlands/.

USGS (U.S. Geological Survey). 2014. U.S. Geological Survey East-Coast Sediment Texture Database. *Woods Hole Coastal and Marine Science Center*. Web page. https://woodshole.er.usgs.gov/project-pages/sediment/.

USGS. 2020. usSEABED Data Output Files—Continental United States, Hawai'i, and Puerto Rico. *usSEABED*. Web page. https://www.usgs.gov/programs/cmhrp/science/usseabed.

USGS. 2021. Flood Decision Support Toolbox. *InFRM (Interagency Flood Risk Management)*. Web map application. https://webapps.usgs.gov/infrm/fdst/?region=fema6.

USGS. 2023. USGS Current Water Data for the Nation. *National Water Information System: Web Interface*. Web page. https://waterdata.usgs.gov/nwis/rt.

USGS-NWRC (USGS National Wetlands Research Center) and CPRA (Louisiana Coastal Protection and Restoration Authority). 2013. *East Marsh Island Marsh Creation (TV-21) 2012 Land-Water Classification*. Map ID: USGS-NWRC 2013-02-0069. https://lacoast.gov/products/sab_net_pub_products/map/original/2013-02-0068.pdf.

Valderrama-Landeros, L., F. Flores-de-Santiago, J. M., Kovacs, and F. Flores-Verdugo. 2018. "An Assessment of Commonly Employed Satellite-Based Remote Sensors for Mapping Mangrove Species in Mexico Using an NDVI-Based Classification Scheme." *Environmental Monitoring and Assessment* 190 (1): 1–13. https://doi.org/10.1007/s10661-017-6399-z.

VanZomeren, C. M., D. Acevedo-Mackey, E. O. Murray, and T. J. Estes. 2019. *Maintaining Salt Marshes in the Face of Sea Level Rise—Review of Literature and Techniques*. ERDC/EL SR-19-4. Vicksburg, MS: ERDC-EL. https://hdl.handle.net/11681/33297.

VanZomeren, C. M., and C. Piercy. 2020. *Thin Layer Placement of Sediments for Restoring Ecological Function to Submerging Salt Marshes*: A Quantitative Review of Scientific Literature. ERDC/TN DOER-E44. Vicksburg, MS: ERDC. https://hdl.handle.net/11681/35373.

VIMS (Virginia Institute of Marine Science). 2023. SAV Program Monitoring and Restoration. *SAV Monitoring and Restoration*. Web page. https://www.vims.edu/research/units/programs/sav/index.php.

Whitbeck, M., A. MuCullough, E. Meyers, and D. Curson. 2019. *Shorters Wharf Tidal Marsh Resilience Project: Implementation Report*. Arlington, VA: The Conservation Fund. https://ecos.fws.gov/ServCat/DownloadFile/165618.

Wilber, D. H., D. G. Clarke, and S. I. Rees. 2007. "Responses of Benthic Macroinvertebrates to Thin-Layer Disposal of Dredged Material in Mississippi Sound, USA." *Marine Pollution Bulletin* 54 (1): 42–52. https://doi.org/10.1016/j.marpolbul.2006.08.042.

Wilber, P., and R. M. Engler. 1993. *Managing Dredged Material Via Thin-Layer Disposal in Coastal Marshes*. EEDP-01-32. Vicksburg, MS: ERDC-WES. https://erdc-library.erdc.dren.mil/jspui/bitstream/11681/8802/1/EEDP-01-32.pdf.

Williams, N. 1944. "Dredging Canals for Servicing Fields in Marsh and Swamp Districts of Louisiana." *Oil and Gas Journal* 43: 95–96.

Wilson, B. 2013. "Rebuilding the Wetlands of Pepper Creek: a Win-Win for Boaters and the Bays." *Inland Bays Journal Spring* 2013. https://www.inlandbays.org/wp-content/documents/final_inland_bays_spring_2013.pdf.

Yepsen, M., J. Moody, and E. Schuster, eds. 2016. *A Framework for Developing Monitoring Plans for Coastal Wetland Restoration and Living Shoreline Projects in New Jersey*. Report prepared by the New Jersey Measures and Monitoring Workgroup of the New Jersey Resilient Coastlines Initiative, with support from the National Oceanic and Atmospheric Administration Coastal Resilience Grant Program (NA14NOS4830006). https://www.conservationgateway.org/ConservationPractices/Marine/crr/library/Documents/Framework-Coastal-Wetland-Shoreline-Projects-New-Jersey.pdf.

Abbreviations List

ac	Acre
ADCIRC	Advanced circulation model
ADCNR	Alabama Department of Conservation and Natural Resources
BU	Beneficial use
BUILD	Beneficial Use—Identifying Locations for Dredge
CARA	Comprehensive archeological and cultural assessment
CDF	Confined disposal facility
CIMS	Coastal Information Management System
cm	Centimeter
CO-OPS	Center for Operational Oceanographic Products and Services
CPRA	Louisiana Coastal Protection and Restoration Authority
CQAP	Construction quality assurance plan
CQCP	Construction quality control plan
CREST	Coastal Resiliency Evaluation and Siting Tool
CWA	Clean Water Act
CWP	Construction work plan
CWPPRA	Coastal Wetlands Planning, Protection and Restoration Act
CZMA	Coastal Zone Management Act
DEM	Digital elevation model
DM	Dredged material
DNREC	Delaware Department of Natural Resources and Environmental Control
DOER	Dredging Operations and Environmental Research
DOTS	Dredging Operations Technical Support
EFH	Essential fish habitat
EMRRP	Ecosystem Management and Restoration Research Program
EPA	U.S. Environmental Protection Agency
ERDC	Engineer Research and Development Center
ESA	Endangered Species Act
EWN®	Engineering With Nature®

