Georgia Coastal Research Council

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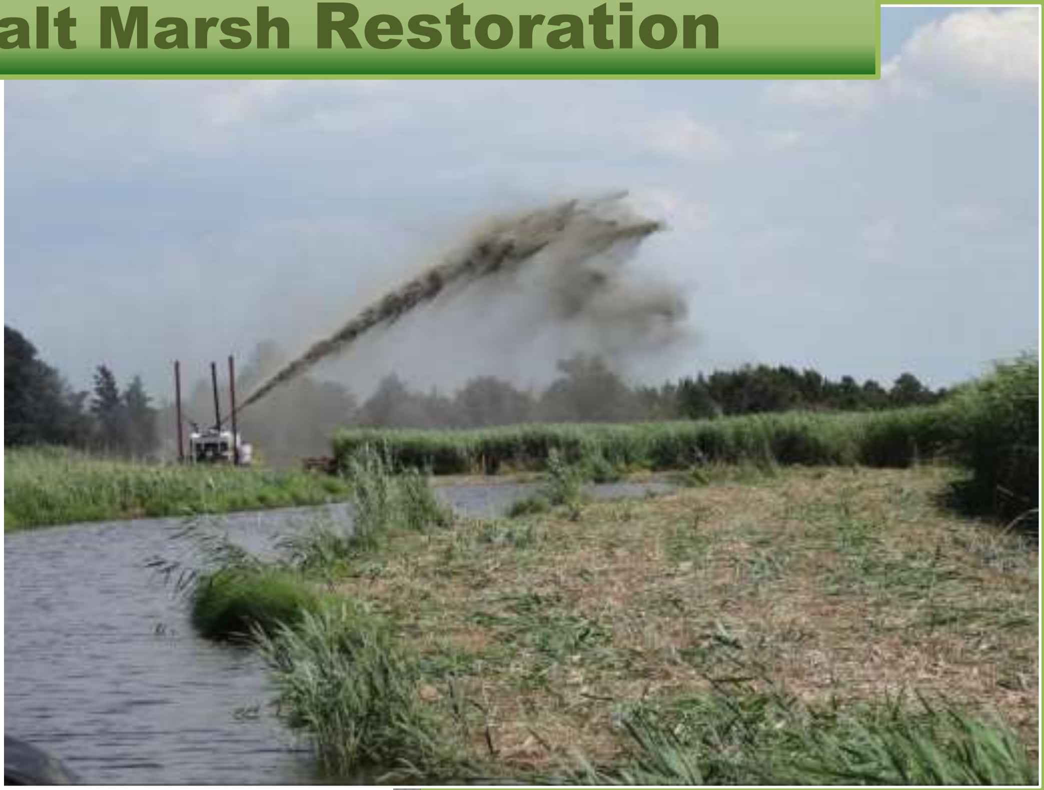
Use of Thin Layer Placement of Dredged Material for Salt Marsh Restoration



Prepared for the Coastal Resources Division, Georgia Department of Natural Resources

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The Georgia Coastal Research Council (GCRC) was established to provide mechanisms for improved scientific exchange between coastal scientists and decision makers, and to promote the incorporation of best-available scientific information into State and local resource management. The Council is not a policy organization, but rather seeks to provide unbiased, objective information about scientific issues. Baseline support for the program is by the Coastal Resources Division of the Georgia Department of Natural Resources (through the Coastal Management Program) and Georgia Sea Grant, with project-specific support from the National Science Foundation and other agencies. For more information, please contact us at gcrc@uga.edu or see our website at: http://www.gcrc.uga.edu.

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Table of Contents

Background

Coastal wetlands are among the most productive environments in the world, providing food sources and breeding habitats for numerous crustaceans, fish, birds, and other plants and animals. They also perform ecosystem functions that are valuable to humans including, filtering pollution, and buffering the coast against erosion by dissipating the wind and wave energy of tropical storms and hurricanes. In fact, a study by Narayan and others (2017) showed that coastal wetlands in New York and New Jersey prevented $625 million in direct flood damages during Hurricane Sandy, reducing damages by more than 22% in half of the affected areas. The study shows that properties in Barnegat Bay, New Jersey that were fronted by salt marshes experienced 16% lower annual flood losses from storms than those without adjoining marshes (Narayan et al. 2017).

Despite all the ecological advantages coastal wetlands supply, they are disappearing at an increasing rate due, in part, to land subsidence, erosion, sediment depletion, and sea level rise. To adapt to such hydrologic and geomorphic changes, marshes must be able to migrate inland or build up sediment and organic soil materials. However, these actions are being impeded by increases in shoreline development, channel diversions, and other human activities. Estimates indicate that 27% of estuarine wetlands that were present in U.S. in the early 1900s have been lost to human activities (Mitsch and Gosselink, 2000).

As awareness of the importance of coastal wetlands has grown, so to have efforts to preserve these ecosystems through restoration of eroding marshes, nourishment of deteriorating marshes, and creation of new marshland from areas that had previously converted to open water or mudflats. One method of potentially slowing wetland loss and stabilizing shorelines against the impacts of sea level rise is to artificially supply failing marshes with additional sediment and organic matter in the form of dredged material. A method of application of dredged material that has become increasingly popular in recent years, thin layer placement (TLP), involves depositing dredged sediments in thin, uniform layers over eroding marshes, emergent marsh vegetation, or shallow bay bottom (Ray 2007).

Thin Layer Placement

Thin Layer Placement broadly encompasses the purposeful placement of sediment or dredged material in a manner that produces a specific disposal layer thickness or ground surface elevation necessary to achieving the overall project objectives. In thin layer placement projects, disposal **layer thickness** typically **ranges from a few centimeters to some fraction of a meter**, depending upon the variation in ground surface or water levels at the site, and the functional objectives the placement is intended to achieve. https://tlp.el.erdc.dren.mil/what-is-tlp/

Photo credit: USFWS https://tlp.el.erdc.dren.mil/prime-hook-national-wildlife-refuge/

TLP is a versatile technique that can be used to restore many intertidal habitats, including all types of tidal marshes and beaches. However, this report is confined to the use of TLP of fine sediments (i.e. silt and clay) in salt marshes. Part I describes TLP and how it is being used for the nourishment and restoration of salt marshes. Part 2 examines how TLP projects are planned and designed. Part 3 discusses the importance of monitoring TLP projects before, during, and after construction. Physical, biological, and chemical parameters that are commonly part of successful monitoring plans are described and results from case studies are discussed with a focus on the parameters useful for Georgia projects. Part 4 provides a discussion of factors that make up a successful TLP project.

Most published studies of TLP, especially those involving long-term monitoring (>2 years), have been conducted in the Gulf states, mainly Louisiana and Alabama. The coastal wetlands of these states are highly susceptible to subsidence due to a variety of factors including sea level rise, channel building, and changes in sediment distribution. Consequently, monitoring results from TLP projects dating from the early 1980s are available and we have relied on this information for the current review. However, TLP is being increasingly used in the Southeast, Mid-Atlantic, and New England states, and we have included these projects wherever possible. Summary information on the 26 TLP projects we reviewed for this report is included in Appendix A.

Part One: Introduction to TLP

In TLP of dredged material, sediment is hydraulically applied as an aerial spray. The duration of the spray in a specific area controls sediment thickness (Mohan et al. 2016). TLP of dredged material was used in marshes in the Gulf of Mexico as early as the 1930s although this was prompted by engineering constraints rather than environmental concerns. At this time, canal dredging through salt marshes was performed with bucket dredges. This equipment placed dredged sediment close to the adjacent canal banks, often causing the edge to collapse and deposit material back into the water. To prevent this, low-pressure hydraulic dredges were used to deposit sediment slurry on to the marshes at a greater distance from canal banks (Schafer 2002). High-pressure spray placement techniques are a more recent development and were first applied in south Louisiana in 1979 (Schafer 2002). Today the hydraulic spray/pipeline dredge is the most commonly used method for TLP projects involving marsh creation or restoration (Chabreck 1999). Unlike traditional dredge material deposition, TLP of sediments on existing marshes is designed to simulate the natural processes of sediment overflow from storm events onto salt marshes and wrack deposition. In these cases, the addition of sediment from water or decayed vegetation can temporarily increase plant productivity (DeLaune et al. 1990). TLP of dredged material provides a more environmentally sensitive way of disposing sediments onto healthy marsh and waterways adjacent to the dredging site (Cahoon and Cowan 1987; LaSalle 1992), although the method is usually used for marsh stabilization or nourishment. TLP application is also used to elevate areas of shallow open water to a level where they can support vegetation (Wilber 1992c; Ford et al. 1999; Schaffner 2010). In these TLP projects, sediments are placed on flat or gently sloping shallow water depressions. In some cases, some sort of confinement structure is used to limit or prevent the applied sediment from spreading away from the placement area (Bray 2008).

Table 1: Potential Advantages and Disadvantages of Thin-Layer Disposal

Adapted from Randell et al. (2000) and Mohan et al. (2016)

Advantages	Disadvantages
Eliminates need for containment ponds or upland containment facilities for dredged material	Limited equipment and methodology choices due to limitations of marsh and wetland environments
Disposal process is similar to natural overlay processes	High winds can change dispersal patterns and shorten spray distances
Reduces cost; No need for spuds and anchors in the dredging	Not cost effective when material consists of coarse sediments
Eliminates long distance pumping	Wetland to be restored must be in close proximity to dredging site to be cost effective
Provides a clean surface layer, which promotes the re-establishment of benthic organisms	Not a viable option if dredged material is contaminated
Enhances and accelerates natural sedimentation processes	Elevation change due to material placement may negatively impact wetland hydrologic characteristics or vegetation patterns
Enables re-establishment of vegetation in degraded wetland areas; Placed sediment may provide nutrients to habitat	Can cause short-term impacts to marsh, with potential effects on benthic organisms
Enables reclamation/restoration of lost or open water intertidal wetland areas	Decomposition of the organic matter in the dredged material can lead to hypoxic conditions that are not conducive to plant growth in poorly drained soils
	Requires trained operators and careful supervision

There are some limitations to the use of TLP (Table 1). Because the depth of deposited material must be thin enough to avoid conversion of wetlands to upland habitat, only relatively small volumes of dredged material can be used (Schafer 2002). Increased concentration of suspended solids and turbidity in the water column may cause temporary negative effects at the placement site and/or in adjacent areas. Covering the bed may smother benthic organisms that may not be able to migrate upwards. Owing to differences in the physical and/or chemical properties of the deposited sediment, organisms that re-colonize the site may be different from those present before treatment. Changes in the benthic community may then have an effect on the fish population in the area (Bray 2008). However, these possible negative outcomes can be avoided through careful and thorough site evaluation and project planning and design.

Evaluations of the effects of TLP application have shown that healthy marsh systems do not exhibit permanent negative impacts following application (Leonard et al. 2002, Wilber 1992b). Although TLP may initially result in flattened vegetation and decreases in benthic organisms, salt marshes are generally able to recover from these disturbances. In fact, the addition of thin-layered sediment can serve to increase plant growth by improving conditions within the growing environment by adding minerals and nutrients, increasing oxygen levels through soil aeration, and reducing the frequency and duration of flooding via elevation increase (Parson and Swafford 2012; La Peyre et al. 2000). Higher elevations also result in greater marsh resiliency and stability over time (Stagg and Mendelsson 2011).

Part Two: Planning TLP Projects

TLP projects require extensive planning and design considerations to assure proper implementation that results in successful marsh restoration/nourishment. This section examines the issues involved in crafting an effective TLP plan and what factors should be considered during project construction.

Table 2: Key Characteristics of Successful TLP Projects
Adapted from Craft 2016, p. 220

Site Selection	• Short fetch • Low wave energy • Gentle (1-3%) slope • Ability to migrate (with sea level rise)
Construction	• Large marsh-open water ratio • Sufficient site drainage • Incorporated microtopography
Maintenance	• Invasive species monitoring and removal • Wrack removal

Successful TLP projects require appropriate planning. Although different groups may follow different protocols, most planning schemes include the following components: identification of the problem(s); setting goals and objectives; conducting a pre-project site survey, and creation of a comprehensive monitoring and maintenance program (Bray 2008).

Problem identification

Problem identification involves defining the undesirable existing conditions at a marsh site and determining whether they can be successfully addressed through a TLP project. The principal issues are: what is the cause of the degradation of a specific marsh system and what is the probability that TLP of dredged material can sufficiently alter the system to produce and maintain the desired results. Along with problem identification lies determining where TLP application is most likely to result in a favorable outcome (Table 2). Characteristics of successful TLP projects include areas of low wave energy and low slopes to make it more likely that placed sediment will remain on the site. Areas with shorter fetches help reduce the amount of wave energy the site will be exposed to. Also desirable is space for the marsh to migrate inland in response to the erosive effects of extreme weather and sea level rise. Site selection involves observation of physical and ecological changes in the marsh system, some of which may appear before the marsh shows obvious signs of loss. For example, there may be distinct biological incidents such as fish kills, sudden drops in fisheries harvests, widespread vegetation die-offs, recurring algal blooms, or invasive species proliferation (Craig et al. 2008).

Site and problem identification requires an understanding of how similarly located healthy, well-functioning salt marsh systems function and identifying the stressors that are impacting the potential project site. Information on factors such as the environmental requirements of the flora and fauna, tidal range, duration and frequency of flooding, and soil nutrient composition in intact, undisturbed wetlands of the same type can help planners detect the presence of physical (e.g., water delivery), chemical (e.g., water quality), and/or biological (e.g., presence of invasive species) problems at a prospective TLP site (Craft 2016). For instance, a TLP project proposing to restore dune, supratidal, and intertidal habitat in the Barataria Basin in the Gulf of Mexico identified the fact that "wetlands are impacted by increased salinity, tidal flux, wave action and storm impacts" as marsh-associated problems in their Environmental Impact Statement (USACE 2012).

Identification of these specific problems allowed planners to move on to the next planning step, setting goals and objectives.

