Sears Point Levee Adaptive Management Project

As-Built Report

March 23, 2022

Prepared by

Stuart Siegel, PhD, PWS, Siegel Environmental LLC

www.siegelenvironmental.com

SIEGEL ENVIRONMENTAL

With

Peter Baye, PhD, Coastal Ecologist

Roger Leventhal, PE, FarWest Restoration Engineering

Dan Gillenwater, PWS, Gillenwater Consulting

Prepared for

Sonoma Land Trust

www.sonomalandtrust.org

SONOMA LAND TRUST

This page left blank intentionally

As-Built Report
Sears Point Levee Adaptive Management Project

March 23, 2022

Table of Contents

Figures

Tables

Photographs

Appendices

(all available for download from Sonoma Land Trust at www.sonomalandtrust.org)

Appendix A. Baseline UAV survey report

Appendix B. As-Built UAV survey report

Appendix C. Baseline and As-Built Imagery, Multiple Segments

Appendix D. Baseline and As-Built Topography, Multiple Segments

Appendix E. As-Built Plan Set

Appendix F. Baseline topographic transects survey report

Appendix G. As-built topographic transects survey report

Appendix H. As-built Port of Sonoma Bay Mud Borrow Area Topography

Appendix I. Annotated Construction Photographs

Appendix J. Before-After Photographs

Appendix K. Construction Certification

Appendix L. Cells 6 and 7 Levee Transects, 2015-2021

This page left blank intentionally

As-Built Report
Sears Point Levee Adaptive Management Project

March 23, 2022

1 Introduction

This report presents the design approach, as-built outcomes and lessons learned during construction of the Sears Point Levee Erosion Adaptive Management Project (the "Project") that was undertaken to address significant wind-wave erosion of existing flood protection and ecotone habitat levees. The Project is located at the Sears Point Tidal Wetland Restoration Project (the "Restoration Project") site, located at the northwest corner of San Pablo Bay in southern Sonoma County, California (Figure 1). The Restoration Project restored over 940 acres of former diked Baylands to full tidal conditions on October 25, 2015 (Figure 2) and built new or upgraded existing levees that are the subject of the Project. The Sonoma Land Trust (SLT) undertook the Project as an adaptive management action of the Restoration Project.

The Project is intended to be a pilot to evaluate and possibly demonstrate the ability of nature-based (soft) approaches to manage wind-wave erosion using methods that continue to support achievement of the original tidal marsh and ecotone levee restoration project goals. This approach is in contrast with more hard traditional engineering approaches commonly used (e.g., rock riprap). In 2016, SLT transferred the property to the U.S. Fish and Wildlife Service which designated it as the Dickson Unit of the San Pablo Bay National Wildlife Refuge.

The purpose of this Project is to reduce erosion sufficiently 1) to allow re-establishment of ecotone levee functions on reconstructed levee slopes of the habitat levee that remain after several years of loss from erosion and 2) to avoid encroachment into the core north flood control levee. The project is addressing about two miles of excessively wave-eroded north and west levees at the Project site (Figure 3) using "**nature-based strategies**" (Siegel Environmental 2020).

A major component of the Restoration Project was a wide, gentle-sloped **"habitat" (ecotone) levee**, constructed with 20:1 to 10:1 slopes and including 10 ponds, to provide the ecological *transition zone* from tidal marsh to uplands and to accommodate marsh migration as sea levels rise (Figure 2). All levees on were constructed from locally excavated bay mud and Reyes soils (specified as elastic silt and/or organic silt[1]) from the site's historic diked hayfields:

[1] Hultgren-Tillis (2011), p23

- The northern habitat levee was constructed on the bayside slope of the new flood control levee (Figure 4). This "core" levee was compacted to 90% with the top 6-inch lift being compacted to 95%. The overlaying and adjacent ecotone levee was compacted to 80% (Steve Carroll, Ducks Unlimited, pers. comm., March 2022), to meet the geotechnical specification to support construction equipment[2].
- The western habitat levee was similarly constructed, with the exception that it was constructed atop and alongside the slope of the existing levee separating the project from the adjacent Sonoma Baylands restoration site. This western levee does not serve any flood control functions. The ecotone part of the levee (the bay side slopes) has experienced the significant erosion and loss of habitat that is the focus of the Project.

This practice of constructing ecotone levee side slopes from local, less competent sediment is a common design practice to reduce high costs and impacts of having to find and transport geotechnically more stable levee core material[3]. However, these lightly compacted (80%) ecotone side slopes require some form of erosion control because they are susceptible to wind-wave and rainfall erosion. To provide erosion control, the Restoration Project constructed nearly 500 "marsh mounds" to function as wind-wave breaks (Figure 2). However, these marsh mounds were not vegetatively stabilized prior to tidal restoration, eroded rapidly, and did not function as widely distributed centers of spreading cordgrass marsh which enhances wave energy attenuation. Project construction also included hydromulch application to the ecotone levee slopes. In the winter following the October 2015 levee breach, SLT seeded the fishtail ecotone levee with a mix of natives and sterile erosion control grass and planted a crop of oat hay on the remainder of the northern levee which was repeated at reduced extent the following winter. Notwithstanding these efforts, the initial intertidal and lower ecotone levee shoreline did not self-stabilize with fringing salt marsh and instead locked into a progressive multi-year net erosion trend with periods of temporary marsh establishment (Siegel Environmental 2020).

The progressive erosion of a wave-cut bench profile in portions of the north and west levees since the 2015 restoration project was originally breached (1) disrupted the intended ecological functions of the habitat levee and the forming tidal marsh at the levee toe; (2) created an unintended, abrupt break between terrestrial and tidal marsh vegetation; and (3) had the potential to impair the tidal flood protection and public access functions, if left unchecked. See Photograph 1 for representative photographs of the erosion.

[2] Hultgren-Tillis (2011), p19
[3] Hultgren-Tillis (2011), p18

SLT constructed this Project under the following regulatory authorizations:

1) **U.S. Army Corps of Engineers:** Letters of Modification, Permit No. 2015-00152N, dated May 4, 2020 and April 29, 2021.
2) **San Francisco Bay Regional Water Quality Control Board:** Concurrences, Order No. R2-2013-0017, dated July 8, 2020 and May 3, 2021.
3) **San Francisco Bay Conservation and Development Commission:** Amendment No. Two, Permit No. M2012.022.02, dated October 21, 2020, and Amendment No. Three, Permit No. M2012.022.03, dated June 17, 2021.

Sears Point Tidal Restoration Area

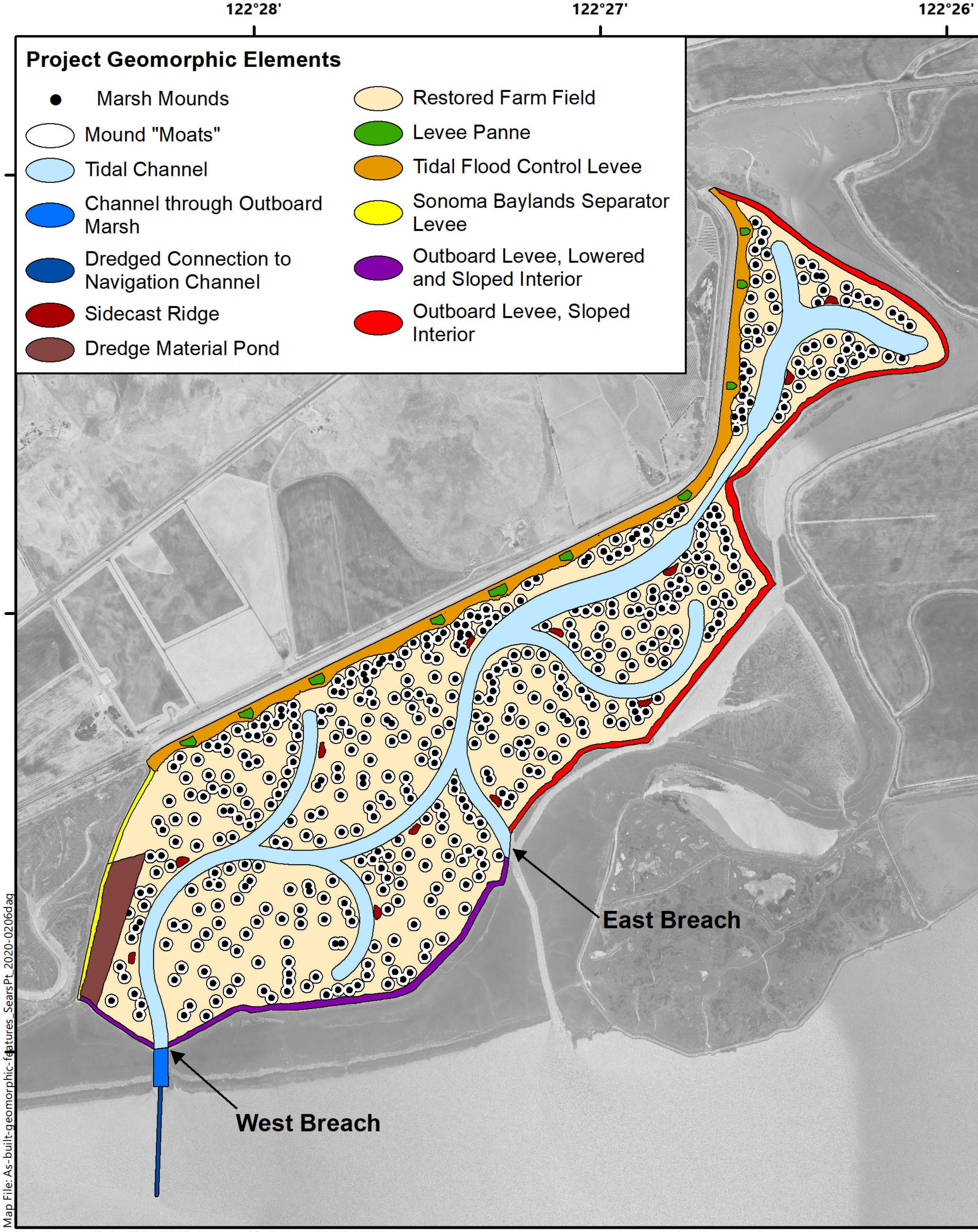
County Land Boundary

Sears Point
Site Location Map
Figure 1

San Francisco Bay National Estuarine Research Reserve

SONOMA LAND TRUST

Data: Sonoma Land Trust, watershed delineation by Camp Dresser & McKee | Aerial Imagery: (c) ESRI, i-cubed 15m eSAT | Map Date: May 2017 | Map Created by J. Kinyon, Sonoma Land Trust



Data Sources: Photo (NAIP, 2016); Geomorphic Features (NERR, 2020)

Sears Point Restoration Project, Sonoma County, CA

As-Built Project Geomorphic Elements

SONOMA LAND TRUST

Gillenwater GillenH2O Consulting

San Francisco Bay National Estuarine Research Reserve

1:24,000 (1" = 2,000' at letter size)

0 1,000 2,000 Feet

0 300 600 Meters

Figure 2

Data sources: Air photo (PAS, 2019; NAIP, 2012); project extent/boundaries (GillenH2O, 2021-2022);

1:24,000 (1" = 2,000' at letter size)