FeS	Iron sulfide
ft	Foot
ft/s	Foot per second
ft^2	Square foot
ft^3/s	Cubic foot per second
GIS	Geographic information system
GPM	Gallon per minute
GPR	Ground-penetrating radar
GPS	Global Positioning System
ha	Hectare
HDPE	High-density polyethylene
in	Inch
JALBTCX	Joint Airborne Lidar Bathymetry Technical Center of Expertise
kHz	Kilohertz
km	Kilometer
km^2	Square kilometer
LASARD	Louisiana Sand Resource Database
LCSG	Lower Columbia Solutions Group
LTFATE	Long-Term Fate of DM Model
m	Meter
m/s	Meter per second
m^3	Cubic meter
m^3/hr	Cubic meter per hour
m^3/min	Cubic meter per minute
m^3/s	Cubic meter per second
MAPTITE	Marsh Analysis and Planning Tool Incorporating Tides and Elevations
MARISA	Mid-Atlantic Regional Integrated Sciences and Assessments
MCR	Mouth of the Columbia River
MDE	Maryland Department of the Environment
MDNR	Maryland Department of Natural Resources
MEM	Marsh Equilibrium Model
MEM-TLP	Marsh Equilibrium Model—Thin-Layer Placement
mm	Millimeter

MMPA	Marine Mammal Protection Act
MSA	Magnuson-Stevens Fishery Conservation and Management Act
n.d.	No data available
NAVD 88	North American Vertical Datum of 1988
NCCOS	National Centers for Coastal Ocean Science
NDVI	Normalized difference vegetation index
NEPA	National Environmental Policy Act
NFWF	National Fish and Wildlife Foundation
NGO	Nongovernmental organization
NIOT	Natural Infrastructure Opportunities Tool
NJDEP	New Jersey Department of Environmental Protection
NJDOT	New Jersey Department of Transportation
NNBF	Natural and nature-based features
NOAA	National Oceanic and Atmospheric Administration
NTP	Notice to proceed
NWP	Nationwide permits
NWR	National wildlife refuge
NWRC	National Wetlands Research Center
OCM	Office of Coastal Management
OM&M	Operations, monitoring, and maintenance
OMR	Office of Maritime Resources
OR&R	Office of Response and Restoration
PSDDF	Primary consolidation, secondary compression and desiccation of dredged fill
QA/QC	Quality control and quality assurance
RHA	Rivers and Harbors Act of 1899
RTK	Real-time kinematic
SAGA	Sediment Analysis and Geo-App
SAIC	Science Applications International Corporation
SAV	Submerged aquatic vegetation
SET	Surface elevation table
SHPO	State Historic Preservation Officer
SONRIS	Strategic Online Natural Resource Information System

THPO	Tribal Historic Preservation Officer
TLC	Thin-layer capping or covers
TLP	Thin-layer placement
TNC	The Nature Conservancy
TOC	Total organic carbon
UNC-Chapel Hill	The University of North Carolina at Chapel Hill
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VIMS	Virginia Institute of Marine Science
WARMER	Wetland Accretion Rate Model of Ecosystem Resilience
WQC	Water quality certification
yd^3	Cubic yard
yd^3/hr	Cubic yard per hour
yd^3/min	Cubic yard per minute

Select Glossary Terms

A

Active management	Involves a more rigorous approach where the management action is conducted in the context of an explicit hypothesis and associated monitoring protocol aimed at determining whether the proposed management action produces a given result (Gold 2006).

B

Baseline data	A set of data gathered to define the historic performance of a system prior to its alteration by human or natural means.
Bathymetry	The measurement of water depth at various places in a body of water: the information derived from such measurements .
Bay	A natural embayment, lake, or pond with fluctuating salinities (0.5 to 30 parts per thousand) in the estuarine environment.
Beneficial reuse	A means of reusing dredged material for a positive environmental benefit.
Benthic	Of, relating to, or occurring at the bottom of a body of water or in the depths of the ocean.
Benthos	Organisms that live on or in the bottom of a body of water.
Berm	A lateral earthen structure used to contain dredged material in placement sites, typically used in confined placement sites.
Bulking factor	The ratio of the volume of dredged material placed in a containment area immediately after dredging to the volume occupied by the same amount of soil in the channel or borrow area.

C

Comprehensive archeological and cultural assessment	Abbreviated as CARA. An assessment used to ascertain the cultural or historic value of an area.
Confined disposal facility	Abbreviated as CDF. A means of containing dredged material using lateral berms or dikes, often used in navigation projects.

Construction duration	Also known as the *contract time*, the estimated total time in calendar days to complete the construction of the proposed marsh-creation project features.
Construction marsh fill elevation	The top of the marsh fill upon the completion of material placement.
Construction work plan	Abbreviated as CWP. A document that describes the construction contractor's means and method to build a project.
Containment structure	A system used to confine dredged material so that effluent quality (of receiving waters) can be controlled.
Creeks	Smaller channels that typically convey water in wetland systems.
Cut volume	The total estimated volume of material required to be dredged from the proposed marsh creation borrow area, which should include the estimated losses due to dredging operations, transport, dewatering, and soil properties.
Cutterhead dredge	A dredge that uses a cutterhead with teeth to dislodge sediments underwater and subsequently transport it via a hydraulic pipeline.