Setting goals and objectives

This step is used to describe the favorable outcomes expected to result from actions designed to address the problems identified at a prospective TLP site. The goal of a project is a general statement of the sought after long-term ecological or biological outcomes (IWWR 2003). It is helpful if the goal statement is simple and clear as the project objectives will be based on this statement (Craig et al. 2008). Project objectives provide specific targets focused on hydrology, soils, topography, and/or biological factors that must be changed on the project site to establish or restore a wetland. It is best if clear goals and objectives are articulated early in the planning process so that they can then be used to guide the project design, construction, and monitoring and evaluation process (Niedowski (2000). In their guide to wetland restoration, the Interagency Workgroup on Wetland Restoration (2003) gives as an example of the goal "restore the natural hydrology and vegetation of a degraded Atlantic coast salt marsh" that might have the following objectives: "restore the natural tidal regime; ensure the mudflat is returned to a level appropriate for vegetation; re-establish dominance of the native plant community, e.g., *Spartina* and *Salicornia* species; and limit the presence of non-native or invasive plant species".

Box 1. Example of a Pre-Project Site Survey Plan (Source: Biohabitats 2007)

The Blackbird Creek Reserve (DE) Ecological Restoration Master Plan lists the following parameters in its pre-construction monitoring plan:

- Record tidal elevation data and pattern at creek and marsh stations and analyze tidal hydrology.
- Perform geotechnical/sediment coring study of marsh plain and selected channel bottom substrate to document historic patterns of sedimentation.
- Conduct an inventory and assessment study of native common reed (*Phragmites australis americanus*) stands.
- Establish tidal wetland baseline research sites (proposed restoration sites and control sites) with hydrology stations, vegetation plots and GPS/photo point monuments to document conditions.

Pre-project site survey

Once goals and objectives have been determined information about the project site's historic and existing conditions can be collected. TLP projects are site specific and the physical and biological characteristics of the proposed project site will influence the design and the likelihood of its success. A pre-project site survey assesses areas that will be directly affected by TLP of dredged material and also includes surrounding areas that may be indirectly affected by the project (Bray 2008) (Box 1). The goals of a site assessment are to:

- Understand former conditions on the site;
- Determine whether a wetland ever existed on the site;
- If a wetland did exist, determine what factors resulted in wetland degradation or loss; and
- Determine the current condition of the site (IWWR 2003).

Past conditions can provide valuable information on impacts to the site that may affect the success of the TLP project. This information can be obtained through examination of historical photos (including aerials) and historical maps of the area (IWWR 2003).

Determination of the current conditions of the prospective site is also critical. Visual inspection of the site provides general information about: topography; evidence of erosion; evidence of drainage and water movement patterns; major vegetation types; human structures and land use; and adjacent land uses (IWWR 2003). In addition to such qualitative data, several quantitative parameters that are often measured in the field include: exact elevations and topography of features; levels of soil nutrients, organic matter and moisture; water flow rates and timing; location of wetland soils, plants, and hydrology; and diversity and cover of native and invasive or non-native plant species (IWWR 2003).

Hydrology

Evaluating the hydrology of a potential TLP project site involves understanding water flow patterns, including oceanic circulation, salinity, tidal influence, and riverine and other freshwater inputs (i.e. runoff, groundwater). Wave climate affects the initial establishment and long-term stability of coastal marshes, and is another important hydrologic consideration. Shoreline characteristics that are useful indicators of wave climate severity include: average fetch, longest fetch, shore configuration, and sediment size (e.g., fine-grained sediments or mud generally indicate low wave energy) (Broome 1999). Tidal range and flood stages are factors that regulate elevation of sites. Tidal range (vertical distance between high and low water) is important in determining the area of the intertidal zone, sediment import/export, concentrations of nutrients and organic matter, and drainage and vegetation zones (Chabreck 1999). There are broad differences of tidal ranges in the U.S. but in general, marsh restoration/creation is easier in areas with

Box 2. Steps for Designing a Wetland Restoration Project.
(Adapted from Mohan et al. 2016)

Select the candidate site
↓
Determine development schedule
↓
Evaluate hydrologic factors
↓
Conduct sampling and evaluate geotechnical properties
↓
Assess dredging options and develop specifications
↓
Assess containment options and develop specifications
↓
Develop biological and vegetation design criteria
↓
Prepare final design

large regular tidal ranges (Broome 1999). Understanding marsh hydrology also requires good information on local bathymetry, given the habitat's sensitivity to small changes in elevation (see below). It is also a good idea to consider potential future changes to the site as a result of sea level rise.

Project design

Once project planning is complete, designing the construction project can begin. During the pre-construction stage, a project team will develop a budget and estimate costs for construction, develop a statement of work, select a construction contractor, determine a schedule, and finalize construction plans (IWWR 2003) (Box 2). Further site evaluation may be necessary regarding logistics of equipment. For example, heavy metal machinery may sink in soft-ground conditions or rust if continually exposed to saltwater (Craig et al 2008). Other factors important in engineering design include: finding an acceptable source of dredged material; capacity of the marsh to hold the volume of material to be dredged; and proximity of the TLP site to the dredging project (Broome 1999). Comparison of sediment characteristics of both the native and dredged material also needs to be conducted during this phase (Mohan et al. 2016). This includes ensuring the dredged material does not contain contaminants such as heavy metals.

Construction considerations

Method of dredge material placement

Decisions about dredge material placement method and the need for containment structures are made during the design phase. Hydraulic dredges use pumps to suction material off the bottom sediment in a slurry (mixture of sediment and water) and propel it via pipeline to the placement site (Reed et al. 2012). The sediment can then be distributed via either low- or high-pressure spraying. In low pressure hydraulic dredging, sediments are softened and liquefied but not slurried. Consequently, the heavier sand and gravel substrate components are deposited nearest the discharge point, resulting in uneven topography. When high-pressure hydraulic application is used, the sediment slurry remains well mixed, which allows for a more uniform topography and grain size distribution (Schafer 2002). The high-pressure spray nozzle can be aimed in any direction so that the dredged material can be deposited discontinuously to avoid small natural drainage streams or sensitive habitats (Cahoon and Cowan 1988) (Fig. 2). In addition, high-pressure hydraulic sprayers can deposit sediments up to 76 m wide as compared to conventional techniques that have disposal widths of around 23 m (Randall et al. 2000). High-pressure hydraulic dredging can also be used in shallow, open water to spread very thin layers of material over a large area (Bailey 2005; La Peyre et al. 2009; Slocum et al.

Figure 2. TLP of dredged material using high pressure hydraulic spray during restoration of marshland in the Blackwater National Wildlife Refuge, Maryland.

Photo credit: https://tlp.el.erdc.dren.mil/blackwater-national-wildlife-refuge-restoration/

2005). In general, use of high-pressure hydraulic dredging is more cost effective than alternative techniques because is eliminates the need for long distance pumping of dredged material (Randall et al. 2000).

Containment structures

TLP of dredged material with fine sediment in shallow open water areas or habitats exposed to high wind and wave actions may require containment measures to prevent erosion or diffusion of unconsolidated sediments (Schafer 2002). Such measures may also be needed to provide temporary protection to newly planted vegetation while it is becoming established. Containment and protection has been successfully attained in TLP projects with the use of earthen dikes, sandbags, erosion-control mats, and plant rolls (Broome 1990). Other containment structures can be removed or allowed to deteriorate as the need for retention decreases (Fig. 3). For example, geotubes are sand/dredged material filled geotextile tubes made of permeable but soil-tight geotextile. The desired diameter and length of the tubes are project specific and based on site conditions. A TLP project in Barataria Basin, LA is planning on using geotubes filled with sand from the project site to contain loose sediments (USACE 2012). Hay bales are used with relatively high frequency on the east coast as are coir (coconut) logs. For example, in the Blackwater Wildlife Refuge (Chesapeake Bay, MD), high pressure spraying was used to restore eight acres of open water to intertidal wetland. Dredged material was pumped into containment areas surrounded by straw bale dams and into a pre-existing depression. Sites were allowed to settle and were then planted (Nemerson 2007). Similarly, in a demonstration TLP project in Pepper Creek, DE, the Delaware Department of Natural Resources and the USFWS used straw bales and waddles to contain sediment (Whitin 2007).

Figure 3. Example of the use of bagged oyster shells as containment for TLP of dredged sediment on marshland in the John H. Chafee National Wildlife Refuge, RI.

Photo credit: https://tlp.el.erdc.dren.mil/john-h-chafee-national-wildlife-refuge/

TLP thickness

Site-specific conditions determine the optimum thickness for TLP additions to distressed marshes. Dredged material must be applied at sufficient elevation to allow for growth of native vegetation and benthic organisms. This requires a balance: if the sediment placements are too thin vegetation may not be able to become established, especially in high energy areas (VIMS 2014). On the other hand, when application of dredged material is too thick marsh elevation may rise to a level that is too high for vigorous plant growth, leaving the marsh vulnerable to invasive species (Wilber 1992a). A too thick application may also smother benthic organisms. In the 26 case summaries examined for this report, the optimum depth of dredged material ranged from 10-15 cm (Nester and Rees 1988; Wilber 1992c; Schrift et al. 2006; Mendelssohn 2011; Graham and Mendelssohn 2013) although Wilber (1992b) found that 5 cm was best for preserving the native flora and fauna of his study site.

Net elevation gain is a function of: the amount of sediment applied; consolidation of the applied sediment layer (which generally occurs in one to 12 months), and the amount of compression that occurs within the underlying substrate due to the additional overlying sediment (which generally requires one to five years) (Graham and Mendelssohn 2013). Therefore, calculating appropriate thickness for TLP sediment requires an understanding of target elevations, the type of sediment that will be used, the extent of dewatering, and sediment compression (Ray 2007). Fine sediments (silt and clay, <63 mm in diameter), which tend to have higher water content and low densities, make the final elevation of TLP projects harder to predict once they dry compared to substrates that are composed of sand or gravel (Chabreck 1999).

In some cases, modeling can be used to estimate the correct volume of dredged material that should be applied. A study by Bailey and others (2017) used two models to predict the behavior of dredged material: SETTLE, which models initial behavior during placement and dewatering, and PSDDF, which models longer term consolidation factors such as primary consolidation, secondary compression, and desiccation of dredged fill. The authors tested these models in three areas within the Edwin B. Forsythe National Wildlife Refuge in New Jersey that were being considered for marsh restoration via TLP of material dredged from multiple nearby NJDOT channels. Two potential dredge sites had majority silt sediment and the third was primarily sand. Modeling results showed that applying fine sediment dredge material at a target level of 30 cm would achieve uniform fill elevation but variable fill thickness following consolidation. The authors concluded that it was not possible to achieve the target elevation across the entire site due to the variable topography and if the goal

Table 3: Inundation Tolerances for Coastal Marshland Vegetation
(Adapted from Hladik 2016)

	Elevation (m)	MLW	MSL	MHW
***Spartina alterniflora* (tall)**	Maximum	2.07	1.05	0.05
	Minimum	0.55	-0.46	-1.46
	Mean	1.58	0.56	-0.44
***Spartina alterniflora* (medium)**	Maximum	2.31	1.30	0.30
	Minimum	1.46	0.45	-0.55
	Mean	1.99	0.98	-0.02
***Spartina alterniflora* (short)**	Maximum	2.35	1.34	0.34
	Minimum	1.81	0.79	-0.20
	Mean	2.09	1.07	0.07
Spartina virginica	Maximum	2.50	1.49	0.49
	Minimum	1.97	0.96	-0.04
	Mean	2.17	1.15	0.16
Distichlis spicata	Maximum	2.31	1.30	0.30
	Minimum	2.00	0.98	-0.02
	Mean	2.17	1.16	0.16
Batis maritima	Maximum	2.51	1.50	0.50
	Minimum	2.06	1.04	0.05
	Mean	2.21	1.20	0.20
Juncus. Roemericanus	Maximum	2.68	1.66	0.67
	Minimum	1.88	0.87	-0.13
	Mean	2.23	1.22	0.22
Boorichia frutescens	Maximum	2.71	1.70	0.70
	Minimum	2.16	1.15	0.15
	Mean	2.44	1.43	0.43

was to achieve the target elevation for the average site condition, then a lower fill elevation would be needed (Bailey et al. 2017).

Another consideration when designing TLP projects is evaluating the degree to which the natural marsh elevation can be altered before it converts to a different habitat type. Salt marsh vegetation is sensitive to inundation period, salinity, and tidal regime and even a slight elevation change can affect changes in vegetation type (Table 3.). For example, in a project in Gull Rock, N.C., Wilber (1992b) found that while placing dredged material in a 5 cm layer did not lead to a significant change in vegetation or marsh use by animals, a 10 cm sediment layer may have altered the site's soil drainage, resulting in conditions that favored different marsh plant species from those of the control native marsh.

Ongoing maintenance

Ongoing maintenance is often necessary to insure the success of transplanted vegetation. Maintaining the vegetation may require controlling non-native and invasive species; controlling herbivores; replacing plants; mowing, burning, and/or other activity reinstating or mimicking the natural disturbance regime; reducing or preventing human intrusion; and controlling local pollutants (Niedowski 2002). Water quality changes caused by turbidity and sedimentation may also lead to plant die off (Erftemeijer et al. 2013). Where the shoreline is exposed to wave action, replacement of plants that are washed out may be necessary. Wrack or litter along drift lines should be removed if there is danger of smothering plants. Invasion by undesirable plant species may be a problem (Broome 1999), and most practitioners agree that at least three to five years of maintenance is required to combat non-native vegetation on a site (Craig et al. 2008).

Of the 26 case studies examined in this report, 16 included information about how revegetation was accomplished following TLP of sediment. Of these 16, 6 projects required the replanting of native plants in the form of plugs (USACE 2017), seeding (Curston et al. 2016, Moran et al. 2016) or peat pots (Frame et al. 2016). The primary objective of all these projects was marsh restoration, and they all took place in the Mid-Atlantic and New England regions.

In addition to ongoing attention to transplanted vegetation, a maintenance plan might also consider repairing structures and maintaining monitoring and other equipment. It is therefore a good idea to prepare a maintenance plan in advance of construction.