0 1,000 2,000 Ft

0 300 600 M

Sears Point Levee Adaptive Management

Figure 3

Project Area and Site Features

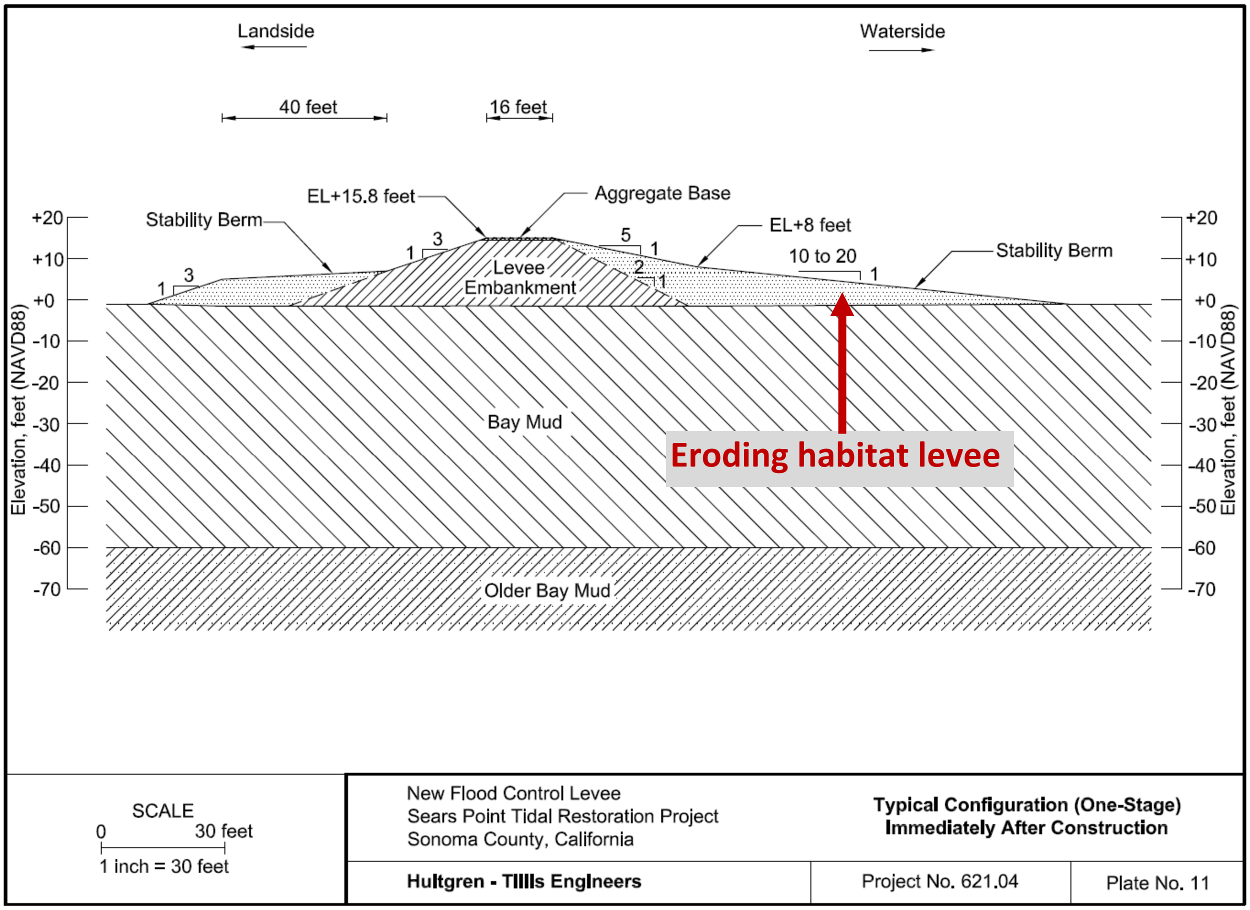
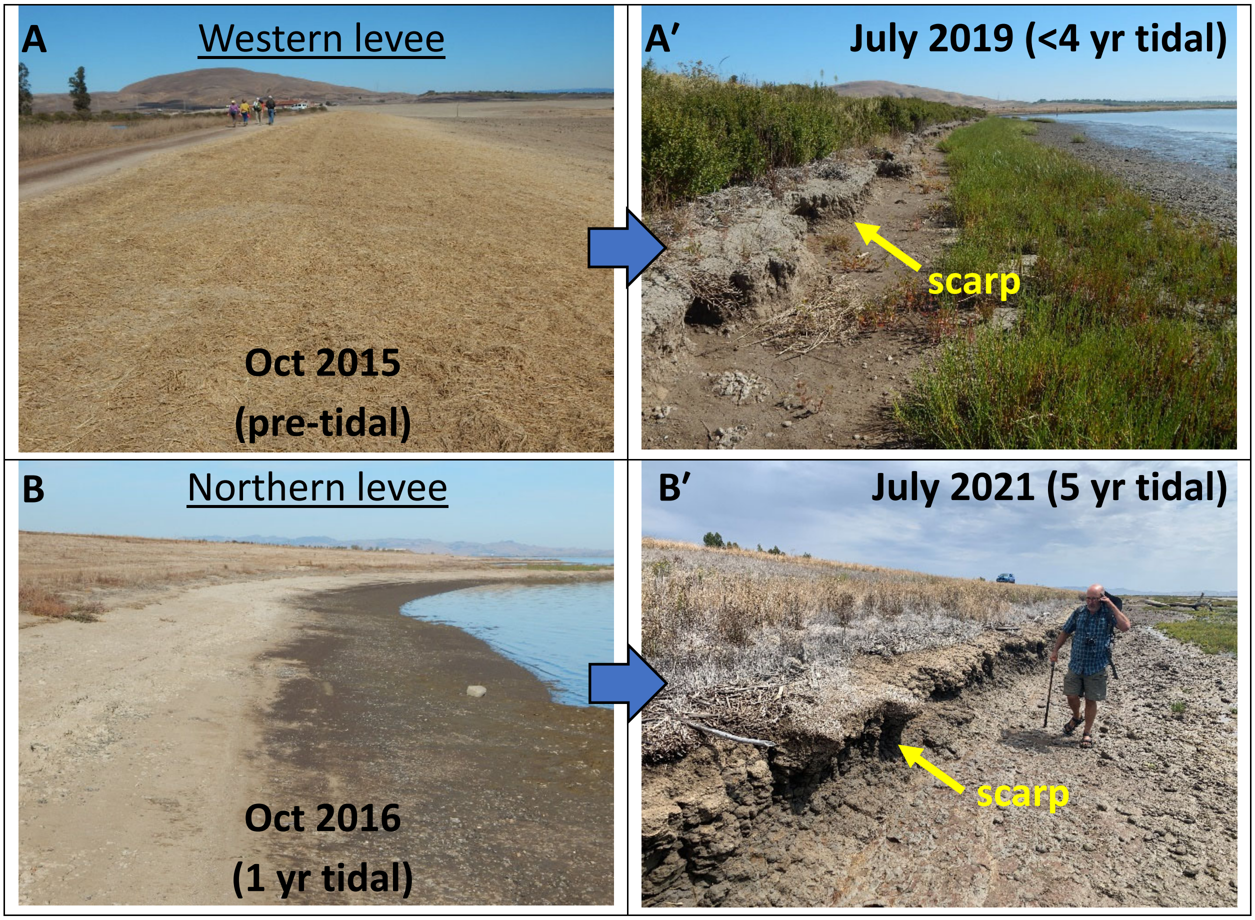


Figure 4. Schematic of Core and Habitat Levee Design and Erosion Area

Source: Hultgren-Tillis 2011



Photograph 1. Examples of Eroding Levee Triggering Adaptive Management Project

2 Design Overview and Basis Summary

Nature-based Living Shoreline Design

The adaptive management pilot Project focused on using "appropriate and feasible" erosion management measures that are compatible with the original ecological objectives and design approach of the original tidal marsh restoration project. The approach focused on using effective ecosystem-based shoreline stabilization techniques that rely on the use of natural sediment (muds and gravel), vegetation, and organic materials at various tidal heights, from higher mudflat through salt marsh and into the terrestrial transition zone (i.e., from about midway between mean tide level (MTL) and mean high water (MHW) up to highest tide line). This design basis originated from the inherent incompatibility between conventional engineered placement of static shoreline armoring ("hardening" shorelines with rock slope protection) and the importance of restoring a dynamic, continuous transition zone (ecotone) supporting native vegetation gradients between high salt marsh and the highest tides (Photograph 2). This "living shoreline" approach also seeks to avoid to the maximum extent possible other artificial stabilization materials and structures for erosion control that are sometimes included in "soft" shoreline stabilization or "living shoreline" methods, such as erosion control geotextile fabric, wave-break berms, rock sills, geotextile tubes, fences, etc. Conventional artificial stabilization materials would likely require both costly installation and post-stabilization removal along the extensive length of proposed erosional shoreline treatment (about 2 miles in total), or it would risk leaving persistent, intrusive, adverse influences in the stabilized transition zone if their remnants were left in place. The only such material used here were metal anchors used for placed logs.

Photograph 2. Shoreline stabilization by armoring (not desired for Sears Point)
Shoreline stabilization by armoring (rip-rap, rock slope protection) eliminates the high salt marsh-terrestrial transition zone and high tide refuge habitat for marsh wildlife. Armoring or other stabilization techniques that impede or exclude continuous transition zone vegetation would be incompatible with Sears Point Wetland Restoration Project ecological objectives.

The "**living shoreline**" approach to erosion control here is to emulate and modify local ecosystem-based processes and materials compatible with dynamic vegetative stabilization. The design basis is to establish initial physical threshold conditions from progressive erosion to deposition and vegetation establishment, triggering positive feedbacks between physical and biological shoreline processes that lead to progressive spread of wave-damping vegetation. The methods and materials for this Project design are based on observed local landforms, sediment transport processes, and vegetation dynamics within contrasting barren erosional and vegetated marsh-dominated shoreline reaches on the project site. No modeling or quantitative analysis was performed.

The Project design was based upon multiple observed local shoreline cycles of “erosion – re-initiation of marsh vegetation – sediment deposition – and return to erosion” occurring between 2016-2019 (since inception of tidal restoration and significant wave action). These processes were selected as the focus for the local approach to “living shoreline” adaptive management actions, and the basis for conceptual designs (Siegel Environmental 2020), as described below and summarized in Table 1.

Table 1. Basis of Design Elements

Design Element	Basis of Design
Scarp grading	Interrupt the positive erosion feedback of wave-reflective scarp profiles
Large woody debris (LWD) placement	Act as local low-crested wave breaks and traps for coarse sediment, sheltering pioneer salt marsh seedlings; mechanism for enhancing marsh nucleation (centers of pioneer marsh establishment and accretion) and vegetative roughness to trap accreted sediment and provide complex habitat structure
Mud placement, below MHHW	Dynamic wave transport of swash bars (mud beach ridges) shoreward to interact with patchy salt marsh vegetation, maturing into natural high salt marsh berms
Mud placement, above MHHW	Fill depressional areas that had formed atop the ecotone levee slope and where horizontal spaces were too tight or vegetation too extensive to grade surrounding soils
Temporary Brush fence	Temporary reduction in wave energy around new cordgrass transplants to prevent erosion from undermining them
Gravel veneer, below MHHW	Resist surface erosion in gaps exposed to wave action among mud mounds, and facilitate seedling colonization and marsh stabilization
Gravel veneer, above MHHW	Resist surface erosion in the high tide zone of maximum wave exposure, and protect seedling roots during periods of high wave action, facilitating vegetative stabilization and deposition
Gravel toe berm	Establish a wave-deposited dynamic vegetated high salt marsh berm that is resilient to extreme storm wave action at high tide and inhibits re-initiation of erosional scarps, with

Design Element	Basis of Design
	flexibility to roll landward with higher sea level and wave runup (Aramburu Island gravel storm berm model)
Pacific cordgrass planting	Increase wave attenuation and support establishment of native tidal salt marsh habitats
Creeping wildrye sod transplanting	Increase soil shear strength at and below the high tide line, increasing perennial vegetative roughness to attenuate wave energy and resist erosion as sea level and maximum wave runup rise

Field Observations Informing the Nature-based Living Shoreline Design

The nature-based living shoreline design constructed at Sears Point originated from several field observations at Sears Point and at other San Francisco bay area marshes.

Intertidal wave-attenuating fringing salt marsh belts

Localized belts (discrete zones) of low salt marsh (*Spartina foliosa*) and middle salt marsh (dominant saltgrass, *Distichlis spicata*, and pickleweed, *Sarcocornia pacifica*) attenuate wave energy over short distances in their lee (landward) (Photograph 3). These belts have developed only in sporadic locations because widespread excessive rates of erosion during the growing season prevent them from establishing as seedling colonies that grow to critical, wave-resilient size before episodes of wind-wave erosion occur. There is an approximate 2-3 year lag between initiation and establishment of tall, dense, efficient wave-damping salt marsh belts, depending on growth and establishment rates that can be manipulated to some extent.