D

Delaware Department of Natural Resources and Environmental Control	Abbreviated as DNREC. The State of Delaware's environmental and resource protection agency.
Digital elevation model	Abbreviated as DEM. A representation of the bare ground (bare earth) topographic surface of the Earth excluding trees, buildings, and any other surface objects (https://www.usgs.gov/faqs/what-digital-elevation-model-dem).
Dredge pipeline corridor	A spatially delineated corridor of sufficient width to deliver the slurry from the marsh creation borrows area to the marsh fill area via a temporary dredge pipeline.
Dredged material	Abbreviated as DM. Sediment that is removed by dredging.
Dredging	To deepen (a waterway) with a machine that remove earth usually by buckets on an endless chain or a suction tube: to deepen with a dredge.

Dredging Operations and Environmental Research Program	Abbreviated as DOER. Program within the U.S. Army Engineer Research and Development Center that is focused on advancing dredging technology and environmental aspects of dredging.

E

Earthen containment dike	An earthen containment dike is an earthen feature constructed along the perimeter of the marsh creation area, is typically required to confine the hydraulically dredged material, and is constructed using in situ material.
Ecology	A branch of science concerned with the interrelationship of organisms and their environments: the totality or pattern of relations between organisms and their environment.
Ecosystem Management and Restoration Research Program	Abbreviated as EMRRP. U.S. Army Engineer Research and Development Center’s ecological restoration and technology advancement research program.
Engineer’s estimate of probable construction cost	A detailed construction cost estimate developed by the design engineer or the engineer of record for the proposed work.
Engineering With Nature®	Abbreviated as EWN®. A proprietary term by the U.S. Army Corps of Engineers, which aims to advance the practice of nature-based solutions in coastal protection and restoration, as well as in flood risk management.
Environmental window	Time frame during which dredging may be prohibited that is set to protect sensitive biological resources or their habitats from the effects of dredging or material placement operations.
Equipment access corridor	A spatially delineated marine or land-based route of sufficient width to provide equipment and personnel access to and from the project site throughout the project construction duration.
Erosion	Loss of sediment from aquatic or shorelines due to ongoing wave, water, or other environmental forces.
Estimated operations, monitoring, and maintenance cost	Abbreviated as OM&M. The OM&M cost is project specific and may include the following bid items: vegetative plantings, containment-dike gapping, and profile surveys.

F

Fauna	Animal life, especially the animals characteristic of a region, period, or special environment.
Flora	Plant, bacterial, or fungal life, especially life characteristic of a region, period, or special environment.

G

Geomorphology	A science that deals with the relief features of the earth and seeks an interpretation of them based on their origins and development: the features dealt with in geomorphology.

H

Healthy marsh elevation	The healthy marsh elevation is determined by taking several average marsh elevations (CPRA survey standards) in areas deemed healthy by an experienced field biologist.
High-density polyethylene	Abbreviated as HDPE. A linear version of polyethylene, a light versatile synthetic resin made from the polymerization of ethylene (https://www.britannica.com/science/high-density-polyethylene).
High-pressure discharge	This technology involves the use of a contraction section at the pipeline discharge (typically a nozzle) that increases the slurry's exit velocity such that the resultant jetting action propels the slurry in an arc shaped pattern.
Hydraulic dredge	A floating machine that removes material from the marine bottom by entraining it in induced water flow and transports it in a closed conduit to the marsh creation area or other designated deposit area.
Hydraulic dredging	A type of dredging that uses a hydraulic pipeline to convey the dredged material as a slurry.
Hydrographic surveying	Acoustic or mechanical means of measuring physical features of an underwater area.

I

Intertidal zone	The area between high and low tides.

L

Long-Term Fate of Dredged Material Model	Abbreviated as LTFATE. U.S. Army Corps of Engineers' model that is used to simulate the dispersion of placed dredged material in the aquatic environment.
Long-term monitoring	A combination of tools and techniques to assess the performance of a system over time.
Louisiana Coastal Protection and Restoration Authority	Abbreviated as CPRA. The State of Louisiana's coastal protection and ecological restoration agency.
Low-pressure discharge	This technology consists of either an open end of pipe without any attachment, or it can be equipped with a spreader plate; a device placed to absorb velocity energy of the slurry to slow and direct it to provide better control over point placement or reduce impacts to wetland surfaces or in the water column.

M

Macroalgae	Species of macroscopic, multicellular, marine algae (Google).
Marsh	A type of freshwater, brackish water, or saltwater wetland that is found along rivers, ponds, lakes, and coasts and experiences periodic or permanent inundation. Marshes are dominated by emergent, grass-like, herbaceous vegetation species. A majority of Louisiana's coastal marsh is intertidal.
Marsh creation	Typically accomplished by the placement of hydraulically dredged material into confined, open-water, degraded marsh areas to the elevation required to achieve the project intertidal marsh objectives for the project design life.
Marsh creation area	The total acres (hectares) of land delineating the proposed marsh creation features, typically defined within the earthen containment dikes.
Marsh creation borrow area	The area spatially delineating the dredge template for the construction of the proposed marsh creation area.

Marsh creation volume	The total estimated volume of marsh creation fill material required to construct the proposed marsh creation area to the preferred construction marsh fill elevation using the hydraulically dredged material from the proposed marsh creation borrow area.
Marsh Equilibrium Model	Abbreviated as MEM. A model that simulates the transformation and evolution of marsh plains, including possible future equilibrium conditions.
Marsh Equilibrium Model—Thin-Layer Placement	Abbreviated as MEM-TLP. A MEM that simulates the effects of thin-layer placement.
Marsh nourishment	"A restoration technique that can refer to either the direct placement of a thin-layer of sediment through spray or hydraulic dredging or from the 'spilling' of a thin-layer of sediment over marsh that is adjacent to an uncontained restoration project" (CPRA 2008).
Marsh nourishment area	A marsh nourishment area is the total acres (hectares) of land delineating the proposed marsh nourishment features.
Marsh nourishment volume	The total estimated volume of marsh nourishment fill material required to construct the proposed marsh nourishment area to the preferred construction marsh fill elevation using the hydraulically dredged material from the proposed marsh creation borrow area.

