Conceptual Design Report

TISCORNIA MARSH HABITAT RESTORATION AND SEA LEVEL RISE ADAPTATION PROJECT

Prepared for
Marin Audubon Society

July 2018

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550 Kearny Street
Suite 800
San Francisco, CA 94108
415.896.5900
www.esassoc.com

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ACRONYMS

Acronym	Definition
BAC	Bay Area Coastal Study
BCDC	San Francisco Bay Conservation and Development Commission
BFE	Base Flood Elevation
Canal	San Rafael Creek Canal
CCC	California Coastal Commission
CEQA	California Environmental Quality Act
CIMIS	California Irrigation Management Information System
CoSMoS	Coastal Storm Modeling System
DEM	Digital Elevation Model
DMMO	Dredged Material Management Office
EFH	Essential Fish Habitat
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
ITP	Incidental Take Permit
LSAA	Lake and Streambed Alteration Agreement
MAS	Marin Audubon Society
MLLW	Mean Lower-Low Water
MLW	Mean Low Water
MSL	Mean Sea Level
MTL	Mean Tidal Level
MHW	Mean High Water
MHHW	Mean Higher-High Water
MSFCMA	Magnuson-Stevens Fishery Management and Conservation Act
NAVD88	North American Vertical Datum of 1983
NEPA	National Environmental Protection Act
NHPA	National Historic Preservation Act of 1966
NMFS	National Marine Fisheries Service
NRC	National Resource Council
NOAA	National Oceanographic and Atmospheric Administration

Acronym	Definition
OCOF	Our Coast Our Future
OPC	California Ocean Protection Council
PG&E	Pacific Gas and Electric
RIRA	California Ridgway's Rail
RTK-GPS	Real-Time Kinetic Global Positioning System
RWQCM	Regional Water Quality Control Board
SHPO	State Historic Preservation Office
SLC	State Lands Commission
SCC	California State Coastal Conservancy
SMHM	Salt Marsh Harvest Mouse
SWAN	Simulating Waves and Nearshore software developed by TU Delft
SWEL	Still Water Elevation Level
TWL	Total Water Level
WARMER	Wetland Accretion Rate Model for Ecosystem Resilience
WDR	Water Discharge Requirements
WHAFIS	Wave Height Analysis for Flood Insurance Studies
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

1. INTRODUCTION

Marin Audubon Society (MAS) acquired Tiscornia Marsh, located at the mouth of the San Rafael Canal, in 2008. The 20-acre Tiscornia Marsh property, which was donated by Mary Tiscornia, consists of vegetated marsh, mudflats, shoreline levee, and a 500-foot reach of public trail that connects segments of the Bay Trail (Figure 1). ESA is working with MAS to develop conceptual restoration designs for the marsh. There are currently two main concerns for the Tiscornia Marsh property. First, the tidal marshlands have experienced considerable erosion over the past 30 years, retreating as much as 200 feet, with approximately 3 acres lost. This erosion has resulted in the significant loss of habitat for the endangered Ridgway's rail and salt marsh harvest mouse, migratory shorebirds, and other important marsh wildlife. Second, the levee segment on the Tiscornia property is relatively low, and therefore at risk of overtopping during an extreme coastal flood event. Both of these conditions are expected to worsen in the coming decades as sea level rises.

MAS applied for, and was awarded a grant to develop nature-based design concepts to address sea level rise at Tiscornia Marsh. The grant is from the Marin Community Foundation and is administered by the California State Coastal Conservancy (SCC). The two primary project goals stated in the grant are:

- **Goal 1:** Prepare and choose a preferred alternative that utilizes nature-based sea-level adaptation strategies at Tiscornia Marsh for the bay and upland edges that provide this segment of the San Rafael shoreline with an adaptation solution consistent with City-wide strategies to be developed over the long term. Alternatives could be expanded to include some city property.

- **Goal 2:** Raise awareness of climate change and sea level rise issues within the adjacent disadvantaged community and other residents.

While the goals are related, this report primarily focuses on the first goal of developing a concept design for nature-based sea-level rise adaptation strategies at Tiscornia Marsh. The two main site components addressed by the concept design(s) are the existing marsh, including the eroding Bay edge, and the upland edge, including the levee.

Concept designs were developed under a multi-step process. We first articulated the multiple – sometimes competing – project objectives based on input from MAS, the City of San Rafael (City) and other stakeholders. Next, we developed a suite of concept design alternatives, based on an understanding of existing conditions, projected future conditions, and opportunities and constraints of the site. We evaluated these alternatives relative to how well they achieved the project objectives. We also considered input from the City, SCC and residents of the adjacent Canal neighborhood of San Rafael, as solicited through two public meetings. Ultimately MAS selected its preferred alternative to move forward toward final design and implementation.

As noted, public outreach to the Canal neighborhood and consideration of their input was an important part of this project. Douglas Mundo and ShoreUp Marin led the public outreach, with support from Stuart Siegel. Public outreach included two public meetings, and a community site walk. The first public meeting aimed to raise awareness of sea level rise, coastal flooding, and nature-based adaptation solutions. The second public meeting was focused on obtaining public input on the alternatives. Members of the public were also able to submit comments on the Tiscornia Marsh website created by Shore Up Marin and also on Marin Audubon Society's website.

This report has been prepared by Environmental Science Associates (ESA), with contributions from Stuart Siegel of Siegel Environmental, Barbara Salzman and Ed Nute of MAS, and Marilyn Latta of SCC.

Project need and objectives are listed in Section 2. Existing conditions are described in Section 3, and site opportunities and constraints are listed in Section 4. Development and evaluation of concept alternatives is described in Section 5, and alternatives are evaluated under Section 6. The preferred alternative is discussed in greater detail in Section 7, including anticipated construction methods, permitting considerations and next steps for implementation.

2. PROJECT NEED AND OBJECTIVES

This section provides an overview of the project need, and presents project goals and objectives.

2.1 Site Location

Tiscornia Marsh is located on the south bank of the San Rafael Canal in San Rafael, CA (**Figure 1**). Tiscornia Marsh is bounded on the west by the Al Boro Community Center and Pickleweed Park, a soccer field, and diked salt marsh, all of which are enclosed by a combined perimeter levee and trail. This property to the west is owned by the City of San Rafael. To the north is San Rafael Canal and to the east is the Bay, consisting of various parcels owned by the City of San Rafael, the federal government and the State of California (**Figure 2**). South of the Tiscornia Marsh levee is a vacant lot and children's playground (Schoen Park) owned by of the City of San Rafael, then Spinnaker Point Drive, other streets and residential areas of the Canal Community. The MAS-owned section of levee connects with the City's levee to the west and east. This levee continues to the south along the San Rafael Bay shoreline, past the Spinnaker and Baypoint developments and the Canalways property, then down to near the Richmond-San Rafael Bridge. This levee is part of the San Francisco Bay Trail.

2.2 Project Need

There are currently two main concerns for the Tiscornia Marsh property: loss of marsh through erosion, and the need for tidal flood protection for the adjacent Canal Community.

The tidal marsh has experienced considerable erosion along its bayward edge, losing approximately 3 acres over the last 30 years (**Figure 1**). Loss of the existing marsh reduces the amount of already scarce habitat for the Ridgway's rail, salt marsh harvest mouse, and other native wildlife, and diminishes its wave-dissipation benefits. The cause of this erosion appears to be primarily driven by wind waves, but may also be exacerbated by boat wake and periodic dredging of the San Rafael Canal. Under current conditions, erosion is expected to be ongoing, and erosion rates will likely increase as sea level rises. Given the current rate of erosion, this important remnant habitat may be completely lost in the coming decades if no action is taken.

The second concern is flood protection. The low-lying Canal Community adjacent to Tiscornia Marsh is currently at risk to coastal flooding, as is a significant extent of Central San Rafael that occupies what was once tidal marshlands and open bay. The area is currently in the Federal Emergency Management Agency (FEMA) 100-year floodplain (**Figure 3**), and will be increasingly susceptible to flood hazards as sea level rises, as described in Marin County's recent Marin Bay Waterfront Adaptation Vulnerability Evaluation (BayWAVE) (BVB, 2017).

SOURCE: Background Image from Google Earth

Tiscornia Marsh Habitat Restoration . D160888.0

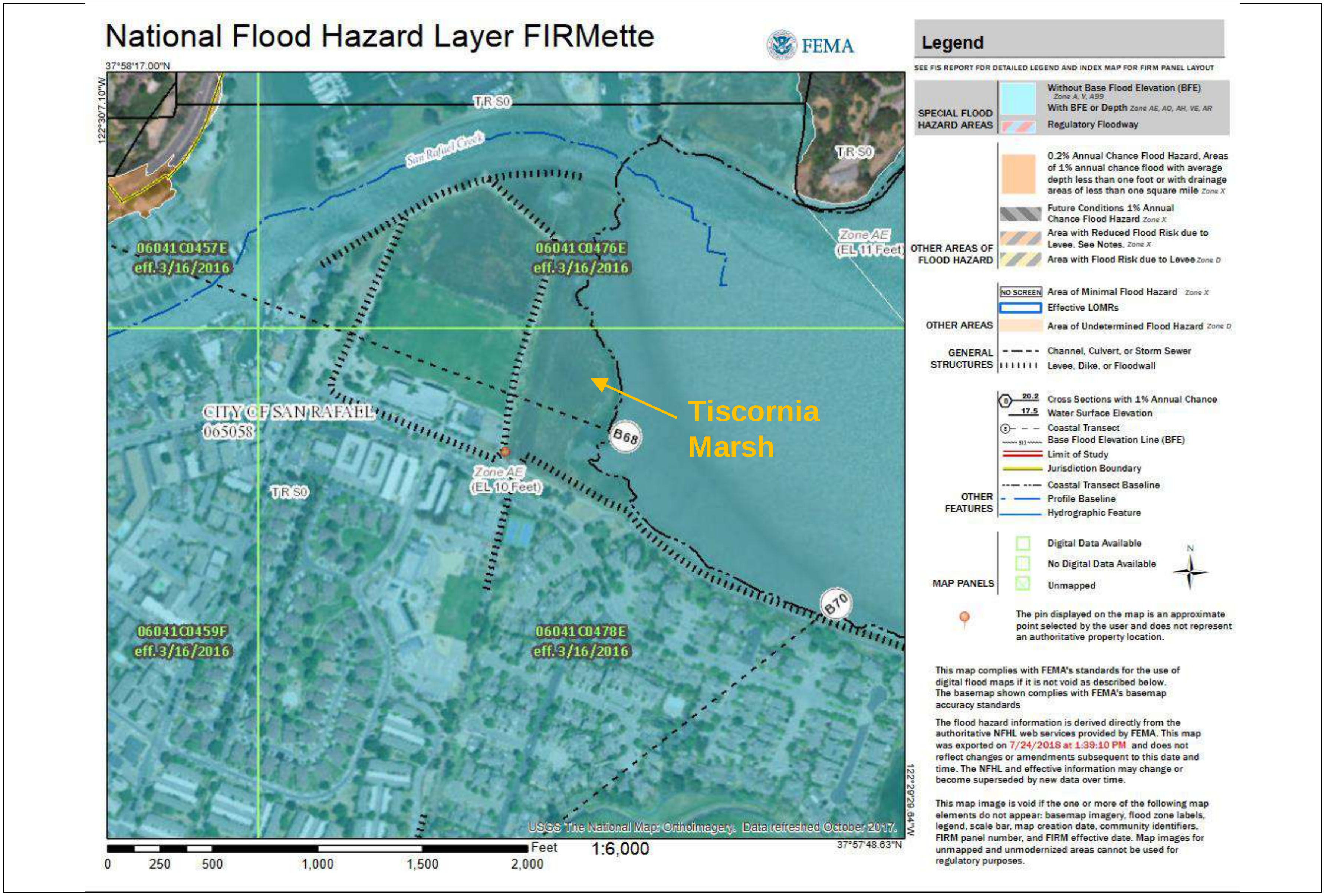
Figure 1
Site Map

SOURCE: Map produced by Siegel Environmental with publically available parcel information

Tiscornia Marsh Habitat Restoration Arial **.D160888.0**

Figure 2

Parcel boundaries for Tiscornia Marsh and neighboring properties



SOURCE: FEMA

Tiscornia Marsh Habitat Restoration. D160888.00

Figure 3

FEMA 2016 Flood Insurance Rate (Flood Zone) Map

Much of the Canal District lies below high tide elevations, requiring pump stations to remove storm water and shoreline levees to protect against coastal flooding. The existing shoreline levee extends from Pickleweed Park, east along the San Rafael Canal and south along San Rafael Bay to the Marin Rod and Gun Club, and includes the Jean and John Starkweather Shoreline Park. Most of this levee was raised and improved with construction of the Bay Trail about 15 years ago, except for three segments: that at Tiscornia Marsh, around the adjacent diked marsh, and at Canalways, an 85-acre undeveloped, diked property further south. The levee segment on the Tiscornia property is relatively low compared to the rest of the levee, and in need of raising.