Photograph 3. Observed Wave Damping Benefits of Vegetation at Sears Point
Even narrow marsh belts of flexible, dense shoots of established saltgrass and cordgrass (A, Sears Point southwestern levee), or pure cordgrass (B, Sears Point tidal inlet) cause significant damping of erosional wave energy over short distances of 10-20 ft.

Pioneer colonization of wave-scoured and depositional mud surfaces by native mid to high intertidal salt marsh vegetation

At Sears Point, initiation of wave-attenuating fringing salt marsh above MTL has been repeatedly interrupted by cycles of wind-wave erosion during the growing season as well as in the winter storm season. To establish fringing salt marsh, seedling and juvenile plant growth and development must reach critical size (root anchoring and spread) by the end of the growing season to outpace the rate of surface erosion or undermining by waves (Photograph 4). Otherwise, persistent eroded barrens develop, and compacted levee foundation substrate (relatively more resistant to root penetration) becomes exposed and increases vulnerability of pioneer plants. Reducing short-term surface erosion rates within seedling colonies, in order to enable them to reach critical, resilient individual and patch size, is therefore a potential shoreline stabilization process to integrate with other measures.

Photograph 4. Root systems and uprooted plants

Root systems of pioneer salt marsh plants (A - pickleweed, B - cordgrass) are exposed by rates of erosion that uproot them during the growing season, before plants can establish, anchor themselves, and spread. Uprooted plants wash up on shore (C), leaving exposed, scoured compacted levee foundations that resist root penetration (D) and promote vulnerable, shallow seedling root systems. Summer 2018.

Deposition of large driftwood and establishment of "nursery" wave shelter zones

A half dozen or so large driftwood logs have arrived at Sears Point over the past few years. These embedded coarse woody debris in the upper intertidal zone create "wave shadow" shelter zones in their lee, which act as local traps for coarse sediment and local nurseries for pioneer salt marsh seedlings (seed deposition among debris, sheltered "safe sites" for seedling growth and establishment during long intervals between potential erosion). These are observed nuclei for primary salt marsh succession and development of wave-attenuating marsh zones (Photograph 5). Large driftwood is currently scarce and local in the high intertidal zone. Augmentation of driftwood (individual pieces and jams or aggregates) in the high marsh zone is a mechanism for enhancing marsh nucleation (centers of pioneer marsh colonization and accretion) and providing habitat complexity (shelter, moisture refuge, predator refuge, and support for climbing marsh plant canopies).

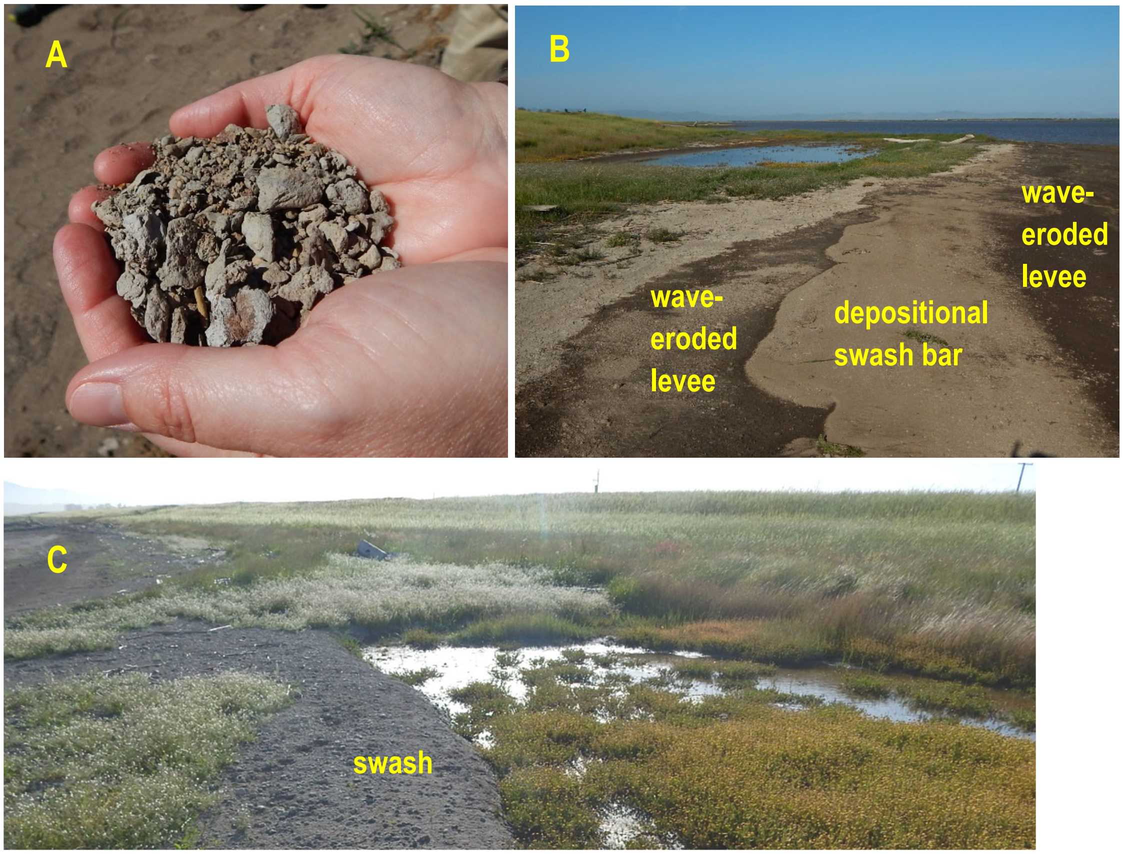
Photograph 5. Vegetated sediment deposits behind large driftwood
Vegetated sediment deposits form locally in wave shadows behind large driftwood, north shore, Sears Point, 2019.

Coarse granular bay mud beach deposition as beach landforms in zones of prevalent levee erosion

During the first two years of tidal restoration, the erosion of compacted bay mud from the constructed levee slopes generated large volumes of sand-sized and gravel-sized mud granules. These adobe-like aggregates of native fine clay-silt sediment behave physically like coarse beach sediment (Allen 1987, Ghandour *et al*. 2013, 2016), and form temporary wave-deposited swash bars (beach deposits) in the uppermost intertidal and wave runup zones, where storm wave erosion impacts on the levee profile are otherwise most intensive (Photograph 6). These mud-grain swash bars migrate onshore during spring high tides that coincide with high wind-wave action that otherwise erodes and suspends cohesive bay mud. Coarse, porous beach particles sap the erosional backwash of waves by infiltration in their large pore spaces, and high frictional energy loss of rolling granules. These hardened bay mud granules will eventually disintegrate back to unconsolidated silt and clay, but they can potentially form temporary depositional marsh berms long enough to establish pioneer vegetation on otherwise wave-cut, eroded levee benches (Photograph 6).

Mud-grain swash bars, deposited on the Sears Point north shore with alongshore patterns, concentrated updrift (west) and downdrift (east) of shoreline protrusions (the ten headlands with ponds, or outcrops of relatively resistant, compacted muds in the constructed levee). The location of these deposits indicated a role of high tide swash-zone longshore drift, due to oblique wave approach from the west – a shoreline configuration that can be manipulated and reinforced to “train” swash bar deposition.

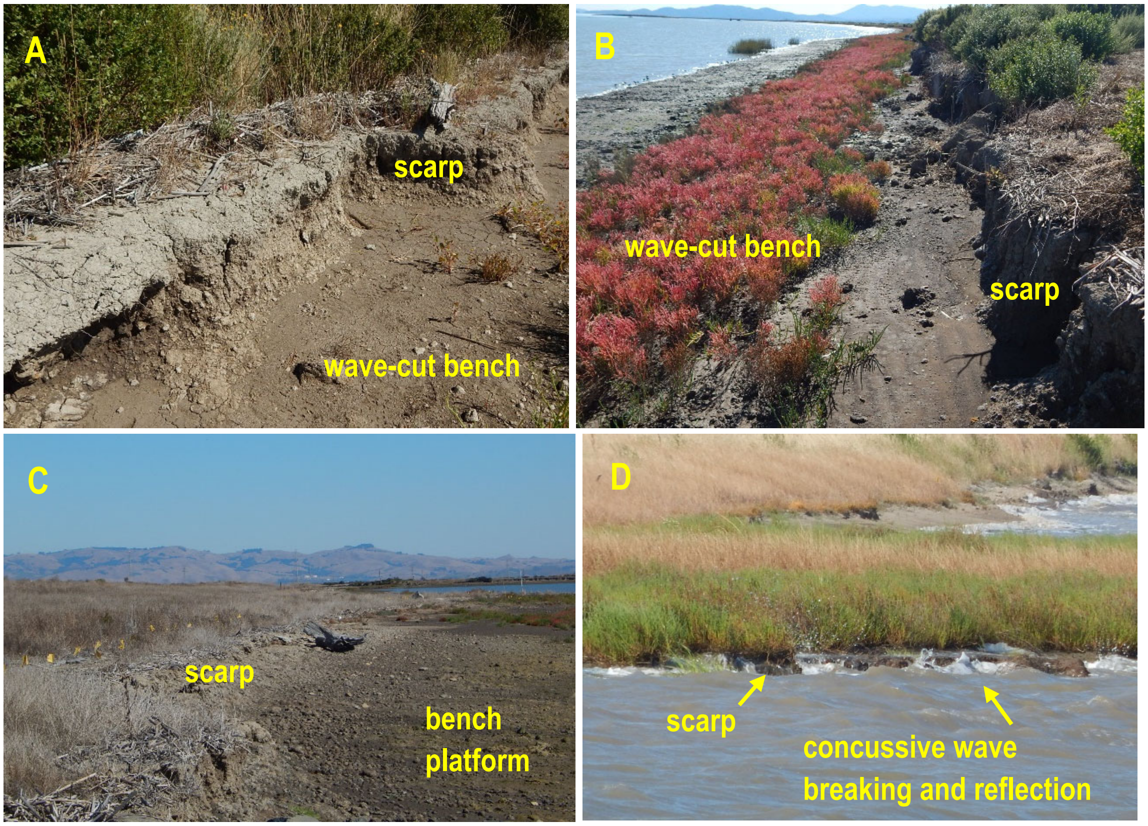
Swash bar accretion is an atypical and unexpected shoreline process in tidal marsh restoration sites and was first observed at Sears Point. The adaptive management project design replicated this distinctive, spontaneous and rapid depositional process. It may have a more widespread potential use as an alternative, nature-based method of establishing high marsh berms and recovering eroded marsh or levee edges with coarse mud aggregates where cohesive bay mud slopes are prone to wind-wave erosion and a supply of suitable dry bay muds is available.



Photograph 6. Aggregates of cohesive, dried clay-silt bay mud sediment
Aggregates of cohesive, dried clay-silt bay mud sediment (A) erode from compacted Sears Point northern levee in the uppermost spring intertidal zone (near or above MHW, where they are subject to drying during neap tides in summer). Eroded aggregates are subsequently deposited by wind-waves as shoreward-migrating swash bars (small upper intertidal to supratidal beach ridges); B-C) up to about 0.5 ft thick, composed of particles equivalent to sand or gravels.

Wave-reflective vertical scarp profiles

Once a cliffed wave-cut bench (near-vertical scarp) forms by severe backshore erosion in weakly consolidated sediments (Photograph 7, A-B), waves at mid-tide stages break on a more dissipative genthly-sloped bench. At the highest tides, waves break on the steepest, most intensively wave-reflective profile, concentrating erosional wave energy at the scarp toe (undermining the base, triggering slope failure) or on the scarp wall itself, where concussive wave breaking and reflection occurs (Photograph 7, C-D). The scarp profile creates a positive feedback for intensive erosion until scarp retreat (progressive erosion toward the shore) flattens the profile to a dissipative one. This positive erosional feedback also creates a turbulent, barren, unvegetated scour zone where waves are reflected (Photograph 7 A-C). Re-grading the steep profile to a gentler slope, combined with additional measures to damp wave energy seaward of the scarp and initiate vegetative stabilization (Photograph 7 A-D above), can interrupt the positive erosion feedback of wave-reflective scarp profiles.



