APPLICATION OF LABORATORY AND MODELING TOOLS TO DESIGN THIN LAYER PLACEMENT PROJECTS FOR MARSH NOURISHMENT

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ABSTRACT

Thin layer placement of dredged material is experiencing a renaissance, being used to restore degraded marshes. In designing constructed marsh nourishment projects, elevation is critical to optimizing its function. However, as dredged material is placed as a slurry (water and sediment mixture), the dredged material settles rapidly and consolidates to a lower elevation. Placing dredged material to a proper initial elevation so as to achieve a desirable elevation for marsh function over the long term is critical for project success. Laboratory testing and modeling tools are available to predict consolidation for designing thin layer placement projects.

These tools were recently applied to evaluate consolidation at planned and ongoing marsh restoration projects on the U.S east coast using maintenance dredged material from nearby navigation channels. The existing elevation across these marsh sites varies such that the sites consists of relatively deep subtidal pools, intertidal vegetated marsh and predominantly exposed vegetated marsh. Sediments within the channels were sampled and analyzed for geotechnical properties as well as suitability from a contaminant standpoint. Evaluation of the channel sediments showed very different materials within the separate channels, ranging from relatively sandy material to highly organic and fine-grained material. The behavior of these materials with respect to placement and consolidation will be highly variable. Laboratory column settling tests and consolidation testing were used to predict the behavior of each channel material.

Depending on how the material is placed hydraulically, sand is likely to deposit near the pipe discharge, while the fines could be expected to flow away from the pipe, resulting in a range of thicknesses of both sand and fine-grained materials. Sand deposits are expected to undergo very little consolidation while the finer material is expected to consolidate greatly. Conversely, the marsh foundation is expected to undergo measurable settlement from a deposit of sand but very little from a deposit of fine-grained or organic material. The Primary Consolidation, Secondary Compression and Desiccation of Dredged Fill (PSDDF) model was used to evaluate the elevation change over time for a range of placement elevations and thicknesses for the different material types. The subsequent information can be used to predict the resulting landscape in the months or years after placement for a given fill elevation.

Keywords: PSDDF, dredged material, consolidation, thin layer placement, beneficial use

INTRODUCTION

Beneficial use of dredged material for wetlands nourishment and restoration is currently experiencing a renaissance. This resurgence is due, in part, to the diminishing capacity to place or dispose of material dredged from navigation channels, in conjunction with the realization of the deleterious effects that sea level rise is having on wetlands. Marsh nourishment, a subcategory of thin layer placement, is practiced by placing dredged material in thin layers so as to build elevation without smothering existing marsh vegetation. This method allows better coverage and improved recovery times over placement of thicker lifts. A primary goal of marsh nourishment is to build elevation capital. As functional ecological efficiencies of marshes rely on elevation of the placed material, the dredged material thickness, both short-term and long-term, is a fundamental parameter for effective design, construction and maintenance of a sustainable marsh.

In designing constructed marsh restoration projects, it is important to know how much material should be placed initially in order to achieve a functional elevation at some point in the future. Dredged material placed for marsh restoration is typically placed hydraulically as a slurry, which enables the material to be pumped or sprayed across the

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area. During placement and initial dewatering, the solid particles settle out of the slurry. Coarse grained particles (sand sized) settle out near the discharge, whereas finer particles settle more slowly and can travel farther from the discharge. After initial dewatering, the fine-grained sediments will continue to consolidate over time, whereas the sands tend to undergo significantly less consolidation. The weight of the added sediment may also cause consolidation of the existing wetland foundation soils. Henceforth, the elevation of placed material changes over time subsequent to placement as a function of dredged material type and thickness as well as properties of the foundation (Figure 1). In order to effectively design marsh restoration to achieve a desired elevation, it is important to be able to predict the elevation change over time.

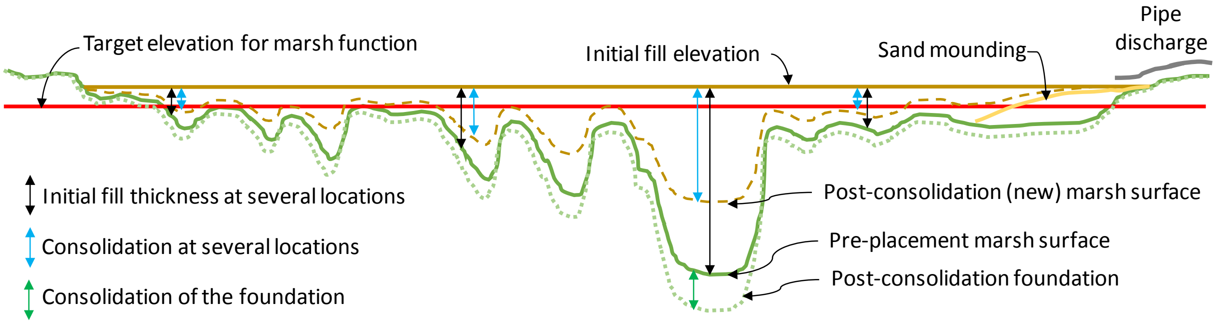

Figure 1. Conceptual marsh topography changes as a result of dredged material placement and consolidation.

Models and supporting laboratory evaluation methods have been developed and verified to simulate the settling and consolidation of dredged material within a confined disposal facility (CDF). The SETTLE model (Hayes and Schroeder 1992) is used to evaluate initial sediment behavior during placement and dewatering, and can be used to design CDF’s storage and evaluate effluent water quality. Compression settling data, derived from laboratory column settling tests, is a primary input to the model. The model determines the average concentration of settled solids for fine-grained material (smaller than 75 µm, passing the #200 sieve). Material larger than 75 µm consolidates significantly less than smaller grain sizes, therefore the model sums the volume of the coarse grain and settled fine grain fractions which results in the storage requirement volume. The model provides conditions (volume occupied by sand, volume of fines and fines concentration) at the end of a single placement event. In order to assess the long-term volume and elevation of a placement area (which could potentially receive multiple lifts) a consolidation model is employed.

The Primary Consolidation, Secondary Compression and Desiccation of Dredged Fill (PSDDF) model (Stark 1996) was developed to simulate longer term consolidation of dredged material placed in a CDF. The PSDDF model considers the geotechnical characteristics of both the foundation and placement materials including consolidation behavior typically determined through laboratory consolidation tests. The model outputs the consolidated surface elevation at a user defined time in the future (months, years). Further, the model calculates the magnitude of each layers consolidation as well as the percent to which it is consolidated. The combination of the SETTLE and PSDDF models provides for a holistic approach to estimating placement volume and elevation over a large range of time scales, i.e., from days to multiple years.