Cost

TLP of dredged sediment can be an expensive disposal option. For example, use of TLP of 60K cyd of dredged material to restore 25 cubic acres of marsh and beach as part of the Ninigret Pond Salt Marsh Restoration and Enhancement Project in Narragansett, RI cost approximately $1.4 million (Whitin 2017). The total cost per unit area of marsh depends on the cost of the dredged material and the sediment disposal depth. For instance, if dredge material is priced at \$3.00 m^3, the cost/hectare for a 5-cm layer is \$2,000 and the cost for a 20-cm layer is nearly \$8,000 (Shafer 2002b). Other primary costs include transport of dredged material to the marsh location, removal of sediment contaminants if necessary, and preparation of the site to reduce wave erosion (VIMS 2014).

The cost of a TLP project can be reduced by choosing potential wetland restoration sites that are as close as possible to the dredging area. Dredged material is often moved as a mixture of sediment and water through temporary floating or submerged pipelines. As pipelines increase in length, the cost of dredging increases. The maximum useful length of pipelines for moving dredged material is dependent on a number of factors, including sediment grain size and dredge size (Shafer 2002a). The cost of TLP of dredged material can also be reduced by choosing sites in low energy areas with relatively intact vegetation so that only shallow sediment additions are necessary and less effort is needed to minimize losses caused by erosion (i.e., containment structures) (VIMS 2014)

Part Three: Monitoring and Evaluation

Monitoring programs ensure that TLP projects are executed according to the goals and objectives established in the project's plan and design and also allow interested parties to learn and gather experience for future projects (Bray 2008). There are numerous monitoring parameters that can be used to examine how a TLP project may affect the treated marsh site (Box 3). The goal of the monitoring plan is to select the key parameters and sampling strategies that will most likely result in the collection of reliable and useful data to help determine the project's effectiveness in creating or restoring ecosystem services (Craig et al. 2008) (Table 4).

Table 4: Development of Salt Marsh Ecosystem Services Following Creation/Restoration
Source: Craft 2016 (p. 216)

	Time (yrs)[a]
Productivity and Habitat Functions	
Primary production	3-5
Benthic algae	<1-2
Microbial activity	5-15
Benthic invertebrates	5-20
Epifauna and finfish	2->15
Water and wading birds	3-10
Songbirds	10-15
Regulation Function	
Sedimentation	1-3
Nutrient (N, P) retention	1-5
C sequestration	3-5
N cycling	10-20
Outwelling of nutrients	1-5
Soil formation	10-100s

a. Time represents years to reach equivalence to a mature natural marsh.

Once specific parameters have been selected, based on the project's objective, target values should be set. A target value is the desired numerical metric that will be met within a specified period of time. For example, if a project objective is to restore percent cover of wetland vegetation to that of a healthy wetland, the parameter measured is percent cover of wetland vegetation which may be set at 80 percent of reference within three years (Craig et al. 2008).

Methodologies used in monitoring programs vary by the parameter being measured. Examples of current methods used to measure vegetation recovery following TLP treatment include:

- Establishing transects and/or quadrats and identifying all species within the boundaries, then mapping the dominant communities

- Collecting percent vegetative cover along transects
- Determining aboveground and belowground biomass
- Measuring height of plants in treated marsh sites compared to untreated, control marsh sites (Craig et al. 2008).

Monitoring of soil condition is determined by measuring bulk density, organic matter, and nutrients through laboratory analyses. Macroinvertebrate response can be evaluated by measuring the number of species and the number of individuals within each species as well as biomass. Fauna are monitored through field studies and visual identification.

Box 3: Monitoring Plan from the Louisiana Coastal Area Barataria Basin Barrier Shoreline Restoration Project (USACE 2012)

Objective 1: Restore and improve various barrier headland/island habitats that provide essential habitats for fish, migratory birds, and other terrestrial and aquatic species, mimicking, as closely as possible, conditions which occur naturally in the area.

Performance Measure: Habitat composition.

Desired Outcome: Provide a distribution of acreage between habitat types that matches the predicted acreages of the barrier island habitats at a particular point in time. For the Caminada Headland, desired acreage for marsh will be within 15% of 1,186 acres. For Shell Island, the desired marsh acreage would be within 15% of 393 acres for Placement Area 10 and15% of 382 acres for Placement Area 15.

Monitoring Design: Habitats will be classified using aerial photography to assess trends in conversion of marsh to open water. One pre-construction and three post-construction site monitorings will be performed. Site visits will monitor plantings and check accuracy of aerial photography assessments.

Objective 2: Increase sediment input to supplement long-shore sediment transport processes along the gulf shoreline by mechanically introducing compatible sediment, and increasing the ability of the restored area to continue to function and provide habitat with minimum continuing intervention.

Performance Measure: Island elevation changes.

Desired Outcome: Maintain elevation profile that matches the predicted profiles of the associated barrier island landscape features at a particular point in time. Desired elevations would match the elevation classifications of the WVA: marshes between 0 feet +2 feet.

Monitoring Design: Topographic surveys will be used to determine the cross shore profile and volumes of the barrier islands in order to characterize the changes that are occurring in the sediment budget and barrier platform stability over time. One pre-construction and three post-construction site monitorings will be performed.

Monitoring should be conducted throughout the life of a TLP project. This means data should be collected pre-, during, and post-construction. The parameters measured remain the same for all three project stages, but the information collected is used for different purposes. Pre-construction monitoring establishes the project site's baseline conditions which will provide the basis of comparison when determining how well the project's goals were carried out (Erftemeijer et al. 2013). Ideally, these data are collected under a broad range of conditions over at least a one year period at both the project and reference sites (Bray 2008).

In the monitoring that occurs immediately following completion of the project, the actual construction results are surveyed, recorded, and compared to the design and construction plans. For TLP projects this will likely include information on the volume of dredge material applied, the area of application, and sediment depth. Turbidity may also be measured, and, where projects include vegetation replacement and/or invasive species control, information about planting density, invasive species remaining, or other measurable outcomes may be collected (Craig et al. 2008). Where TLP sediments have been applied on vegetated areas, plant cover and condition (e.g., degree of smothering) are usually recorded.

The post-construction monitoring plan connects information gathered from pre-construction to some future time (one, five, or ten years) with the TLP project's goals and objectives to determine success. Vegetation changes are commonly used in these evaluations, but measurements of soil, fauna, and hydrologic characteristics are also frequently analyzed.

Data from sites treated with TLP dredged material are compared to control sites to determine how closely characteristics such as vegetative cover and production resemble the reference marsh. The control sites should be far enough away from the project site to escape the reach of the TLP application, but close enough to be as similar as possible to the project site. Considerations for choosing a reference site include water depth, plant cover, species composition, water currents, turbidity, and waves (Erftemeijer et al. 2013).

A monitoring plan also establishes data collection intervals (e.g., annually, biannually) most appropriate for each parameter measured. The length of the monitoring program varies widely. The usual standard for tidal marsh systems is quarterly sampling for at least two years although five years is recommended (Niedowski 2002).

Below, we review the results of 13 studies that have been conducted to evaluate various physical, chemical, and biological parameters that can determine the effectiveness of TLP application of dredged material projects in salt marshes and shallow open water areas. Table 5 provides a summary of these projects.

Table 5. Summary of TLP Studies

Project Name	Sediment Type	Depth	Tidal Range	Project Description	Monitoring Protocol	Monitoring Results	Citation(s)
Fowl River, AL 1986	40% sand, 50% silt, and 10% sandy clay	~15 cm	~0.4 m	The project's objective was to place 145K m^3 of DM in a 96-hectare disposal area at ~ 15 cm.	As part of the monitoring program, the following environmental studies were conducted pre-, during, and post-dredging/disposal: • Precision bathymetry (for thin-layer thicknesses ranging between 15 and 20 cm) and sediment profile imagery (for thin-layer thicknesses <15 cm) • Water quality (total suspended solids (TSS) and dissolved oxygen concentrations) • Infauna abundance • Fish abundance and diversity	• 6 weeks after disposal, DM covered 129 hectares. The thickness of dredged material was < 15 cm over 36% of the area, 16 to 30 cm over 48% of the area, and > 30 cm over 16% of the area. • Open-water disposal did not lead to unacceptable water quality conditions. Temporary elevations in TSS concentrations were confined to the disposal and buffer areas. • Infauna recolonization of the DM occurred rapidly. Areas receiving < 15 cm had abundances similar to controls 2 weeks after placement. Areas with >15 cm of DM required about 20 weeks to reach control levels.	Nester and Rees 1988; Wilber 1992c
Mississippi Sound, AL/MS 1992/93	Plastic clays, poorly graded sands, and silty sands	≤ 30 cm	0.5 m	6 areas of 300 acres located in the MS Sound were treated with TLP of DM during three separate disposal events.	Each DA was monitored predisposal, during disposal, short-term post-disposal, and long-term post-disposal. Multiple parameters were monitored to examine the water quality and responses of benthic macroinvertebrates.	One year post-disposal, the overall abundance of infauna increased at the disposal sites as compared to the reference sites. The water quality data indicated that the impacts of TLP on water quality were of short-term nature.	Rees and Wilber 1994; Wilber et al. 2007
Glynn Co., GA 1978	Clay, coarse sand, and mixed clay, and sand	8-91 cm	2.0 m	Three types of DM, coarse sand, mixed sand and clay, and clay, at 6 depths (8, 15, 23, 30, 61, and 91 cm), at 3 different stages of plant growth (February, July, and November) were measured.	The experimental setups, experimental control areas, and adjacent marsh controls were monitored monthly for two years for culm, live crab, crab burrow, and marsh snails' density determinations. The soil chemistry and tidal data for experimental area were also determined.	*Spartina* was able to penetrate up to 23 cm of each type of DM and had growth and production rates nearly equal to that of the control marsh. Crabs recolonized areas covered with up to 23 cm of clay DM and 15 cm of sand. Snails rapidly recolonized material placed 8 and 15 cm deep. Faunal recovery may depend on the proximity of the placement site to natural populations and the extent of the smothered areas.	Reimold et al. 1978

St. Bernard Parish, Lake Coquille, Terrebonne Parish, Dog Lake, LA N/A	N/A	18-36 cm (Lake Coquille) 10-15 cm (Dog Lake)	~0.4 m	DM from a 150-m canal/slip dredge operation was thin-layer sprayed on adjoining marsh and waterways. The project involved dredging a canal through saline marsh to access an open-water drilling location.	Assessment of the two sites by ground and aerial surveys occurred at 2 weeks, and at 8, 11, 14, and 19 months after project completion.	Vegetation was initially smothered at both sites although some survived around the edges. Limited vegetative colonization took place within 8 and 14 months. Lake Coquille was revegetated after 2 years, while the fringes and more lightly sprayed areas of the Dog Lake disposal site were revegetated in < 1 year. There was evidence of marsh invertebrates at the Dog Lake site. There was full recovery measured by percent cover by dominant plant species after 6 years, although differences in plant species composition persisted.	Cahoon and Cowan 1987; LaSalle 1992
Barataria Bay, LA 1986-87	Fine sand 40%, coarse-fine silt 28%, clays 32%	2-5 cm (1986) 4-10 cm (1987)	~0.3 m	Sediment was hand-pumped from an adjacent basin onto 12 plots in a salt marsh.	Aboveground biomass production of *Spartina alterniflora* was assessed as well as the nutrient status of the clipped vegetation. Vertical accretion rates were determined.	Accretion rates in the deteriorating marsh were 0.44 cm/year in comparison to 0.8 to 1.0 cm/year in the reference marsh. The addition of sediment resulted in a significant increase in aboveground biomass and was higher in the marsh areas that received higher sediment applications. The vegetation contained significantly higher concentrations of Fe, Mn, and P in treated areas than reference areas. Transpiration rates and leaf conductance were also higher in areas receiving material.	DeLaune et al. 1990
Northern Mississippi River Delta, LA 1996	N/A	2-8 cm	~0.3 m	TLP was used to restore surface elevations in a non-subsided marsh and an adjacent subsided marsh that had converted to shallow open water.	Soil elevation measurements were recorded prior to DM application and every 3 months for 18 months following application using sedimentation-erosion tables. Vegetation response was assessed using percent cover and root biomass.	Vegetation was initially flattened at the disposal site, and soil organic content was lower than reference values. TLP placement immediately increased shallow water elevation to 12 cm. After this initial increase, the site continuously lost elevation during the subsequent 20 months due to erosion of the unconsolidated sediments. However, elevation was raised sufficiently to allow *S. alterniflora* to invade via rhizome	Ford et al. 1999

						growth from the adjacent marsh. Within 1 year after spraying the shallow water site, soil bulk density, percent organic matter, root and rhizome biomass and volume of newly laid sediments, had all returned to or exceeded levels measured prior to spraying.	
Southern Mississippi River Delta, LA 1992, 1997, 2007	9% sand, 43% silt, 47% clay	< 2 cm, < 15 cm, 15-30 cm > 30 cm (1992, 1997) 2-10 cm, 8-11 cm, 10-17 cm (2007)	3.2 m	In 1992, a hydraulically dredged sediment slurry (85% liquid/15% solids), accidentally spilled onto an adjacent submerging salt marsh. The resulting sediment gradient was used to evaluate the effects of added sediment depth on plant community structure and soil condition. A follow up study was conducted in 1998 to measure long-term elevation change. A resilience and stability experiment was completed 15 years (2007) following sediment addition to the marsh surface that included clipping the vegetation to the soil surface or herbicide application. Vegetation responses following the disturbances were recorded.	Elevation, soil physicochemical parameters, including exchangeable nutrients (NH4-N, P, Ca, Mg, K, Na, Fe, Mn, Cu, and Zn) and vegetation parameters such as above-and below-ground biomass and percent cover were assessed over time.	• (1992) Areas receiving intermediate and high amounts of sediment (15–30 and 30–60 cm, respectively, after 2 years showed increased plant cover and aboveground biomass. • (1998) Percent plant declined from the 1992 levels and occurred at more moderate elevations (5–15 cm). This deposition zone appeared to benefit from an increase in marsh elevation and bulk density, along with an initial input of sediment-sorbed nutrients. These effects declined with time as sediment compacted and nutrients became depleted. • (2007) Salt marshes that received moderate amounts of sediment addition (2–11 cm) were more resilient than natural marshes. The primary regulator of enhanced resilience and stability in the restored marshes was the alleviation of flooding stress observed in the natural marsh. However, stability reached a sediment addition threshold at an elevation of 11 cm. Declines in resilience and stability above the sediment addition threshold were principally influenced by relatively dry conditions that resulted from insufficient and infrequent flooding at high elevations.	Mendelssohn and Kuhn 2003; Slocum et al. 2005; Stagg and Mendelssohn 2011