Both of these concerns – marsh loss and flood protection – are exacerbated by the current lack of a functional wetland-upland transition along the marsh's landward boundary. Currently the marsh transitions abruptly to the relatively steep levee embankment. A broad, gently-sloped wetland-upland transition would provide both ecological and flood benefits, including high tide refugia for native marsh wildlife, shoreline erosion protection through wave-dampening, and allow for marsh landward transgression under future sea level rise.

2.3 Goals and Objectives

One of the two primary goals of the grant is to "prepare and choose a preferred alternative that utilizes nature-based sea-level rise adaptation strategies at Tiscornia Marsh for the bay and upland edges that provide this segment of the San Rafael shoreline with an adaptation solution consistent with City-wide strategies to be developed over the long term. Alternatives could be expanded to include some city property."

Two main objectives to attain this goal are described in the grant:

- **Objective for Bay edge of marsh: "**Identify the setting and mechanisms leading to this marsh edge erosion and develop conceptual alternatives for shoreline stabilization and, if possible, accretion to rebuild lost marsh to enhance wildlife functions and retain tidal marsh for its shoreline protection functions. Marsh shoreline alternatives could include stabilization utilizing native plants, other natural materials and/or organisms where appropriate to the setting, and /or facilitate marsh accretion using sediment. Examples of natural systems from around Marin County and the bay will be drawn upon to identify possible alternatives."

- **Objective for upland edge of marsh: "**Develop a CEQA-ready preliminary design that will lead to construction of a raised "habitat" levee incorporating wetland-upland transition ecological features consistent with a high public use area. Levee design alternatives should include, to the extent possible, a gradually sloping levee that will allow for tidal waters to migrate up and provide a well-vegetated high-tide transition zone for the endangered species and other species that use the marsh. The top of the levee would be planned to connect with the Bay Trail."

To guide this study, we translated the above objectives into multiple design objectives that could be used to evaluate the concept alternatives. These more detailed objectives were formulated considering input from MAS, SCC, the Canal Community, the City, and other stakeholders.

The objectives for the vegetated marsh, including its eroding Bay edge, are to:

- Reduce current loss of vegetated marsh due to marsh edge erosion.
- Reduce future loss of vegetated marsh due to marsh “drowning” through sea level rise.
- Enhance habitat for endangered marsh species, including Ridgway’s rail and salt marsh harvest mouse.
- As secondary ecological objectives, provide habitat for other wildlife, including shorebirds, ducks and other water birds, as well as native fish and oysters, including those species currently utilizing the site.
- Preserve and/or enhance the wave dissipation and flood protection functions of the marsh.
- Serve as a demonstration project for nature-based sea level rise adaptation strategies for San Francisco Bay.

The objectives for the upland edge, including the existing levee, are to:

- Improve ecological function of the outboard levee slope to benefit the endangered species and other native marsh and wetland-upland transition zone species.
- Contribute to local efforts to increase the level of flood protection for Central San Rafael by raising\reconfiguring the segment of levee adjacent to Tiscornia Marsh to reduce frequency of wave overtopping.
- Be compatible with adjacent public access uses, including the Bay Trail on the levee top and the City park/playground on the landward side of the levee.
- Allow for future adaptation as sea level rises.

2.4 Defining Future Conditions

Because this project is centered on the development of a strategy for nature-based sea-level rise adaptation, the planning horizon (the amount of time an organization will look into the future when preparing a strategy or plan) for evaluating future conditions is an important consideration. It is common to select a planning horizon for a restoration project, and then predict future conditions within this horizon. For this project, we selected a 50-year planning horizon, recognizing that our predictions for sea-level rise and the corresponding marsh sedimentation will have a number of uncertainties, especially as global and local predictions for sea-level rise are continually being revised, and sediment supply changes over time.

Though the exact rate of sea level rise is uncertain, the expected bay-wide decline in suspended sediment available for marsh accretion (Schoellhamer 2011, BCDC and ESA PWA 2013, Schoellhamer et al. 2018, Appendix A), means that the existing marsh surface of the project site will likely be inundated more frequently in the future. Sediment deposition is expected to at least partially slow this rise in inundation frequency through building marsh elevation, but local suspended sediment concentrations are relatively low (Appendix A) and are expected to decline in the future (Schoellhamer 2011). Increased inundation of the marsh would in turn have several effects:

- Eventual conversion of low marsh areas to mudflat, and conversion of high and mid marsh areas to mid and low marsh, respectively.
- More frequent exposure of the existing levees surrounding the site to erosive wave action during high tides.

We selected the 50-year horizon partly because this is the period within which significant marsh conversion would be expected to occur (see Section 6.1) given a medium emissions sea level rise scenario. For the scenarios with faster sea level rise, this conversion would be expected to occur sooner.

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3. EXISTING CONDITIONS

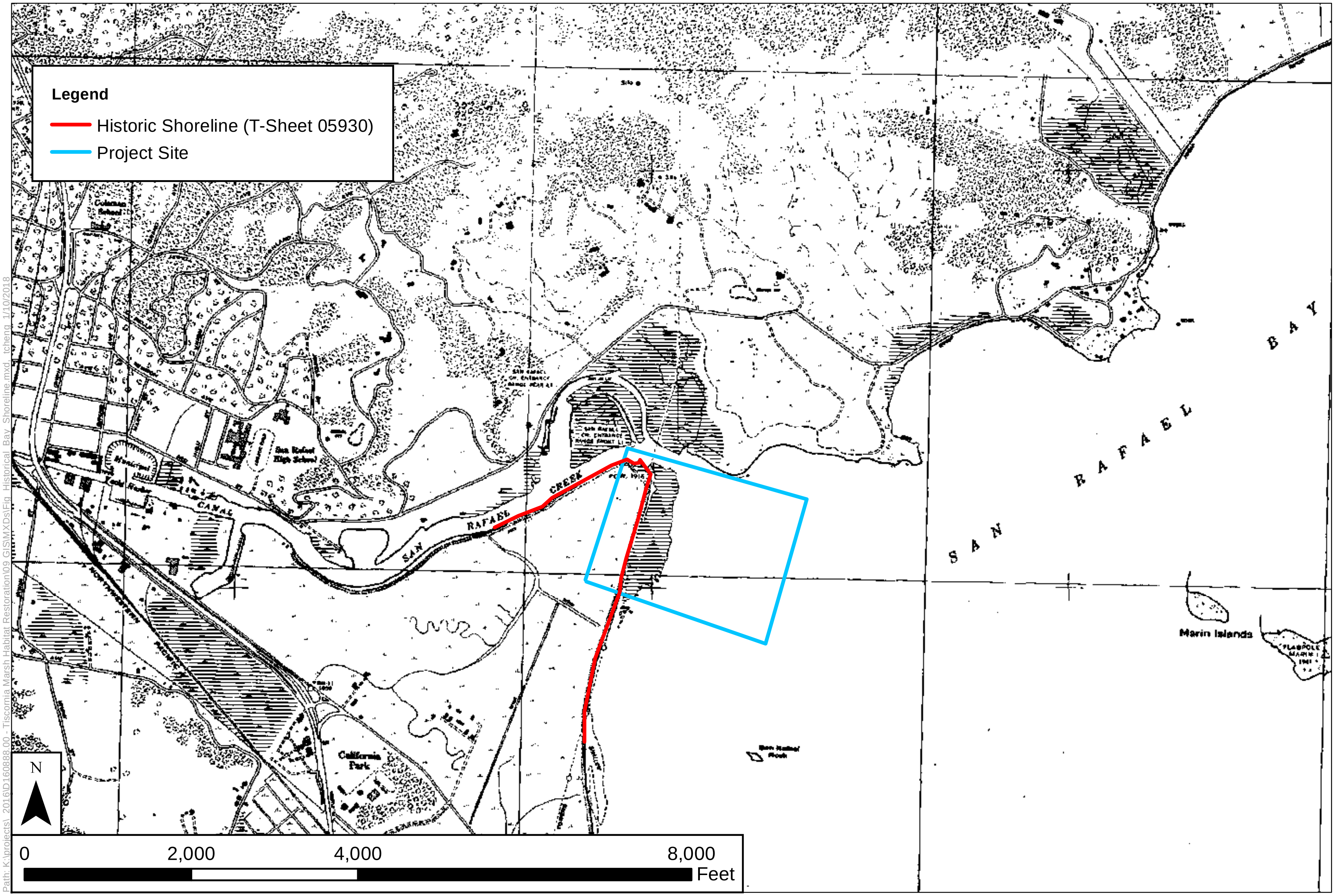
This section presents our understanding of existing conditions, an overview of historic conditions, and our projection of future hydrologic conditions.

Tiscornia Marsh is one of a very few small areas of tidal marsh in Central San Rafael. Historically, tidal marshes extended deep into what today is downtown San Rafael, and the mapped historic shoreline (see SFEI 2018) shows that the levee along the west side of Tiscornia Marsh was the wetland/bay shoreline. Tiscornia Marsh thus most likely formed from accretion on the mudflats. The marsh is comprised of a thin band of high marsh habitat, dominated by pickleweed (*Salicornia pacifica*) which transitions abruptly from a 3- to 4-foot escarpment to a wide mudflat extending bayward. This band of marshland is most narrow at its north end, expands along the adjacent soccer field, and becomes very thin as it curves eastward along the shoreline levee bordering the south end of the marsh. A single tidal channel enters the marsh from the northern San Rafael Canal edge and extends southward through most of the length of the marsh.

There are two Pacific Gas and Electric (PG&E) power line towers located within the marsh, which can be accessed by two wooden service walkways. One walkway runs generally northeast to southwest to a tower within the northern portion of the marsh, and the second runs in west-east to the tower adjacent to the bayward edge of the marsh. This tower was formerly surrounded by pickleweed marsh, which has since eroded as described below.

3.1 Site History and Ongoing Erosion

Prior to the development the San Rafael Regional Shoreline, Tiscornia Marsh was the edge of open bay/mudflats immediately adjacent to a larger marsh complex that existed from a little east of today's shoreline deep into downtown San Rafael, with San Rafael Creek bisecting and supporting much of this tidal marsh. By 1943, marsh had accreted on the mudflats bayward of what was the historic wetland shoreline and that had been leveed by that time. The general site location is illustrated in **Figure 4** on top of the 1853 U.S. Coast and Geodetic Survey T-Sheet for the area, which is available from SFEI. Given the complex history of sediment supply to San Francisco Bay, ongoing sea-level rise, and long term development, marsh areas in and around Central San Rafael (including the remnant fringing marsh that now comprises the project site) has probably varied in shape over the past two centuries (BCDC and ESA PWA 2013). Aside from the larger scale changes that were occurring throughout the Bay within the past century, sediment delivery to the site was also altered by the development of the City of San Rafael and the filling of the Bay and construction of the Spinnaker neighborhood to the south. Today's bayshore levees that encompass the Spinnaker and Baypoint neighborhoods, Canalways, and the properties further south to the Richmond Bridge east of Kerner Boulevard were constructed sometime after 1950 and before 1968 (Siegel Environmental 2016). More recently, recurrent maintenance dredging of San Rafael Creek for navigation purposes has created a local sediment sink adjacent to the marsh.



SOURCE: NOAA (T-Sheet)

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Figure 4
Historical Marsh Shoreline
NOAA T-Sheet 05930 (1943)

ESA

Aerial images dating from 1987 indicate that the marsh has been eroding rapidly in the last several decades. We examined this trend by downloading and georeferencing the available images, and tracing the marsh edge at each point in time. **Figure 5a** shows the range of marsh shorelines, overlain with four marsh survey transects surveyed by ESA in September 2017 (see Section 3.2.1). The linear erosion over time for each of the four marsh transects is depicted in **Figure 5b**. The retreat of the bayward marsh edge has been most rapid at the northern edge of the site, eroding at a rate of 4-5 feet per year 2004, when most aerial images were available. The rate of retreat decreases with distance moving south along the marsh edge, declining to as little as 1 foot per year where the marsh intersects the shoreline.

3.2 Site Topography

Surface topography is available for the Tiscornia Marsh area from several sources:

- 2010 LiDAR topography data available from the NOAA (OCM 2018), and
- 2017 topographic survey conducted by ESA (Appendix B).