Although a marsh environment is not exactly the same as a CDF, these models are currently the best tools available for predicting elevation change associated with settling and consolidation for thin layer placement. The U.S. Army Corps of Engineers (USACE) Dredging Operations and Environmental Research (DOER) program is currently conducting research to gain a better understanding of the physical processes involved in placement, dewatering and settlement of dredged material in marsh environments (effects on vegetation on placement density, plant transpiration and rooting on consolidation, impact of placement techniques on sand separation and distribution, etc.) to optimize the use of PSDDF. In support of this effort, the U.S. Army Engineer Research and Development Center (ERDC) is providing technical assistance to the U.S. Fish and Wildlife Service (USFWS) in the design of potential wetlands restoration projects at the Edwin B. Forsythe National Wildlife Refuge (Forsythe NWR). These projects are currently early in the design phase and the results of modeling activities described in this paper are preliminary and will be refined. While these modeling techniques are being applied to provide an understanding of the consolidation behavior of the dredged material proposed for placement at the potential sites, the DOER program's objective is to conduct post placement elevation monitoring to evaluate and optimize the performance of these modeling tools.

Background

The study area is located in Ocean County, New Jersey. The marsh areas are located along the landward side of the back-barrier bay, Barnegat Bay. Three areas were selected by the NWR as potential restoration sites as means to restore degraded marsh areas: Good Luck Point near Toms River, and Brick A and B near the Metedeconk River (Figure 2). An environmental assessment of the study area was conducted by contractors under USFWS, and was used to determine appropriate target elevations for high and low marsh in the placement areas. The existing elevation across the areas is variable, with some pannes, ponds, and ditches, which would result in varying post-placement dredged material thicknesses. Laboratory evaluation of various navigation channel sediments was used to develop the necessary parameters for modeling potential placement operations and developing elevation curves that can be used to select initial dredged material placement elevation(s).

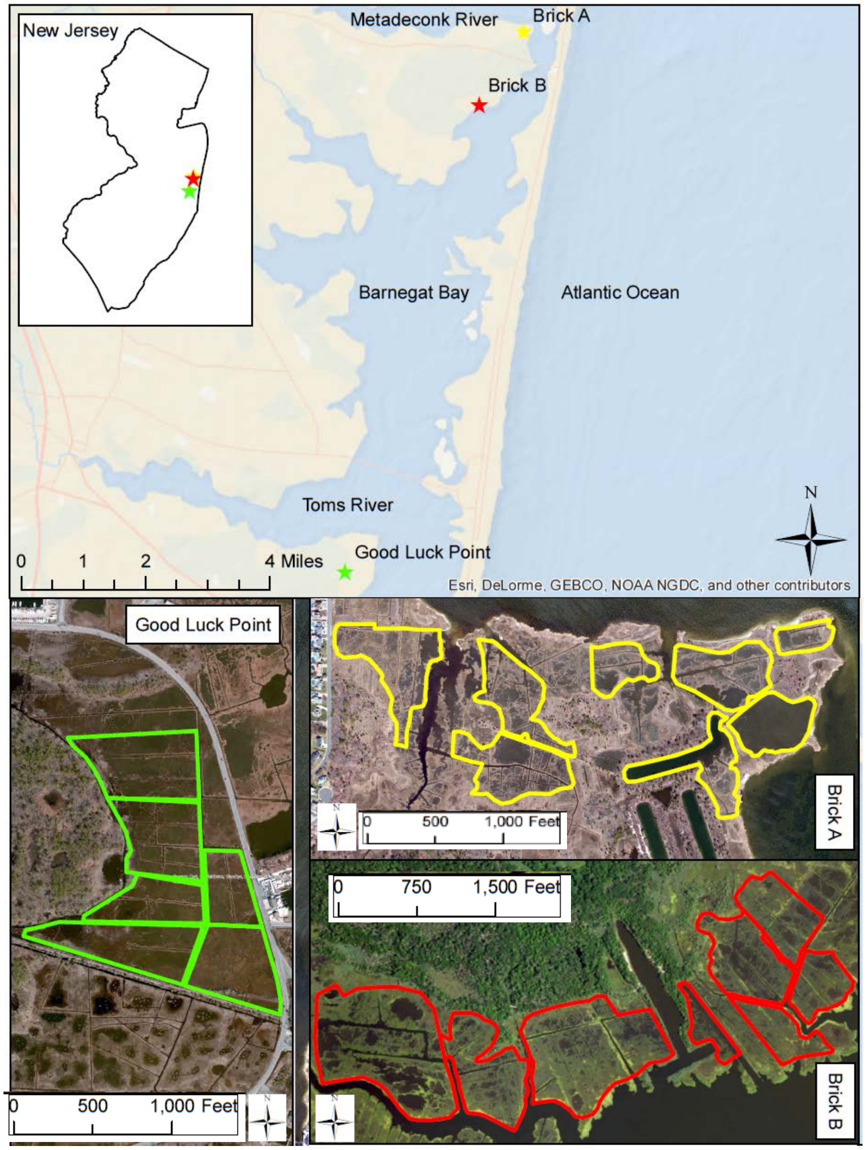

Figure 2. Marsh restoration areas within Edwin B. Forsythe National Wildlife Refuge, NJ

METHODS AND MATERIALS

The evaluation involved collection of sediment from the proposed dredging locations, and laboratory analysis of sediment properties including settling and consolidation behavior. An iterative modeling process was then used to estimate a fill elevation and volume, application of the SETTLE model to predict conditions at the end of placement of that volume, and prediction of the elevation change as the material consolidates over time using the PSDDF model. The modeling process can be repeated, adjusting the initial fill elevation until a desirable post-consolidation elevation is achieved for the majority of the site.

Dredged Material Evaluation

Sediment was collected by the New Jersey Department of Transportation (NJDOT) from separate channels that could potentially be dredged and placed on the marsh. Based on location and preliminary grain size analysis, the sediments were composited as: Beaver Dam Creek-South, Kettle Creek/Kettle Creek-Sailors Quay, and Good Luck Point, and are assumed to represent the fine-grained materials to be placed at Brick A, Brick B, and Good Luck Point, respectively. Water content and percent organic matter were measured gravimetrically. Salinity of the pore water was measured as total dissolved solids. Grain size was measured using a Coulter laser diffraction particle size analyzer. Specific gravity of the solids was then estimated based on the percent organic matter, assuming a specific gravity of 1.1 for the organic content, and 2.68 for the mineral content. Atterberg limits of the Kettle Creek/Kettle Creek-Sailors Quay and Beaver Dam Creek-South composites were evaluated using the American Society for Testing and Materials method D4318-10e1 (ASTM 2010). The Good Luck Point composite was determined to be too sandy to perform the Atterberg limits tests.