Bayou Lafourche, LA 2002	Scatlake muck (semi-fluid, mineral soil frequently flooded with salt water	11-16 cm 13-18 cm 20-25 cm 28-36 cm above control marsh	0.3 m	Schrift et al. (2006) and Stagg and Mendelssohn (2011) assessed the recovery of a dieback marsh after hydraulically dredged sediment-slurries were applied to the site to compensate for post-dieback soil consolidation. Tong et al. (2012) studied the stability and resiliency of this marsh through an experimental vegetation disturbance of clipping and herbicide application.	Monitored plant variables included percent cover, stem density, and species richness. Monitored soil physicochemical properties included soil physical properties (i.e.: bulk density, moisture content) and exchangeable nutrients (i.e., phosphorus, ammonium, sulfide). Plant and soil properties were assessed 5 and 7 years after sediment application.	• 2 years after placement, marshes in the low elevation areas (11-16 cm) were the most similar to reference marshes in plant cover and species richness due to reduced inundation and the addition of P with the DM. • After 7 years, total aboveground biomass, live biomass, stem density, and height of *S. alterniflora* were equivalent to the reference marsh. • The addition of sediment to the marsh improved its resiliency and stability following vegetation disturbance.	Schrift et al. 2006; Stagg and Mendelssohn 2011; Tong et al. 2012
Paul J. Rainey Wildlife Sanctuary, LA 2008	80% silt and clay	0-10 cm, 10-15 cm, 15-20 cm	~0.5 m	Sediment was hand-pumped from the adjacent canal onto 20 plots in a brackish marsh.	Physicochemical properties, elevation, and sulfur, iron, and manganese cycling were monitored over three years.	• 3 years post-placement, elevation gains of 3 cm were seen in the highest deposition areas due to consolidation and compression of the organic material below. • Increased plant productivity resulting from nutrient additions with as little as 15–20 cm of sediment was observed. • The thicker layers of DM placement resulted in decreases in sulfide concentration and increases in sulfate concentration which may be the result of lower sulfate reduction rates with an increase in redox potential or interactions with iron and manganese that was present in the DM. • This research suggests that a minimum sediment-application threshold of 10–15 cm exists below which elevation is lost, and above which elevation is gained and ecosystem function is enhanced.	Graham and Mendelssohn 2013
Mississippi River delta region in southern	N/A	15-60 cm	~0.3 m	The objectives of this study were to examine short- and long-term effects of thin-layer dredge disposal on brackish marsh structure and function and	Elevation and sediment accretion was measured both short- and long-term as was aboveground vegetation, belowground vegetation,	Vegetative cover and productivity response were minimal for deteriorating vegetated marshes with the short-term response data	La Peyre 2009

Louisiana 2009				nonvegetated interior ponds (ong-term only). The six study sites were treated with sediment additions between 1999 and 2006 using a low-pressure hydraulic dredge to pipe a slurry of DM over the marsh surface. The sediment slurry consists of a high water to solids ratio (>80% water) piped over the marsh so that sediments sheet flow and settle across the marsh and pond surfaces.	percent cover, and soil bulk density. Soil organic matter and bulk density was measured short-and long term and redox potential and soil nutrient concentrations were measured long-term.	showing no significant impact of sediment enhancement and long-term trends indicating decreasing productivity over time. In marsh habitat that was vegetated before enhancement, aboveground vegetation biomass decreased over time and there was no change in belowground biomass. In contrast, trajectory models of vegetative cover and productivity in interior pond sites showed increases over time indicating that, for restoration of interior ponds, sediment enhancement may prove valuable.	
Gull Rock, NC 1982	Primarily clay, silt, and fine sand	5 and 10 cm	0.1 m	A 120-m access channel to the Lake Landing Canal was constructed in Wysocking Bay. About 8,000 to 12,000 m^3 were excavated and spread on marsh on both sides of the canal.	Marsh characteristics examined quantitatively included aboveground plant biomass, plant density (leaves/m^2 for black needle rush, shoots/m^2 for all other species), relative elevation, soil bulk density, soil organic content, and macroinfauna density. Qualitative sampling included examinations of fiddler crab abundance, fish abundances, and soil layering.	Some smothering of vegetation occurred during disposal operations, due mainly to the large volumes of water involved in the spraying operations, and revegetation occurred relatively quickly. Placing DM in a 5 cm layer did not lead to a significant change in vegetation or marsh use by animals. However, placement of DM in a 10 cm layer may have altered soil drainage, resulting in conditions that favored different marsh plant species.	Wilber (1992b)
Masonburo Island, NC (North Carolina National Estuarine Reserve) 2000	50% fine sands, 50% muds	2-10 cm	1.2 m	Approximately 8 m^3 of DM was taken from disposal banks adjacent to the AIWW and manually placed in deteriorated and non-deteriorated marsh plots behind Masonboro Island, NC.	The following parameters were evaluated to achieve the main purpose of this project: thin layer thickness, *S. alterniflora* density, benthic community assemblage and abundance, benthic microalgal analysis and soil oxidation reduction potential (ORP) in deteriorating and non-deteriorating marsh sites. Most of these parameters were measured every other month for approximately 1 year, except for benthic infaunal samples which were collected 2 weeks pre-placement,	Sediment placed on deteriorating marsh plots increased *Spartina* stem density by 2nd growing season to reference levels, but had little to no effect on overall plant height. The addition of 2-10 cm of sediment on deteriorating marsh surfaces increased vascular plant stem densities and microalgal biomass. There were no long-term impacts to the infaunal community. Sediment additions resulted in higher redox values in both treated and control marshes; the thicker the layer the	Croft et al. (2006); Leonard et al. (2002)

					and 6 weeks and 1 year post-placement. Sediment characteristics such as organic content, dry bulk density and grain size distribution were measured on an annual basis.	higher the redox response. Results indicated that periodic additions over time may offset sediment deficiencies and have beneficial effects in terms of infaunal abundance and plant biomass.	
Wolf Trap Alternate Open Water Disposal Site, Chesapeake Bay, NC 2010	Coarse silts (40–50%); very fine sands (40-60%)	>15 cm, 5 ≤ 15 m, 1 ≤ 5 cm	N/A	2 areas (Cell B & C) were studied within the Wolf Trap Alternate Disposal Area. Cell B received 4.5 million m^3 of sediment in 1987. Cell C received 1.9 million m^3 of material in 1989. Approximately 60% and 40% of the total material was discharged into the Cells B and C, respectively, during the 3 months prior to the initiation of environmental sampling. The objective was to determine how disturbance severity affected the patterns and rates of recovery of macrobenthic community structure, including number of species, total abundance, total biomass, and community composition.	Macrobenthic organisms were collected over a 10-year period for all 3 sediment depths. Species richness, abundance, and biomass were measured and patterns and rates of recovery were determined.	Sediment disposal was found to have few significant effects when dredged material overburden thickness was ≤15 cm. At the highest disturbance severity it took about 1.5 years or less from the time the monitoring program began for the macrobenthic assemblages to converge with other disposal cell treatments and the reference stations, in terms of species richness, abundance, biomass, and community composition.	Schaffner 2010

DA = Disposal area

DM = Dredged material

MCY = Million cubic yards

PA = Placement areas

TSS = Total suspended solids

Physical parameters

Monitoring efforts generally measure elevation and soil characteristics (bulk density, organic matter, nutrient content).

Elevation

The environmental benefits of TLP vary depending on the initial elevation of the marsh and the amount of sediment added (Craft 2016). Therefore, it is important to determine any immediate elevation changes that occur upon placement of TLP and to measure the elevation fluctuations that may result due to soil consolidation, compression, and accretion.

Several studies of elevation and accretion following TLP application show that the sediment elevations increase in the short term and then decrease over time due to erosion of unconsolidated sediments (Wilber 1992c, Leonard et al. 2002). Graham and Mendelssohn (2013) conducted a study of a brackish marsh in Rainey Wildlife Sanctuary, Louisiana in which they hand-pumped sediment onto experimental plots in increments of 0-10 cm, 10-15 cm, and 15-20 cm. They found that, although sediment placement initially increased soil surface elevation, many treatments had subsided to pre-sediment surface elevations and did not differ from reference areas by the end of the 2.5 year study period. However, those areas that received the greatest amount of sediment (> 15 cm) did have final elevation gains of < 3 cm and these areas also had greater plant production compared to untreated reference plots (Graham and Mendelssohn (2013). Similarly, a study in the Mississippi Delta in Louisiana evaluating short- and long-term elevation changes in vegetated marsh and adjacent shallow-water habitat following TLP treatment found an immediate increase of shallow water elevation to 12 cm. After this initial increase, the site continuously lost elevation during the subsequent 20 months of the study due to erosion of the unconsolidated sediments. Despite this decrease in elevation, the shallow water bottoms could support emergent wetland vegetation, which recolonized via rhizome growth from the adjacent vegetated marsh edges. The authors concluded that sustainability against erosion may depend on the treated area’s proximity to vegetated areas (Ford et al. 1999).

Other studies have shown that TLP amendments may improve the long-term resiliency and stability of deteriorating marsh sites. A study in the Mississippi Delta in Louisiana compared two marshes that had received TLP subsidies: one after 15 years (Venice) and the other after 5 years (Fourchon). The Venice site had been monitored over several years (Mendelssohn and Kuhn 2003, Slocum et al. 2005, Schrift et al. 2008. The Fourchon site was especially interesting because it was affected by sudden marsh dieback in 2000 and restored through TLP treatment in 2002. For purposes of the study, resilience was defined as the rate of recovery after disturbance and stability was described as the ability of the vegetation to recover to within at least 95% of the control. In Venice, TLP sediment application resulted in significantly higher resilience (33-39% recovery/month) compared to the reference area (17% recovery/month), whereas the effect of sediment addition on resilience was not statistically significant at Fourchon. For both sites, moderate sediment additions (2-11 cm) resulted in the greatest odds of stability compared to the reference marsh. The authors speculated that intermediate levels of sediment addition promoted resilience by lessening impacts of excessive inundation while still maintaining sufficient soil moisture. At both sites, resilience was negatively associated with soil conditions typical of water-logged soils, which appeared to be enriched with increasing elevation. However, above the 11-cm threshold, a severe drop in soil moisture may have limited recovery in areas of high elevation and low flood frequency (Schrift 2008). The odds of stability were an order of magnitude higher in the Venice site compared to Fourchon, which may indicate that restored sites become more stable over time (Stagg and Mendelssohn 2011).

Bulk density

Sediment bulk density is the dry weight of soil (both solids and pore space) per unit volume. Higher soil bulk densities indicate higher organic matter content and such soils have a greater ability to take up and sequester nutrients (Mitsch and Gosselink, 2000). Soils with high organic matter content have been shown to provide more nutrients on a per volume basis when compared to organic salt marsh soils (Mendelssohn and Kuhn 2003). Therefore, bulk density is commonly used in TLP monitoring as a way of gaging project success.

Generally, sediment bulk density increases after TLP applications and this effect is positively correlated to the amount of sediment applied (Leonard et al. 2002, La Peyre et al. 2009, Ford et al. 1999, Mendelssohn and Kuhn 2003). For example, in 1982, maintenance dredged material was sprayed into brackish marshes on both sides of Landing Lake Canal and on a nearby island site near Wysocking Bay, North Carolina**.** The canal marshes received an average of 5 cm of dredged material, while the island site averaged 10 cm. Sampled 10 years later, soil bulk density at the island site was 3 times higher than the reference, while the bulk density of the canal marshes was 1.1 times higher (Wilber 1992b, 1992c). However, this effect may diminish over time. Mendelssohn and Kuhn (2003) found that marshes receiving moderate amounts of TLP sediment benefitted from increased soil bulk density but this effect decreased as sediment compacted and nutrients were depleted by recolonized vegetation (see also Tong et al. 2012).

Organic material

Soil organic matter consists of plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by organisms. Soil organic matter is slow to develop, and created and restored marshes typically contain less organic matter than older restored marshes or mature natural marshes (Craft 2016). This is often borne out in TLP monitoring programs where organic content is measured to determine return to pre-application conditions (Leonard et al. 2002, Wilber 1992b, 1992c). For example, in a study by Croft and others (2006) that took place in Masonburo Island, North Carolina, the organic content of material was measured during both the first and second summer after TLP application onto deteriorated (>200 *S. alterniflora* stems m^2) and non-deteriorated (<150 stems m^2) marsh sites, both of which were compared to non-treated controls. In the TLP treated sites, organic content in the non-deteriorated sites was greater than in the deteriorated sites during both years (10.8% and 10.3% as compared to 5.9 % and 8.0%). Although there was no change in the non-deteriorated TLP treated sites between sampling periods, organic content in the non-deteriorated control site (no TLP treatment) increased significantly. In contrast, the deposition of organic material in the deteriorated TLP treated marsh sites significantly increased from the first sampling period to the second as opposed to the deteriorated control site (no TLP treatment) (Croft et al. 2006).

Nutrients

Nitrogen and phosphorus are likely to be growth limiting factors along eroding shorelines (Broome 1999). While phosphorus is abundant in many fine textured sediments such as those found in marshes along the Georgia coast (Broome 1990), marshes created from dredged material often contain more sand, less nitrogen, and sometimes less phosphorus than natural marshes (Craft 2016). Because of the importance of nutrients to the potential success of recolonizing vegetation, they are frequently monitored (La Peyre et al. 2009, Slocum et al. 2005).