Existing grades at the site, based on the 2010 DEM, are shown on **Figure 6**. It should be noted that elevations may likely have an upward vertical bias due to existing vegetation. To supplement existing topographic data, ESA conducted a ground survey on September 19th, 2017. The ground survey included 10 transects of the southern levee along the site, a crest profile of the levee behind Tiscornia Marsh, and 4 transects that characterize the marsh plain, edge, and several hundred feet of the adjacent mudflat. An additional transect was surveyed in the diked marsh north of Pickleweed Park on October 27th, 2017. These data are summarized in Appendix B, and described briefly here for context.

3.2.1 Marsh and Mudflat Transects

Figure 7 illustrates the four marsh transects surveyed in September 2017. The existing levee that forms the western boundary of Tiscornia Marsh varies in elevation from roughly 10-12 feet NAVD88[1], and, moving east, the ground surface transitions rapidly into the marsh in a narrow (20-30 foot) band of upland to high-marsh transitional elevation land. This band drops from the levee into mid marsh dominated by pickleweed (*Salicornia pacifica*). This mid-marsh zone comprises the majority of the existing marsh area. The marsh plain varies in elevation from approximately 5.5 to 6.5 feet NAVD88, ranges from 150 to 500 feet wide, and covers approximately 8 acres. The marsh is narrowest at the northern edge of the site, in the vicinity of the PG&E towers (see Transect 1 in Figure 7). In the northern half of the marsh, the width between the levee and the bayward edge varies from 150 to 200 feet. The outboard edge is a steep scarp that drops to the adjacent mudflat elevation of approximately 2 feet NAVD88.

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1 North American Vertical Datum of 1988

SOURCE: ESRI (Aerial Image)

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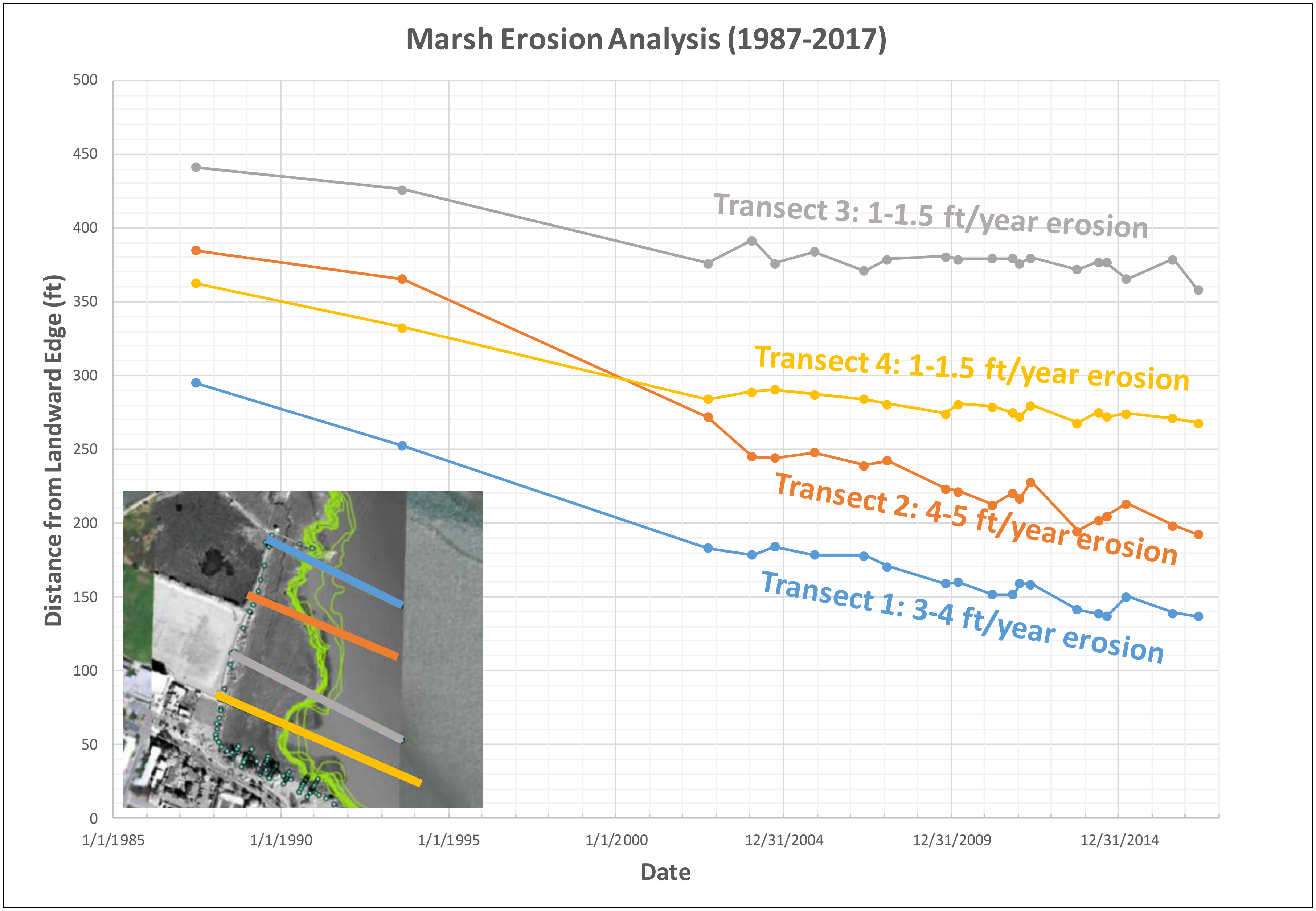
Figure 5a

Marsh Erosion Analysis using Historic Aerials (1987 to present)

ESA



SOURCE: Background Image from Google Earth

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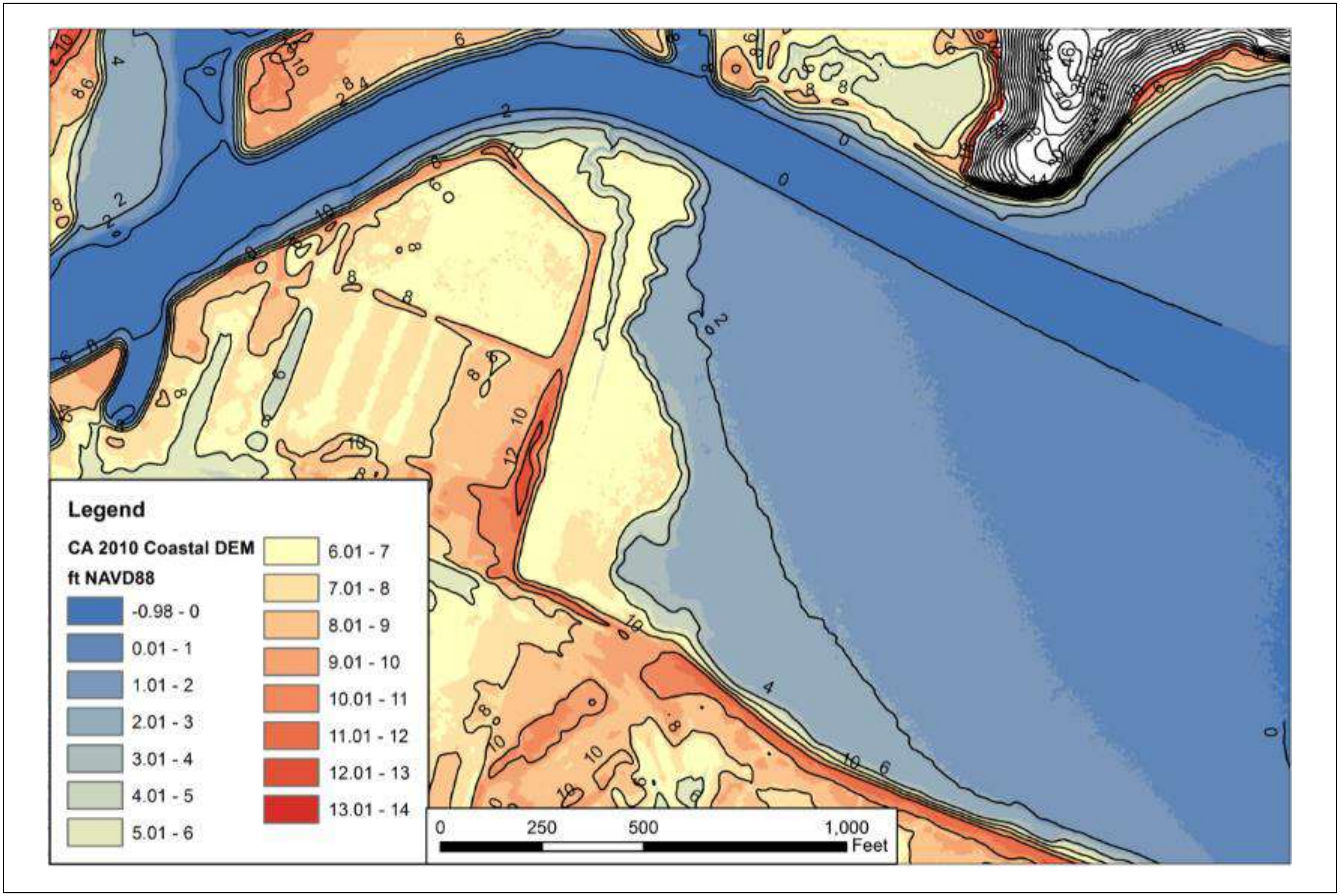
Figure 5b

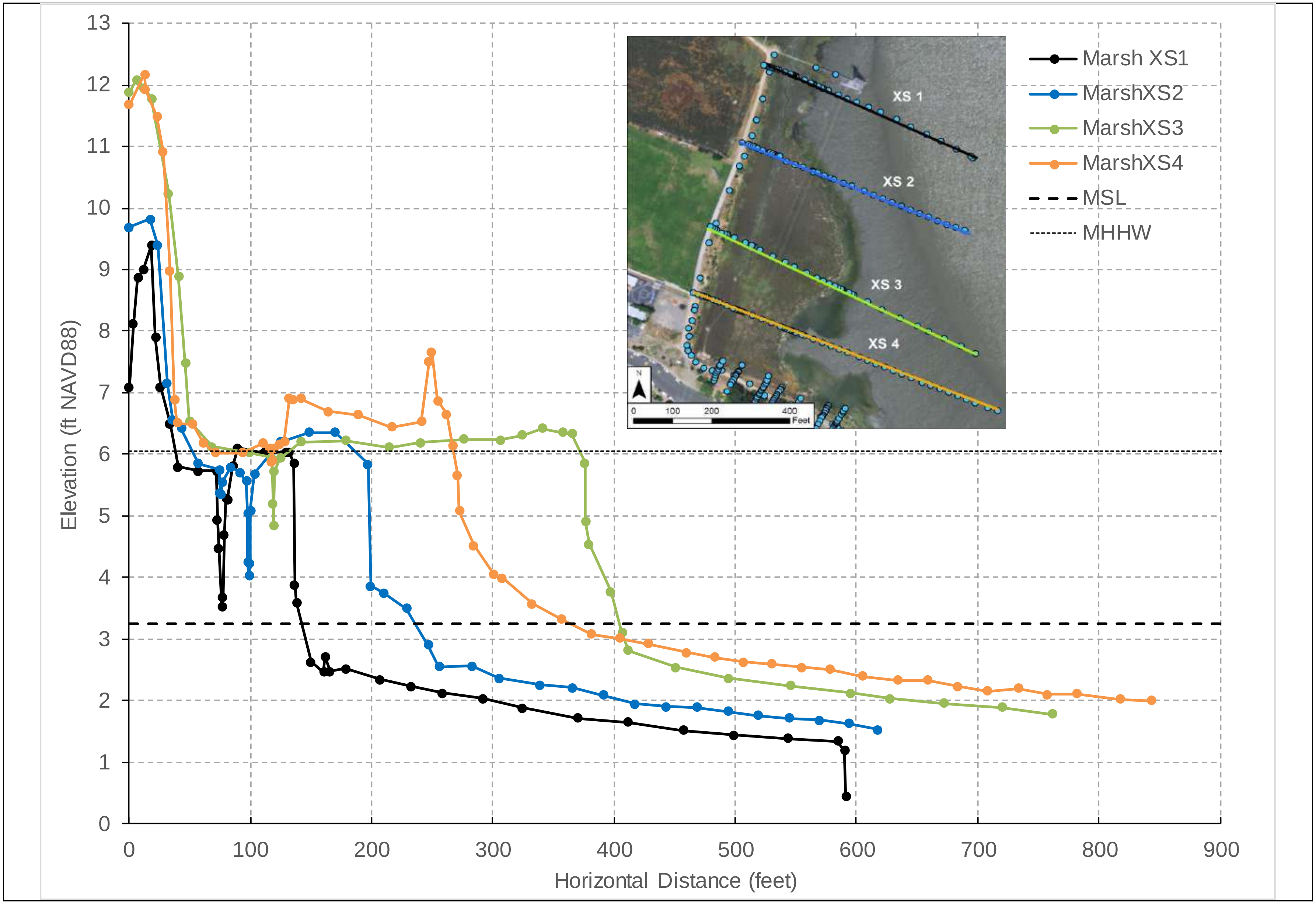
Tiscornia Marsh erosion rates after 1987.