Results, shown in Table 1, show Good Luck Point as primarily sandy material, whereas Kettle Creek/Kettle Creek-Sailors Quay is primarily silt with a relatively high organic content. The Beaver Dam Creek composite was highly organic (24%). Although the grain size analysis showed 19.2 % to be of sand size, the coarse material is primarily organic, as very little sand could be visually detected in the sample.

Table 1. Geotechnical characteristics of Forsythe composite sediments

	Good Luck Point Composite	Kettle Creek – Kettle Creek-Sailors Quay Composite	Beaver Dam Creek – South Composite
Salinity, ppt	21.05	20.24	22.42
Total Solids, g/L	615.0	392.9	431.5
Water Content, % by wt	124.1	214.0	211.2
Organic Matter, % by wt	5.4	13.4	24.0
Estimated Specific Gravity	2.59	2.47	2.30
Grain size by volume:			
% Sand size	54.4	26.1	19.2
% Silt size	36.0	55.1	65.8
% Clay size	9.6	18.8	15.0
Atterberg Limits:			
LL		127	264
PL		52	128
PI		75	136
USCS Classification	SM	MH	OH

Column settling tests (USACE 2015, Palermo et al. 1978, Palermo and Thackston 1988, Thackston et al. 1988) were performed on the three composite materials. The composite samples were prepared by adding water to generate a slurry representative of the solids content expected to be discharged from the pipe (typically 80-90% water). This solids content in grams per liter (g/L) was predicted based on a rule of thumb as the percent fines plus three times the percent sands and gravel. Salt was also added to adjust the salinity (Table 1). The slurry was thoroughly mixed, then allowed to settle quiescently for a brief period (minutes) to allow the sand to settle out. (The column settling test and subsequent modeling is specific to the fines portion; i.e., sand is modeled separately.) Because the large organic particles in Beaver Dam Creek-South interfered with testing, the material was passed through a #10 mesh screen to remove the coarser organics. The slurry was pumped into a 20 cm (8 in) diameter settling column (see Figure 3) to a height of approximately 1.8 m (6 ft). Measurements of the sediment-water interface were recorded at intervals over a period of fifteen days. With the help of the SETTLE model, this information was used to determine the zone settling rate and compression settling characteristics. Results for the three composites are shown in Table 2. The supernatant above the interface was also sampled over time from ports spaced every 15 cm (6 in). This information can be used to develop flocculent settling parameters for evaluation of effluent water quality.

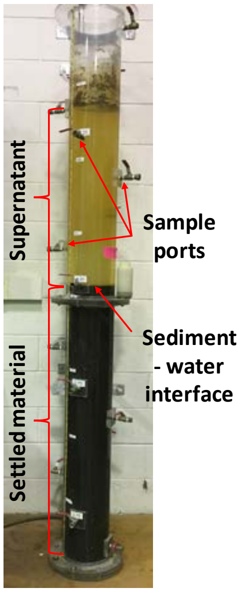

Figure 3. 20 cm (8 in) diameter settling column.

Table 2: Column settling test results for Forsythe composite sediments.

	Good Luck Point Composite	Kettle Creek – Kettle Creek Sailors Quay Composite	Beaver Dam Creek – South Composite
Zone Settling Rate, cm/hr (ft/hr)	10.8 (0.355)	6.83 (0.224)	28.2 (0.924)
Compression Settling Curve coefficients* $C = A\left(\frac{DTime}{2}\right)^B$	A = 172.36 B = 0.1476	A = 210.97 B = 0.0935	A = 80.35 B = 0.1903

* C = concentration of fines at the end of placement (g/L), and DTIME = placement period (days)

Two types of consolidation tests were also performed on the composite samples. The self-weight consolidation test (Cargill 1986) was used to evaluate consolidation of the material under its own weight, rather than higher loadings. Standard oedometer consolidation tests (Cargill 1983) were then used to further develop the consolidation curves under higher stresses.

Self-weight consolidation tests were performed on three composite sediments. Standard oedometer tests (USACE 1986, USACE 2015) were performed by the ERDC Geotechnical and Structures Laboratory for three composite samples. Data from both the self-weight and standard oedometer tests were combined to develop e - log p (void ratio vs. effective stress) and e - log k (void ratio vs. permeability) curves for the composites (Figure 4). To evaluate the consolidation in areas that are primarily sand due to separation from the hydraulic slurry, consolidation curves were selected for a sand material from the database within the PSDDF model.

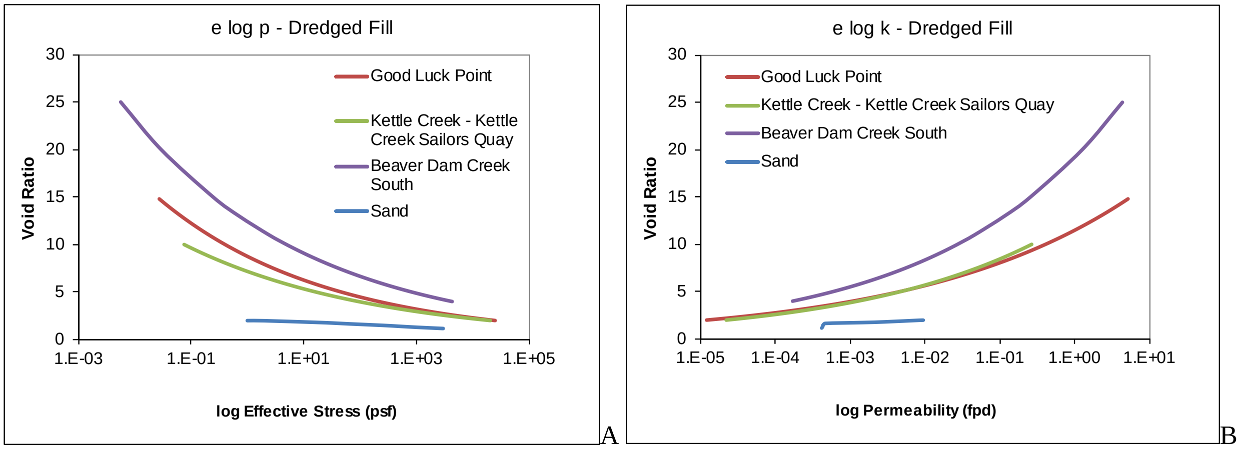

Figure 4. Curves for e - log p (A) and e - log k (B) for Forsythe composite materials and sand.