Mendelssohn and Kuhn (2003) examined 110 acres of rapidly subsiding marsh near Venice, Louisiana, which received up to 60 cm of sediments from a hydraulic dredge pipeline spill in 1992. The site, a deteriorating intertidal, saline marsh, was divided into five areas based on amount of sediment burial: 0 (reference), trace amounts, < 15 cm, 15-30 cm, and > 30 cm. Results indicated that both interstitial and exchangeable nitrogen concentrations were lower with greater sediment addition, but only the decrease in interstitial nitrogen was significant. However, given the high plant biomass in areas receiving the most sediment addition plus the initially high NH4–N content of the fill soil, the authors speculated that the relatively low nitrogen status of soils in the areas with more sediment was at least partly due to plant uptake and removal. They added, however, it was possible that alternating periods of flooding and drying in sites receiving the most sediment might have also contributed to the low nitrogen levels in these areas since these conditions would promote nitrogen loss through leaching and denitrification (Mendelssohn and Kuhn 2003).

Interstitial phosphorus concentrations in the same study rose significantly from the reference (0 cm) to the 15-30 cm sites but decreased to concentrations similar to the reference in sites receiving more than 30 cm. Exchangeable phosphorus concentrations showed a similar pattern, significantly increasing from the reference to the 30 cm sites. In contrast, interstitial and extractable phosphorus concentrations both increased with sediment subsidy. Sites receiving more sediment had a higher soil mineral content than areas that received less fill. Soil phosphorus is usually closely associated with mineral matter because of the high retention capacity that the mineral fraction has for this plant nutrient. Therefore, sites receiving less sediment addition would be likely to have soils with lower available phosphorus contents. Thus, plant production may have been further increased in the highest sites because of the increased concentrations of plant available phosphorus in these areas, especially if the high initial soil nitrogen resulted in a phosphorus deficiency (Mendelssohn and Kuhn 2003).

Chemical parameters

Redox potential

Oxidation–reduction (redox) state is mainly controlled by microbial activity, and is used to measure anaerobic conditions in the soil. During respiration, microbes use organic substances as electron donors. Because redox potential (Eh) is affected by the activity of living microbial communities, changes in external conditions that affect microbes, such as availability of organic matter, can lead to changes in Eh values (Fiedler et al. 2007).

Measurements of redox potential in sediment following TLP application generally show that higher Eh values (e.g. higher oxygen levels) correlate with higher sediment additions (Croft et al. 2006, Slocum et al. 2005, Mendelssohn and Kuhn 2003). A study by Leonard and others (2002) collected soil Eh measurements from a TLP treatment site on Masonburo Island, North Carolina bimonthly at treated (deteriorated and non-deteriorated) and control sites (deteriorated, non-deteriorated, and natural marsh) between August 2000 and November 2001. Sediment additions resulted in higher Eh values in both deteriorated and non-deteriorated treated marshes and the highest Eh values were associated with areas that received the thickest sediment additions. In general, the sediment became more reduced (anoxic) with depth. Sediments in the treated non-deteriorated sites exhibited significantly higher Eh levels (i.e., more oxygenated) than sediments in the treated deteriorated sites and this occurred for the control sites as well. Although not always significant, mean Eh levels increased in the second growing season compared to the first growing season in both non-deteriorated and deteriorated marsh types for both treated and controlled sites. In general, the most oxygenated profiles were associated with thicker treatments. The authors suggested that these changes in Eh improved soil conditions and led to the observed improvement of vegetation cover in the deteriorated sites (Leonard et al. 2002).

Biological parameters

The biological features generally monitored in a TLP treatment site include plant communities and benthic micro- and macroinvertebrates.

Vegetation

Vegetative response to TLP application is the most usual parameter measured in project monitoring. Variables that are used to characterize the success of plantings include: above and belowground biomass, number of plant stems, and height and basal area (Lewis 1999, Broome 1999). Other useful measurements include percent cover, percent cover by species, and number of colonizers. At least three to five years of monitoring is recommended to determine if vegetated growth on treated marsh sites is comparable to similar natural marshes (Broome 1999).

In addition to the quantitative data described above, qualitative data can also be useful for evaluating vegetation. Aerial photographs can show the extent of plant cover at the site and ground-level photographs can be used for identification of some plant species, general degree of plant growth, and general water levels. General observations such as water clarity, floating vegetation or macroalgae, bird species presence, vegetation condition (stressed, flowering, healthy), presence of invasive plants, evidence of erosion, and the integrity of structures can also be included in a monitoring program (Craig et al. 2008).

Plants

The response of marsh vegetation to sediment depth is often the definitive factor researchers use to determine the success of a TLP marsh project (Cahoon and Cowan 1988, LaSalle 1992, Slocum et al 2005, Schrift et al., 2008, Tong et al. 2012, DeLaune et al 1990, Croft et al. 2006). In an early study on St. Simons Sound in Glynn County, Georgia by Reimold and others (1978), three dredged material types (sand, silty sand, and silt) manually placed in six layers of sediment thicknesses (8, 15, 23, 30, 61, and 91 cm) were examined for up to 21 months (two growing seasons) after placement. Results indicated that *S. alterniflora* stems penetrated sediment up to 23 cm deep regardless of the sediment type but were unable to survive the highest sediment additions (61 and 90 cm). Recovery from the 8- to 23-cm layers was generally from new shoots penetrating the dredged material, with seedlings accounting for the limited recovery of the 61- and 91-cm layers. More shoots emerged from the sandy and silty-sand material than from the silty material, however, shoots growing in silt tended to have higher biomass. The authors speculated that this may have been caused by the higher nutrient content of the silty material or reduced competition for nutrients from other shoots. At the end of the experiment it was unclear whether complete recovery had occurred in the 8- to 23-cm treatments. Although biomass in these plots matched the control plots, it was considerably lower than in nearby reference marshes (Reimold et al., 1978).

Subsequent studies of TLP of dredged material have found that sediment addition favorably affects plant production. A TLP addition study in Louisiana found that placement of 10 cm of sediment on a deteriorating salt marsh resulted in a two-fold increase in *S. alterniflora* above ground biomass production after the second growing season (DeLaune et al. 1990). Ford and others (1999), also in Louisiana, demonstrated a three-fold increase in percent cover of a deteriorating *S. alterniflora* salt marsh one year after 2.3 cm of dredged material was applied to the surface. The results of a study on Masonburo Island, North Carolina by Leonard and others (2002) indicated that the addition of dredged material on the surface of deteriorated marshes led to a two-fold increase in vascular plant stem densities over non-deteriorated sites. However, stem densities were not significantly affected by the depth of TLP sediment added to non-deteriorated and deteriorated marsh sites.

More recent studies of vegetation recovery following TLP treatment have focused on finding an optimum sediment level that will result in improved productivity without smothering the plants. In a study of a marsh near Venice, Louisiana that had been covered with dredged sediment from a hydraulic dredge pipeline spill in 1992, Mendelssohn and Kuhn (2003) found that two years post-spill, total vegetative cover was higher at marshes that received dredged materials than at reference marshes. The degree of increase was a function of dredged material thickness, with layers greater than 30 cm having higher values than those receiving < 15 cm or 15-30 cm. These sites also had the highest sand content, while sites with lower levels of dredged material were predominately silts and clays. The authors attributed the higher plant growth to increasing site elevations, which reduced the depth of flooding, increased soil aeration, and provided higher nutrient concentrations for plants. Slocum and others (2005) continued this study on the same Venice marsh. They reported that over five years (1993-1998) a shift towards better plant growth occurred at more moderate elevations. In 1993, the highest plant cover (90%) was found at the highest sediment depth (20 cm). By 1998, the highest plant cover had shrunk to 55% and was found at the moderate 5-15 cm depth. In fact, by 1998 (the end of the study), areas receiving this moderate amount of sediment had 10% more cover than areas receiving the highest sediment, and showed better vegetative growth than reference marshes (Slocum et al. 2005).

Studies by several other researchers seem to confirm that moderate sediment elevations of 10-20 cm are most likely to result in vegetation recovery. In an experimental TLP treatment study, sediment was placed on non-deteriorated and deteriorated plots on a back barrier marsh on Masonboro Island, North Carolina at depths of 10 cm, 5 cm, and 2.5 cm (Croft et al. 2008). Comparison of mean stem densities at the end of the 2nd growing season after treatment showed that both the non-deteriorated and deteriorated plots receiving 10 cm of sediment had significantly more *S. alterniflora* shoots than the deteriorated plots receiving 2.5 cm. The sediment depth did not significantly affect plant height in either marsh type (Croft et al. 2008). Similarly, Graham and Mendelssohn (2013) determined that nourishment with <10 cm of sediment had the potential to decrease absolute soil surface elevation, and is not considered effective for increasing soil surface elevation or enhancing the function of the non-deteriorated brackish marshes they studied in the Rainey Wildlife Sanctuary in Louisiana. They therefore suggested that a minimum sediment-application threshold of 10–15 cm exists below which elevation is lost, and above which elevation is gained and ecosystem function is enhanced. Some researchers found that slightly higher sediment layers were also able to stimulate plant recovery without negative effects. In their study of a recovering dieback marsh near Leeville, Louisiana, Schrift and others (2008) found elevations averaging 14 and 20 cm above ambient marsh elevation had rapid plant recruitment and species richness similar to that of healthy reference marsh sites. Elevation treatments above sediment levels of 20-36 cm showed either marginal or no recovery.

Species composition is also an important factor to consider when evaluating vegetation recovery, because a successful marsh restoration using TLP must not experience drastic habitat changes following treatment. Cahoon and Cowan (1988) examined two brackish marshes in Louisiana (Lake Coquille and Dog Lake) 11 and 17 months after dredged material disposal. At both sites, placement of dredged material initially smothered most of the aboveground vegetation. Eight to 14 months later (about one growing season), limited recolonization by *S. alterniflora*, glassworts, and *Distichlis spicata* (saltgrass) was evident, presumably via new shoots emerging from old rhizomes. Midway through the second post-disposal growing season, vegetation cover had increased but had not yet reached the presumed predisposal levels (Cahoon and Cowan 1988). LaSalle (1992) returned to these sites in 1992, about six years after the original study and found that both marshes had healthy stands of vegetation. Species distributions and abundances in the Lake Coquille disposal area were similar to nearby reference areas. However, the Dog Lake disposal and reference areas differed in several ways. The disposal area consisted predominantly of *S. alterniflora* and glassworts, whereas *D. spicata*, needle rush, and *S. alterniflora* dominated reference areas. Furthermore, shoot density was about 20% less in the disposal area (LaSalle 1992). Similar habitat shifts were found by Wilber and others (1992b), who examined a marsh in Gull Rock, North Carolina, approximately 10 years following TLP treatments of dredged material. The two disposal areas they sampled both had healthy stands of vegetation, but the species differed compared to reference areas. One site, which had received 5 cm of sediment, had slightly less *J. roemerianus* than an adjacent reference area, and shoot density was 25% lower. A second site, which had received 10 cm of sediment, had mostly *D. spicata* and *S. alterniflora*, while the reference areas had greater amounts of *J. roemerianus* and *D. spicata*. Shoot density at this site was 40% lower than at reference areas (Wilber et al. 1992b). In contrast, Mendelssohn and Kuhn (2003) found no alteration of plant species composition in their study of a subsiding marsh two years following placement of 30 cm of sediments from a hydraulic dredge pipeline spill.

Benthic microalgae

Benthic microalgae (BMA) are a source of food, energy, and cover for many organisms and are important primary producers in estuarine systems. BMA depend on adequate sunlight for growth, and can be negatively affected by the turbidity that can accompany sediment resuspension.

Two studies from Masonburo Island, North Carolina demonstrate the effect TLP treatment has on BMA biomass. In 2002, Leonard and others measured mean sediment chlorophyll a in control, deteriorated, and non-deteriorated sites both before and after TLP treatment. Prior to TLP treatment, non-deteriorated sites, which were characterized by healthy *Spartina alterniflora*, showed significantly higher BMA biomass than deteriorated sites. Post TLP treatment, all sites receiving sediment additions (2 cm, 5 cm, and 10 cm) had significantly higher mean BMA biomass than the control sites, although there were no differences among the treatments. Over the duration of the study the taxonomic diversity of BMA was basically unchanged even though the biomass was affected (e.g., increased in treated deteriorated sites) (Leonard et al 2002). Similar results were obtained by Croft et al. (2006) in a study on Masonburo, North Carolina. Before sediment placement, mean monthly BMA biomass was significantly higher in the non-deteriorated (66.2 mg chl a m^2) as compared to deteriorated sites (13.3 mg chl a m^2). After sediment placement, there was an increase in mean monthly BMA biomass in both non-deteriorated (90.1 mg chl a m^2) and deteriorated (92.7 mg chl a m^2) sites when compared to the non-deteriorated (61.0 mg chl a m^2) and deteriorated (26.9 mg chl a m^2) control areas. No significant difference in BMA biomass was found between experimentally applied sediment depths (0-10 cm) at either the treated non-deteriorated or deteriorated sites. The authors speculated that BMA biomass increases following TLP sediment treatment may have resulted from increases in substrate grain size (0.11 mm pre-addition to 0.56 mm post-addition) as other studies have suggested that mean grain size is a determinant of BMA biomass and that BMA concentrations also increase with grain size (Croft et al. 2006).

Benthic infauna

Tidal marshes serve as critical habitat and refuge for benthic infauna which, in turn, serve as a food source for many epifaunal species. Negative impacts to the infaunal community could also affect such commercially valuable species as juvenile fish and crustaceans, altering the value of salt marshes as nursery habitat (Leonard et al 2002). Infauna macroinvertebrates are most commonly monitored to assess benthic recovery, usually by substrate sampling (Wilber and Clarke 2007).