N

National Environmental Policy Act	Abbreviated as NEPA. U.S. federal law that protects environmental resources.
Natural and nature-based features	Abbreviated as NNBF. A type of Engineering With Nature® approach that uses nature-based solutions for flood risk management.

O

Open-water thin-layer placement	A method of TLP that has been used as a sediment management tool to maintain littoral sediment supply in coastal and estuarine settings.

P

Performance criteria	A set of standards against which the function of a system is measured against to assess success.
Pipeline	A means of conveying hydraulically dredged sediment to its placement location.
Placement area	A location where material removed by dredging may be placed.
Plans	That part of the construction contract documents, prepared or approved by the engineer, which graphically shows the scope, intent, and character of the work to be completed by the contractor for the proposed project.
Primary consolidation, secondary compression and desiccation of dredged fill	Abbreviated as PSDDF. A U.S. Army Corps of Engineers' model that simulates the placement and subsequent consolidation of dredged material
Production rate	The number of cubic yards (cubic meters) of in situ sediments dredged during a given period and is commonly expressed in cubic yards (cubic meters) per hour.
Project design life	The planned life expectancy of the proposed project features.
Project goal	Achieving a desired outcome at a specific end date employing a specific number of resources (Google).
Project objective	What is planned to achieve by the end of your project (Google).

R

Real-time kinematic	Abbreviated as RTK. An application of surveying to correct for common errors in current global navigation satellite systems (GNSS) (Google).

S

Sediment	It is the naturally occurring material that is broken down by weathering and erosion and is subsequently carried by wind, water, or ice (Wikipedia)
Slurry	Mixture of water and sediment used typically to convey dredged material via pipelines.
Specifications	That part of the construction contract documents consisting of written technical descriptions of materials, equipment, systems, standards, and workmanship as applied to the work to be performed by the contractor for the proposed project.
Submerged aquatic vegetation	Abbreviated as SAV. Vegetation that is present underwater.
Substrate	An underlying support: a layer beneath the surface soil: the base on which an organism lives.
Surface elevation table	Abbreviated as SET. Portable mechanical leveling device for measuring the relative elevation change of wetland sediments (USGS).

T

Target marsh elevation	The target marsh elevation is defined as the marsh elevation derived to achieve the project intertidal marsh objectives for the project design life.
Thin-layer capping or covers	Abbreviated as TLC. A modified TLP approach, has also been used to restore environmentally degraded sediments, such as at legacy contaminated sites.
Thin-layer placement	Abbreviated as TLP. It is defined as the “purposeful placement of thin layers of sediment (e.g., dredged material) in an environmentally acceptable manner to achieve a target elevation or thickness” (Berkowitz et al. 2019).
Tidal channel	Tidal channels are the source of exchange between the marshes and bays.

Topography	The art or practice of graphic delineation in detail, usually on maps or charts, of natural and manmade features of a place or region especially in a way to show their relative positions and elevations: the configuration of a surface, including its relief and the position of its natural and manmade features.
Turbidity curtain	A vendor-manufactured product that aims to break the flow of suspended sediments from dredging to improve water quality.

U

U.S. Army Corps of Engineers	Abbreviated as USACE. U.S. federal agency that is charged with maintenance of U.S. waterways and coastal zone, among other missions; part of the U.S. Army.
U.S. Army Engineer Research and Development Center	Abbreviated as ERDC. U.S. Army's primary research and development center dedicated to advancing technology and practice related to a multitude of missions, including navigation and beneficial use.
U.S. Environmental Protection Agency	Abbreviated as EPA. U.S. federal agency in charge of protecting the environment.
U.S. Geological Survey	Abbreviated as USGS. U.S. federal agency in charge of water resources and data collection related to water and its use.

V

Vegetation	Plant life or total plant cover (as of an area).
Vegetative plantings	Individual plants placed in a systematic alignment or pattern to help establish the growth and sustainability of the marsh system for the project design life.

W

Wetland	Land or areas, such as marshes or swamps, that are covered often intermittently with shallow water or that have soil saturated with moisture.

Appendix A: Key Aspects of Select TLP Case Studies

Respective project parameters in this listing (where available) include: (1) type and size of dredges, (2) placement methods, (3) DM composition and volume, (4) project placement surface area, (5) containment materials, (6) placement thicknesses, (7) shore equipment, (8) project results, and (9) costs.