Modeling

Knowing that the fine-grained dredged fill will consolidate after placement, it was assumed the site would need to be filled above the target elevation in order to achieve the target post-consolidation. An initial fill elevation was selected for modeling the post-consolidation elevation and solved iteratively until the predicted elevation reached the specific target elevation. The modeling results will predict the elevations that would result after a period of consolidation. The modeling effort can then be repeated, adjusting the initial fill elevation accordingly. Target marsh elevations were selected by USFWS for each site based on a survey of the existing vegetation. The target elevations are +19 cm (+0.62 ft) for Good Luck Point; 20 cm (+0.66 ft) and 10 cm (+0.33 ft) for Brick A high marsh and low marsh, respectively; and 23 cm (+0.77 ft) and 13 cm (+0.44 ft) for Brick B high and low marsh, respectively. An initial fill elevation selected for modeling was 30 cm (+1.0 ft) for the fine-grained material. The dredged material volume necessary to fill the site to this elevation [30 cm (+1.ft)] was estimated based on site topography.

The SETTLE model was applied to the three composite samples to determine in situ (in channel) dredging volume that would fill the site to the 30-cm (1-ft) elevation after bulking at the end of placement. Using the compression settling data, the model also predicts the concentration (or void ratio) of fines at the end of placement, which is needed to describe the initial condition of the dredged material for consolidation modeling using PSDDF.

In comparing the available shoal volume in the channel to the available volume at the placement site, it is important to consider bulking, or the volume increase (bulking) due to entrainment of water during dredging. The compression settling curves generated from the column settling results (Table 2) can be used to determine bulking during placement, as follows:

$$\text{Bulking} = V_{\text{final}}/V_{\text{in situ}} \tag{1}$$

$$= C_{in\ situ} \times \left(\frac{Frac_{fines}}{C_{fines,\ final}} + \frac{Frac_{sand}}{C_{sand,\ final}} \right) \tag{2}$$

Where

V_{final} = bulked volume occupied by the dredged material at the end of placement
$V_{\text{in situ}}$ = volume occupied by the sediment in the channel
$C_{\text{fines, final}}$ = concentration of settled fines at the end of placement, g/L
$C_{\text{sand, final}}$ = concentration of settled sand at the end of placement, g/L
$C_{\text{in situ}}$ = concentration of sediment in the channel, g/L
$\text{Frac}_{\text{fines}}$ = fraction of solids that is fine-grained (<75 um); = $M_{\text{fines}}/M_{\text{Total}}$
$\text{Frac}_{\text{sand}}$ = fraction of solids that is sand; = $M_{\text{sand}}/M_{\text{Total}}$
M_{Total} = total mass of solids (sand and fines) (dry weight) in the dredged material

M_{fines} = mass of fines (<75 um) (dry weight) in the dredged material
M_{sand} = mass of sand (>75 um) (dry weight) in the dredged material

$C_{sand,final}$ is generally assumed to be approximately 1,363 g/L (85 lb/cu ft). “Final” refers to at end of placement; “in situ” is in the channel. This information was used to determine the in situ dredging volume required to achieve the fill volume at a given elevation. The information is also useful for determining whether containment is needed during initial placement.

Results from the SETTLE model are given in Table 3 for the three sites.

Table 3. SETTLE output for each placement site.

Parameter	**Units**	**Good Luck Point**	**Brick B**	**Brick A**
Estimated volume to fill to 30 cm (1 ft) elevation	m^3 (CY)	14,783 (19,335)	64,496 (84,357)	104,362 (136,500)
In situ dredging volume to produce bulked volume	m^3 (CY)	4,893 (6,400)	30,582 (40,000)	36,469 (47,700)
Void ratio of fines at end of placement	v/v	11.964	8.064	16.868
Percent of bulked volume occupied by sand	%	14.9	6.6	0.5

It was assumed that the material would initially fill the site to a uniform elevation, producing a range of fill thicknesses across the variable topography (Figure 1). The PSDDF model was used to evaluate the elevation over time for several lift thicknesses within this range for deposits of both sand and fines. Primary input into the model includes: the initial condition (void ratio and thickness) of the newly placed material, consolidation curves for both the dredged material and foundation, local climate information, desiccation parameters for the dredged material, as well as information about the incompressible foundation (bedrock or other incompressible geologic formation far beneath the marsh surface).

Modeling scenarios

Pipeline placement is the most likely placement method for Forsythe NWR. As noted, sands and gravels tend to fall out of the hydraulic slurry rather quickly after discharge, providing a gradation of primarily dense, coarse-grained material near the pipe discharge, to organic materials and fine-grained silts and clays that can flow farther away. Because of the separation and different behavior between coarse- and fine-grained materials, sand is modeled separately from the fines. (Note that for material that is sprayed from a nozzle onto a site, rather than pumped from an open end-of-pipe, this separation may not occur resulting in a more uniform distribution across the surface. Modeling techniques would differ in that case.)

A placement technique being considered is the use of an open end-of-pipe in conjunction with a spreader to place sediment within the deeper ditches, ponds or pannes, which would allow a coarser-grained fraction of the slurry to be deposited in thicker layers to minimize consolidation of these thicker lifts. As the Brick A site has two relatively deep ponds [estimated elevations of -1.3 m and -4.4 m (-4.2 ft and -14.3 ft, respectively)], the sand placement was modeled as 1.5-m and 4.3-m (5-ft and 14-ft, respectively) lifts. Because sand consolidates very little, it was also assumed that sand would not be allowed to mound above the target elevations. Henceforth for modeling lifts of sand deposits, the fill elevation was selected as the site’s target marsh elevation. (This is conservative, as greater consolidation of the foundation is expected under the loading of thick sand lifts.)

Modeling scenarios include placement of fines from each of the three composites at thicknesses ranging from 15 cm to 60 cm (0.5 ft to 2 ft), and placement of sand at approximately 1.5-m and 4.3-m (5-ft and 14-ft) thick lifts to account for placement in the deeper placement areas at Brick A. The fines were modeled as placement to +30 cm (+1.0) ft elevation above reference datum, which was above the design target elevation for high marsh. The sand was modeled as being placed to the respective design target elevations for the ponded areas.

Consolidation curves

The consolidation curves for the fill materials and sand were developed as discussed above (Figure 3). Little consolidation of the foundation is expected under the thinner lifts of material across most of the sites. However, consolidation may be significant beneath the thicker lifts in the ponded areas, especially if the fill material is primarily sand. Several surrogate foundation consolidation curves were analyzed in PSDDF to identify a potential range of foundation settlement values at the sites. Craney Island consolidation curves are built into the PSDDF database, and represent a compressible foundation. The consolidation curves generated from 24-m (80-ft) cores previously examined by ERDC from a wetland site in Louisiana were used as well. Surface samples [top 0.3 m (1 ft) depth] from a nearby wetland at Avalon, NJ were collected and analyzed as well to generate a surrogate consolidation curve, although the shallow surface sample may not be representative of the deeper foundation material. While none of these surrogate curves precisely represent the foundation conditions at Forsythe NWR, they were utilized in PSDDF to illustrate a range of possible consolidation values. Figure 5 below provides the e log p and e log k curves for these three foundation materials. Although some compression of the foundation is expected, because of the thin lifts, this compression is not expected to be greatly significant, and all modeling of the fines layers was done using the Craney Island compressible foundation curves.