Two studies of benthic infaunal data in Masonburo Island, North Carolina (Leonard et al. 2002, Croft et al. 2006) suggest that while sediment placement (up to 10 cm) may have a short-term effect on community structure, recovery occurs within ten months. Furthermore, over the long-term, sediment additions did not negatively affect benthic infaunal diversity or abundance (Leonard et al. 2002). A similar study found significant increases in infaunal species abundance after one year as compared to 6 weeks after sediment addition. Results were comparable in both deteriorated and non-deteriorated marsh sites, regardless of the depth of TLP sediment treatment (Croft et al. 2006). Another study by Wilber and others (2007) of the effect of benthic community responses to TLP treatment assessed three open water sites in the Mississippi Sound that received 15 cm of sediment. Total infaunal abundance was similar to pre-disposal and reference conditions within 3–10 months of sediment treatment. The authors concluded that size distributions of some taxa (e.g., gastropods and hemichordates) indicated that adults recolonized the newly deposited sediments either through vertical migration or lateral immigration from adjacent areas (Wilber et al. 2007). On a Louisiana marsh which received TLP sediment treatments in an effort to spur recovery from sudden dieback, Tong and others (2012) found that the specific effects of TLP treatment varies depending on the degree of elevation and which variable is chosen to confirm marsh recovery. Their findings showed that moderately treated marsh elevations (34-37 cm) restored the overall macroinvertebrate community to that of undisturbed reference marshes compared to high (39 cm) and low (30 cm) surface elevations. However, if the measure of marsh recovery was epifaunal taxa such as gastropods, the optimum TLP sediment depth would be that of the low surface elevation sites (Tong et al. 2012). Another study by Schaffner (2010) showed that benthic infauna recovery may depend on length of time and degree of sediment depth. The study region was the Wolf Trap Alternate Open Water Disposal Site and nearby benthic habitat of lower Chesapeake Bay (NC). Both sediment depth and date of sampling were important factors explaining the patterns and rates of recovery for species richness, abundance, biomass, and community composition, but sediment had minimal effects when the thickness was ≤15 cm. It took 1.5 years or less following the cessation of disposal activities for richness, abundance, biomass and community composition at high disposal severity (>15 cm) to attain levels measured at reference stations (Schaffner 2010).

Summation

The results discussed above suggest that TLP of dredged material on salt marshes increases soil surface elevation and soil bulk density, decreases the frequency and duration of inundation, supplies minerals that precipitate hydrogen sulfide, and fertilizes plants with nutrients, which increases primary production (Ford et al. 1999, Mendelssohn and Kuhn 2003, Slocum et al. 2005, Schrift et al. 2008, Stagg and Mendelssohn 2010). These combined effects, in turn, produce a plant community that is more resilient to disturbance from extreme weather events and sea level rise compared to untreated marshes (Slocum and Mendelssohn 2008, Stagg and Mendelssohn 2011).

Success of TLP treatment of dredged material on Jekyll Creek, Georgia will be assessed by the re-establishment of native vegetation through natural colonization over time. Many of the studies described above found that vegetation in place at the time of TLP sediment treatment is initially smothered (Cahoon and Cowan 1987, LaSalle 1992, Wilber 1992b, Ford et al. 1999). While in some cases recovery time could last as long as 14 months (Cahoon and Cowan 1987), in others it occurred "relatively quickly" (Wilber 1992b). It is clear, however, that vegetation does benefit from sediment addition (DeLaune et al. 1990, Ford et al. 1999). Results from several studies have determined that sediment elevations of 10-20 cm are most likely to lead to successful vegetation recovery (Mendelssoln and Kuhn 2003, Slocum et al. 2005, Croft et al. 2008, Graham and Mendelssoln 2013), although recovery to pre-treatment levels may require two (Schrift et al. 2006), three (Graham and Mendelssohn 2013), or up to seven years (Stagg and Mendelssohn 2011,). Because vegetation recovery is dependent on sediment depth, close attention to the level of dredged material applied to the project site is also important.

Table 6. Frequency of Parameters Included in the Monitoring Protocols of 21 TLP Projects*

	Monitoring Parameter	Number Included	Percentage Included
Physical Parameters	Elevation	9	43%
	Bulk density	5	24%
	Organic matter	6	29%
	Nutrients	4	19%
	Total suspended solids	4	19%
Chemical parameter	Redox potential	3	14%
Biological Parameters	Vegetation	16	76%
	Macroinvertebrates	9	43%
	Fauna	10	48%

* Five of the 26 case summaries included in Appendix A had no monitoring protocol information and/or no monitoring results.

The 26 case summaries reviewed for this report contain monitoring programs that measure several physical, chemical, and biological parameters (Table 6). However, there may be limitations as to the feasibility of designing an extensive monitoring program. In these cases, determining which parameters are most important for accessing the success of a project is the primary concern. Based on the objectives of the Jekyll Creek TLP project, the most helpful measurements for assessing effectiveness include measurements of vegetation height, productivity, and percent cover. Vegetative community composition should also be characterized and monitored to guard against invasive species encroachment and possible changes in habitat following TLP treatment. In addition, measurements of soil surface elevation following sediment application should be taken to determine whether optimal height for plant production was attained.

Part Four: Conclusions

Thin-layer placement involves an inherent tradeoff between the possibility of restoring salt marsh characteristics and functions and the potential damage created by the large initial disturbance caused by the addition of dredged material. Although there is no clear-cut way of determining a successful TLP project, some common characteristics have emerged from previous projects that can potentially inform future TLP marsh restoration projects.

Studies measuring potential recovery from TLP of dredged material look at many different variables including analysis of vegetation, soils, fauna, and hydrologic characteristics. In general, the research reviewed here has shown that increasing the quantity of applied sediment increases the mineral matter content of the soil, soil bulk density, substrate nutrient and trace metal concentrations, and soil redox potential. Most of these responses are due to the increase in elevation following TLP, which reduces flooding and prevents the soil from becoming waterlogged and anoxic. Oxidized soils favor aerobic and facultative anaerobic bacteria that do not produce toxic hydrogen sulfide during respiration, which promotes plant production. Reduced flooding also promotes aeration of the rhizosphere by plant roots since more aboveground tissue is exposed to the air for a longer period of time (Croft et al. 2006).

While TLP can improve marsh recovery, there is an optimal level of sediment addition beyond which further accumulation results in delayed recovery of soil, vegetation, and benthic fauna. This may be caused by sediment elevation being so high, flooding is reduced too much which results in lower nutrient availability, drought-like conditions, and a decrease in plant and benthic production (Stagg 2009). Monitoring data from the Gulf States shows that if the sediment depth is less than 30 cm (ideally 15-30 cm), vegetation and benthic recovery can occur in one to two years (Mohan et al. 2016).

Reaping the benefits of TLP while avoiding the pitfalls is why planning, designing, and monitoring each project are so important. With thorough and precise data collection concerning the topography, hydrology, and ecology of the marsh site, it is possible for TLP to provide an environmentally friendly way of restoring and nourishing salt marsh habitats.

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Appendix A: Twenty-Six Thin Layer Placement Case Summaries

The following is a compendium of thin-layer placement projects in the Gulf of Mexico, the Southeast, the Mid-Atlantic and New England. There is also one project from California. Each project summary includes the year the project took place, the type and depth of sediment applied, and the approximant tidal range of the area in which the TLP project took place. A brief description of the project, the monitoring protocol, and monitoring results is also provided. Each summary ends with citations to academic studies of the project and/or links to online information.

Gulf of Mexico

Fowl River, Mobile Bay, AL

Year of project: 1986

Sediment type: 40% sand, 50% silt, and 10% sandy clay

Sediment depth: 15 cm

Tidal range: ~0.4 m

Reason for project: Dredged material disposal

Vegetation source: N/A

Project description: The project's objective was to place 145K m^3 of dredged material in a 96-hectare open water disposal area at ~ 15 cm.

Monitoring protocol: As part of the monitoring program, the following environmental studies were conducted pre-, during, and post-dredging/disposal:

- Precision bathymetry (for thin-layer thicknesses ranging between 15 and 20 cm) and sediment profile imagery (for thin-layer thicknesses smaller than 15 cm)
- Water quality (total suspended solids (TSS) and dissolved oxygen (DO) concentrations)
- Infauna abundance
- Fish abundance and diversity

Results: Precision bathymetry and sediment profile imagery showed that 6 weeks after disposal had ceased, dredged material covered 129 hectares. The thickness of dredged material was <15 cm over 36% of the area, 16 to 30 cm over 48% of the area, and >30 cm over 16% of the area. Open-water disposal did not lead to unacceptable water quality conditions. Temporary elevations in TSS concentrations were generally confined to the disposal and buffer areas. Further, TSS concentrations had very little effect on DO concentrations. Recolonization of the dredged material by infauna occurred rapidly. Areas whose overburden was <15 cm had infaunal abundances similar to background levels 2 weeks after dredging. Areas that received > 15 cm of dredged material required about 20 weeks to approximate background levels. Total fish abundances (not reviewed in this article) did not appear to be affected by the dredging, but some species may have been attracted to the disposal area for a short time (i.e., spot and fringed flounder).

Citation(s): Nester and Rees 1988; Wilber 1992c; TLP Factsheet: Fowl River

Mobile Bay, AL

Years of project: 2012/2014
Sediment type: N/A
Sediment depth: < 30 cm
Tidal Range: ~0.5 m
Reason for project: Sediment budgeting/Dredged material disposal
Vegetation source: N/A
Project Description: Thin layer placement was planned for six historical open-water disposal areas used prior 1986. About 9 MCY dredged material were placed in a thin layer in 2012. The results of this program indicated that TLP of dredged material in the Bay will have negligible impact, hence a long-term in-bay TLP program was approved in 2014. That year, a further 1 MCY of dredged material was placed in a thin layer in-bay.
Monitoring protocol: A monitoring and modeling program were established to evaluate short and long-term fate and transport of in-bay TLP.
Results: Both TLP efforts resulted in less erodible material in the sediment surface, and a quick recovery of the benthic community. Results of the monitoring and modeling efforts concluded that the placed dredged material is less erodible than the native bay bottom sediment due to its fine grained cohesive properties. Additionally, material placed in thin-layer fashion 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 into the Bay's natural sediment transport system such that it will not impact other natural resources within the Bay. Monitoring results from 2012 indicate that the placed material consolidated, and that the benthic community recovered quickly.
Citation(s): Parson et al. 2015; TLP Factsheet: Mobile Bay

Mississippi Sound, MS & AL

Year of project: 1992-93
TLP sediment type: Plastic clays, poorly graded sands, and silty sands
TLP sediment depth: ≤ 30 cm
Tidal range: 0.5 m
Reason for project: Dredged material disposal
Vegetation source: N/A

Project description: Six areas of 300 acres located in the MS Sound were treated with TLP of dredged material during three separate disposal events.

Monitoring protocol: Each disposal area was monitored predisposal, during disposal, short-term post-disposal, and long-term after post-disposal. Multiple parameters were monitored to examine the water quality perturbations and responses of benthic macroinvertebrates caused by thin layer placement. Monitoring for water quality was conducted for multiple samples in two areas that received maintenance material, two that received new-work material, and two reference areas. Sampling for benthic community responses was conducted at three disposal and reference areas.

Results: One year post-disposal, the overall abundance of infauna increased at the disposal sites as compared to the reference sites. The two disposal sites that had a higher sand fraction had a higher infaunal abundance and recovered faster in terms of infauna. The establishment of suspension feeders such as Oweniid polychaetes may have increased due to the increase of sand availability. The water quality data indicates that the impacts of TLP on water quality were of short-term nature.

Citation(s): Rees and Wilber 1994; Wilber et al. 2007; TLR Factsheet: Mississippi Sound

Paul J. Rainey Wildlife Sanctuary in Vermillion Parish, LA

Year of project: 2008

TLP sediment type: 80% silt and clay

TLP sediment depth: 0-10 cm, 10-15 cm, 15-20 cm

Tidal range: ~0.5 m

Reason for project: Marsh nourishment

Vegetation source: Natural re-vegetation

Project description: Sediment was hand-pumped from the adjacent canal onto 20 plots in a brackish marsh.

Monitoring protocol: Physicochemical properties, elevation, and sulfur, iron, and manganese cycling were monitored over three years.

Results: Three years post-sediment augmentation elevation gains of 3 cm were seen in the highest deposition areas because of consolidation and compression of the organic material below. Increased plant productivity was observed despite small elevation gain due to nutrient additions. In addition, the thicker layers of dredged material placed on the marsh resulted in decreases in sulfide concentration and increases in sulfate concentration. The decrease in sulfide concentration with thicker dredged material applications may be the result of lower sulfate reduction rates with an increase in redox potential or interactions with iron and manganese that was present in the dredged material. Although only small elevation gains were realized with greater sediment additions, increased plant productivity resulting from nourishment with as little as 15–20

	cm of sediment will help to maintain realized elevation gains and prolong the effects of sediment nourishment on marsh surface elevation. This research suggests that a minimum sediment-application threshold of 10–15 cm exists below which elevation is lost, and above which elevation is gained and ecosystem function is enhanced.
Citation(s):	Graham and Mendelssohn 2013; TLP Factsheet: Paul J. Rainey Wildlife Sanctuary

Northern Mississippi River Delta, Plaquemines Parish, Venice, LA

Year of project:	1996
TLP sediment type:	N/A
TLP sediment depth:	2-8 cm
Tidal range:	~0.3 m
Reason for project:	Marsh nourishment
Vegetation source:	Re-vegetation through rhizome growth from adjacent marsh
Project description:	TLP was used to restore surface elevations in a non-subsided marsh and an adjacent subsided marsh that had converted to shallow open water. Sediments pumped onto the marsh resulted in a thickness 2.3 cm greater than pre-disposal elevations and a factor of 10 greater than natural accretion at simultaneously monitored reference sites.
Monitoring protocol:	Soil elevation measurements were recorded prior to dredged material application and every three months for 18 months following application using sedimentation-erosion tables. Vegetation response was assessed using percent cover and root biomass.
Results:	Vegetation was initially flattened at the disposal site, and soil organic content was lower than reference values. TLP placement immediately increased shallow water elevation to 12 cm. After this initial increase, the site continuously lost elevation during the subsequent 20 months due to erosion of the unconsolidated sediments. However, elevation was raised sufficiently to allow *S. alterniflora* to invade via rhizome growth from the adjacent marsh. Within 1 year after spraying the shallow water site, soil bulk density, percent organic matter, root and rhizome biomass and volume of newly laid sediments, had all returned to or exceeded levels measured prior to spraying. The authors concluded that TLP of dredged material at the shallow water site was effective at restoring and maintaining marsh elevation after 1.5 years. However, if sediment deposits are not soon completely stabilized via further vegetative colonization, erosion may eventually lower elevations to the level where emergent vegetation cannot persist.
Citation(s):	Ford et al. 1999; TLP Factsheet: Northern Mississippi River Delta, Louisiana