Project name and date	Material volume and type	Dredge type and size	Placement method	Placement thickness	TLP project surface area	Lateral confinement	Shore equipment	Parameters monitored	Notes on project outcome
Pepper Creek, Delaware **2013**	9,000 yd³ (6,900 m³) Fine grained	Swinging ladder cutterhead 10 in (254 mm)	High-pressure discharge mounted on barge	9.05–11.81 in (23–30 cm) 9–12 in (22.86–30.48 cm) 0.75–1.0 ft (30.48–22.86 cm)	47* ac (19* ha)	Used existing topography and hay bales in tidal creeks.	None	Volume, elevation, vegetative recovery	Marsh elevation was reestablished successfully while protecting channel and pool areas; vegetative recovery is on track, as expected.
Fourchon, Louisiana **2002**	Unknown Soil texture varied significantly (58% sand), compared to all other areas of lower sediment addition (4%–22% sand)	Cutterhead	Low-pressure discharge	Unvegetated with 5–7 in (13–18 cm) of sediment Unvegetated with 8–10 in (20–25) cm of sediment Unvegetated with 11–14 in (28–36 cm) of sediment Vegetated with 7–9 in (18–22 cm) of sediment "Pop-up" marsh, where a portion of the marsh became buoyant and settled on top of the sediment application	18.5 ac (7.5 ha)	Degraded salt marsh was divided into four cells through the construction of small earthen dikes. The cells were hydraulically connected through culverts and breaks in the levees that allowed for tidal exchange.	Unknown	n/a	Sediment application to a disturbed marsh improved the rate of plant recovery. The improved recovery was the result of reduced inundation with higher elevations and the addition of phosphorus with the DM. After 7 years, total aboveground biomass, live biomass, stem density, and height of *Sporobolus alterniflorus* were equivalent to the reference marsh. The addition of sediment to this marsh improved the resiliency and stability following an experimental vegetation disturbance by clipping and herbicide application. At the highest sediment application thickness, prolonged periods of drying led to a decrease in marsh recovery.

Project name and date	Material volume and type	Dredge type and size	Placement method	Placement thickness	TLP project surface area	Lateral confinement	Shore equipment	Parameters monitored	Notes on project outcome
Gull Rock, North Carolina **1982**	15,000* yd³ (11,500* m³) Primarily clay, silt, and fine sand	Maintenance material auger head 6 in (305 mm) New work auger head 6 in (305 mm)	6-in (15 cm) discharge split into two 3-in (8 cm) "independent" high-pressure discharges Range of jet 150* ft (45.72 m) One 3.5-in-diameter, high-pressure discharge	"Ranged from 1 to 10.2 cm (0.4 to 4 in) but was generally 5 cm (2 in)" "1 to 20 cm (4 in to 8 in), which was generally 10 cm (4 in)"	n/a	n/a	n/a	n/a	Nine years after TLP, the canal and marsh site were monitored to capture the long-term effects of the placement activities. All the parameters evaluated in the long term are indicative of productive marshes. TLP at the marsh sites reduced or eliminated adverse impacts to habitat and smothering of existing vegetation as compared to conventional placement in marshes. Some smothering of vegetation occurred during placement because of the large volume of water involved in the spraying operations; however, revegetation occurred relatively quickly.
Fowl River, Mobile Bay, Alabama **1986**	190,000 yd³ (145,300 m³) 40% sand, 50% silt, 10% sandy clay	Cutterhead 20 in (508 mm)	Barge-mounted, low-pressure discharge with baffle plate	Less than 6 in (15 cm) over 36% of the area, 6–12 in (15–30 cm) over 48% of the area, and greater than 12 in (30 cm) over 16% of the area	319* ac (129 ha)	None	None	n/a	TLP of DM did not have a significant impact on fish and infauna abundance. Recolonization of the DM by infauna occurred rapidly.
Gulfport Harbor/ Mississippi Sound **1992/1993**	2,000,000 yd³ (1,529,000* m³)	Cutterhead	Barge-mounted, low-pressure discharge	5.9 in (15 cm) 6 in (15.24 cm) 0.1 ft (3.05 cm)	600 ac (243 ha)	None	None	Volume, elevation	Similar disposal and reference sites established similar benthic community assemblages, and the size distributions of some taxa suggest adults recolonized the thin layer of DM either through vertical migration or lateral immigration from adjacent areas.

Project name and date	Material volume and type	Dredge type and size	Placement method	Placement thickness	TLP project surface area	Lateral confinement	Shore equipment	Parameters monitored	Notes on project outcome
Mobile Bay, Alabama **2012**	9,000,000 yd³ (6,881,000 m³) Fine grained	Cutterhead 30 in (760 mm)	Low-pressure anchor barge with spreader	12* in/1.0* ft (30.5* cm)	n/a	None	None	n/a	Modeling based on monitoring from this project indicates that TLP in Mobile Bay will have negligible impact on navigation channel infilling, total suspended sediments, and Mobile Bay bottom morphology. Sediment introduced by TLP will only contribute modestly to these processes. As a result of the TLP monitoring and modeling efforts, the Mobile Bay Interagency Working Group concluded that a long-term option for conducting within-bay, thin-layer disposal should be pursued.
Mouth of Columbia River, Oregon **2014 (now continued annually)**	500,000 yd³ (382,000 m³) Coarse grained	Hopper dredge 6,423 yd³ (4,911 m³)	Bottom dump doors	2 in/0.2 ft (5 cm)	n/a	None	None	n/a	Monitoring included acute crab response, currents, hydro surveys, crab mortality, etc. to successfully address stakeholder concerns.
Blackwater NWR I, Maryland **2003**	n/a	Cutterhead Swinging ladder 10 in (255 mm)	Hull-mounted, high-pressure discharge	n/a	2.5 ac (1 ha)	Straw bales	n/a	Volume, elevation, vegetative recovery	The material was placed in two lifts of small thickness, which allowed the sites to become revegetated in a short period of time.
Blackwater NWR II, Maryland **2017**	19,900a m³ 26,000a yd³	Cutterhead Swinging ladder 10 in (255 mm)	Crim-mounted high pressure	4–6 in (10–15 cm)	40 ac (16 ha)	n/a	Two marsh buggies with hydraulic excavators	Volume, elevation, vegetative recovery	