SOURCE: Topography and bathymetry provided by CA State Coastal Convservancy

NOTE: marsh topography not corrected for LiDAR bias due to vegetation

Figure 6
Site topography in 2010.



SOURCE: ESA survey

Tiscornia Marsh Habitat Restoration . D160888.0

Figure 7

Tiscornia Marsh survey transects from September 19, 2017.

Moving south, the marsh widens to 200 to 500 feet. At the southernmost transect (Transect 4 in **Figure 7**), the mid marsh transitions to low marsh dominated by cordgrass (*Spartina foliosa*), and the edge escarpment is generally lower or is replaced by a more gradual gradient between mid and low marsh and mudflat. At Transect 4, the adjacent mudflat is higher than in northern transect locations (2-3.5 feet NAVD88). In general, the mudflat slopes downward toward the Canal from south to north, which is also apparent from the 2010 DEM (Figure 6). This is likely a response to the local sediment transport patterns, which are described in Section 3.4.7.

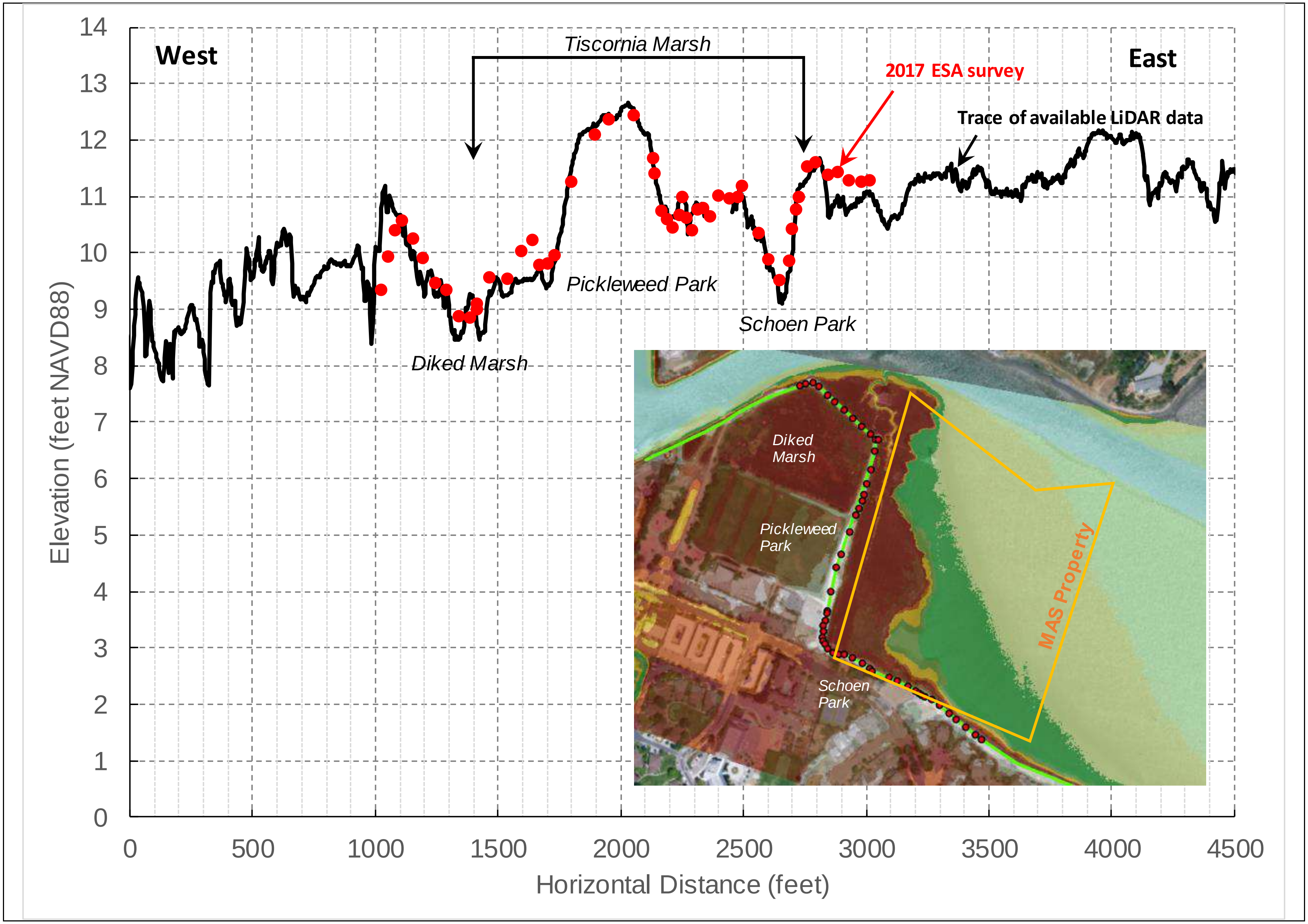
The diked pickleweed marsh immediately north of Pickleweed Park (west of Tiscornia Marsh and separated from the tidal marsh by the levee), has a roughly compatible surface elevation to the outboard pickleweed-dominated marsh surface in Tiscornia Marsh. Although only one transect was collected in the diked marsh, surface elevations tended to be roughly 5.5 to 6.5 feet NAVD88. This area does not appear to have any direct hydrologic connection to the tidal marsh, San Rafael Canal or San Rafael Bay.

3.2.2 Existing Levee

Figure 8 shows a profile of the levee crest to the immediate south and west of Tiscornia Marsh. Farther west and east, where survey data were not collected, the 2010 Marin County DEM was traced along the levee crest to give a larger picture of the levee elevations around this part of the Canal District. In general, the lowest segment of levee near the site is around 9-9.5 feet NAVD88 near Schoen Park, along the southern edge of the MAS property. The levee is lower, 7.5-8 feet NAVD88, on the west side of the diked marsh. The highest elevation is approximately 12 feet NAVD88 in front of the soccer field at Pickleweed Park. A series of transects across the levee (traversing from Schoen Park to Tiscornia Marsh) are shown in Appendix B.

3.2.3 Datums and Benchmarks

For the 2017 topographic survey of the levee and marsh, we used standard real-time kinetic global positioning system (RTK-GPS) surveying techniques to establish temporary vertical and horizontal controls. The survey tied into the North American Horizontal Datum of 1983 (NAD83) and North American Vertical Datum of 1988 (NAVD88). Appendix B provides more detail on the specific survey benchmarks used for this study.



Notes: Solid line represents a trace of 2010 LiDAR data. Circles represent spot elevations from ESA's 2017 ground survey.

Figure 8
Levee profile adjacent to Tiscornia Marsh.

3.3 Biology & Ecology

3.3.1 Vegetation

The marsh plain is dominated by pickleweed (*Salicornia pacifica)*, with thin bands of Pacific cordgrass (*Spartina foliosa*)[2] along its bayward edge and along the single tidal channel traversing the marsh. Gumplant (*Grindelia stricta* var. *angustifolia*), saltgrass (*Distichlis spicata*), jaumea (*Jaumea carnosa*), and marsh rosemary (*Limonium californicum*) also occur in scattered patches across the marsh. Plants restricted to the upper edge of the marsh include fat hen (*Atriplex patula*) and alkali heath (*Frankenia grandiflora*).

The upland boundary of Tiscornia Marsh, along the perimeter levee separating it from Pickleweed Park and the diked marsh, is comprised primarily of nonnative annual grasses, with scattered coyote brush (*Baccharis pilularis*), and acacia (*Acacia* sp.). Invasive plant species present in this zone include fennel (*Foeniculum vulgare*), wild radish (*Raphanus sativus*), and curly dock (*Rumex crispus*). Recently, volunteers have conducted native plantings and management of non-natives for STRAW (Students and Teachers Restoring a Watershed) and Point Blue Conservation Science. This has occurred along a portion of the levee fronting Pickleweed Park, and a recently-awarded Measure AA grant from the San Francisco Bay Restoration Authority is intended to fund a continuation of this work along additional parts of the levee.

Vegetation communities in tidal wetlands are defined by tidal hydroperiod, salinity, soils drainage and species competition. Typical vertical vegetation zones and approximate range of elevations for Tiscornia Marsh are identified in **Table 1**. (Note that these general elevation bands are consistent with limited spot elevations measured onsite, but are not based on a comprehensive vegetation survey.)

TABLE 1
VEGETATION ZONES IN TISCORNIA MARSH

Tidal Vegetation Zone	Dominant Plant Species	Approximate Tidal Range	Approximate Elevation Range (ft NAVD88)
Mudflat/Tidal Channel		<MTL	<3.3
Low Marsh	Pacific cordgrass	MTL to MHW	3.3 – 5.5
Mid Marsh	pickleweed, jaumea	MHW to MHHW	5.5 - 6.1
High Marsh	pickleweed, salt grass, gumplant, fat hen, alkali heath	MHHW to highest tide	6.1 – 7.3

[2] Tiscornia Marsh is one of several marshes included in the SCC's Invasive Spartina Project (ISP), which is a coordinated regional effort to eradicate multiple introduced species of *Spartina* (cordgrass). The ISP has successfully removed *Spartina densiflora* along the outer edge of the Tiscornia Marsh.

3.3.2 Wildlife

A diverse assemblage of wildlife is common in the area. Small mammals likely using the marsh and adjacent seasonal wetlands (diked marsh) and uplands likely include California ground squirrel (*Otospermophilus beecheyi*), black-tailed jackrabbit (*Lepus californicus)*, striped skunk (*Mephitis mephitis*), raccoon (*Procyon lotor*), Opossum (*Didelphis virginiana*), California vole (*Microtus californicus*) and house mouse (*Mus musculus*). The levee and bordering uplands also likely support western fence lizard (*Sceloporus occidentalis*), San Francisco alligator lizard (*Elgaria coerulea corulea*), and coast garter snake (*Thamnophis elegans terrestris*). Salt marsh harvest mouse (*Reithrodontomys reviventris*) has also been documented and is discussed further in Section 3.3.4 below.

The site is an important foraging area for large wading birds such as great egret (*Ardea alba*), snowy egret (*Egretta thula*), black-crowned night heron (*Nycticorax nycticorax*), and great blue heron (*Ardea herodias*). West Marin Island, just off shore, provides nesting habitat to the largest heron and egret rookery in the San Francisco Bay area—and one of the largest in northern California. There are over 500 nesting pairs of great and snowy egrets, and great blue and black-crowned night herons. At low tides, the marsh plain and mudflats are used by shorebirds including dowitchers (*Limnodromus* spp.), black-necked stilt (*Himantopus mexicanus*), American avocet (*Recurvirostra americana*), greater yellowlegs (*Tringa melanoleuca*), and willet (*Tringa semipalmata*); and at high tides by waterfowl including canvasback (*Aythya valisineria*), mallard (*Anas platyrhynchos*), greater scaup (*Aythya marila*), bufflehead (*Bucephala albeola*), and ruddy duck (*Oxyura jamaicensis*). The shallow waters of the Bay adjacent to Tiscornia Marsh are also important rafting habitat for these waterfowl species.

3.3.3 Aquatic Habitat

San Rafael Canal and the nearshore waters of San Rafael Bay provide shallow subtidal and intertidal mud bottom estuarine habitat for a wide variety of fish, wildlife and invertebrate species. Riprap and other shoreline structures, such as piles, provide some solid substrates.

A twelve-month aquatic habitat survey of the Canal and nearshore waters adjacent to Tiscornia Marsh was conducted for the Corps of Engineers by the U.S. Fish and Wildlife Service in 1989 (Weinrich 1990). Benthic samples at the mouth of the Canal yielded numerous polychaete worms, as well as clams and snails. Three species of crabs were found: Dungeness (*Metacarcinus magister*), red rock (*Cancer productus*), and yellow shore crabs (*Hemigrapsus oregonensis*). Twenty-two species of fish were captured in the Canal and in San Rafael Bay during the year-long survey. The most common species (accounting for 91 percent of the total fish captured) were northern anchovy (*Engraulis mordax*), shiner perch *(Cymatogaster aggregata)*, yellowfin goby *(Acanthogobius flavimanus)*, threadfin shad *(Dorosoma petenense)*, and butter sole *(Isopetta isolepis)*. Seventeen species captured are endemic to California waters. Five introduced species were captured: Mississippi silverside (*Menidia audens*), threadfin shad, striped bass (*Morone saxatilis*), yellowfin goby and chameleon goby (*Tridentiger trigonocephalos*). Other aquatic species found included jellyfish, comb jellies, and two species of bay shrimp. (Weinrich 1990).