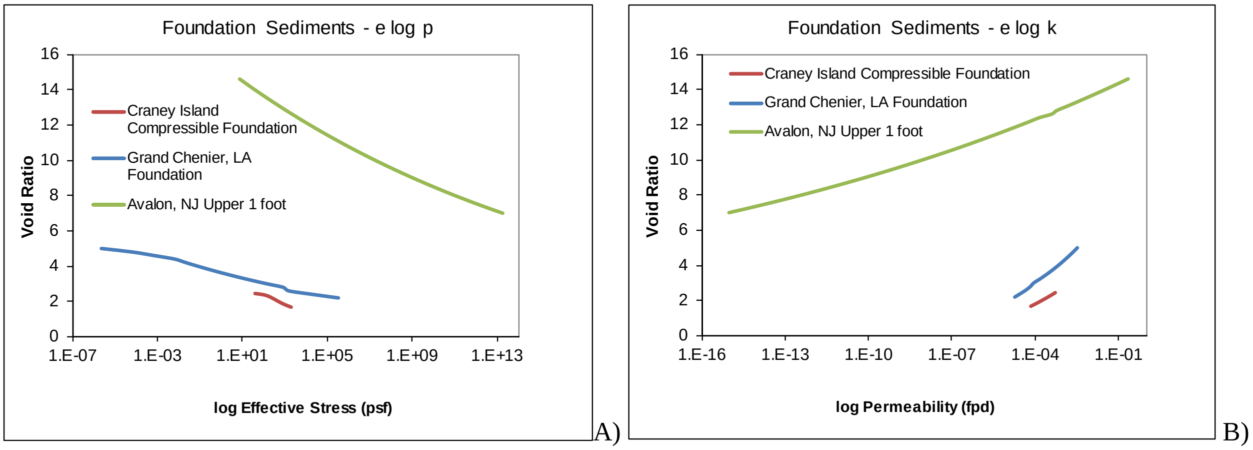

Figure 5. Curves for e - log p (A) and e - log k (B) for potential foundation materials.

Desiccation coefficients for each of the materials were determined based on material properties and PSDDF guidance (Stark 1996). Monthly average precipitation and pan evaporation were obtained for the New Brunswick, NJ area. The depth to an incompressible foundation layer was estimated to be around 79 m (260 ft), based on local geology. An average water table of 0 ft was applied. The model was generally set up to provide output from 30 days up to 5 years after placement, although the primary point of interest was one year after placement.

RESULTS

Fines Consolidation

At Good Luck Point, the design target elevation (at the time of this analysis) for all cells was +20 cm (0.62 ft). The existing topographic elevations at the 6.5-hectare (16-acre) Good Luck Point site range from approximately -24 cm (-0.8 ft) up to and above the design target elevation. The PSDDF model was used to simulate fill to an elevation of 30 cm (1 ft), from pre-placement elevations of -30 cm (-1 ft), -15 cm (-0.5 ft), 0 cm (0 ft), and +15 cm (+0.5 ft) [or thicknesses from 60 cm to 15 cm (2 ft to 0.5 ft)]. PSDDF analysis results in Figure 6 show that the elevation after one year of consolidation would range between +26 cm (+0.87 ft) [teal solid line (top) where the pre-placement elevation is +15 cm (+0.5 ft)] to +6.5 cm (+0.21 ft) [orange, solid line (bottom) where the pre-placement elevation is -30 cm (-1.0 ft)]. The actual pre-placement elevations fall somewhere within this range, with an average elevation around +6 cm (+0.2 ft).

Based on the relationship between pre-placement elevation and the elevation after 1 year of consolidation (see Figure 7), areas that are initially at a pre-placement elevation around -2.7 cm (-0.09 ft) would consolidate to the target elevation after one year. As the average pre-placement elevation is +6 cm (+0.2 ft), most of the site would be above the design target elevation, on average +23 cm (+0.75 ft). For an average pre-placement elevation of 6.4 cm (0.21 ft), it appears a fill elevation of +23 cm (0.77 ft) would yield the target elevation after one year of consolidation.

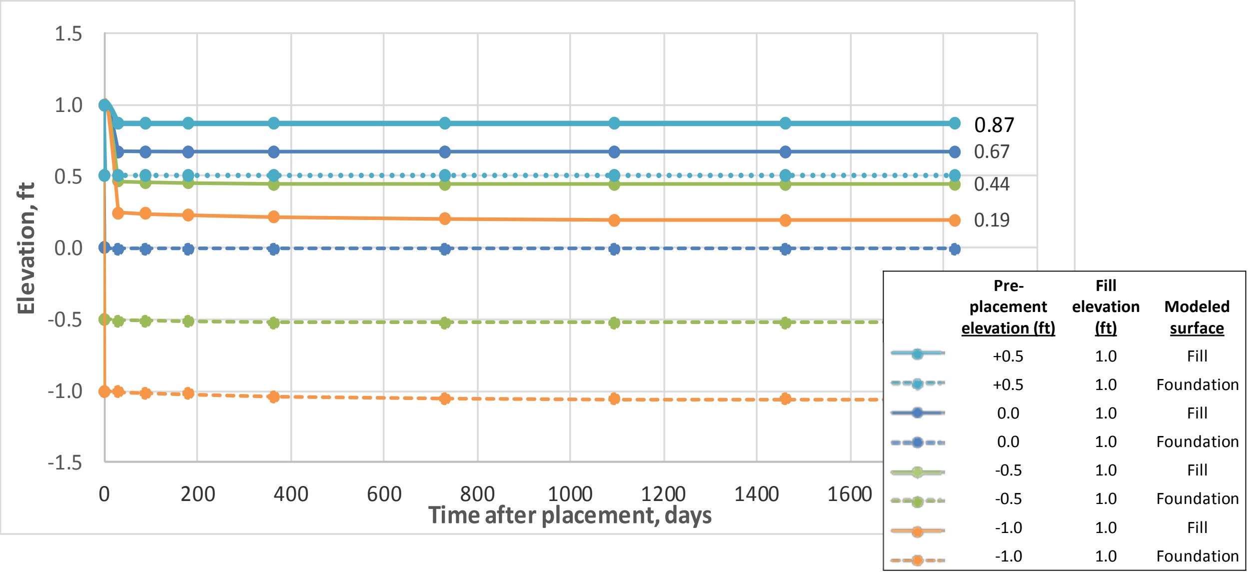

Figure 6. Good Luck Point – Consolidation of material placed to +30 cm (1-ft) elevation. The dotted lines represent the consolidation of the compressible foundation.