Photograph 7. Actively retreating vertical wave-cut scarps
Actively retreating vertical wave-cut scarps about 0.5-2 ft high form in the northern segment of the western levee (A), and along most reaches of the northern levee at and between constructed pan berms (B, C). Once this steep "cliff" profile develops, erosional wave energy concentrates at the scarp and its toe (scour zone) at high tides, when concussive wave breaking and reflection occurs (D).

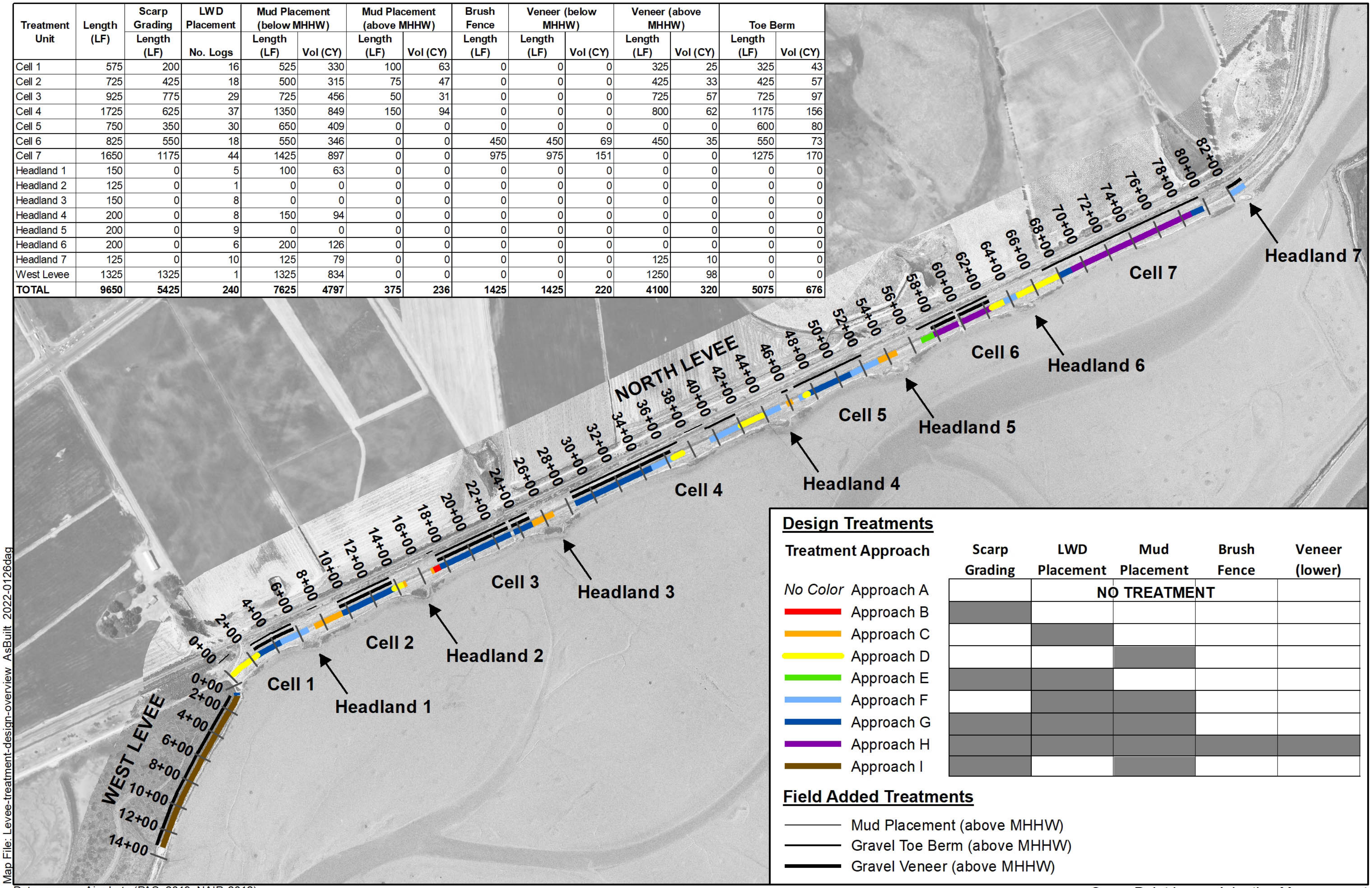
3 Adaptive Construction and As-Built Design Plan Sets

SLT and its design team made “adaptive” modifications to the project during construction. These modifications all fell within the suite of design elements and quantities approved under the regulatory authorizations. Appendix E provides the As-Built Plan Sheets, updated from the July 22, 2021 Final Design Plan Sheet. Figure 5 provides the site overview of the constructed design elements. Table 2 provides an overview of the design changes made. Table 3 presents quantity changes design vs. as-built, by cell and headland.

In summary:

- 50 fewer logs were installed than in the design
- 1,107 cubic yards less bay mud was placed than in the design
- 701 cubic yards more gravel was placed than in the design
- 275 linear feet more of eroded scarp was graded than in the design

Treatment Unit	Length (LF)	Scarp Grading	LWD Placement	Mud Placement (below MHHW)		Mud Placement (above MHHW)		Brush Fence	Veneer (below MHHW)		Veneer (above MHHW)		Toe Berm	
		Length (LF)	No. Logs	Length (LF)	Vol (CY)	Length (LF)	Vol (CY)	Length (LF)	Length (LF)	Vol (CY)	Length (LF)	Vol (CY)	Length (LF)	Vol (CY)
Cell 1	575	200	16	525	330	100	63	0	0	0	325	25	325	43
Cell 2	725	425	18	500	315	75	47	0	0	0	425	33	425	57
Cell 3	925	775	29	725	456	50	31	0	0	0	725	57	725	97
Cell 4	1725	625	37	1350	849	150	94	0	0	0	800	62	1175	156
Cell 5	750	350	30	650	409	0	0	0	0	0	0	0	600	80
Cell 6	825	550	18	550	346	0	0	450	450	69	450	35	550	73
Cell 7	1650	1175	44	1425	897	0	0	975	975	151	0	0	1275	170
Headland 1	150	0	5	100	63	0	0	0	0	0	0	0	0	0
Headland 2	125	0	1	0	0	0	0	0	0	0	0	0	0	0
Headland 3	150	0	8	0	0	0	0	0	0	0	0	0	0	0
Headland 4	200	0	8	150	94	0	0	0	0	0	0	0	0	0
Headland 5	200	0	9	0	0	0	0	0	0	0	0	0	0	0
Headland 6	200	0	6	200	126	0	0	0	0	0	0	0	0	0
Headland 7	125	0	10	125	79	0	0	0	0	0	125	10	0	0
West Levee	1325	1325	1	1325	834	0	0	0	0	0	1250	98	0	0
TOTAL	**9650**	**5425**	**240**	**7625**	**4797**	**375**	**236**	**1425**	**1425**	**220**	**4100**	**320**	**5075**	**676**



Design Treatments

Treatment Approach	Scarp Grading	LWD Placement	Mud Placement	Brush Fence	Veneer (lower)
No Color Approach A	NO TREATMENT				
Approach B (red)	■				
Approach C (orange)		■			
Approach D (yellow)			■		
Approach E (green)	■	■			
Approach F (light blue)		■	■		
Approach G (blue)	■	■	■		
Approach H (purple)	■	■	■	■	■
Approach I (brown)	■		■		

Field Added Treatments

- Mud Placement (above MHHW)
- Gravel Toe Berm (above MHHW)
- Gravel Veneer (above MHHW)

Data sources: Air photo (PAS, 2019; NAIP, 2012);
Design data (SE, 2022)

1:12,000 (1" = 1,000' at letter size)
0 500 1,000 Ft
0 150 300 M

Sears Point Levee Adaptive Management

Figure 5

SONOMA LAND TRUST
SIEGEL ENVIRONMENTAL

Adaptive Management Treatment Overview

Table 2. Summary of Changes Between Design and Construction, by Cell and Headland

Design Feature	Change	Locations Changed	Basis of Change
Log placement	Reduced logs from 272 to 239	North levee	Reduced space available above MHW; Reduced need for bayward logs in expanded cordgrass zone on flatter, wider, lower wave-cut bench
	Reduced logs from 18 to 1	West levee	Reduced space available above MHW; Expanded vegetation reduced space for log placement
Scarp grading	Added 245 LF	Cells 1, 2, 3, 7	• Cell 1: reduced need to avoid damage to native salt marsh transition zone vegetation, due to erosion loss since design. • Other cells: field fit grading needs
Bay mud placement	Reduced total quantity from 6,140 to 5,033 CY, or -1,107 CY	Throughout site	• Application rates to meet project design specifications proved lower than anticipated • Areas of natural vegetation expansion needed less mud to meet design specifications
Gravel toe berm	Added 3,625 LF, 381 CY	Cells 1-5	Successful early performance in cells 6 and 7 during major October 2021 storm made clear the value of this design element across much of northern levee. Field fit slightly reduced applied volumes in cells 6 and 7.
Gravel veneer above MHHW	Added 2,850 LF, 222 CY	Cells 1-4, 6, Headland 7	• Successful test in cells 6, 7 during major October 2021 storm illustrated value of this adaptive management design element. • Placed in advance of gravel toe berm. At time of placement, toe berm completed in cell 5 and partially completed cell 4.
	Added 1,250 LF, 98 CY	West levee	
Creeping wild rye	Harvested sod on-site vs. preserved remnant patches	North levee	• Sporadic patch size and location made salvage labor too high • Extensive beds on site readily harvested and placed, making labor far less intensive at scale and outcome more robust
	Increased area receiving revegetation	Most of north and west levee	Extent of levee slope construction disturbance indicated benefit of broader revegetation effort

Table 3. Quantity Changes Between Design and Construction, by Cell and Headland

Treatment Unit	Length (LF)	LWD Placement (no. logs)			Mud Placement (below MHHW)						Mud Placement (above MHHW)						Brush Fence (Length, LF)
					Shoreline Length (LF)			Volume (CY)			Shoreline Length (LF)			Volume (CY)			
		Design	As-Built	*Change*	Design	As-Built	*Change*	Design	As-Built	*Change*	Design	As-Built	*Change*	Design	As-Built	*Change*	No change
Cell 1	575	7	16	9	200	525	325	200	330	130	0	100	100	0	63	63	0
Cell 2	725	13	18	5	500	500	0	500	315	-185	0	75	75	0	47	47	0
Cell 3	925	26	29	3	750	725	-25	765	456	-309	0	50	50	0	31	31	0
Cell 4	1725	52	37	-15	1325	1350	25	1350	849	-501	0	150	150	0	94	94	0
Cell 5	750	20	30	10	575	650	75	590	409	-181	0	0	0	0	0	0	0
Cell 6	825	19	18	-1	575	550	-25	570	346	-224	0	0	0	0	0	0	450
Cell 7	1650	57	44	-13	1675	1425	-250	1710	897	-813	0	0	0	0	0	0	975
Headland 1	150	13	5	-8	50	100	50	70	63	-7	0	0	0	0	0	0	0
Headland 2	125	9	1	-8	0	0	0	0	0	0	0	0	0	0	0	0	0
Headland 3	150	12	8	-4	25	0	-25	30	0	-30	0	0	0	0	0	0	0
Headland 4	200	12	8	-4	25	150	125	35	94	59	0	0	0	0	0	0	0
Headland 5	200	14	9	-5	50	0	-50	40	0	-40	0	0	0	0	0	0	0
Headland 6	200	10	6	-4	150	200	50	155	126	-29	0	0	0	0	0	0	0
Headland 7	125	8	10	2	100	125	25	125	79	-46	0	0	0	0	0	0	0
West Levee	1325	18	1	-17	0	1325	1325	0	834	834	0	0	0	0	0	0	0
TOTAL	9650	290	240	-50	6000	7625	1625	6140	4798	-1342	0	375	375	0	235	235	1425

Treatment Unit	Length (LF)	Scarp Grading (Length, LF)			Veneer Placement (above MHHW)						Toe Berm						Veneer (below MHHW) (Vol, CY)
					Shoreline Length (LF)			Volume (CY)			Shoreline Length (LF)			Volume (CY)			
		Design	As-Built	*Change*	Design	As-Built	*Change*	Design	As-Built	*Change*	Design	As-Built	*Change*	Design	As-Built	*Change*	No change
Cell 1	575	0	200	200	0	325	325	0	25	25	0	325	325	0	43	43	0
Cell 2	725	395	425	30	0	425	425	0	33	33	0	425	425	0	57	57	0
Cell 3	925	820	775	-45	0	725	725	0	57	57	0	725	725	0	97	97	0
Cell 4	1725	625	625	0	0	800	800	0	62	62	0	1175	1175	0	156	156	0
Cell 5	750	350	350	0	0	0	0	0	0	0	0	600	600	0	80	80	0
Cell 6	825	550	550	0	0	450	450	0	35	35	450	550	100	92	73	-19	69
Cell 7	1650	1215	1175	-40	0	0	0	0	0	0	1000	1275	275	203	170	-33	151
Headland 1	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Headland 2	125	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Headland 3	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Headland 4	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Headland 5	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Headland 6	200	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Headland 7	125	0	0	0	0	125	125	0	10	10	0	0	0	0	0	0	0
West Levee	1325	1225	1325	100	0	1250	1250	0	98	98	0	0	0	0	0	0	0
TOTAL	9650	5180	5425	245	0	4100	4100	0	320	320	1450	5075	3625	295	676	381	220

4 Baseline and As-Built UAV Imagery, Photogrammetry and Topographic Transects

The Project flew aerial imagery and photogrammetry for baseline conditions on June 16 and 30, 2021 and as-built on December 9, 2021, utilizing unmanned aerial vehicles operating off the Refuge property. Data reports for each flight are in Appendix A and Appendix B, respectively.