In 2017 Environmental Science Associates (ESA) conducted fish sampling in the (restored) Hamilton Wetlands Preserve, approximately 6 miles north of Tiscornia Marsh. This effort resulted in capture and identification of 1841 individual fish, representing 12 species including native species: northern anchovy, Pacific herring (*Clupea pallasii*), Pacific staghorn sculpin (*Leptocottus armatus*), three-spined stickleback (*Gasterosteus aculeatus*), topsmelt (*Atherinops affinis*), California halibut (*Paralichthys californicus*), and Chinook salmon (*Oncorhynchus tshawytscha*); as well as non-native species: chameleon goby, yellowfin goby, rainwater killifish (*Lucania parva*), Shokihaze goby (*Tridentiger barbatus*), and striped bass (HDR et al. 2017).

Information on Olympia oysters (*Ostrea lurida*) is provided from the SCC's San Francisco Bay Living Shorelines: Near-shore Linkages Project. This first living shorelines project in San Francisco Bay focused on restoration of two native species, eelgrass (*Zostera marina*) and Olympia oysters (*Ostrea lurida*) (Boyer et al. 2016). This pilot-scale project was implemented at two locations, the San Rafael shoreline off Spinnaker Point, and at Eden Landing Ecological Reserve in Hayward. The San Rafael site included a small-scale test of various oyster substrates including reef balls, oyster ball stacks, oyster blocks, and a "layer cake" design, all made of "baycrete" (20% cement and 80% native Bay materials). Monitoring conducted 4 years after implementation has indicated that oysters recruited readily to the small "baycrete" structures. Measures of these structures early in the project indicated that twice as many oysters were present at lower and mid-level elevations (approximately 0 to 8 inches below mean lower low water (MLLW), respectively) than at the high elevation (~+20 inches above MLLW). More oysters were present on vertical rather than on horizontal faces. The north sides of the elements also typically had 50% more oysters than did south sides. These differences have diminished over time with oyster densities declining at the low and mid-elevations. This may be the result of competition with other sessile species, which are more abundant at lower tidal elevations, or due to greater predation at lower tidal elevations (Boyer et al. 2016).

3.3.4 Special Status Species

Two State and Federally listed endangered species, the salt marsh harvest mouse (*Reithrodontomys reviventris*) and Ridgway's rail (*Rallus longirostris.obsoletus*) have been documented to be present in Tiscornia Marsh.

Salt Marsh Harvest Mouse

The salt marsh harvest mouse (SMHM) is endemic to the marshes which border San Francisco, San Pablo, and Suisun Bays. There are two subspecies of SMHM: the northern subspecies (*Reithrodontomys raviventris halicoetes*) is found in the Marin Peninsula and San Pablo and Suisun Bays (Shellhammer 2000). The southern (*R. r. raviventris*) lives in the marshes of Corte Madera, Richmond and South San Francisco Bay (Shellhammer 2000). Occurrence of both subspecies within this small range is highly fragmented.

The primary habitat of the SMHM is the middle to upper zone of salt and brackish marshes. The SMHM is dependent on dense vegetation cover, usually in the form of pickleweed (*Salicornia pacifica*, the dominant salt marsh vegetation in the Bay) and other salt dependent or salt tolerant vegetation. Optimal SMHM habitat has dense vegetative cover, with a high percentage cover of pickleweed, and has contiguous dense and tall cover in which the mice can escape extreme water levels without excessive exposure to predation. SMHM may also move into grasslands adjacent to marshes during extreme high tides if dense cover is present. The mouse is largely herbivorous with pickleweed known to be its primary food source. Loss of habitat due to the diking and filling of wetlands has been the major factor contributing to the decline of the SMHM.

Trapping studies conducted in 1990 for the US Army Corps of Engineers resulted in capture of fourteen SMHM in Tiscornia Marsh and fifteen in the adjacent diked wetland Pickleweed Park (Flannery and Bias 1990 as reported in USACE 1992). No other records of recent captures or trapping efforts in that area have been found, however based upon habitat suitability resource agencies would likely assume presence of this species for the purposes of project environmental compliance.

California Ridgway's Rail

The California Ridgway's rail (formerly known as the California clapper rail and hereafter RIRA) is a secretive, hen-like waterbird, that lives in salt and brackish tidal marshes in the San Francisco Bay. This species once occupied coastal California tidal marshes from Humboldt Bay southward to Morro Bay, and estuarine marshes of San Francisco Bay and San Pablo Bay to the Carquinez Strait (Raabe et al. 2010). Resident populations are currently limited to San Francisco Bay, San Pablo Bay, Suisun Bay, and associated tidal marshes.

RIRA occur almost exclusively in tidal salt and brackish marshes with unrestricted daily tidal flows, adequate invertebrate prey food supply, well developed tidal channel networks, and suitable nesting and escape cover during extreme high tides (Raabe et al. 2010). RIRA depend on mudflats or very shallow water within a network of tidal channels where there are both abundant invertebrate populations and taller plant material to provide cover, refuge during high tides, nesting opportunities above high tides and wave action, and protection from predators. RIRA rely on marsh plants such as Pacific cordgrass (*Spartina foliosa*), bulrush (*Bolboschoenus maritimus*), and pickleweed for breeding and feeding.

As part of the San Francisco Estuary Invasive Spartina Project, Olafson Environmental Inc (OEI) has conducted annual monitoring of RIRA at treatment sites since 2010. RIRA were detected in Tiscornia Marsh in 2010, 2011, 2012, 2016 and 2017. Monitoring recorded six (6) RIRA in 2016 and eleven (11) in 2017 (OEI 2016, OEI 2018). In its report on the 2017 RIRA monitoring, OEI notes about the Tiscornia Marsh site:

> "Surprisingly, this small marsh fragment had one of the highest density rail populations of all sites surveyed by OEI in 2017. The site is small, relatively isolated, and does not support exceptional rail habitat, however it has supported an intermittent population of Ridgway's rails. … It is likely a pair has been successfully breeding at the site since [2016]." (OEI 2018)

3.4 Hydrology and Geomorphology

3.4.1 Wind Climate

Local winds generate the wind waves that are an important driver for the observed erosion of the marsh edge, and for sediment transport patterns along the mudflat and marsh edge. Conceptual models for these processes are described in more detail in Section 3.5 Conceptual Models.

Wind data were collected from the California Irrigation Management Information System (CIMIS) at Point San Pedro (Station #157), and also at the NOAA monitoring stations at Chevron Pier (#9414863) and at Point Potrero (#9414847). An additional local wind monitoring station near Point San Pedro available from Weather Underground is summarized in Appendix A to give additional local context. Wind data were analyzed in Matlab©, to summarize direction and speed statistics, and were bracketed into 5-mile per hour (mph) intervals and displayed on wind roses to provide an understanding of the directionality.

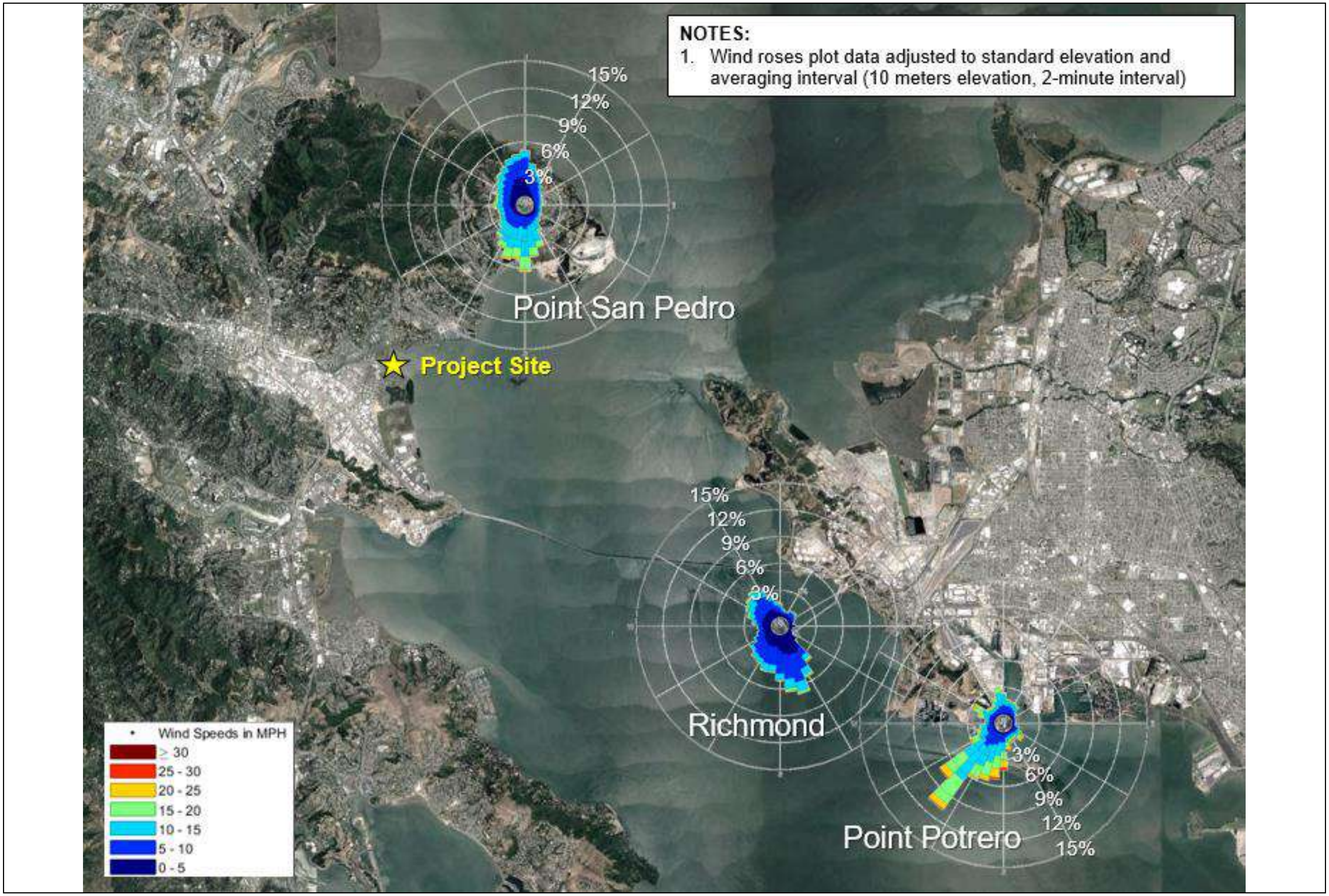
Though local winds generate the waves that drive geomorphic processes at Tiscornia Marsh, the local shoreline orientation limits their effect by constraining the wind waves that reach the marsh to a limited number of dominant fetches. This is especially true because Tiscornia Marsh is set back relative to the adjacent shorelines, and is likely shielded entirely from northerly or southerly winds by the local topography. Longer wind fetches (direct lines of sight across the Bay surface that are uninterrupted by topography) provide greater waves than short fetches, and these tend to be aligned to the northeast (‘Carquinez fetch’), and to the southeast (‘Richmond fetch’).

Figure 9 shows wind roses (illustrations of wind direction and speed) at each of the sites near Tiscornia Marsh. The Point San Pedro and Richmond sites suggest that the southeasterly Richmond and Berkeley fetches are especially important for generating waves that arrive at the site. The importance of these fetches is also apparent in the 30-year hindcast of wave conditions at the site used by FEMA to map coastal flooding (DHI 2011) described below.

3.4.2 Tidal Hydrology

The hydrology of the project site is controlled by the local tidal water levels in San Rafael Bay, which periodically inundate the marsh and adjacent mudflats. Since tides can vary locally throughout the Bay, it was important to compare local conditions against longer tidal records of nearby locations before assessing the potential response of the site to sea-level rise.

Local tidal conditions were assessed by installing a pressure gage to measure water levels at the site for a five-week period in 2017, and comparing the local record against longer tidal records documented nearby. Water levels adjacent to the marsh were measured from September 19th to October 27th, 2017, and these data were processed in Matlab© to obtain short-term tidal datums representative of the measurement period (**Table 2**). Water levels were referenced to the NAVD88 vertical datum by surveying the gauge and local benchmark, which is described in more detail in Appendix B.