Project name and date	Material volume and type	Dredge type and size	Placement method	Placement thickness	TLP project surface area	Lateral confinement	Shore equipment	Parameters monitored	Notes on project outcome
Seal Beach, California **2016**	10,320* m³ 13,500* yd³ Coarse grained	Cutterhead 8 in (200 mm), then a cutterhead 12 in (300 mm)	High (barge mounted) and low-pressure discharge	10 in, plus minus average of 2 in (25 cm, plus minus average of 5 cm)	8* ac (3.2 ha)	Hay bales, straw waddles, sandbags, and geotextile fabric and 6-ac (2.4 ha) vegetated buffer	Marsh Master	Volume, elevation, vegetative recovery	Intensive post construction monitoring started and will continue for 5 years.
Marine Corps Base Camp Lejeune, Freeman Creek, North Carolina	n/a	Diaphragm pump	Low-pressure discharge with baffle	2–4 in/0.17–0.33 ft (5–10 cm)	800 ft² (75 m²)	Coir logs	None	n/a	Is being monitored every two months for the first two years, and then annually.
Avalon, New Jersey **2014 2015**	42,050 m³ 55,000 yd³ Fine grained with 27% sand	Cutterhead no. 1 14 in (356 mm) Cutterhead no. 2 10 in (254 mm)	Shore crib-mounted, open-pipe, low-pressure discharge with spreader and high-pressure discharge (range 70* ft)	1.2–19.7 in/0.1–1.6 ft (3–50 cm), with an average of 9 in (23 cm) on marsh platform; the average was more than 36 in (91 cm) in pools	45* ac (18.2* ha)	Coir logs 6 in (15 cm), 12 in (30 cm), 16 in (41 cm), and 20 in (51 cm) in diameter	Marsh Master	Elevation; accretion; placement extent; water levels; depth of placement; sediment characteristics (OM, N, P, S, grain size); benthic infauna and epifauna; nekton; birds; plant height; plant species; plant cover; plant biomass; water chemistry; soil-bearing capacity	Total project cost between 2014 and 2017 was $2,503,000; does not include additional monitoring being conducted between 2018 and 2021.

Project name and date	Material volume and type	Dredge type and size	Placement method	Placement thickness	TLP project surface area	Lateral confinement	Shore equipment	Parameters monitored	Notes on project outcome
Fortescue, New Jersey **March 5–20, 2016**	6,490 yd^3 (4,961 m^3)	12-in (305 mm) hydraulic cutterhead dredge (12-in [305 mm] diameter intake pipe and 12-in [305 mm] diameter discharge pipe)	Direct pumping, Y valve system	0–18 in (0–46 cm), average 6 in (15 cm)	6.6 ac (2.67 ha)	Inner perimeter consisted of 12-in (30.48 cm) diameter Filtrexx SiltSoxx, which are fabric tubes filled with hardwood chips, most of which were stacked in a pyramid to the appropriate target elevation. The outer perimeter consisted of a single layer of 6-in (15.24 cm) diameter tubes.	Two marsh buggies with hydraulic excavators One Marsh Master One skid steer	Elevation; accretion; placement extent; water levels; depth of placement; sediment characteristics (OM, N, P, S, grain size); benthic infauna and epifauna; nekton; birds; plant height; plant species; plant cover; plant biomass; water chemistry; soil-bearing capacity	Cost was $4,861,000, but this included the cost for dune and beach restoration as well; does not include additional monitoring being conducted between 2018 and 2021.
Jamaica Bay–Big Egg Marsh, New York **2000**	8,000 yd^3 (6,120 m^3)	Cutterhead swinging ladder 8 in (203 mm)	High-pressure discharge (4-in [10-cm] nozzle) spray range 130* ft (39.62 m)	“Generally, 20 cm (8 in)” “A maximum of 43 cm (17 in) was placed in certain areas that required more material in order to be above the reference plane” “lowest lying mud flats and drainages required an approx. thickness of 100 cm (39 in)”	2 ac (0.8 ha)	Silt fence, hay bales, supplemental containment with high turbidity using black plastic construction fence. “The material placement was guided by polyvinylchloride pipes arranged in a grid pattern.”	n/a	Volume, elevation, vegetative recovery	“Smooth cordgrass showed 100% survival, germination (maximum seedling density was 74 seedlings/ft^2 at placement site), and regrowth in most of the site, with the exception of the areas affected by erosion. One year after placement, smooth cordgrass did not survive when the thin layer thickness was greater than 8 in; survival and layer thickness had an inverse relationship (Harmon 2006). The plastic fence kept geese away until summer 2004. The placement site was successfully transformed into a silty-organic saltmarsh, covered with smooth cordgrass, and colonized by different animal communities.”

Project name and date	Material volume and type	Dredge type and size	Placement method	Placement thickness	TLP project surface area	Lateral confinement	Shore equipment	Parameters monitored	Notes on project outcome
Prime Hook, Delaware **2014–2016**	600,000[a] yd³ (459,000[a] m³)	Three swinging ladder cutterheads	Hull-mounted, high-pressure discharge and a barge-mounted, high-pressure discharge	Placed on mudflats and very shallow open water	8,000 ac (3237.5 ha)	Earthen containment dike to prevent sediment inflowing	Marsh buggy	Volume, elevation, vegetative recovery	Aerial Seeding
John H Chafee National Refuge, Rhode Island **2016 and 2017**	24,000 yd³ (18,350 m³) 90%* sand, 10% fines	Barge-mounted, hydraulic excavator with cutterhead and hydraulic pump (6-in [152 mm] discharge) attachment on stick	n/a	Less than 4 in (10 cm)	14 ac (5.7 ha)	3,000 bags of clam and oyster shells for containment and marsh edge erosion protection	Bulldozer with CAD files to improve accuracy	Volume, elevation, vegetative recovery	Extensive monitoring prior to restoration and construction was completed and will continue as the saltmarsh recovers. Monitoring efforts include estuarine fish, salt marsh nekton, water quality, tidal flow and volumes, shoreline conditions, salt marsh elevations, and bird usage.
Ninigret Pond Salt Marsh, Rhode Island **2016 and 2017**	30,000 yd³ (23,000 m³)	Cutterhead swinging ladder 8 in (200 mm)	Low-pressure discharge	n/a	38 ac (15.4 ha)	n/a	Marsh buggy with hydraulic excavator Small dozer	Volume, elevation, vegetative recovery	