The results are provided in this report as follows:

1) Figure 6 provides the baseline imagery for the entire Project area
2) Figure 7 provides the as-built imagery for the entire Project area
3) Appendix C provides the baseline and as-built imagery "close up" views, consisting of 11 frames to cover the Project area in detail
4) Appendix D provides the baseline and as-built photogrammetry-derived topography "close up" views, consisting of 11 frames to cover the Project area in detail

We collected baseline topographic transects (26 transects) on May 6, 2021 (Appendix F) and as-built transects (48 transects including the 26 baseline transects) as construction proceeded (November 5, 8, 24 and 26, 2021, Appendix G). Both surveys were conducted with RTK-GPS (Real-time kinematic global positioning system) equipment. The as-built plan set sheets 9 through 11 (Appendix E) present the data plots for all these transects. Figure 9 presents representative transects to illustrate the nature of the constructed change. It is important to note that the "as-built" data for the project elements designed to be mobile (placed bay mud and gravel toe berms) represent conditions at time of the survey and not at time of material placement which may have been days or weeks prior.

Map File: drone-orthoimagery_SearsPt_June2021_2022-0111

Data sources: Basemap (NAIP, various);
Orthomosaic imagery (EnviroDrones, 2021)

1:15,600 (1" = 1,300' at letter size)

0 650 1,300 Ft

0 200 400 M

Sears Point Levee Adaptive Management

SONOMA LAND TRUST

SIEGEL ENVIRONMENTAL

Figure 6

June 16 and 30, 2021 (Pre-Construction) Orthomosaic Imagery

Map File: drone-orthoimagery_SearsPt_Dec2021_2022-0111

Data sources: Basemap (NAIP,various);
Orthomosaic imagery (SFEI, 2021)

Sears Point Levee Adaptive Management

1:15,600 (1" = 1,300' at letter size)

0 650 1,300 Ft

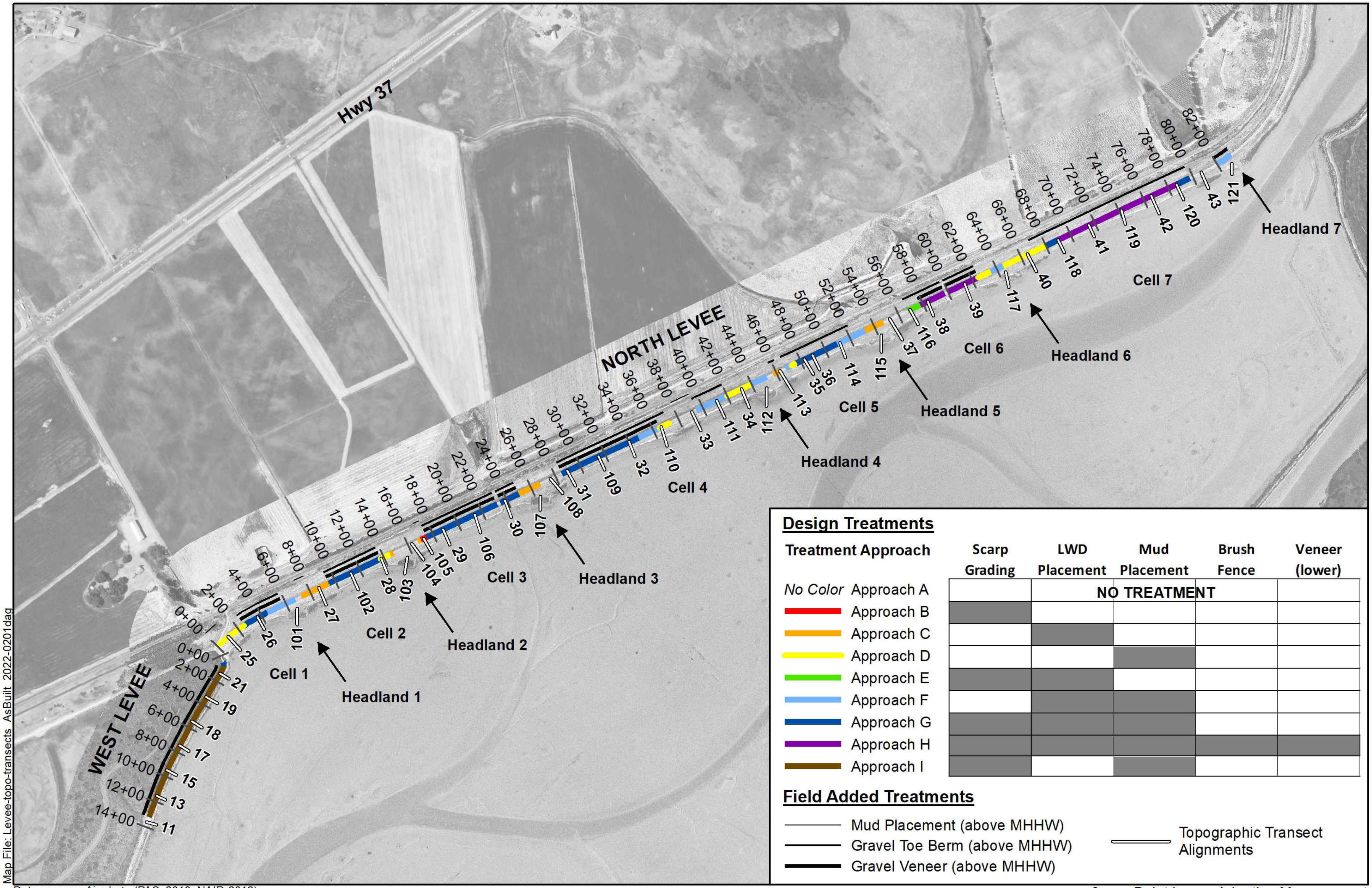
0 200 400 M

SONOMA LAND TRUST

SIEGEL ENVIRONMENTAL

Figure 7

December 9, 2021 (Post-Construction) Orthomosaic Imagery



Data sources: Air photo (PAS, 2019; NAIP, 2012);
Design data (SE, 2022)

1:12,000 (1" = 1,000' at letter size)

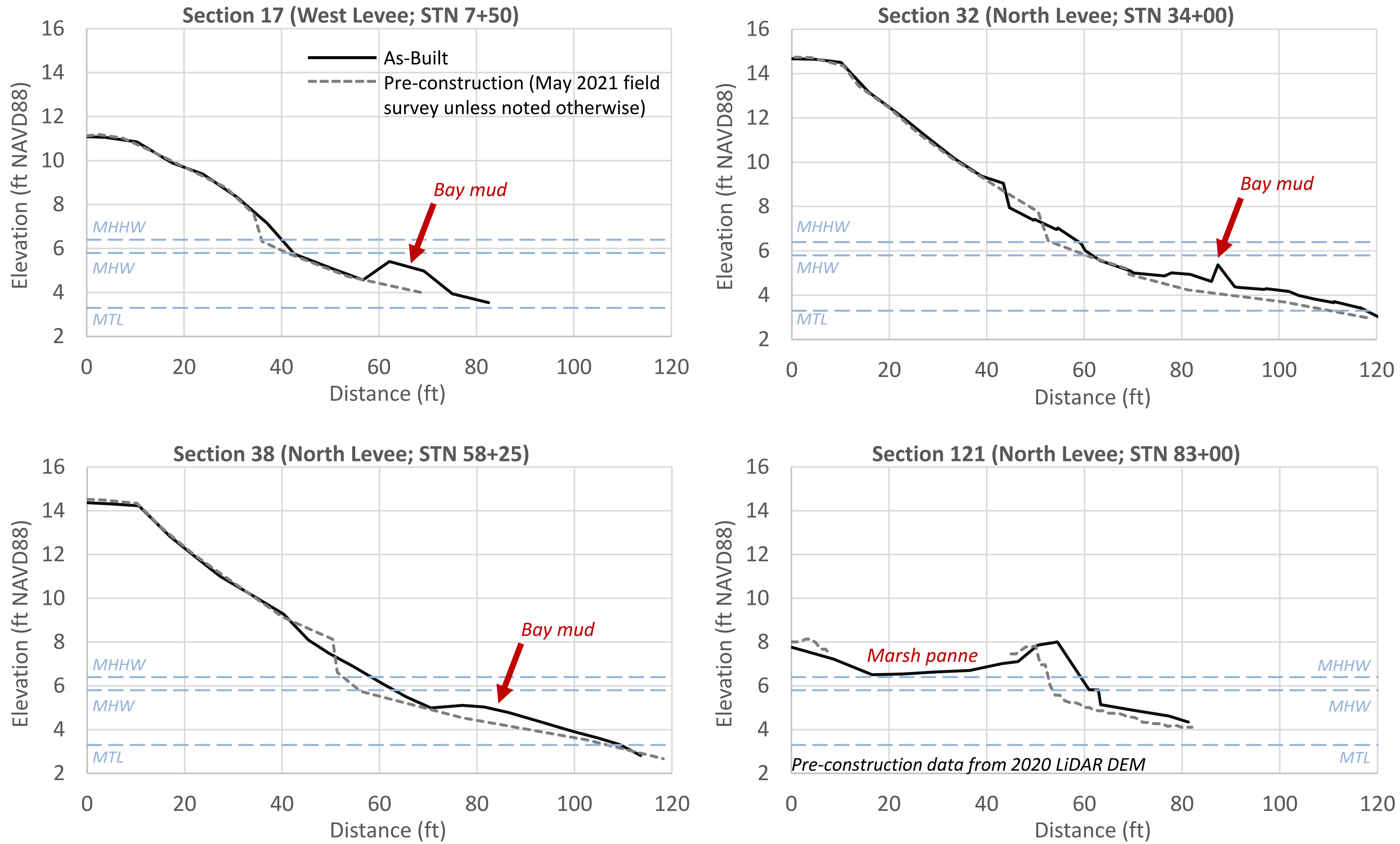
0 500 1,000 Ft

0 150 300 M

Sears Point Levee Adaptive Management

Figure 8

As-Built Topographic Transect Locations



File: Fig-09_representative XS plots_Sears Pt_2022-0320sws.pptx

SONOMA LAND TRUST

SIEGEL ENVIRONMENTAL

Sears Point Levee Adaptive Management Project
Sonoma County, CA

Figure 9

Representative As-Built Levee Topographic Cross Sections

5 Construction Summary

5.1 Construction Sequence

Construction followed the schedule and sequence shown in Table 4.