Southern Mississippi River Delta, LA

Year of project:	1992, 1997, 2007

TLP sediment type:	9% sand, 43% silt, and 47% clay
TLP sediment depth:	< 2 cm, < 15 cm, 15-30 cm, and > 30 cm (1992, 1997); 2-10 cm, 8-11 cm, 10-17 cm (2007)
Tidal range:	0.3 m
Reason for project:	Marsh nourishment
Vegetation source:	Natural re-vegetation
Project description:	In 1992, a hydraulically dredged sediment slurry (85% liquid/15% solids), accidentally spilled onto an adjacent submerging salt marsh. The resulting sediment gradient was used to evaluate the effects of added sediment depth on plant community structure and soil condition. Five years following the original study (1998), sediment consolidated and compacted such that relative elevations ranged from 0 to 22 cm (as compared to 40 cm in the 1992 study). This study extends evaluation by Mendelssohn and Kuhn (2003) and investigates whether its positive effects lasted over a 7-year period. A resilience and stability experiment was completed 15 years (2007) following sediment addition to the marsh surface that included clipping the vegetation to the soil surface or herbicide application. Vegetation responses following the disturbances were recorded.
Monitoring protocol:	(1992 & 1998) Elevation, soil physicochemical parameters, including exchangeable nutrients (NH4-N, P, Ca, Mg, K, Na, Fe, Mn, Cu, and Zn) and vegetation parameters such as above-and below-ground biomass and percent cover were assessed over time.
Results:	(1992) Sediment enrichment improved salt marsh plant growth by increasing soil aeration, mineral matter content and available nutrients. Areas receiving intermediate and high amounts of sediment (15–30 and 30–60 cm, respectively, after 2 years showed increased plant cover and aboveground biomass. (1998) In 1993 percent cover reached 90% at 10–22 cm relative elevation, but by 1998 the highest percent covers were 55% and were found at 5–15 cm relative elevation. The moderate deposition zone (2-12 cm) appeared to benefit from an increase in marsh elevation and bulk density, along with an initial input of sediment-sorbed nutrients. These effects declined with time as sediment compacted and nutrients became depleted, but despite these declines the sediment-enriched soils remained very different from those not receiving sediment. Sediment enrichment monitoring results of 1–2 yr (Mendelssohn and Kuhn 2003), overestimated restoration success when there is an increase in growth due to a sediment fertilizer effect. (2007) Salt marshes that received moderate amounts of sediment addition with elevations at the mid to high intertidal zone (2–11 cm) were more resilient than natural marshes. The primary regulator of enhanced resilience and stability in the restored marshes was the alleviation of flooding stress observed in the natural, unsubsidized marsh. However, stability reached a sediment addition threshold, at an elevation of 11 cm, with decreasing stability in marshes above

this elevation. Declines in resilience and stability above the sediment addition threshold were principally influenced by relatively dry conditions that resulted from insufficient and infrequent flooding at high elevations. Although the older restored marsh has subsided over time, areas receiving too much sediment still had limited stability 15 years later, emphasizing the importance of applying the appropriate amount of sediment to the marsh. In contrast, treated marshes with elevations 2–11 cm were still more resilient than the natural marsh 15 years after restoration, illustrating that when performed correctly, sediment slurry addition can be a sustainable restoration technique.

Citation(s): Mendelssohn and Kuln 2003; Slocum et al. 2005; Stagg and Mendelssohn 2011; TLP Factsheet: Southern Mississippi River Delta, Louisiana

Bayou Lafourche, LA

Year of project:	2002
TLP sediment type:	Scatlake muck (semi-fluid, mineral soil frequently flooded with salt water)
TLP sediment depth:	11-16 cm, 13-18 cm, 20-15 cm, and 28-26 cm above reference marsh elevation
Tidal range:	0.3 m
Reason for project:	To assess the recovery of a salt marsh dieback area after hydraulically dredged sediment-slurries were applied to compensate for post-dieback soil consolidation.
Vegetation source:	Natural re-vegetation
Project description:	The study assessed the recovery of a dieback marsh after hydraulically dredged sediment-slurries were applied to the site to compensate for post-dieback soil consolidation.
Monitoring protocol:	Plant variables included percent cover, stem density, and species richness. Soil physicochemical properties included soil physical properties (i.e.: bulk density, moisture content) and exchangeable nutrients (i.e., phosphorus, ammonium, sulfide). Plant and soil properties were assessed five and seven years after sediment application.
Results:	Two years after sediment recharge, marshes in the low elevation areas (11-16 cm) were the most similar to reference marshes in plant cover and species richness. The improved recovery was the result of reduced inundation with higher elevations and the addition of P with the dredged material. After 7 years, total aboveground biomass, live biomass, stem density, and height of *S. alterniflora* 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 lead to a decrease in marsh recovery.
Citation(s):	Schrift et al. 2006; Stagg and Mendelssohn 2011; Tong et al. 2012

St. Bernard Parish, Lake Coquille, LA/ Terrebonne Parish, Dog Lake, LA

Year of project: N/A
TLP sediment type: N/A
TLP sediment depth: 18-36 cm (Lake Coquille); 10-15 cm (Dog Lake)
Tidal range: ~0.4 m
Reason for project: Disposal of dredged material
Vegetation source: Natural re-vegetation
Project description: Dredged material from a 150-m canal/slip dredge operation was thin-layer sprayed on adjoining marsh and waterways. This project involved dredging a canal through saline marsh to access an open-water drilling location. The dredged material was discharged using thin-layer spray disposal onto one side of the canal marsh.
Monitoring protocol: Assessment of the two sites by ground and aerial surveys occurred at 2 weeks, and at 8, 11, 14, and 19 months after project completion.
Results: Vegetation was initially smothered at both sites although some survived around the edges. Limited vegetative colonization took place within 8 and 14 months. Lake Coquille was revegetated after 2 years, while the fringes and more lightly sprayed areas of the Dog Lake disposal site were revegetated in < 1 year. There was evidence of marsh invertebrates (e.g., new crab burrows) at the Dog Lake site. There was full recovery measured by percent cover by dominant plant species after 6 years. Some differences in plant species composition persisted after 6 years. Preliminary results indicate that, unlike conventional spoil disposal, spray disposal does not directly convert marsh to upland habitat because, to date, all colonization has been by intertidal marsh species.
Citation(s): Cahoon and Cowan 1987; LaSalle 1992

Barataria Bay, LA

Year of project: 1986, 1987
TLP sediment type: Fine sand 40%, coarse-fine silt 28%, clays and organics 32%
TLP sediment depth: 1986 application: 2-5 cm; 1987 application: 4-10 cm
Tidal Range: ~0.3 m
Reason for project: Marsh nourishment
Vegetation source: Natural re-vegetation
Project Description: Sediment was hand-pumped from an adjacent basin onto 12 plots in a salt marsh.
Monitoring protocol: Aboveground biomass production of *Spartina alterniflora* was assessed as well as the nutrient status of the clipped vegetation. Vertical accretion rates were determined.
Results: Accretion rates in the deteriorating marsh were 0.44 cm/year in comparison to 0.8 to 1.0 cm/year in the reference marsh. The addition of sediment resulted in a significant increase in aboveground biomass and was higher in the marsh areas that received higher sediment applications. The vegetation contained

	significantly higher concentrations of Fe, Mn, and P in treated areas than reference areas. Transpiration rates and leaf conductance were also higher in areas receiving material. The addition of sediment to the marsh surface increased plant productivity due to an increase in elevation that reduced inundation and Increased nutrient supply.
Citations:	DeLaune et al. 1990; TLP Factsheet: Barataria Bay, LA 2017

Galveston GIWW, Laguna Madre, TX

Year of project:	Ongoing
TLP sediment type:	Placement areas 203 = N/A; PA 232 = ~ 8 cm
TLP sediment depth:	Placement areas 203 = 27% sand; PA 232 = 17% sand
Tidal range:	~0.3 m
Reason for project:	Marsh nourishment/Dredged material disposal
Vegetation source:	Natural re-vegetation
Project description:	PA203 is an upland site about 2 miles long. TLP of dredged material from the GIIW will be placed first in the unconfined portion of this PA until the confined area is reached and then the rest will be placed in the leveed section of the PA. PA 232 consists of a chain of small islands with extensive seagrass beds. As of 2014, TLP placement of dredged material in the Laguna Madre open bay placement area 203 was completed.
Monitoring protocol:	N/A
Results:	N/A
Citation(s):	USACE and ICT 2002; TLP Factsheet: Galveston GIWW, Laguna Madre; USACE Laguna Madre Updates

Galveston GIWW Dredging West Bay

Year of project:	2012 (ongoing)
TLP sediment type:	N/A
TLP sediment depth:	N/A
Tidal range:	~0.3 m
Reason for project:	Marsh nourishment/Dredged material disposal
Vegetation source:	Natural re-vegetation
Project description:	Two permitted placement areas (PA) were used for TLP of maintenance dredged material to promote marsh restoration of intertidal habitat fringe marsh. As of January 2012, TLP efforts had already been completed on PA 63 and placement of a substantial amount of dredged material was scheduled for PA 62. One of the issues with the placement areas is that placed material is re-worked by tides and storms, and current sediment thickness is expected to significantly increase during the summer growing season.
Monitoring protocol:	The site will be monitored pre- and post-construction for seagrass and thin layer thickness. For PA 62, a seagrass survey was performed prior to placement and

	the amount of dredged material to be placed was reduced by half. A long-term monitoring plan for seagrass beds will be developed by the ICT for both PAs. A post-placement survey was planned for PA 63 to determine layer thickness and elevations as part of long-term monitoring efforts.
Results:	N/A
Citation(s)	TLP Factsheet: Galveston GIWW, West Bay

Southeast

Glynn County, GA

Year of project:	1978
TLP sediment type:	Clay, coarse sand, and mixed clay and sand
TLP sediment depth:	8-91 cm
Tidal range:	2 m
Reason for project:	Marsh nourishment/Dredged material disposal
Vegetation source:	Natural re-vegetation (shoots and seeds)
Project description:	Three types of dredged material, coarse sand, mixed sand and clay, and clay, at six depths (8, 15, 23, 30, 61, and 91 cm), at three different stages of plant growth (February, July, and November) were measured.
Monitoring protocol:	The experimental setups, experimental control areas, and adjacent marsh controls were monitored monthly for two years for culm, live crab, crab burrow, and marsh snails' density determinations. The soil chemistry and tidal data for experimental area were also determined.
Results:	*Spartina* was able to penetrate up to 23 cm of each type of dredged material and exhibited biological growth and production nearly equal to that in undisturbed marsh. The study also included an assessment of the impact of smothering on selected species of crabs and snails. Crabs recolonized areas covered with up to 23 cm of clay dredged material and 15 cm of sand. Snails rapidly recolonized material placed 8 and 15 cm deep. Faunal recovery may depend on the proximity of the disposal area to natural populations and the extent of the smothered areas. The results from this pilot study indicated that marsh elevation could be altered through thin layer placement of dredged material up to 23 cm without loss of the functional values of the ecosystem and environment.
Citation(s):	Reimold et al. 1978; TLP Factsheet: High Salt Marsh in Georgia

Freeman Creek, NC

Year of project:	2017 (ongoing)
TLP sediment type:	N/A
TLP sediment depth:	5-10 cm
Tidal range:	0.9 m

Reason for project:	Marsh nourishment
Vegetation source:	Natural re-vegetation
Project description:	The purpose of this demonstration project is to provide the foundation for use of TLP of dredged material in similar locations by developing a list of parameters and model predictions that are necessary for applying TLP to coastal wetlands. The results of the Coastal Wetland monitoring program indicate that the marsh platform at the project site is 20-25 cm below "optimal" growth elevations for *Spartina alterniflora*.
Monitoring protocol:	Marsh surface elevation, *Spartina alterniflora* biomass, sediment grain size, carbon content, and percent organic matter were measured in all plots before sediment addition, and will be monitored every two months for the first two years, and then annually.
Results:	N/A
Citation(s):	TLP Factsheet: Freeman Creek, NC

Masonburo Island, NC (North Carolina National Estuarine Reserve)

Year of project:	2000
TLP sediment type:	50% fine sands, 50% muds
TLP sediment depth:	2-10 cm
Tidal range:	1.2 m
Reason for project:	Marsh nourishment
Vegetation source:	Natural re-vegetation
Project description:	Approximately 8 m^3 of dredged material was taken from dredged material disposal banks adjacent to the AIWW and manually placed in deteriorated and non-deteriorated marsh plots behind Masonboro Island, NC.
Monitoring protocol:	The following parameters were evaluated to achieve the main purpose of this project: thin layer thickness, *S. alterniflora* density, benthic community assemblage and abundance, benthic microalgal analysis and soil oxidation reduction potential (ORP) in deteriorating and non-deteriorating marsh sites. Most of these parameters were measured every other month for approximately a year, except for benthic infaunal samples which were collected 2 weeks pre-placement, and 6 weeks and 1 year post-placement. Sediment characteristics such as organic content, dry bulk density and grain size distribution were measured on an annual basis.
Results:	Sediment placed on deteriorating marsh plots increased *Spartina* stem density by 2nd growing season to reference levels, but had little to no effect on overall plant height. The addition of 2-10 cm of sediment on deteriorating marsh surfaces increased vascular plant stem densities and microalgal biomass. There were no long-term impacts to the infaunal community. Sediment additions resulted in higher Eh values (e.g. higher oxygen levels) in both deteriorating and non-deteriorating marshes, the thicker the layer the higher the Eh. Results also

	showed that adding sediment caused incremental changes in deteriorated plots toward non-deteriorated conditions, suggesting that periodic additions over time may offset sediment deficiencies and have beneficial effects in terms of infaunal abundance and plant biomass.
Citation(s):	Croft et al. 2006; Leonard et al. 2002; TLP Factsheet: Masonburo Island