SOURCE: CIMIS and NOAA wind gages

Tiscornia Marsh Habitat Restoration . D160888.0

Figure 9

Wind roses for local NOAA and CIMIS wind gages near Tiscornia Marsh.

TABLE 2
TIDAL DATUMS IN VICINITY OF PROJECT SITE

	Nearby NOAA Tidal Datum Elevations (1983-2001 Tidal Epoch) ft NAVD88			Measured Tidal Elevations (Sep 17-Oct 29, 2017) ft NAVD88		Estimated Tiscornia Tidal Datums[5] ft NAVD88
	Chevron Pier[1]	Point San Pedro[2]	Point San Quentin[3]	Chevron Pier	Tiscornia Marsh	
Mean Higher High Water	6.06	6.04	5.95	5.90	5.81	6.06
Mean High Water	5.45	5.44	5.34	5.60	5.49	5.45
Mean Tide Level	3.29	3.33	3.29	3.49	--[4]	3.31
Mean Sea Level	3.26	3.24	3.24	3.47	--[4]	3.24
Mean Low Water	1.13	1.22	1.23	1.39	--[4]	1.23
Mean Lower Low Water	0.00	0.17	0.17	0.60	--[4]	0.17
NAVD88	0.00	0.00	0.00	0.00	--[4]	0

1 NOAA NOS Station 9414863, Richmond
2 NOAA NOS Station 9415009, Point San Pedro
3 NOAA NOS Station 9414873, Point San Quentin
4 Mudflats adjacent to Tiscornia Marsh prevented water levels from dropping below 2.3 feet NAVD88, so MLLW, MLW, MSL, MTL could not be estimated
5 MHHW and MHW adopted from NOAA Richmond gauge, while lower datums were estimated as an average of Point San Pedro and Point San Quentin values. Standard NOAA (2003) method could not be used to estimate lower tidal datums at the site due to influence of the adjacent mudflats.

The gauge was located approximately 50 feet offshore of the marsh scarp edge, in an area where the mudflat elevations are higher than low tides, so only the Mean High Water (MHW) and Mean Higher High Water (MHHW) were estimated from the record. To develop estimates of tidal datums at the site, we took the following approach:

- We estimated short-term datums at the ESA Tiscornia Marsh gauge and NOAA Richmond gauge for September 19th to October 27th, 2017.
- We also compared established tidal datums at the NOAA Richmond gauge (5 miles southeast) and at two local stations at Point San Pedro (3 miles northeast) and Point San Quentin (2 miles southeast).

In general, short-term estimates of MHW and MHHW from fall 2017 were within about 0.1 feet between Tiscornia Marsh and the NOAA Richmond gauge. Comparing datums among the three established gauges listed in Table 2 indicates that MSL, MTL, MHW, and MHHW are very close for all three sites. However, MLW and MLLW tended to be higher at the stations nearer to Tiscornia Marsh. Since the mudflats adjacent to Tiscornia Marsh cut off low tide levels, the standard NOAA (2003) method could not be used to obtain tidal datums at the site. Given the similarity of the Richmond and Tiscornia data, Richmond datums for MHHW and MHW are adopted, while lower datums (MSL, MTL, MLW, MLLW) are estimated at the site by averaging the Point San Pedro and Point San Quentin datums.

3.4.3 Wave Climate

We examined the local wave climate by using hindcasted conditions from 2006 to 2010 to understand seasonal and interannual variability. As described below, we also developed a local wind wave model for San Rafael Bay to look at spatial patterns in more detail for the dominant fetches.

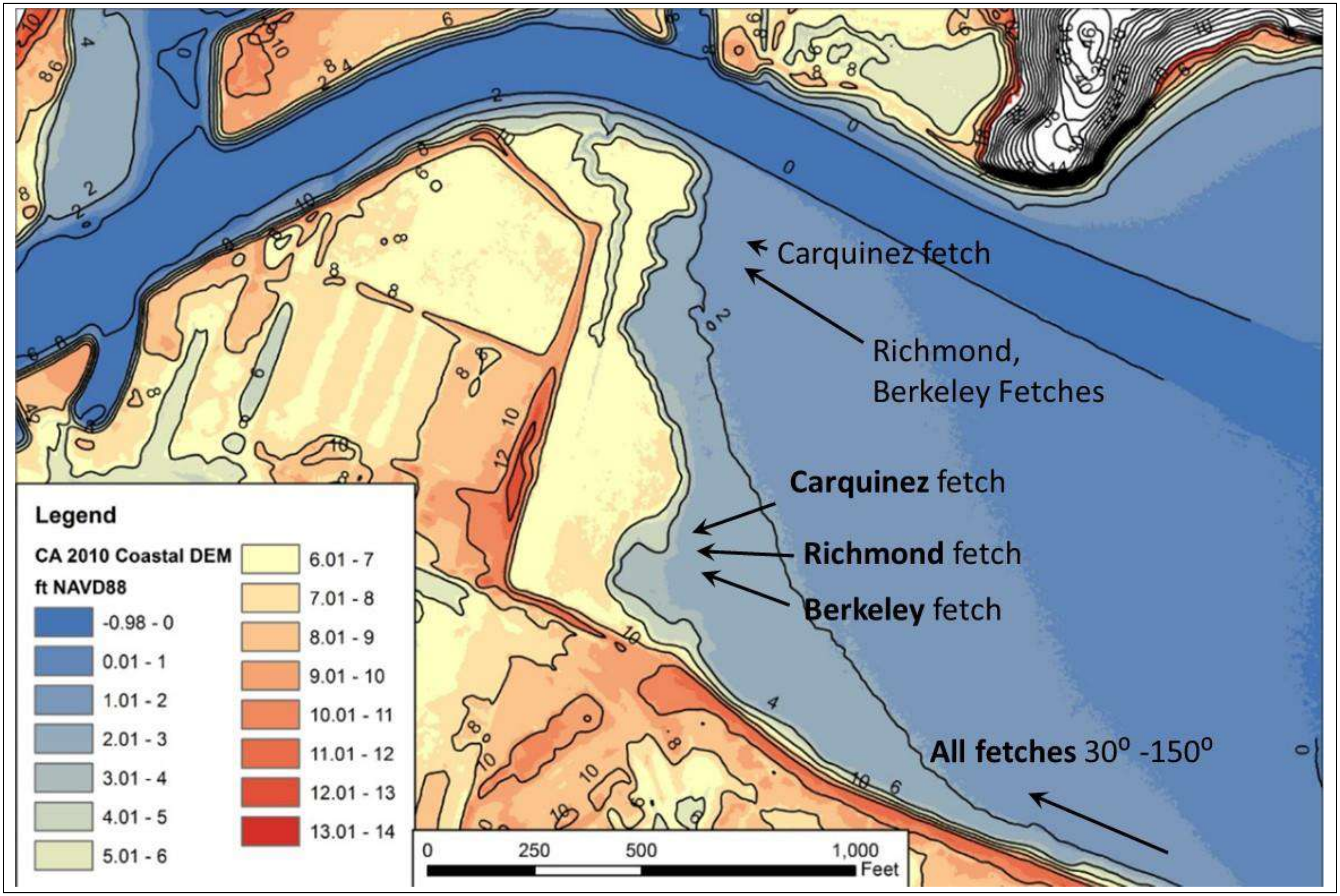
Temporal Patterns

Wave characteristics, including significant wave height, peak period, and mean direction, were extracted from a Central and North Bay wave hindcast for the coastal hazard modeling study conducted by DHI (2011). This hindcast was used to understand flooding conditions along the Bay shoreline, and the available 30-year hindcast used to calibrate the model was used to understand wave statistics throughout the Bay. The Central Bay region is defined as the area bounded by the San Mateo Bridge, Richmond Bridge and Golden Gate Bridge. The North Bay is defined as the region north of the Richmond Bridge and east toward Antioch. For the purposes of this study, wave hindcasts were extracted from July 2006 to July 2010, to provide a sufficient time period to characterize long term wave statistics at Tiscornia Marsh. These data were evaluated for three sites along Tiscornia Marsh, as illustrated in **Figure 10**.

All locations near the marsh experience relatively modest wave heights that are typically between 0.25 and 1 foot. The directionality of the arriving waves is strongly dependent on the exposure of different areas to the dominant wave fetches. As expected from the wind data, the southeasterly Richmond fetch produces the largest waves along the northern edge of Tiscornia Marsh, where scarp erosion is most severe. At this location, Point San Pedro appears to shelter the northern edge of the marsh from waves arriving from the Carquinez fetch. In contrast, the southern edge of Tiscornia Marsh experiences more waves arriving from the east or northeast, although southeasterly waves still dominate. Farther east, toward Spinnaker Point, the shift toward more exposure to easterly and northeasterly waves continues. Based on an extreme value analysis of the wave record, the 10-year and 20-year wave height experienced near the edge of Tiscornia Marsh is 2.2 and 2.5 feet, respectively.

Spatial Patterns

Though the wave time series helps to portray the causes of ongoing scarp erosion at the site, it is important to also look more closely at spatial patterns of waves along the marsh edge to better understand sediment transport. As part of the concurrent Giant Marsh restoration in the Central Bay, ESA developed a wind wave model using the Simulating Waves and Nearshore (SWAN) software. The existing model was refined in San Rafael Bay for the purposes of this project.



SOURCE:

- Background bathymetry data provided by California Coastal Conservancy (2010)
- Sediment transport directions inferred from ESA SWAN model

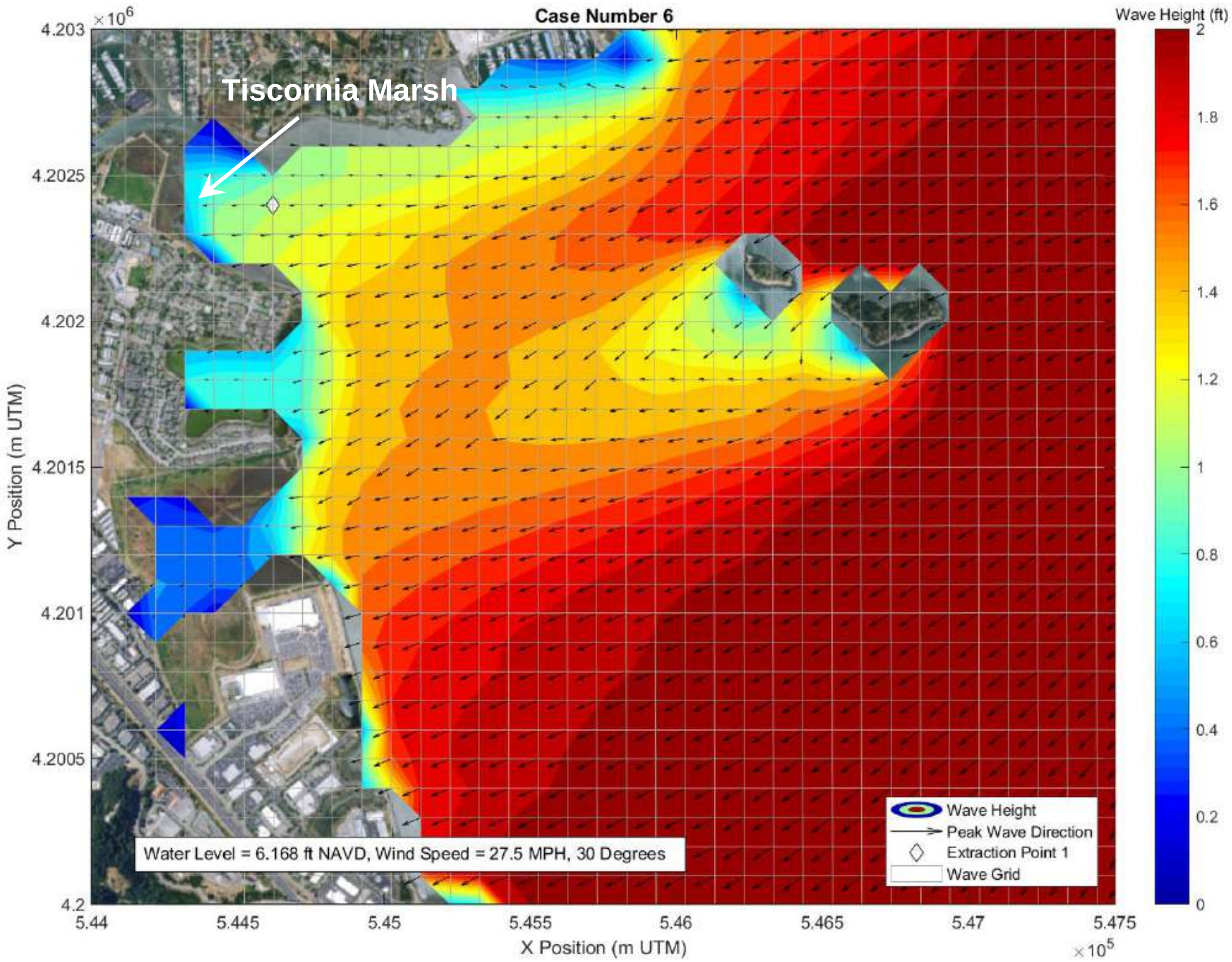
Figure 10
Conceptual model of sediment transport adjacent at Tiscornia Marsh. Arrows indicate direction of net sediment transport when waves arrive from specified fetch.