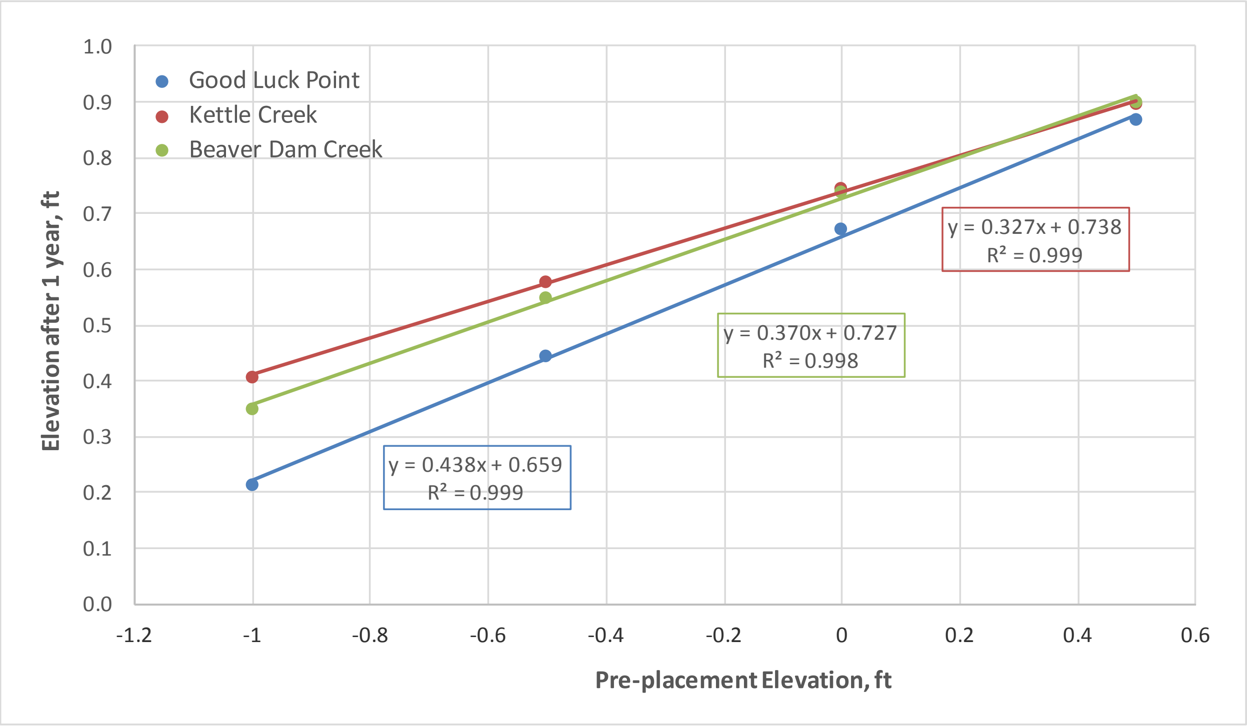

Figure 7. Pre-placement elevation vs. elevation after 1 year of consolidation for each placement site [for initial placement to + 30 cm NAVD88 (+1 ft)].

The targeted high and low marsh elevations at Brick B at the time of this analysis were +23 cm (+0.77 ft) and +13 cm (+0.44 ft), respectively, with 94% of the area targeted for high marsh. The existing elevation is around -27 cm (-0.90 ft) at the lowest point, with an average elevation around +8.0 cm (+0.26 ft). Figure 8 shows the elevation change over time for the fines of the Kettle Creek/Kettle Creek Sailors Quay material placed at the Brick B site to an elevation of +30 cm (+1.0 ft). The results show that after a year, the modeled thicknesses would reach elevations between +12 cm (+0.41 ft) and 27 cm (+0.90 ft), reaching 25 cm (+0.82 ft) at the average pre-placement elevation. Based on Figure 7, material placed to +30 cm (+1.0 ft) from a pre-placement elevation of -28 cm (-0.91 ft) would consolidate to the low marsh target elevation (13 cm (0.44 ft)) and areas around +3.0 cm (+0.10 ft) elevation prior to placement would reach the +23 cm (+0.77 ft) high marsh design target elevation. Therefore, on average, placement to +30 cm (+1.0 ft) is too high, and a lower fill elevation should be selected for both the high and low marsh areas.

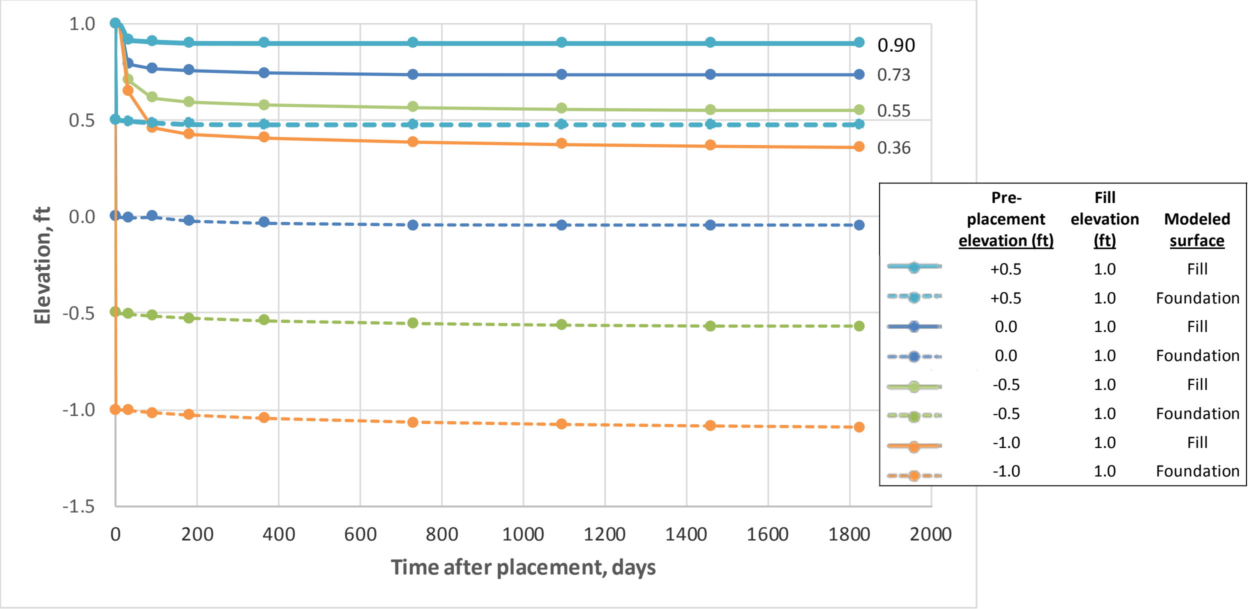

Figure 8. Brick B – Consolidation of Kettle Creek material placed to +30 cm (+1 ft) elevation. The dotted lines represent the consolidation of the compressible foundation.