Gull Rock, NC

Year of project:	1982
TLP sediment type:	Primarily clay, silt, and fine sand
TLP sediment depth:	5 and 10 cm
Tidal Range:	0.1 m
Reason for project:	Dredged material disposal/marsh nourishment
Vegetation source:	Natural re-vegetation
Project Description:	A 120-meter access channel to the Lake Landing Canal was constructed in Wysocking Bay. About 8,000 to 12,000 cubic meters was excavated and spread on marsh on both sides of the canal.
Monitoring protocol:	Pre-monitoring, the more common types of vegetation at the site were black needle rush *(Juncus roemerianus),* saltgrass *(Distichlis spicata),* smooth cordgrass *(Spartina alterniflora),* and saltmeadow cordgrass *(S. patens).* Marsh characteristics examined quantitatively included aboveground plant biomass, plant density (leaves/m^2 for black needle rush, shoots/m^2 for all other species), relative elevation, soil bulk density, soil organic content, and macroinfauna density. Qualitative sampling included examinations of fiddler crab abundance, fish abundances, and soil layering.
Results:	Although some smothering of vegetation occurred during disposal operations, this was mainly due to the large volumes of water involved in the spraying operations, and revegetation occurred relatively quickly. Placing dredged material in a 5 cm layer did not lead to a significant change in vegetation or marsh use by animals. The repercussions of placing dredged material in a 10 cm layer are less clear. Although such placement did not lead to creation of upland or high marsh habitat, it may have altered soil drainage, resulting in conditions that favored a different marsh plant community.
Citation(s):	Wilber 1992; TLP Factsheet: Gull Rock, NC

Mid-Atlantic

Pepper Creek, Assawoman Wildlife Area, Dagsboro, DE

Year of project:	2013
TLP sediment type:	N/A
TLP sediment depth:	15-46 cm applied; average 30 cm
Tidal range:	1.2 m

Reason for project: Marsh nourishment
Vegetation source: Natural re-vegetation
Project description: Ten hectares of marsh were sprayed with varying thicknesses of dredged material. As a precaution, hay bales and straw logs were used as containment structures until sediments could settle.
Monitoring protocol: Small areas where grasses were knocked down by the spray force were replanted. Plant cover, surface elevation, and belowground biomass was measured 2 years following construction.
Results: Results showed that the material was placed uniformly at acceptable levels. The marsh was rebuilt and re-vegetated and is showing signs of recovery.
Citation(s): Whitin 2007; TLP Factsheet: Pepper Creek

Prime Hook National Wildlife Refuge, Sussex County, Milton, DE

Year of project: 2016 (ongoing)
Sediment type: N/A
Tidal range: 1.2 m
Reason for project: Marsh nourishment
Vegetation source: Planted with *Spartina paten*s and *Spartina alterniflora* plugs
Project description: The tidal marsh restoration project was completed in September 2016 by dredging channels within impounded areas. Approximately 30 miles of channels were dredged across the 4,000-acre tidal marsh restoration area. The channels allow water exchange and flow that lowered the water level to expose existing mudflats. In addition, dredged sediments were sidecast from the dredge to elevate open water areas to allow plant growth. *Spartina paten*s and *Spartina alterniflora* plugs were planted in exposed mudflats after channel restoration was completed.
Monitoring protocol: Monitoring of vegetation, wildlife, and physical conditions (water quality and marsh elevation) prior to restoration was conducted and will continue to be monitored to assess the success of this restoration project.
Results: Restored marshes were covered with new vegetation after one growing season in many areas where there was shallow open water prior to restoration. The first documented piping plover nest was identified on the restored shoreline along with other nesting shore birds of interest. Monitoring of the biological and physical response of the tidal marsh to restoration will continue over upcoming years.
Citation(s): TLP Factsheet: Prime Hook National Wildlife Refuge

Blackwater National Wildlife Refuge, Cambridge, MD

Year of project: 2002 and 2014 (Shorter's Wharf)
TLP sediment type: N/A (2002); Fine grained material (2014)
TLP sediment depth: N/A (2002); 8-15 cm (2014)

Tidal range:	0.5 m
Reason for project:	The purpose of this project is to prevent the loss of approximately 40 acres of high tidal marsh within Blackwater NWR at Shorter's Wharf to erosion and to increase resiliency to relative sea level rise and storm impacts through habitat restoration measures.
Vegetation source:	Hydroseeding (seeds mixed with dredge spray)
Project description:	(2002) About 3.2 hectares of open-water intertidal wetland area were successfully restored. Containment sites were formed using straw bale dams. Sites were planted after sediment settled. (2014) A thin layer of material was sprayed in 2, 1-2 acre sites and placed hydraulically. Hydroseeding was attempted by adding seeds to the dredged material spray. The material was placed in 2 lifts of small thickness which allowed the sites to become revegetated in a short period of time.
Monitoring protocol:	N/A
Results:	(2002) Post placement monitoring indicated revegetation occurred immediately within the refuge and outside of the treatment area as well. (2014) Monitoring is ongoing and shows success with ample biodiversity post-placement.
Citation(s):	Curston et al. 2016; Moran et al. 2016

Avalon, NJ

Year of project:	2016
TLP sediment type:	16% clay, 50% silt, and 34% fine sand
TLP sediment depth:	1.3 to 50 cm
Tidal range:	1.4 m
Reason for project:	Demonstration project/marsh restoration
Vegetation source:	Unknown
Project description:	As a demonstration project, about 50K CY of dredged material was placed in designated marsh areas in two phases: 1st small (6 acres), 2nd larger (42 acres).
Monitoring protocol:	Vegetation monitoring is measuring percent cover, stem height of dominant plant species, and above/belowground biomass. Monitoring of epifaunal macroinvertebrates is measuring species richness, categorical abundance of species, and categorical abundance of crab burrows. Monitoring is ongoing.
Results:	Directly following TLP treatment, all vegetation and epifaunal macroinvertebrate parameters greatly decreased both in comparison to their pre-treatment levels and to the control marsh. Ongoing monitoring at the site indicates that a number of shorebirds, horseshoe crabs, oysters, and terrapins are using the site.
Citation(s):	Whitin 2017; Yepsen et al. N/D

Ring Island, NJ

Year of project: 2014
TLP sediment type: N/A
TLP sediment depth: ~12 cm
Tidal range: 1.4 m
Reason for project: Marsh restoration
Vegetation source: Unknown
Project description: A two-acre area of Ring Island was treated with TLP and also a habitat creation area for Black Skimmers.
Monitoring protocol: Vegetation monitoring is measuring percent cover, stem height of dominant plant species, and above/belowground biomass. Monitoring of epifaunal macroinvertebrates is measuring species richness, categorical abundance of species, and categorical abundance of crab burrows. Monitoring is ongoing.
Results: Directly following TLP placement, all vegetation and epifaunal macroinvertebrate parameters greatly decreased both in comparison to their pre-treatment levels and to the control marsh.
Citation(s): Yepsen et al. N/D

Fortescue, NJ

Year of project: 2014-2016
Sediment type: 96% fine sand
TLP sediment depth: 0 to 60 cm
Tidal range: 1.4 m
Reason for project: Marsh restoration
Vegetation source: Unknown
Project description: About 15,000 CY of sediment was sprayed 1.5 miles to restore 14 acres of degraded salt marsh and three acres of beach along Delaware Bay.
Monitoring protocol: Vegetation monitoring is measuring percent cover, stem height of dominant plant species, and above/belowground biomass. Monitoring of epifaunal macroinvertebrates is measuring species richness, categorical abundance of species, and categorical abundance of crab burrows. Monitoring is ongoing.
Results: Directly following TLP placement, all vegetation and epifaunal macroinvertebrate parameters greatly decreased both in comparison to their pre-treatment levels and to the control marsh.
Citation(s): Whitlin 2017; Yepsen et al. N/D

Stone Harbor, NJ

Year of project: 2014
TLP sediment type: 96% fine sand
TLP sediment depth: N/A
Tidal range: 1.4 m
Reason for project: Marsh restoration

Vegetation source:	Unknown
Project description:	About 7,000 CY of sediment was dispersed over 0.5 acres.
Monitoring protocol:	Ongoing
Results:	Long-term monitoring is still underway, but initial vegetation response is somewhat positive. Ultimately created Black Skimmer habitat rather than true salt marsh.
Citation(s):	Rochette 2014; Whitin 2017

Jamaica Bay Marsh Islands, NY

Year of project:	2003
TLP sediment type:	N/A
TLP sediment depth:	20 cm, 23 cm, 100 cm
Tidal range:	1.4 m
Reason for project:	Marsh nourishment/habitat restoration
Vegetation source:	Planting of smooth cordgrass from peat pots.
Project description:	A silt fence was placed around the low-lying areas of the marsh. Hay bales, wooden stakes and sisal twine were used to provide primary containment for the placement area. Supplemental containment was provided in areas with high turbidity using a black plastic construction fence. Following placement, the site was planted with smooth cordgrass for about 6 weeks. A plastic fence was also installed to keep geese from eating the plants.
Monitoring protocol:	One year of pre-construction monitoring was done.
Results:	The northwest edge of the filled area was impacted by wind-driven waves, resulting in an erosion belt 60 m long by 3–5 m wide that lost 20–40 cm of elevation. Another place of long-fetch is in the southeast, where eroding waves created another erosion belt 20 m long by 5 m wide that lost at least 20 cm of elevation. In the first spring after planting, the smooth cordgrass in peat pots, spaced 50 cm apart, showed nearly 100% survival and regrowth. In the first year after the treatment, however, we observed that the smooth cordgrass survived only when it received 20 cm or less of sand cover. The thinner the layer, the greater the survival. By 2004, the restored marsh was being colonized by fiddler crabs, eastern mud nassa, common periwinkle, and fishes, worms, and insects.
Citation(s):	Frame et al. 2006; TLP Factsheet: Jamaica Bay– Big Egg Marsh 2016

New England

Narrow River Estuary in the John H. Chafee National Wildlife Refuge, RI

Year of project:	2016 (ongoing)
TLP sediment type:	90% fine sands, 10% fines
TLP sediment depth:	< 10 cm
Tidal range:	1.1 m
Reason for project:	Habitat restoration

Vegetation source: Plantings of native salt marsh plants

Project description: Multiple areas of a 14 acres marsh site with signs of stressed vegetation and expanding pond areas were targeted to receive sediment. The sediment was obtained from channel dredging for eelgrass restoration in a nearby tidal flat. The dredged material was placed on the marsh surface mechanically with a bulldozer that reads computer aided design files to increase accuracy of placement and reach target elevations for high marsh habitat. Areas receiving more than 8 cm of dredged material will be planted with native salt marsh plants during the growing season. In order to protect against marsh edge erosion and to hold sediment and water on the marsh platform, 3,000 bags of clam and oyster shells were used a containment structure.

Monitoring protocol: 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

Results: Initial indications are that the project should be successful.

Citation(s): TLP Factsheet: John H. Chafee National Wildlife Refuge; Whitin 2017

Ninigret Pond Salt Marsh Restoration & Enhancement Project, Narragansett, RI

Year of project: 2016/2017 (ongoing)

TLP sediment type: Finer grain material

TLP sediment depth: 0-30 cm

Tidal range: 1.1 m

Reason for project: Marsh restoration

Vegetation source: Plantings of native salt marsh plants

Project description: Approximately 30,000 CY of dredge material was placed on 25 acres of degraded salt marsh. Additional planting was necessary.

Monitoring protocol: N/A

Results: N/A

Citation(s): Whitin 2017

Sachuest Point National Wildlife Refuge, Middletown, RI

Year of project: 2016

TLP sediment type: Finer grain material

TLP sediment depth: 3-30 cm

Tidal range: 1.1 m

Reason for project: Marsh restoration

Vegetation source: Plantings of native salt marsh plants

Project description: Nearly 11,000 CY of dredged material was applied to 11 acres of marsh. The material was dredged hydraulically and placed on the marsh platform to dry out; placement occurred by means of spreading and grading the material with a lightweight amphibious excavator.

Monitoring protocol: N/A

Results: N/A

Citation(s): Whitin 2017

West Coast

Seal Beach, CA National Wildlife Refuge

Year of project:	2016 (ongoing)
TLP sediment type:	Finer grain material
TLP sediment depth:	25 cm
Tidal range:	1.2 m
Reason for project:	Habitat restoration
Vegetation source:	Natural re-vegetation
Project description:	Twenty-five cm of thin layer of dredged material was placed over 8 acres of low elevation salt marsh from Dec 2015 to Mar 2016. This site has the lowest mean elevation of 8 California marshes where survey-grade elevations were conducted by USGS. Approximately 17,000 CY of clean dredged material was placed on the site. A hay bale barrier and a 6-acre vegetated buffer were maintained between the TLP site and adjacent channels in order to reduce sediment runoff and avoid impacts to marine species including eelgrass beds and marine mammals. A control site within the refuge was established as part of the experimental design.
Monitoring protocol:	Within two years of the sediment placement, project goals are to obtain: a) an 8-cm minimum increase in the marsh plain elevation compared to pre-project conditions, b) cordgrass stem lengths equivalent to pre-project conditions, and c) an increase in foraging and nesting of Ridgway's rails. The monitoring program includes both pre- and post-construction monitoring and encompasses vegetation species type and coverage, diversity and abundance of macroinvertebrates and birds, soil salinity, cordgrass height/stem density and invertebrate community structure.
Results:	The average elevation change for the treated site between pre-and post-placement was +23.4 cm while the control site showed a decrease of -0.39 cm. Immediately following treatment, invertebrate abundances decreased significantly on the placement site. Abundance increased 6 months after treatment and had returned to pre-treatment levels by 1 year. Cordgrass is extending into the site from the adjacent 50-foot buffer area and from groups of plants that were not fully buried beneath the added sediment. Plant community monitoring is ongoing. A variety of shorebirds, seabirds, and raptors have been observed on the treated site.

Citation(s): Garvey and Brodeur 2016; USFWS 2017; TLP Factsheet: Seal Beach National Wildlife Refuge