We used the model to evaluate the local wave conditions for a series of wind directions (30º to 150º from north) and wind speeds (2.5 mph to 32 mph). We assumed a water level of MHHW, when the marsh scarp at the project site would be exposed to wind wave action. **Figures 11** and **12** illustrate the wave patterns that would result from wind speeds of 27.5 mph and fetch directions of 30º and 150º (Carquinez and Richmond fetches, respectively). For the Carquinez fetch, waves were only on the order of 0.5 foot at the northern edge of the marsh, but increased to 0.5-1.0 foot at the southern edge and 1.0-1.5 feet farther east, near Spinnaker Point. The directionality of the waves suggested that the net sediment transport would be toward the southern edge of the marsh. For the dominant Richmond fetch, waves were larger at the northern edge of the marsh (1.0-1.5 feet) and minimal at the southern edge. The directionality suggested waves arriving at the north edge would transport suspended sediment north toward the San Rafael Canal, whereas waves arriving at the southern marsh edge would again transport sediment to the south, collecting at the southern corner of the site.

3.4.4 Sea-Level Rise

The accumulation of greenhouse gases in the Earth's atmosphere is causing and will continue to cause global warming and resultant climate change. For the coastal setting, the primary exposure will be an increase in sea levels (e.g., mean tide, high tide) due to thermal expansion of the ocean's waters and melting of ice sheets.

State planning guidance for coastal flood vulnerability assessments call for considering a range of emission scenarios (OPC 2013; CCC 2015). The California Ocean Protection Council (OPC) first released a statewide sea level rise guidance document in 2010 following Governor Schwarzenegger's executive order S-13-08. After being adopted by the OPC, this interim guidance document informed and assisted state agencies to develop approaches for incorporating sea level rise into planning decisions (OPC 2011). The OPC (2011) document was updated in 2013 (OPC 2013) after the National Resource Council (NRC) released its final report *Sea level Rise for the Coasts of California, Oregon, and Washington* (NRC 2012), which provided three projections of future sea level rise associated with low, mid, and high greenhouse gas emissions scenarios, respectively. The most current version of sea level rise projections is from the Ocean Protection Council in 2018 (OPC 2018). Whereas the prior guidance (OPC 2013) delineates future scenarios by specific greenhouse gas emission scenarios, the new guidance (OPC 2018) provides a more probabilistic approach, giving ranges of likely sea-level rise amounts in the future.



SOURCE: ESA SWAN model

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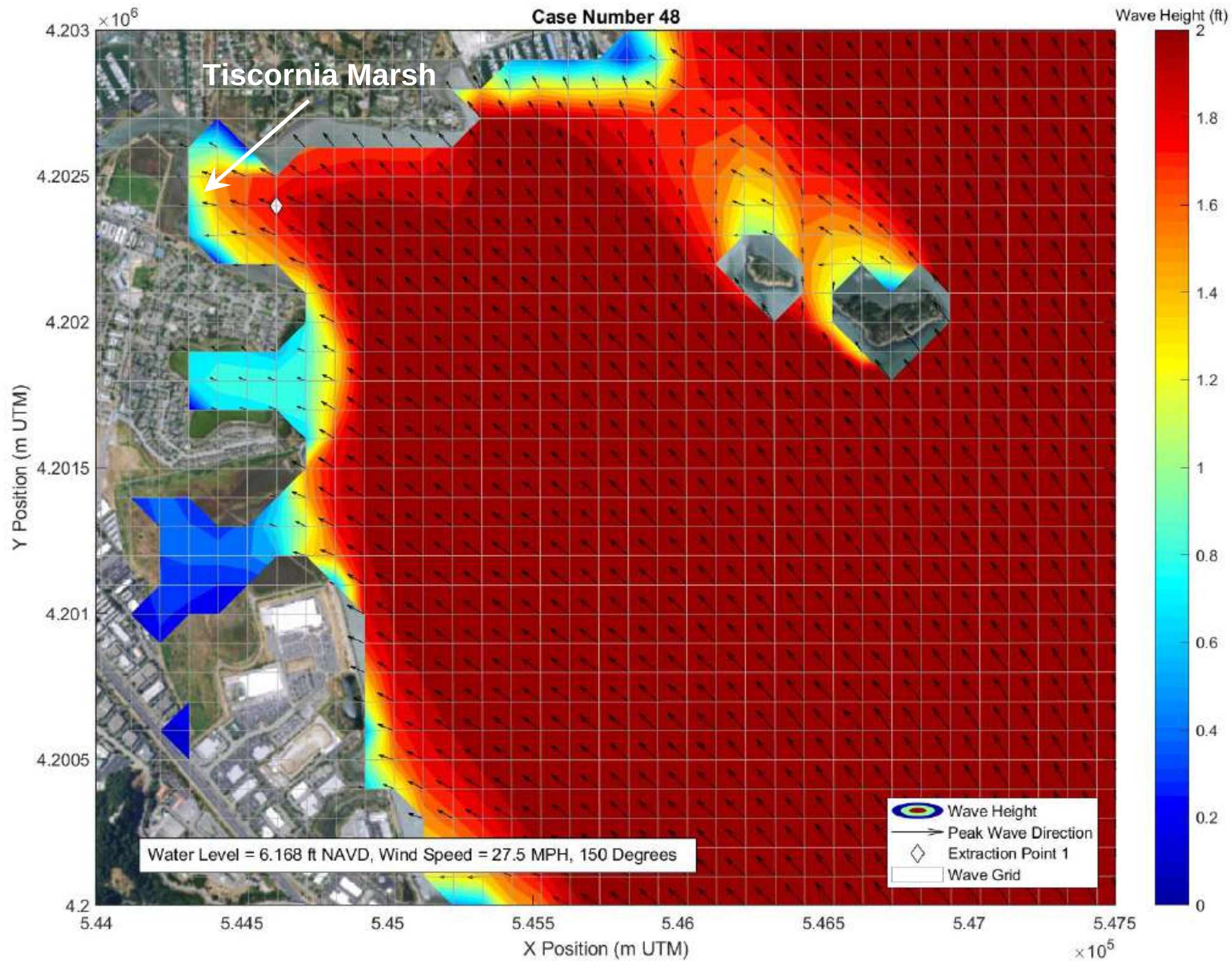
Figure 11

Predicted wind-wave heights and directions for 27.5 mph wind speed from a 30º fetch angle.



SOURCE: ESA SWAN model

Tiscornia Marsh Habitat Restoration . D160888.0

Figure 12

Predicted wind-wave heights and directions for 27.5 mph wind speed from a 30º fetch angle.

Table 3 presents sea level rise projections from OPC (2013) and OPC (2018). The values for relative sea level rise[3] at 2030, 2050, 2070, and 2100 for San Francisco Bay are relative to sea level in 2000, and include regional projections of both mean sea level rise and vertical land motion of -1.5 millimeters per year for the San Andreas region south of Cape Mendocino.

TABLE 3
STATE GUIDANCE: SEA-LEVEL RISE PROJECTIONS FOR CALIFORNIA[1]

Scenario	2030	2050	2070	2100
OPC (2013) State Guidance				
Low Range	0.2 feet	0.4 feet	0.7 feet	1.5 feet
Mid Curve	0.5 feet	0.9 feet	1.6 feet	3.1 feet
High Range	1.0 feet	2.0 feet	3.2 feet	5.5 feet
OPC (2018) State Guidance				
Likely Range	0.5 feet	1.1 feet	1.5 - 1.9 feet	2.4 – 3.4 feet
1-in-200 Chance	0.8 feet	1.9 feet	3.1 – 3.5 feet	5.7 – 6.9 feet

[1] Values are for the San Andreas region south of Cape Mendocino, where the vertical land motion is approximately -1.5 mm per year – indicating subsidence

SOURCE: Table 5.3, NRC (2012)

For this project, we consider a single sea level rise horizon of 2070 (~50 years), and consider a local sea-level rise values of 1.7 feet at Tiscornia Marsh. This is the midpoint of the likely range of sea-level rise of 1.5 – 1.9 feet from OPC (2018), and similar to the OPC (2013) medium emissions scenario prediction of 1.6 feet. An increase in local Bay levels by 1.7 feet would lead to significant changes in hydrology at Tiscornia Marsh (as the marsh would be inundated more frequently), as well as a corresponding increase in wind wave exposure of the surrounding levee.

Although higher amounts of sea-level rise are possible by 2070 (as indicated by a 1-in-200 chance of 3.1 – 3.5 feet of sea-level rise in Table 3), the amount of 1.7 feet is shown in Section 6 to have a significant effect on habitat conditions at the site. For sea-level rise higher than 1.7 feet, these affects would still occur, but would be expected to happen sooner than the 2070 horizon.

3.4.5 Flood Conditions

Data on flood conditions at the project site were investigated from several sources, including the Federal Emergency Management Agency (FEMA) and Marin BayWAVE study (BVB 2017).

FEMA Flood Study

FEMA performed detailed coastal engineering analyses and mapping of the San Francisco Bay shoreline within the nine San Francisco Bay Area counties under the Bay Area Coastal (BAC) Study. This study revised and updated the flood and wave data for the Marin County Flood

[3] The term *relative sea level rise* indicates that the local effects of vertical land motion are included in the sea level rise projection

Insurance Study (FIS) report and Flood Insurance Rate Map (FIRM) panels along the San Francisco Bay shoreline. The revised coastal study became effective on March 16, 2016.

The updated FIRM is shown on **Figure 3**. The Base Flood Elevation (BFE) for the 100-year event varies along the San Rafael shoreline from elevations 10 to 12 feet NAVD88. The BFEs reflect that Total Water Level (TWL), which includes still water elevation level (SWEL), wave setup[4], and wave runup. The 100-year SWEL along the San Rafael shoreline is a constant 9.7 feet NAVD88. Therefore, the variability in BFEs is due to varying wave conditions predicted along the shoreline.

FEMA calculated TWLs for various transects along the shoreline. Wave hazards were analyzed using two primary methods depending on the shoreline type (FEMA, 2014). Steep-sloped shorelines and shoreline structures (e.g. steep revetments, vertical walls) were analyzed with wave run-up. Shallow-sloped shorelines and inland topography (e.g., marshes, developed areas) were analyzed with overland wave propagation, or WHAFIS (Wave Height Analysis for Flood Insurance Studies).

The FEMA BAC study includes a transect that bisects Tiscornia Marsh and Pickleweed Park. At this location, a shallow-sloped, “natural” shoreline was assumed, and waves were estimated using WHAFIS. The estimated TWL is 10.1 feet NAVD88, resulting in a Base Flood Elevation of 10 feet NAVD88[5]. The next closest transect to Tiscornia Marsh is roughly 800 feet to the east (bayward), where the shoreline was classified by FEMA as “revetment road.” At this transect, the TWL, estimated using both WHAFIS and wave runup, is 11.9 ft NAVD88. The approximately 2-foot increase in TWL, as compared to Tiscornia Marsh, is due to increased wave environment (more exposed, greater wind fetch) and differing shoreline conditions (steep outboard levee slope).

As previously noted, the majority of the neighborhood adjacent to Tiscornia Marsh is classified in the FIRM as Zone AE. Zone AE is defined as the flood insurance rate zone that corresponds to the 1-percent annual chance floodplain (also referred to as the 100-year flood zone). The FIRM indicates that the levees around the site are not FEMA accredited and thus do not provide protection against the 1% annual-chance flood.

Marin BayWAVE Study

The Marin BayWAVE study provides vulnerability assessments for cities throughout Marin County, including San Rafael (BVB, 2017). Potentially hazardous designations in this study are based on modeling results from the Coastal Storm Modeling System (CoSMoS), developed by USGS. CoSMoS provides predictions of coastal flooding with future sea level rise and extreme events from daily conditions to 100-year recurrence intervals. Currently, projections are available for the north-central coast, San Francisco Bay and southern California, and are accessible via Our Coast, Our Future (OCOF).