Table 4. Construction Sequence Overview

Activity	Time Period
Materials: Log delivery	Spring and summer 2021
Prepare staging area and mobilize equipment	Week of 8/23/2021
Trail closure	8/25/2021
Site preparation (staking, haul route protections, SWPPP measures)	Week of 8/23/2021
Construction initiation	8/26/2021
Materials: Soils borrow from Port Sonoma	~9/1/2021 to 10/7/2021
Materials: Gravel deliveries	Periodically during construction. Rock delivery began with the toe berm/veneer gravel on 9/1 and finished on 12/3 with the quarry fines for levee trail resurfacing
Construction completion	12/2/2021
Site closure (resurface levee, cleanup site and staging area)	11/29/2021 – 12/3/2021
Construction closure site walk	12/6/2021
Trail reopening	12/6/2021

5.2 Description of Construction Approach by Element

Appendix I presents a series of annotated photographs that illustrate the construction of each of the project elements. The following discussions describe construction of each element.

Mid-intertidal brush fence

In cells 6 and 7, temporary brush fences were placed in two sub-parallel rows near MTL. These two cells received this additional treatment based on the greater degree of mudflat erosion observed in early 2021, relative to the other cells, as began planning for construction. The function of brush fencing is to provide temporary localized wave baffles (increased roughness causing local wave energy attenuation) to reduce risks of wave erosion around new cordgrass plug transplants during establishment and early growth stages in 2021 through spring 2022.

Coyote brush branches were manually cut from trunks on shrubs in designated areas (dense, decadent stands) bordering railroad tracks in between Sonoma Baylands and Sears Point project site. Cut brush was stacked and hauled by truck to the shoreline for installation by field crews. Cut brush was loaded on a large aluminum mud sled which was pulled into position near the MTL by a long-reach excavator. The sled was dragged on the mud surface in pace with installation sites (**Error! Reference source not found.**). The cut end of branches was manually inserted into deep (approximately 2 ft) soft, semi-fluid mud at oblique angles, with brush ends facing east, away from the predominant wave approach direction. Alternating branches were crisscrossed and overlapped, interlocking tangled successive branches (braided pattern). Branch bases were inserted at least 1 foot below mud surface level. Two brush fence rows, about 5-7 ft apart, were installed on mudflats near the toe of the sloping levee bench, where some previous cordgrass transplants survived, and where supplemental cordgrass plugs were transplanted following brush fence placement.

Photograph 8. Brush Fence Installation

Sacrificial dry aggregate bay mud mound placement

Dry aggregate bay mud was excavated and trucked from the Port Sonoma dredged mud storage areas (old dredge ponds last added to 15-20 years ago and long drained) and stockpiled near the barns in the southeast corner of Leonard Ranch (see Plan Sheet 2, Appendix E). Dry mud broke into cohesive aggregates during this excavation, transport, and stockpiling, yielding clasts (aggregates) ranging from cobble to gravel and sand size. Aggregate bay mud was further fragmented (lower cobble size frequency, higher gravel-sand size clasts) during loading and transport by excavator and trucks delivering it to the long-reach excavator used for placement.

The design placement zone for aggregate bay mud was from MHW (5.8 ft NAVD88) down to mid-point between MHW and MTL (4.6 ft NAVD88), below placed logs. By the time of construction, some of these mud placement areas remained unvegetated accreted mud, but others had been colonized by cordgrass and/or pickleweed in variable density and patch sizes. Since the basic purpose was to facilitate vegetative stabilization, avoidance of direct smothering of the new salt marsh patches was a priority for adapting the design during construction (Photograph 9).

Photograph 9. Placement of Dry Aggregate Bay Mud Around Vegetation
The long-reach excavator worked carefully around emergent vegetation

Larger blocks of aggregate bay mud mounds were placed immediately bayward of embedded logs, where salt marsh vegetation was absent or very sparse (Photograph 10). Gaps (shore-normal swales) were left between logs to prevent obstruction of tidal drainage between new mounds. Where vegetation was present, aggregate dry mud was placed in barren patches amongst the vegetation and also sparsely within the vegetation. Here, bay mud mounds were placed with high precision around patches of cordgrass and pickleweed seedling-juvenile transition plants, and mature patches. Direct partial burial of standing pickleweed and cordgrass patches with large numbers of closely spaced plants, with minimal lodging (flattening stems horizontally), was performed by shaking the excavator bucket over the patches as the bucket was raised, slowly precipitating granular dry mud over the plants. This adaptation technique was developed by the equipment operator to cope with increased dispersion of pioneer salt marsh plants in target deposition zones.

Photograph 10. Placement of Dry Aggregate Bay Mud Below Logs

On the west levee, where larger patches of cordgrass extended below the continuous salt marsh fringe, additional aggregate bay mud mound placement was more irregular, fitted around cordgrass patches instead of log gaps. Drifting aggregate mud after placement partially choked some of the gaps.

Embedded log (mimic natural driftwood) placement

Sets of logs were selected by size and type for each cell and stockpiled on the levee near installation locations. Log end locations in the upper intertidal zone were flagged days prior to placement. Log spacing and orientation were modified to adapt to a narrower high marsh zone (MHW to MHHW closer to the scarp position, caused by recent acceleration of erosion prior to construction). Log orientations were set to align parallel with predominant wind-wave crests (S-SW) directly observed at the shore during the summer of construction (subjective visual estimation) (e.g., Photograph 10). Shallow trenches were made by a short-reach excavator working from wood mats on either firm ground on the lower levee slope, or on berms over high salt marsh (pickleweed). Logs were placed into the shallow trench by the excavator bucket with a “thumb”. The margins of the log were backfilled with mud, and logs were secured in place by metal cables anchored by “duckbills” and, for a handful of logs, with 4x4 untreated wood posts. Where wood anchors were used, the tops were cut to match the log, to avoid creating raptor perches. Coyote brush was installed to emerge from both sides of the log, to aid in promoting sediment deposition. Coyote brush placement took place before and after log installation, depending on what proved most effective. See Photograph 11.

Photograph 11. Installation of logs and fringing coyote brush

Sacrificial gravel toe berm placement

Coarse mixed alluvium, composed primarily of pea gravel with variable mixture of sand and mud, was trucked to the north levee. The contractor used an excavator to place immediately below the observed position of the highest winter drift-lines (maximum wave runup position during highest tides with high waves; approximately 8-9 ft NAVD88), in the form of a temporary, low, steep sacrificial berm (Photograph 12). The initial berm is intended to erode and re-deposit as a better-sorted, mobile gravel swash bar (low beach ridge and beachface deposited over the re-graded bay mud levee slope). This redistribution occurs via winter high tides with high wave action and some spring high tides in summer with high wave action. The late-stage evolution of the wave-redeposited gravel berm aimed towards high salt marsh and transition zone vegetation, following the gravel storm berm model at constructed at Aramburu Island (Gillenwater and Baye 2022, SFEI and Baye 2020). The final gravel berm and beachface formed dynamically s and was not constructed to a specific location and height. The wave-deposited gravel berm is aimed at inhibiting re-initiation of scarps in underlying bay mud levee slopes and at absorbing high wave energy. Though originally included for cells 6 and 7 only, this gravel placement was added to the remaining north levee cells during the construction phase to inhibit levee erosion and provide an additional layer of protection for higher energy events.

Photograph 12. Sacrificial Berm at Placement and During Wave Reworking

Gravel lag armor placement, above MHHW

A *thin* veneer of coarse, ¾" angular gravel (quarry drain rock) was placed over the wave-impacted upper intertidal zone and into the transition zone above the logs (Photograph 13). The purpose of this thin gravel veneer is to resist surface erosion and reduce wave exposure of seedling roots during periods of high wave action. The thickness of the armor layer was aimed at one particle, with gravel cover density allowing some exposure of underlying bay mud to facilitate interstitial salt marsh seedling establishment. This veneer is distinct from the gravel toe berm in that is intended to remain where placed as a static erosion protection feature, whereas the toe berm is intended to be wave re-deposited to place its erosion protection functions in locations to where natural processes move it. Gravel was placed by shaking the excavator bucket while slowly raising it and swinging it laterally by the skilled equipment operator, allowing fine control of how fast the bucket sprinkled the gravel . The angular gravel was gently tamped into moist mud to embed it in the surface.

Photograph 13. Gravel veneer thin layer above logs placed before gravel toe berm

Gravel lag armor placement, below MHHW

In cells 6 and 7 only, a thin veneer of coarse, 2-3" angular gravel (quarry drain rock) was placed over the eroded lower terrace in advance of the bay mud placement. This veneer is intended to resist surface erosion if the bay muds are fully transported down-shore and are not replaced by muds drifting in from up-shore. This extra treatment was deemed necessary following the April 2021 site visit, reflecting observations of active erosion of the previously deposited bay mud and further into the underlying constructed habitat levee. The closer presence of the deep and wide primary tidal channel of the restored marsh may have reduced the wave dampening effects of the broader mudflat present elsewhere at the site (see Figure 2 and Figure 8).

Creeping wildrye sod placement and sod fragment dispersion

Creeping wildrye (*Leymus triticoides*) is a sod-forming, soil-stabilizing native coarse perennial rhizomatous grass adapted to lowland soils, including slightly saline and alkaline seasonal wetland soils. It is designed to increase soil shear strength and vegetative surface roughness at and below the high tide line, to resist erosion as sea level and maximum wave runup rise. On the north levee, soil disturbance zones or patches of the levee slope (caused by local intensity of equipment operation or material stockpiling) were rehabilitated by mechanically planting and shallowly burying large fragments of dormant, dry sods of native creeping wildrye obtained from large, established borrow stands on site. Dry-dormant sods approximately 0.5 ft thick (concentrated zone of root and rhizome mats) were lifted from borrow source stands by the long-reach excavator and stacked on a flat-bed truck during cool, overcast weather conditions or morning hours (to minimize desiccation injury). Harvested sods were immediately trucked to planting sites. A short-reach excavator cut a shallow pit, and crews manually placed a sod fragment about 2 ft in diameter in the pit. The excavator shallowly buried (2-5 inches) the sod by pushing loose soil over it with the teeth of the bucket and tamping it (light compaction) with the back of the bucket. Each sod planting operation cycle completed normally in less than two minutes, with a crew of two working in synch with the excavator.

On the west levee, extensive disturbance from re-grading occurred instead of localized disturbance patches. Sod dispersal was modified to be incorporated more extensively in the final grading and recompaction of the west levee. Batches of freshly harvested creeping wildrye sods were deposited on the levee slope and worked into the topsoil by multiple passes of a box grader, followed by light track-walking by heavy vehicles for compaction. This process dispersed fragments of rhizomes and sods more extensively, in smaller fragments, in variable depths below the surface above 6 inches. The final grade was lightly watered by dust control trucks to minimize desiccation injury of rhizome fragments after dispersal in dry weather.

5.3 Visual Outcomes: Before-After Photographic Comparisons

Appendix J presents a series of annotated photographs that illustrate site conditions before and after project construction.

5.4 Certification of Completion

Appendix K presents the engineering construction certification.

6 Lessons Learned

This section describes the initial lessons learned to-date. The Project will continue to collect and analyze monitoring data over the next four years and will update this list of lessons learned and the application to other restoration projects of this type.

6.1 Adapting to Worsening Site Erosion during Design, Permit, and Construction

The site continued to have worsening erosion between the time project planning started in mid 2019 through permits in 2020, a 2020 construction cycle that didn’t get underway because of Covid, wildfires, and time of year, a reassessment of site conditions in April 2021, and construction from September to December 2021. Coastal systems are inherently dynamic and impacted by the larger and less frequent, unpredictable storm events. Therefore, the design and construction needed to anticipate and adapt to the occasional unpredictable high energy events as well as the persistence of erosion forces and geomorphic feedback loops that can tip the natural system into an unstable cycle.

The most challenging adaptation requirements for the project's implementation were due to external drivers of internal shoreline erosion rates. External climate-induced variables included:

- Winter storm timing (in relation to high tides), intensity, storm track direction (higher wave exposure from SE to SW storms), and frequency
- Drought (influencing tributary stream sediment supply to San Pablo Bay mudflats, the local suspended sediment supply for the project's mudflat accretion)
- Non-storm thermal breeze velocity and duration (prolonged periods of high summer wind-wave action during spring tides).