Source: ERDC (U.S. Army Engineer Research and Design Center). 2023. *Case Studies by Project Type*. Thin-Layer Placement of Dredged Materials. Web page. https://tlp.el.erdc.dren.mil/case-studies-by-project-type/.

Note: *Approximately

Abbreviations:
ac—acre
cm—centimeter
DM—dredged material
ft—foot
ft²—square foot
ha—hectare
in—inch
m³—cubic meter
mm—millimeter
n/a—not applicable or data not available
NWR—National Wildlife Refuge
TLP—thin-layer placement
yd³—cubic yard

Appendix B: Checklists for TLP Project Phases

Table B-1. *TLP Project Planning Considerations Checklist*

☐ Define TLP project goals.
☐ Identify potential sites (dredging and TLP).
☐ Perform logistics analysis (transport mode, distance).
☐ Define habitat zones and success criteria.
☐ Identify potential sites (dredging and placement).
☐ Perform logistics analysis (transport mode, distance).
☐ Identify development time frame.
☐ Decide on placement cells, lift thickness, wetland-establishment time frames.
☐ Preliminary site screening
☐ Are sites compatible with TLP project goals?
☐ Are there regulatory constraints which may affect design considerations?
☐ Gather relevant site data.
☐ Large-scale topography and bathymetry (from available, published sources)
☐ Generic soil and sediment types
☐ General descriptors of vegetation zones and types
☐ Benthic characteristics (species, abundance)
☐ Hydrodynamic conditions
☐ Tidal ranges
☐ Cultural and archaeological resources
☐ Land rights (easements, right-of-way)
☐ Infrastructure (pipelines, cables, etc.)
☐ Determine preliminary sizing of TLP project (assuming target elevations and lift thickness).
☐ Develop alternatives analysis and cost estimates.
☐ Identify potential funding sources.
☐ Select preferred alternative.

Table B-2. *Checklist for Engineering Design of TLP Projects*

☐ Define project goals and success criteria.
☐ Obtain site data.
☐ Topography and bathymetry, including channels, marsh pannes, and other features.
☐ Vegetation density and types
☐ Geotechnical information for dredge and native (surface and subsurface) sediments
☐ Tidal flow regimes, ranges, and velocities
☐ Determine site area for placement and target elevations and lift thickness (including tolerances).
☐ Site access and staging area plans
☐ Material sourcing (for TLP)
☐ Develop regulatory permitting strategy and incorporate regulatory constraints into design.
☐ Decide on dredge type and specifications (depending on contracting mechanism).
☐ Determine optimal placement method (spray, baffles, etc.).
☐ Determine desired production and work schedule.
☐ Determine DM volume relationships (in situ volume versus placement bulking).
☐ Determine DM consolidation and subsurface settlement impact on elevation over time.
☐ Decide on lateral containment, if any.
☐ Protect natural channels and drainage features?
☐ Determine requirements for site drainage and turbidity control.
☐ Develop engineering design—plans, specifications, and cost estimate.
☐ Determine means and methods for placement tracking (volumes and lift thickness).
☐ Develop procurement strategy.
☐ Long-term monitoring plan
☐ Adaptive management plan and identify entity who will execute the plan.

Table B-3. *Construction Checklist for TLP Projects*

☐ Align goals and obtain cooperation between owner, contractor and key stakeholders.
☐ Check whether value engineering or constructability review was performed.
☐ Prequalify contractors, or review key experience criteria as part of bid requirements.
☐ Perform bid neutralization analysis, if possible, to compare bids more fairly.
☐ Review best-management practices and conformance to regulatory stipulations to minimize environmental impacts on wetlands.
☐ Check whether placement accuracies are reasonable.
☐ Do not overprescribe means and methods.
☐ Are preconstruction measurements complete?
☐ Contour mapping, surveys, and construction staking
☐ Mark access for construction personnel, equipment, and pipeline transportation corridors.
☐ Encourage innovation with respect to field equipment.
☐ Use of high-pressure and low-pressure (traditional end-of-pipe spreader) spray
☐ Onboard versus end-of-pipe nozzles
☐ Optimize slurry placement (place sands using natural hydraulic sorting).
☐ Shaker screens to screen off debris
☐ Single versus multiple discharge points
☐ Single versus multiple placement areas on-site
☐ Use of amphibious and low-ground-pressure equipment (swamp buggies)
☐ Shoreline and bank stabilization construction techniques and operations
☐ What kind and how much lateral containment should be used?
☐ Provisions to work 24-7 (including nighttime operation)
☐ Clear contingencies for weather delays
☐ Construction monitoring plan
☐ Conduct field review after completing construction.
☐ Incorporate adaptive management into long-term monitoring strategy.