At Brick A, the target elevations for high and low marsh are +20 cm and +10 cm (+0.66 ft and +0.33 ft), respectively, with about 2/3 of the site targeted for high marsh. The Brick A site has several relatively deep ponded areas approximately 40 cm (1.3 ft), 1.3 m (4.2 ft), and 4.4 m (14.3 ft) deep. Excluding these deep areas, the remaining area has an average elevation around +3 cm (+0.1 ft). Figure 9 shows the elevation change over time for placement of Beaver Dam Creek dredged material at the site to an elevation of +30 cm (+1 ft) with lift thicknesses ranging from 15 cm to 61 cm (0.5 ft to 2 ft) [pre-placement elevations +15 cm to -30 cm (+0.5 ft to -1 ft)]. For the modeled fill thicknesses, the elevations after one year would range from +11 cm (+0.35 ft) to +27 cm (+0.90 ft), and on average would be around 23 cm (+0.77 ft), which is above the design target elevations. Based on Figure 7, this level of fill would consolidate after one year to the low marsh target elevation +10 cm (+0.33 ft) in areas where the pre-placement elevation is -36 cm (-1.18 ft), and to the high marsh elevation of +20 cm (+0.66 ft) where the pre-placement elevation is -6 cm (-0.20 ft). For the average pre-placement elevation, it appears a fill elevation of +18 cm (+0.59 ft) would consolidate to the high marsh target elevation, and fill to 24 cm (0.78 ft) would consolidate to the low marsh target elevation.

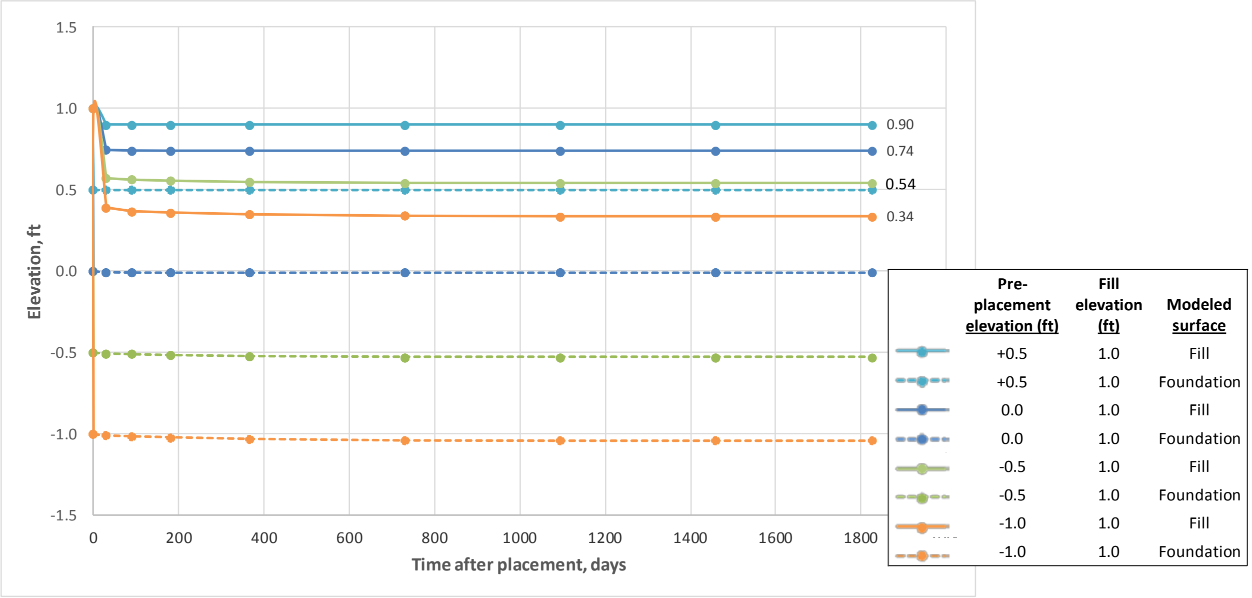

Figure 9. Brick A – Consolidation of Beaver Dam Creek material placed to +30-cm (+1-ft) elevation. The dotted lines represent the consolidation of the compressible foundation.

The discussion above is specifically for the areas where the fines deposit. The sand fraction would be expected to deposit near the end of the pipe discharge, and experience significantly less consolidation compared to the fines-deposited areas. If placing thin lifts, little consolidation of the foundation would also be expected. Therefore the sand deposits were not modeled, except for areas such as the ponds which may have relatively thick lifts of sand.

The weight of thicker lifts of sand is likely to result in more consolidation of the compressible foundation. Therefore the potential foundation conditions were considered for the possible sand deposition in the deep ponds of the Brick A site. Figure 10 shows placement of sand up to the target elevation for the two deep ponds [BRA-8 at about 1.5 m (5 ft) and BRA-10 at about 4.5 m (14.6 ft) deep] in Brick A, assuming the three separate surrogate foundation conditions. For these sets of conditions, a 1.5-m (5-ft) lift of sand placed in the ponded area in BRA-8, up to an elevation of +21 cm (+0.7 ft), would result in consolidation of the foundation up to 15 cm (0.5 ft) after a year and less than 30 cm (1 ft) over five years. Note that the selected consolidation curve does allow for some consolidation of the sand material, up to 15 cm (0.5 ft) for placement of 4.5 m of sand. The resulting elevation would be between -9 cm (-0.29 ft) and +17 cm (+0.55 ft) after one year, and between -20 cm (-0.67 ft) and +12 cm (+0.4 ft) after five years, and would continue to consolidate over the longer term. Placement in the deep pond in cell BRA-10, 4.5-m (14.6-ft) fill to the target elevation of +10 cm (+0.33 ft) would result in similar consolidation of the foundation material [+14 cm (+0.47 ft) to +27 cm (+0.89 ft) after five years]. Based on the curves in Figure 10, it appears consolidation will not taper off significantly after 5 years and consolidation of the material (foundation and fill) could be expected to continue.