These variables can and did cause major short-term deviations from long-term average trends, which make short-term prediction of erosion rate practically impossible at a time-scale relevant to permitting, contracting, and construction.

The project delays during the global SARS covid-19 crisis coincided with significant short-term increases in shoreline erosion rates and elevation change between final design and start of construction. Many of the wave-damping and sediment placement features were designed for location within a relatively broad zone between MHW and MHHW (eroded bench remnants of the original ecotone slope) present during design phases. At the start of construction, MHW line shifted landward close to the MHHW line, forcing a cascade of adaptive design changes. The scarp retreated rapidly and significantly, and grew higher, over extensive areas during permitting, contracting and early construction phases. The rapidly changed profile compressed the upper intertidal zone above MHW and widened the zone between MTL and MHW in a more concave profile. This rapid, significant shift affected the tidal emergence time and elevation of dry aggregate mud and logs, and "squeezed" their relative positions into a narrower zone, requiring more regular, less heterogeneous placement. This upper intertidal (high marsh) design "squeeze" corresponded with a broader mid-intertidal cordgrass zone landward – overlapping with the log and aggregate dry mud placement zone.

One "lesson learned" from this experience is that **adaptive management of actively eroding shorelines needs to build in ongoing short-term monitoring during planning and the flexibility to make design modifications into construction**, to build a project that is responsive to site conditions. A related lesson learned is that since large events such as that experienced in October 2021 during construction which real-time tested the design cannot be counted on, integrating dynamic site conditions into design for these larger events should be given due consideration even if they elevate costs. Schedules for projects like this are driven by inherently unpredictable variables and implemented in a somewhat unpredictable schedule contingent on regulatory, grant funding, contracting variables, and pandemics. Practical low-cost, expedient, approximate but accurate monitoring of erosion rates and elevation change in representative shoreline profiles should begin in design phases and be repeated at key points during planning. The related "lesson learned" is to **incorporate bounded flexibility into permits** so that adaptive design modifications do not require further regulatory approvals and the associated time and cost requirements they entail. For example, with this project, the permits required a second amendment for the spring 2021 design modification to add the brush fence, gravel veneer, and gravel toe berm in cells 6 and 7, as these design changes added slightly more fill.

6.2 Real-Time Design Adaptation to In-Progress Performance

The project design incorporated a suite of nature-based elements, with each levee reach receiving various combinations of these elements (Figure 5). As the many aspects of the design basis illustrated (Section 2), this project (and likely many future nature-based projects) will inherently be experimental. This experimental nature drives the need for real-time assessment during construction to the extent possible, to inform real-time design adjustments that may arise. Design adjustments for a tidal marsh restoration project shoreline must also anticipate and accommodate ultimate vegetation and habitat-forming ecological interactions, long after short-term dominant physical driver events like significant wave erosion episodes.

During construction planning, Dixon Marine (the contractor), SLT and the design team discussed construction sequencing approaches. Two bookend approaches were considered – 1) build each design element sequentially from one end of the levee to the other, and 2) build all elements within a cell then move to the next cell. We opted in general for the second approach, starting with cells 6 and 7 that had the most treatment elements and were the farthest distance. This proved very beneficial. About the time work on these two cells wrapped up, the storm of October 23-25, 2021 hit, with its strong winds and extensive rainfall over the course of about two days. As the intensity of the upcoming storm became clear, SLT and the design team elected to use the opportunity to real-time assess how the more intensive treatments in cells 6 and 7 performed relative to the less intensive cell 5 treatments that were mostly built.

Observations from immediately after the storm demonstrated the effectiveness of the gravel veneer and toe berm additional design elements used in cells 6 and 7. Consequently, SLT and the design team elected to include these treatments for cells 1 through 5 and the west levee, where construction had not yet started or was just getting underway. These design changes were placement of 1) a thin veneer of ¾" gravel on the graded levee slopes above the placed logs (above MHHW) and 2) a gravel toe berm at the toe of the graded levee slopes above the logs. To keep within regulatory authorized materials volumes, the project reduced the quantity of dried bay mud used (see Table 3). The gravel berm design approach was already demonstrated to be compatible with long-term tidal transition zone vegetation at Aramburu Island (SFEI and Baye 2020) and did not represent a trade-off between restoration design and physical erosion management. The "lesson learned" is three-part: 1) **build the nature-based project in a way that facilitates real-time efficacy assessment** during construction so as to inform possible modifications, 2) **make those assessments**, and 3) **apply to making real-time design modifications**. The ability to make modifications depends on permit flexibility (see pervious lesson learned).

The other lesson learned during this process was not to get too far ahead with scarp grading, as it would be exposed to erosion until the associated erosion features of LWD and dried bay mud were placed.

6.3 Design Adaptation to Availability of Suitable Materials

6.3.1 Large woody debris

The conceptual design was based on somewhat irregular logs with attached limb bases, trunks and roots, and large tree rootwads, used as wavebreaks and sediment traps (logs with rootwads, cylindrical straight logs, irregular logs and limbs). The project anticipated high-density (low buoyancy) eucalyptus wood and Sudden Oak Death (disease)-killed coast live oaks as wood sources. These non-commercial wood types are supplied by emergency tree removals from storm windthrow or landslides, or cull logs (non-merchantable timber) from commercial logging operations. Large waste wood supplies are not usually stored, and are only temporarily available before disposal, so availability is short-term. During the drought and wildfire-dominated years of the project, most large waste wood supplies were from utility tree clearing or hazard tree removals during and following wildfires, rather than windthrow or landslides. This resulted in a supply of logs dominated by cylindrical, straight bole segments cut to fit on logging trucks. The reduced structural complexity of regular, straight log sections required adaptation during implementation on the ground, after final design.

Mainly cylindrical logs were in fact available. Many logs were eucalyptus, with high-density wood. Their relatively low buoyancy worked well for initial stabilization of embedded logs. Less suitable Douglas-fir logs (low-density softwood, excessively buoyant prior to waterlogging) were obtained, but their buoyancy was problematic for initial stabilization.

A practical "lesson learned" from opportunistic large woody debris acquisition (waste wood) is that **optimal irregular wood structure and types for shoreline protection would require advance stockpiling where feasible**. Cooperation among conservation landowners (trusts, conservancies, parks, refuges) and wood suppliers (utilities, road departments) within a region would enable cooperatively sharing and stockpiling of transient LWD supplies for stream or estuary shore restoration work.

6.3.2 Use of dry granular (aggregate) bay mud for shoreline wave transport and deposition in partially vegetated erosion-prone marsh shoreline.

The intensive wave erosion, barren surfaces, and active scarp retreat at the Sears Point shoreline made direct deposition of fine sediment infeasible to rehabilitate or restore the eroded “ecotone slope”. Methods of high salt marsh sediment nourishment in California, such as hydraulic placement of dredged mud in the upper intertidal zone (Thorne *et al.* 2019), require wave-sheltered estuarine marsh environments. Direct deposition of unconsolidated, unvegetated fine sediment in the erosional, energetic shoreline would likely result in repetition of the original erosion processes or require costly and high-impact conventional engineering approaches, such as wavebreak berms or rock rip-rap, that would conflict with the basic ecological objectives for the tidal marsh ecotone. Coarse sediment (estuarine beach), though better adapted to storm wave energy at the shoreline, would also change the ultimate ecological outcome of the project if it replaced native local bay mud. The project compromise design was to apply bay mud in a coarse, dry, aggregate form (mud clasts) that behave similar to gravel and sand in the short-term under wave action, but ultimately supplies bay mud substrate and soil conditions similar to the original ecotone slope.

This project introduced the use of decades-old, weathered and drained bay mud from the disused dredge disposal site at the nearby Port Sonoma. The decades in the dredge ponds subjected these muds to leaching of potential acid sulfates. Mechanical excavation of these dried bay muds produced “granular” aggregates ranging in size typical of sand, gravel and cobble and that readily break up mechanically. The project placed these dried muds mechanically with a long-reach excavator in unconsolidated granular (aggregate) form, in layers. The high precision of placement control by the skilled long-reach excavator operator allowed compatible placement of patchy 15-30 cm “lifts” of sediment around seedling colonies and young plants and in open areas. The non-gleyed surface and subsurface sediment hues and values observed in these borrow muds indicated a reduced risk of acid sulfate soil conditions. The “lesson learned” is that **dried bay mud from dredge disposal ponds has high reuse value** for shoreline projects where high tide wave energy makes direct placement of fine-grained saturated sediments (e.g., via slurry) a high risk for rapid erosion. Such dredge storage ponds were more common regionally in the past, few if any marinas continue with these ponds due to development pressure of surrounding lands. This limitation suggests the value of regional small marina dredge storage ponds to retain this sediment for reuse vs. current in-bay disposal.

6.3.3 Coarse sediment (sand, gravel)

The project obtained suitably heterogeneous "pea gravel" sediment obtained from coarse alluvium removed from flood control channels choked by natural fluvial sediment deposition. Commercial sources of washed, sorted pea gravel were also available, but these would be more costly and energy-intensive (higher potential project carbon footprint). The mixed gravel with small fractions of interstitial mud and sand were suitable for salt marsh seedling colonization and establishment, as well as rapid evolution of low-angle beachfaces and berms. These sources were fortunately available during the project, from sources known to the contractor. The "lesson learned" about coarse sediment availability for estuarine shoreline nourishment is that by knowing its potential utility, **advance stockpiling of suitable sediments would increase the chances of obtaining low-cost, suitable types and volumes of coarse sediment**. To accomplish this, advance coordination with local entities that maintain flood conveyance facilities would be required.

6.3.4 Intertidal brush fence materials, sources, specification, and harvest methods

The project request for proposals left some brush fence specifications and sources to the discretion of the bidder. The successful bid chose the option of manual harvest of cut coyote-brush from local stands. Alternate sources included denser, coarse decay-resistant local acacia and eucalyptus brush, or mechanical removal of coyote brush including rootwads. The manual harvest of cut coyote brush produced mostly thin, stringy tangles of branches, which lacked heavy bases to insert and anchor in mud. Though manually cut coyote brush remained in place, brush density was less than optimal. Direct "plugging" of rootwad-anchored coyote brush shrubs or fragments would likely have resulted in more robust brushfence structure. Similarly, larger and longer cut branches of dense acacia would have provided superior brush fence materials. A "lesson learned" is that **brush fence specifications should include highly prescribed criteria** for source species, stem density/linear foot, and height, and methods of harvest.

6.3.5 Advance on-site supply of native creeping perennial grass sod for low-impact borrowing

The current project was fortunate to have inherited a very large on-site supply of creeping wildrye (*Elymus triticoides*) needed for the last step of this ecotone levee rehabilitation project. Through artifacts of grading done as part of the Sears Point marsh restoration project, accidental establishment of many acres of native creeping wildrye colonies were available to harvest as dry-season dormant vegetative fragments with minimal impact. The dense and nearly pure stands of native grass sod, established spontaneously in advance of this project, provided an effectively unlimited supply of large dry-dormant sod fragments for placement and burial in newly graded levees. The extensive borrow source stands were large enough to allow harvest with minimal impacts, and rapid regeneration of well-spaced harvest patches from dominant native stands. The propagule size and vigor of large clones also supported rapid post-transplant regeneration immediately at the start of the rainy season. A “lesson learned” is that the 3+ year lead time for restoration planning, design, permitting, funding, and implementation could allow comparable on-site borrow source stands of vegetation to be established to supply low-cost, efficiently placed revegetation materials as a part of final grading.

6.4 Early Performance Assessment of Nature-Based Features

6.4.1 Mechanical intertidal “thin-layer” placement of dry aggregate bay mud

Mechanical intertidal “thin-layer” placement of dry aggregate bay mud had not previously been known to be compatible with high survivorship and growth of pre-existing patchy, sparse intertidal salt marsh vegetation. The original project design called for placement of aggregate dry bay mud in the largely barren, unvegetated, eroded areas below MHW. Cordgrass was transplanted in 2019, 2020 and 2021 ahead of construction at low density (about 2 m intervals) at the bayward edge of the wave-eroded bench. In addition, the flattened, wave-eroded benches below MHW in some cells rapidly recruited cordgrass and pickleweed seedings during the 2020-2021 (Covid years) period. This newly establishing vegetation led to modifying the mud placement approach to minimize smothering of young salt marsh vegetation. The construction equipment operator developed a novel technique of placing dry, loose aggregate mud by sprinkling the mud through the teeth of a slowly moving, shaking excavator bucket. This sprinkling technique is apparently novel and unique to this project and directly achieves recovery of the ecotone slope utilizing local ecosystem processes and materials (as stated in the permit application materials, Siegel Environmental 2020).