Appendix C: TLP Workshop Attendees

Name	Organization	Email
Blama, Bob	U.S. Army Corps of Engineers (USACE)–Baltimore District (retired)	Not available
Chafee, Caitlin	Rhode Island Coastal Resources Management Council (RI CRMC)	CChaffee@crmc.ri.gov
Chasten, Monica	USACE–Philadelphia District	Monica.A.Chasten@usace.army.mil
Donegan, Tim	Sevenson Environmental Services	TDonegan@sevenson.com
Douglas, Scott	New Jersey Department of Transportation, Office of Maritime Resources	scott.douglas@dot.nj.gov
Fanz, Dave	New Jersey Department of Environmental Protection	Dave.Fanz@dep.nj.gov
Goulet, Danny	RI CRMC	dgoulet@crmc.ri.gov
Harris, Janine	National Oceanic and Atmospheric Administration	janine.harris@noaa.gov
Harris, Jarred	Mississippi Department of Marine Resources	Jared.Harris@dmr.ms.gov
Hunt, Amy	EA Engineering, Science, and Technology, Inc., PBC (EA)	ahunt@eaest.com
Joffrion, Russ	Louisiana Coastal Protection and Restoration Authority	russ.joffrion@la.gov
King, Phil	Natural Resources Conservation Service	Phillip.King@de.usda.gov
Leo, Kelly	The Nature Conservancy (TNC)	kleo@tnc.org
McCullough, Albert	Sustainable Science, LLC	albert@sustainablescience.com
McDougal, Dan	Dredge America	dan@dredgeamerica.com
Mears, Wendell	Anchor QEA, LLC	wmears@anchorqea.com

Name	Organization	Email
Mohan, Ram	Anchor QEA, LLC and Texas A&M University	rmohan@anchorqea.com; rmohan@tamu.edu
Murray, Elizabeth	U.S. Army Engineer Research and Development Center (ERDC)	Elizabeth.O.Murray@usace.army.mil
Piercy, Candice	ERDC	Candice.D.Piercy@usace.army.mil
Specht, Jackie	TNC	jackie.specht@TNC.ORG
Sumner, Chad	Sumco EcoContracting	csumner@sumcoeco.com
Szimanski, Danielle	USACE–Baltimore District	Danielle.M.Szimanski@usace.army.mil
Timmis, Andrew	J.F. Brennan Company, Inc.	atimmis@jfbrennan.com
Welp, Timothy *(deceased)*	ERDC	—
Whitin, Sam	EA	swhitin@eaest.com

Appendix D: Guidelines Peer Reviewers

Name	Organization	Email
Chasten, Monica	U.S. Army Corps of Engineers (USACE)–Philadelphia District	monica.a.chasten@usace.army.mil
Davis, Ryan	Anchor QEA, LLC	rdavis@anchorqea.com
Donegan, Tim	Sevenson Environmental Services	TDonegan@sevenson.com
Douglas, Scott	New Jersey Department of Transportation, Office of Maritime Resources	scott.douglas@dot.nj.gov
Feagin, Rusty	Texas A&M University	feaginr@tamu.edu
Godsey, Elizabeth	USACE–Mobile District	elizabeth.s.godsey@usace.army.mil
Hayes, Donald	The Dredging Professor LLC (retired U.S. Army Engineer Research and Development Center [ERDC])	Donald.Hayes@gmail.com
Hunt, Amy	EA Engineering, Science, and Technology, Inc., PBC (EA)	ahunt@eaest.com
Joffrion, Russ	Louisiana Coastal Protection and Restoration Authority	russ.joffrion@la.gov
King, Jeffrey	ERDC	jeffrey.k.king@usace.army.mil
McCullough, Albert	Sustainable Science, LLC	albert@sustainablescience.com
McPhail, Brian	ERDC	brian.mcphail@usace.army.mil
Mears, Wendell	Anchor QEA, LLC	wmears@anchorqea.com
Randall, Robert	Texas A&M University	r-randall@tamu.edu
Specht, Jackie	The Nature Conservancy (TNC)	jackie.specht@TNC.ORG
Thorne, Karen	U.S. Geological Survey	kthorne@usgs.gov
Timmis, Andrew	J.F. Brennan Company, Inc.	atimmis@jfbrennan.com
Whitin, Sam	EA	swhitin@eaest.com
Wilson, Bart	U.S. Fish and Wildlife Service	Bart_Wilson@fws.gov
Yepsen, Metthea	TNC	metthea.yepsen@dep.nj.gov

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6. AUTHOR(S)
Candice Piercy, Timothy Welp, and Ram Mohan

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Engineer Research and Development Center (ERDC)
Environmental Laboratory (EL)
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Texas A&M University
400 Bizzell Street
College Station, TX 77873

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14. ABSTRACT

Historically, dredged material (DM) has been placed at the nearest available placement site. There has been an increasing trend of beneficial use projects recently, often using innovative methods. Thin-layer placement (TLP) involves one- to two-foot-thick DM placement, compared to traditional, thicker sediment placement applications, to restore coastal wetlands. The main idea of TLP is to promote the natural recolonization or reestablishment of habitat and benthic species. These guidelines present a roadmap of TLP's evolution and offer easily digestible examples and considerations for TLP applications in wetlands and open-water environments. Offered as a tool to the practitioner, the eight chapters of these guidelines cover the history of TLP, characterization of the project area, setting goals and objectives, project design, construction considerations, monitoring and adaptive management, knowledge gaps, and future research needs. Several case studies are presented as examples of how such applications have been implemented and highlight lessons learned, particularly best-management practices. These guidelines offer consideration of TLP as a critical component in the project development phase, a tool for the sustainable management of DM, and a method that may create, maintain, enhance, or restore ecological function while supporting navigation channel infrastructure and providing flood risk management benefits.

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