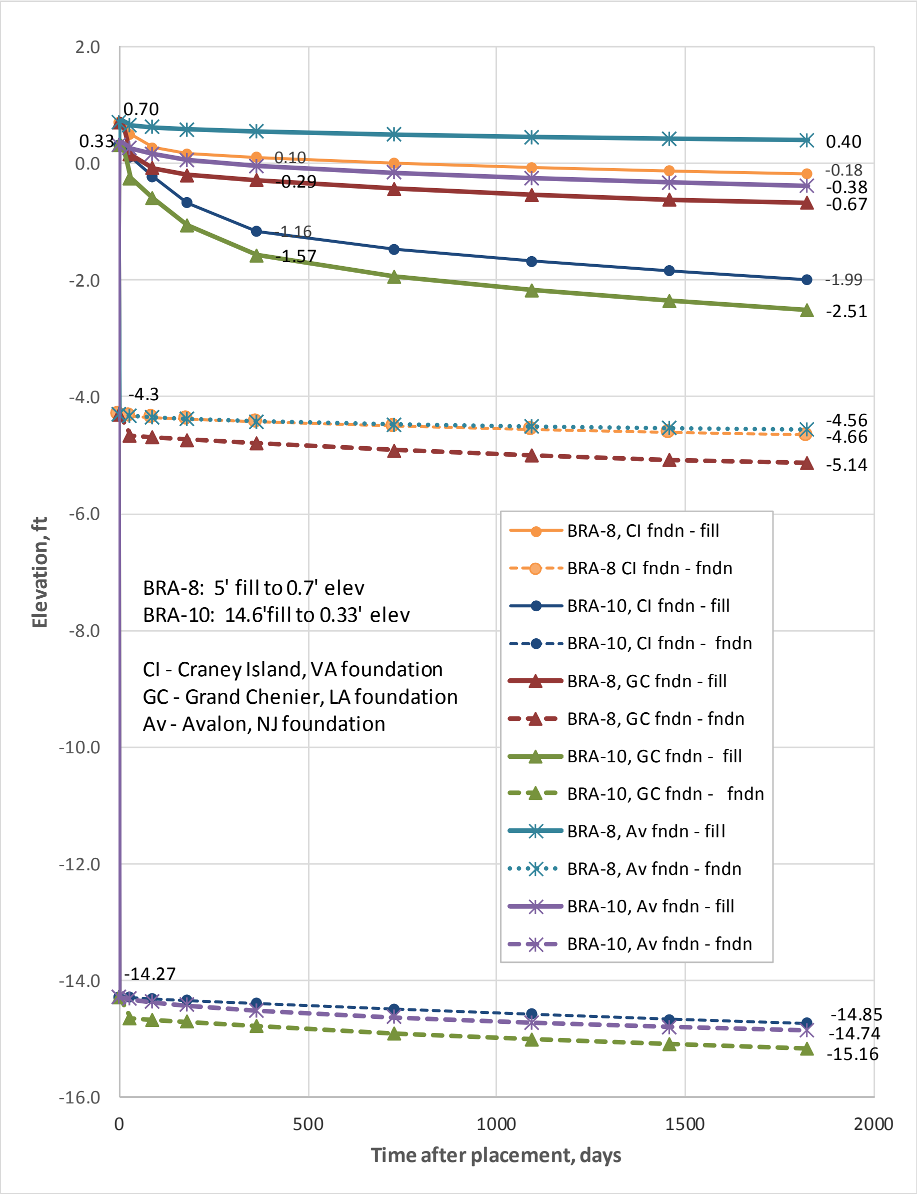

Figure 10. Consolidation of sand in the deep holes in Brick A for varying foundation conditions. The solid lines show elevation of the fill material; the dotted lines show elevation of the foundation.

Although the Avalon and Craney Island foundation materials show very gradual consolidation, the Grand Chenier materials experience most of the consolidation within the 30 days after placement [11 cm (0.37 ft)]. Running the model out to 10 years post-placement for the 4.5-m (14.6-ft) fill scenarios shows the foundation materials had not completely consolidated during that period; the Avalon material consolidating 25 cm (0.83 ft) (12%), Craney Island material 23 cm (0.74 ft) (27%), and the Grand Chenier foundation consolidating 37 cm (1.22 ft) (57%). The Avalon material would settle a total of 2.16 m (7.10 ft) at the end of primary consolidation. Due to the nature of the sample being taken from the upper 30 cm of the site where there was a large fraction of live root mass, it is possibly not representative of the deeper foundation.

Within 5 years of placement, the Good Luck Point, Beaver Dam Creek, and Kettle Creek sediments (fines components of the dredged fill) had consolidated 23 cm (0.75 ft), 19 cm (0.62 ft), and 17 cm (0.55 ft), respectively for the 61-cm (2-ft) lift thicknesses, which is 96%, 94% and 100% of the settlement at the end of primary consolidation.

CONCLUSIONS

This paper described the use of PSDDF to model placement of dredged material at three potential sites within the Edwin B. Forsythe National Wildlife Refuge. While early in the project’s design phase, these preliminary model results showed that the fill elevation of +30 cm (+1 ft) is likely too high to achieve the design target marsh elevations (for both high and low marsh) across most of the sites after a period of one year. In determining a fill elevation, it is important not to overshoot the design target elevation in order to prevent spread of the invasive common reed [*Phragmites australis* (Cav.) Trin. ex Steud.], which tends to dominate at higher elevations. Therefore, the results of this study indicate that additional model runs are needed to investigate placement to lower elevations. One conservative approach is to place material only up to the target elevation for each area; although the entire site will consolidate to below the target elevations, spread of undesirable vegetative species could be avoided. The consolidated elevation should at least be greater than the minimum elevation for *Spartina alterniflora* to establish (low marsh species) over most of the site. Additional material could potentially be added in subsequent dredging cycles.

Evaluation of the three composited fill materials showed the materials to have different properties, which impacts the rate and extent to which they consolidate. Despite being the sandiest, the fines portion of the Good Luck Point sediment showed the most consolidation, with the Kettle Creek/Kettle Creek Sailors Quay material consolidating the least.

Application of surrogate consolidation curves for the foundation material provided a range of what might be expected for the existing marsh foundation at the site. While little consolidation of the foundation is expected for thin lifts, it would be anticipated that the ponded areas would experience a greater amount of consolidation under the weight of thick sand lifts. Additional modeling could be done to determine if similar consolidation occurs for thick lifts of fine-grained material. Also, modeling should be carried out for longer periods to determine how long and the extent to which the foundation will continue to consolidate.

PSDDF modeling, supported by laboratory sediment evaluation is a useful tool for designing thin layer placement projects for marsh nourishment. However, the model was designed for placement in a CDF with periodic placement of thick lifts of dredged material, and therefore does not account for some of the processes occurring within a typical marsh such as fluctuating water tables, and vegetation growth. The effects of these variables are currently being evaluated for incorporation into the model. In the meantime, PSDDF is still a useful tool for understanding the consolidation of dredged material.

While the PSDDF model and supporting laboratory evaluation methods have been developed and verified to simulate the settling and consolidation of dredged material within CDFs, their application to dredged material placed on marshes is limited. The DOER program is currently conducting research to gain a better understanding of the physical processes involved in placement, dewatering and settlement of dredged material in marsh environments (effects of vegetation on placement density, plant transpiration and rooting on consolidation, impact of placement techniques on sand separation and distribution, etc.) to optimize the use of PSDDF.

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