The concern was that direct, instantaneous bulk placement of heavy, granular mud by heavy equipment would crush most young vegetation and seedlings, or lodge them flat and make them unable to regenerate from burial depths they would otherwise tolerate in natural gradual deposition processes. The rate of sprinkling of dry, mud aggregate from the excavator bucket was adjusted by judgment of the equipment operator to enable plants to remain standing erect during placement. The adjusted sprinkling rates largely eliminated destructive burial of 0.5-1 ft “lifts” in sparsely vegetated areas. Subsequent drift of granular mud by wave action also led to non-destructive partial burial (about 6 inches) of established stands of cordgrass in areas adjacent to placement. Limiting initial sprinkling deposition thickness to less than approximately one half of average standing shoot height appeared to minimize “thin layer” impacts to vegetation even weeks after placement.

6.4.2 Short-term drift of wetted aggregate bay mud placed in the intertidal zone

A key design challenge was that the extent of levee retreat necessitated strategies that reconstructed a truncated and steeper habitat levee slope using the minimum fill necessary. Horizontal retreat was up to 50 ft in many places (Appendix L), making it impractical from a cost, construction, and regulatory perspective to rebuild all or a large portion of the original levee profile. Thus, the design turned to a strategy of combining multiple elements. Scarp grading partially restored gentle (about 5:1) side slopes and removed the wave backwash mechanism contributing to erosion. Logs helped to break wave energy. Planted cordgrass, once densities increase, attenuate wind waves. Placement of the dry, aggregate Port Sonoma bay mud, from MHHW down to the midpoint between MTL and MHW, partially restored the lower levee slope and provided a mobile sediment source to rebuild higher intertidal slopes, with all areas intended to promote vegetation establishment.

The observation of widespread swash bar deposition of mud clast sediment (aggregated mud) occurring over several years at Sears Point indicated that naturally flaked and cracked estuarine desiccated mud clasts (Allen 1987, Ghandour et al. 2016) eroded out of the ecotone slope were capable of onshore and longshore transport by wave-driven beach processes. It was uncertain whether artificially crushed dry bay mud aggregates would be transported by waves like naturally formed mud clasts. It was also uncertain whether placing aggregate mud below MHHW (longer duration wetting and potential cohesion interaction among aggregates in each tidal cycle) would result in a consolidation of a self-cemented mud mass, or predominantly mobile large clasts. The project schedule, constrained by contracting and permitting and in need of being constructed to remedy the active shoreline erosion, did not enable pilot tests of the method and materials prior to the full project construction. This need to address the erosion rapidly was understood at project outset, so the design team applied its empirical observations as the basis for reusing the nearby dried bay muds.

Once the dried bay mud was placed, slipface features composed of sand and small gravel-sized mud grains deposited on the landward (down-wave) side of the placed dried bay mud after high wind-wave action, even during construction. Mud was placed below each log and gaps were left between logs as drainage swales. Spit-like and bar-like depositional features composed of mud grains partially choked the swales left between mud mounds. The lessons learned in this case were 1) at least some of the deposited dried bay mud was mobilized and transported like sand and gravel, despite longer wet times at tidal elevations below MHW; and 2) pilot experimental tests would have been helpful to assess mud clast transport from erosion of placed dried bay mud, located at different tidal elevation ranges. Were there time for such pilot experiments, they would have increased understanding of mud clast transport and deposition patterns from different upper intertidal zones above and below MHW. Shorebirds (western sandpipers) repeatedly roosted on the newly placed dried bay mud during mid to higher tides.

6.4.3 Short-term effectiveness of large woody debris as local shoreline wavebreak structures compatible with vegetation establishment

The design specified logs were to embedded in mud at half their diameter in zones mostly above MHW. However, most logs had to be installed at or even a little below MHW, because of ongoing and accelerated erosion that shifted the MHW line close to shore in many cells before and during the construction period. Low-crested logs (smaller diameters; about 1.5 ft) acted as submerged partial wavebreaks during moderate tides, slowing or dragging waves that passed over their submerged crests. These smaller logs did little wave damping at higher tides. Larger diameter logs (2 ft and over) with crests mostly emergent or very shallowly submerged during higher tides and higher wave action, were more effective as wavebreaks at higher tides, creating nearly still-water conditions in their lee during higher tides. The lessons learned in this case would be to use larger diameter logs in general, find logs with more root wads and that are as rough as possible, and consider using multiple logs at different elevations and to fine tune placement elevations based on log diameter to the extent practical.

6.4.4 Pre-waterlog or use low-buoyancy logs

The original conceptual designs called for waterlogging of logs prior to intertidal placement, to ensure high density needed to prevent buoyancy that would risk loosening, lifting, and transporting drift logs during high tides and high wave action. The timing of log delivery, contracting, and construction initiation did not allow for the “pre-waterlogging.” Dense, heavy eucalyptus logs, though dry, remained stable after embedding and anchoring with cables. In contrast, the minority of softwood (douglas fir) logs, with low density wood and higher pore space, more often loosened and pulled anchored cables out of the mud. High density, heavy wood, such as eucalyptus, madrone, and oak, would be preferable for intertidal placement and stabilization as wavebreak features.

6.4.5 Short-term wave transport of mixed gravel, sand, and mud

The design specifications for pea gravel (rounded, mobile gravel) did not specify restrictions on interstitial finer sand or silt. The gravel component matched specifications, but the finer interstitial sediments appeared to inhibit swash infiltration of gravel, increasing backwash and influencing initial beach slopes as finer sand and mud was sorted out. As wet gravel dried, the interstitial fines began to cement the sacrificial berm somewhat. If winter high tides and high waves did not erode and sort this material, the self-cemented features may dessicate, strongly cement, and stabilize vegetatively until future more intense storm wave action fully erodes them. As of February 2022, this has not occurred. All sacrificial steep-sided gravel berms have flattened into low-angle swash bars and beachfaces.

A lesson learned is that if rapid gravel bar reworking by waves is needed, fine interstitial sediment should be minimized (processed, washed gravel). If temporary hardening of sacrificial gravel berms is not problematic, and temporary vegetative stabilization is compatible with habitat objectives, then unprocessed gravels with fines would be acceptable for gravel beach nourishment.

The heterogeneous coarse and finer mixed sediment did not impede longshore drift; spit-like swash bars extended downdrift from placement areas by 20-30 feet in some cells soon after high tides with significant wind-waves. Waves overtopping the sacrificial berms reworked them rapidly into swash bars with natural morphology. Shorebirds (western sandpipers) repeatedly roosted on the newly formed swash bars, as well as the sacrificial gravel berms, during high tides in the construction period.

6.4.6 Expanded lower tidal elevation range for survivorship and growth of transplanted mature cordgrass plugs

The natural lower tidal elevation range of Pacific cordgrass (*Spartina foliosa*) in natural stands of the San Francisco Estuary is variable, but generally above Mean Tide Level (or Mean Sea Level). In rapidly accreting mudflats, tidal substrate elevations are unstable. Tidal submergence tolerance of cordgrass is a function of physiological variables merely correlated with tidal substrate elevation, such as consecutive hours of submergence (constraints on gas exchange, also a function of plant height). The selection of tall, robust cordgrass plugs (rooted plants in firm sediment cores) for transplanting at elevation ranges near or slightly below MTL at the time of transplanting appeared to allow transplants to survive and grow at significant rates over two years, at least on accreting mudflats. In contrast, nearly all natural cordgrass recruitment by seedlings occurred close to MHW, and none ever was observed near MTL. Since the critical threshold of fringing salt marsh width (for effective wave damping and erosion abatement at the high tide line) is a primary objective of the project, the ability to plant large, tall Pacific cordgrass plugs at lower than expected (natural) tidal elevation range, achieving high survivorship and growth, is a significant practical lesson learned about vegetative stabilization. The long-term significance of this finding will depend on monitoring of fringing marsh expansion and consolidation at the bayward (lower elevation range) end of the planting zone in a few years.

6.4.7 Short-term stability of intertidal brush fencing as local wave baffles

Intertidal brush fencing stability was not pilot tested prior to construction. Its feasibility was based on observed multi-year persistence of drowned coyote brush in tidally flooded restoration sites like Cullinan Ranch, drifted coyote brush eroded off of levees and deposited in mudflats, and from the literature where more intensively-built versions are used to dampen boat wake in lakes. Deeply embedding cut brush in soft, semi-fluid to plastic bay mud did in fact result in relatively stable placement of cut coyote brush during the three-month construction period, which included prolonged high wave action and high tides. Recent observations in January 2022 show the brush fences holding fast.

6.4.8 Quantification of local wave climate, sediment transport, and vegetation at the shoreline

The Project design basis used qualitative, opportunisitic observations of complex physical and biological shoreline processes during early stages of development in a highly dynamic, erosional constructed shoreline within a tidal marsh restoration project. The complexity of nature-based solutions, limited experience in utilizing them, and limited quantitative data make such projects more difficult to model and engineer. There are few definitive guidance documents that connect wave climate with these types of solutions. Funds should be identified for long-term monitoring and should include wind and wave data to correlate with shoreline evolution and performance of project design features over time.

References

Allen, J.R.L., 1987. Desiccation of mud in the temperate intertidal zone: studies from the Severn Estuary and eastern England. Philosophical Transactions of the Royal Society of London. B, Biological Sciences, 315(1171), pp.127-156.

Ghandour, I.M., Al-Washmi, H.A. and Haredy, R.A., 2013. Gravel-sized mud clasts on an arid microtidal sandy beach: Example from the northeastern Red Sea, South Al-Wajh, Saudi Arabia. Journal of coastal research, 29(6a), pp.110-117.

GHANDOUR, İ.M., Al-Washmi, H.A., Haredy, R.A. and Al-Zubieri, A.G., 2016. Facies evolution and depositional model of an arid microtidal coast: example from the coastal plain at the mouth of Wadi Al-Hamd, Red Sea, Saudi Arabia. Turkish Journal of Earth Sciences, 25(3), pp.256-273.

Gillenwater, D. and P. Baye. 2022. Year 10 Monitoring Report, Aramburu Island Enhancement Project. Prepared for Marin County Department of Parks and Open Space. March.

Hultgren-Tillis Engineers. 2011. Geotechnical Investigation, New Flood Control Levee, Sears Point Tidal Restoration Project, Sonoma County, California. Prepared for the Sonoma Land Trust, June 28.

Li, S., Li, S., Shan, X., Gong, C. and Yu, X., 2017. Classification, formation, and transport mechanisms of mud clasts. International Geology Review, 59(12), pp.1609-1620.

San Francisco Estuary Institute (SFEI) and Peter Baye. 2020. New Life for Eroding Shorelines: Beach and Marsh Edge Change in the San Francisco Estuary. Publication #984, San Francisco Estuary Institute, Richmond, CA. Version 1.0 (April 2020)

Siegel Environmental, LLC. Peter Baye, FarWest Restoration Engineering. 2020. Levee Erosion Adaptive Management Project Description, Sears Point Tidal Marsh Restoration Project, for authorization under U.S. Army Corps of Engineers 2011-00152N, Regional Water Quality Control Board R2-2013-0017, Bay Conservation and Development Commission M2012.022. Prepared for the Sonoma Land Trust, February 4.

Thorne, K.M., Freeman, C.M., Rosencranz, J.A., Ganju, N.K. and Guntenspergen, G.R., 2019. Thin-layer sediment addition to an existing salt marsh to combat sea-level rise and improve endangered species habitat in California, USA. Ecological Engineering, 136, pp.197-208.

Appendices

All appendices are available for download at www.sonomalandtrust.org
or contact julian@sonomalandtrust.org