4 Though wave setup should be computed to calculate the depth at the toe of the structure during runup calculations on shore barriers, it is often the case that the runup height computed by empirical runup methods are referenced to SWEL. Therefore, the runup height implicitly includes the wave setup contribution.)

5 BFEs are derived from TWLs by interpolated between transects and rounding results to the nearest foot.

Tiscornia Marsh and the adjacent Canal district are designated as vulnerable areas in the 10-inch sea level rise scenario. Canal Drive and Spinnaker Point Drive, which border the project site, are classified as vulnerable transportation assets in the near term modeling scenarios. Compared to the FEMA FIRM, the BayWAVE study provides more information on relevant timelines and sea level rise projections for the project site.

3.4.6 Flood Protection

Much of the Canal district lies below high tide elevations. Pump stations are employed to remove storm water, and some of the shoreline levees have been constructed to protect against coastal flooding. The existing shoreline levee extends from Pickleweed Park, south along the San Rafael Canal to the Marin Rod and Gun Club, and includes the Jean and John Starkweather Shoreline Park. Most of this levee was raised and improved with construction of the Bay Trail about 15 years ago, with the exception of two segments: at Tiscornia Marsh, and at Canalways, an 85-acre property to the south. The shoreline to the west, upstream along the San Rafael Canal, also has various features that provide flood protection but because of the extensive shoreline and over-water development, the nature and elevations of this shoreline reach are not well established.

ESA surveyed the levee crest within the vicinity of Tiscornia Marsh. We also estimated the levee crest elevation beyond the surveyed portions from the available LiDAR data, which is assumed to be less accurate (**Figure 8**). In addition, we interpolated survey data from a 2007 ground survey (RTK GPS) from Oberkamper Associates for the Spinnaker Point Levee. As we did not have the source data, we interpolated from the survey map. The levee elevations from west to east range along a total levee centerline distance of approximately 4,500 feet as follows:

- Perimeter of Pickleweed Park: 9.7 to 12.4 feet NAVD88
- **Tiscornia Marsh property: 8.9 to10.5 feet NAVD88**
- Spinnaker Point (north side): 11.3 to 12.2 ft NAVD88
- Spinnaker Lagoon (east side): 11.5 to 12.2 ft NAVD88
- Spinnaker Lagoon (south side): 13.1 to 14.1 ft NAVD88

As noted above, the levee segment on the Tiscornia property is relatively low compared to the remainder of the levee.

3.4.7 Sediment Supply

Sediment availability at the site was assessed by Siegel Environmental, and is summarized in detail in Appendix A.

Suspended sediment is supplied to the site by tides, and possibly to a much lesser extent by discharge from San Rafael Creek (Canal). The latter is likely a small and sporadic source because most of the watershed is developed, meaning that formerly erodible surfaces have been paved. Scaling the watershed relative to Corte Madera Creek and noting the difference in land cover between the two watersheds indicates that the supply of sediment from San Rafael Creek is dwarfed by the volumes that have been periodically dredged from the Canal by the U.S. Army

Corps of Engineers (USACE). This implies that the mudflat adjacent to Tiscornia Marsh extending east toward the San Pablo Bay navigation channel supplies the majority of the sediment delivered to Tiscornia Marsh, San Rafael Creek, and local marinas including Loch Lomond.

Tides and local wind waves cause bed sediments to become suspended in the water column. Flood tides that rise high enough to inundate the marsh surface deposit sediment onto the marsh and vegetation also captures sediment on the marsh plain. This process is described in more detail by Williams and Orr (2002) and BCDC and ESA PWA (2013). Deposition also occurs on the mudflats, but is enhanced locally in areas that are sheltered from wind waves, or where drops in the bed elevation cause sediment to fall out of suspension. San Rafael Creek acts as a sediment sink, as its bed is maintained lower than the surrounding mud flat by periodic dredging to allow navigability. The south to north slope of the mudflat adjacent to Tiscornia Marsh suggests that the south end of the site is a depositional environment.

Sediment availability is a key consideration for the long term adaptability of Tiscornia Marsh to sea level rise. The site receives relatively low amounts of suspended sediment on average. As described in Appendix A, suspended sediment concentrations (SSC) at the site, based on data from China Camp State Park and offshore of Spinnaker Lagoon and an estimated conversion factor from the measured turbidity values to sediment concentration, have median values in the range of 34-44 mg/L and average values in the range of 64-82 mg/L.

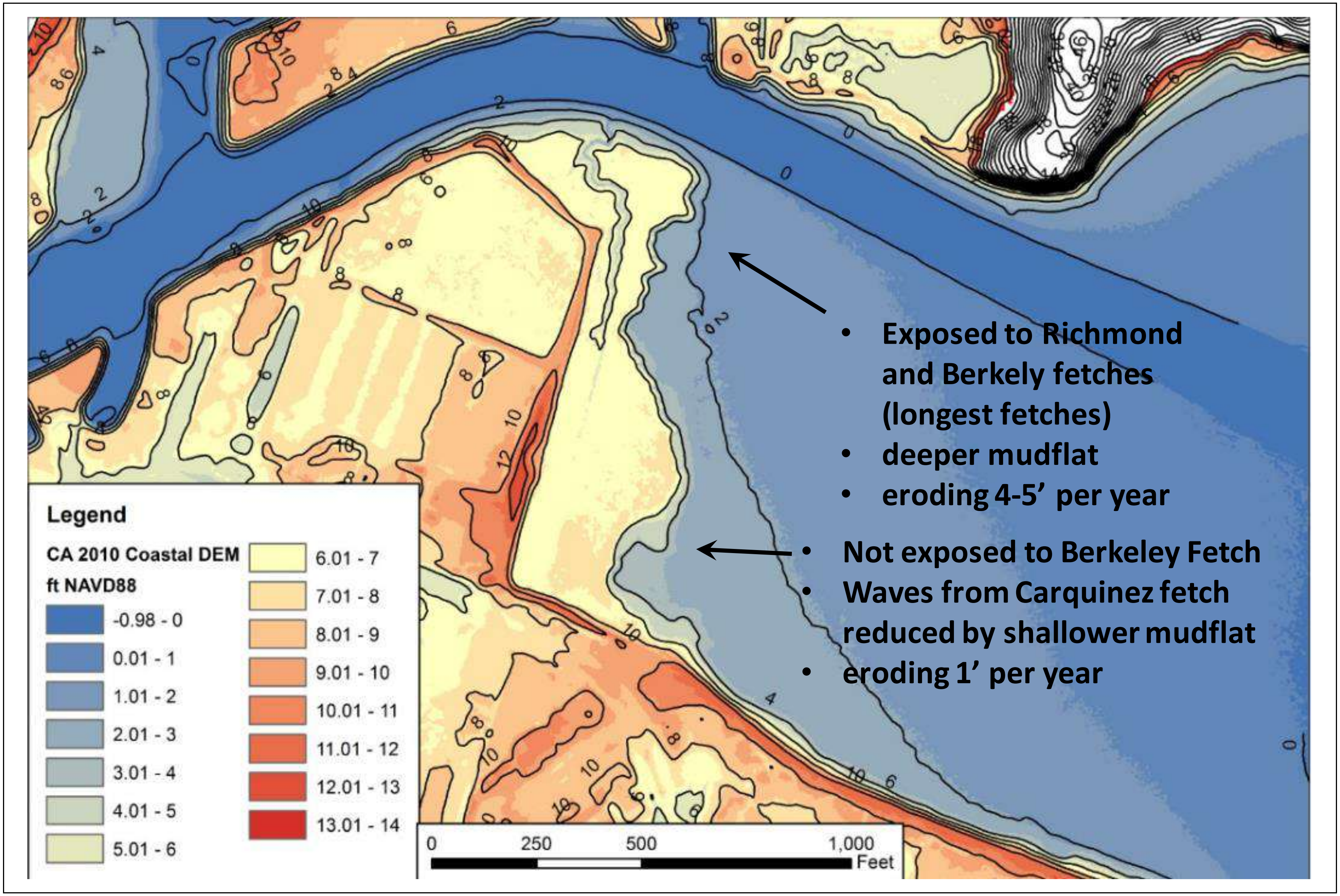
3.5 Conceptual Models

In order to understand the potential resiliency of Tiscornia Marsh in the face of climate change and rising sea level, we developed schematic conceptual models of marsh scarp erosion and sediment transport patterns at the site. These models were used to integrate the information from the sediment supply memorandum (Appendix A), wind data, and wave modeling at the site, in a way that can inform the conceptual design. The conceptual models were used in developing alternatives, and projecting how they are expected to evolve over time. The anticipated geomorphic and ecological responses to post-project and future conditions are presented in Section 6.1.

3.5.1 Scarp Erosion

Scarp erosion at the site has been most severe in the areas with the most wind wave exposure. As shown in **Figure 13**:

- Scarp erosion at the northern edge of the marsh (4-5 feet/year since 2004) is likely a result of full exposure of the northern marsh to the Berkeley and Richmond wind fetches.
- The lack of escarpments and/or slower rate of retreat at the southern end of the marsh (1-2 feet/year since 2004) is likely because this area is sheltered from full exposure to the Berkeley fetch. Despite being located farther south, exposure to the Carquinez fetch also appears to be small in this portion of the marsh.
- With sea-level rise, these patterns are not expected to change.
- Continued retreat of the marsh could further reduce exposure to the dominant wind fetches, but is not likely to be sufficient to stop erosion.



SOURCE:

- Background bathymetry data provided by California Coastal Conservancy (2010)

Figure 13
Conceptual model of marsh erosion at Tiscornia Marsh.

3.5.2 Sediment Transport

Figure 10 displays the conceptual model for sediment transport at the site, which is based on the following points:

- The majority of sediment arriving to the site is delivered from the mudflat which extends into San Rafael Bay.
- East of the site (near Spinnaker Point), wind waves arriving from the Carquinez and Richmond fetches lead to sediment transport along the San Rafael Bay shoreline toward the southern edge of Tiscornia Marsh.
- At the northern edge of Tiscornia Marsh, wave refraction patterns cause all fetches to drive sediment transport northward into San Rafael Creek.
- At the southern edge of Tiscornia Marsh, wave refraction patterns cause all fetches to drive sediment transport southward, trapping entrained sediment where the marsh and shoreline connect.

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4. OPPORTUNITIES AND CONSTRAINTS

Site opportunities and constraints were used to help guide development of the concept alternatives. The following opportunities and constraints were informed by the existing conditions analysis and stakeholder input. In some cases, a condition can be seen as both an opportunity and a constraint, such as the presence of RIRA or ongoing dredging of the San Rafael Canal.

4.1 Site Constraints

- The marsh is expected to continue to erode under current conditions due to the site's wave exposure, exacerbated by ongoing boat traffic in the Canal.
- The existing overhanging scarp on the eroding Bay edge of the marsh provides favorable habitat for RIRA that should not be disturbed.
- The vegetated marsh-mudflat edge with gentle slopes at the southeast corner of the marsh provides foraging habitat for shorebirds.
- The existing PG&E power lines that traverse the site cannot be disrupted, and access must be maintained to PG&E's single power tower on the site.
- Longshore sediment transport moves sediment from Tiscornia Marsh into the San Rafael Canal. Ongoing dredging of the Canal to maintain navigation will continue to create a local sediment sink, and could contribute to sediment depletion in subtidal marsh areas.
- Dredge sediments from the Canal and/or private marinas that are chemically contaminated are not suitable for reuse in in the restoration project.
- Current USACE and BCDC regulations strictly limit the placement of fill in Baylands.
- The ability to raise the height of MAS's levee is constrained due to the fact that expansion of the levee would impact existing marsh on the north (waterside), and extend onto City property boundary to the south (landside), which includes a children's playground.

4.2 Site Opportunities

- Coarse-grained marsh edge beaches are resilient to the current wave climate, adjusting bedform to a variable wave climate, rather than eroding.
- The bayward edge of the marsh is a gentle-sloped mudflat, which could serve as base for construction of a coarse-grained beach at the marsh edge, which would serve to adjust bedform to a variable wave climate and resist erosion.
- Tiscornia Marsh provides suitable foraging and breeding habitat for RIRA and SMHM.

- The site is well-suited as a nature-based sea-level rise demonstration project, owing to its relatively small size and active environmental stewardship of its owner, MAS.
- Sediment tends to accumulate at the southeast edge of the marsh due to the wave climate, providing potential sediment source for marsh accretion.
- Periodic local dredging of the San Rafael Canal, nearby marinas and private docks, and the Larkspur Ferry Terminal could provide a compatible source of sediment for reuse in a marsh restoration. Local beneficial reuse of dredged material could potentially reduce costs for dredge disposal.
- The vegetated marsh enhances the flood protection function of the landward levee by absorbing wave energy and reducing wave runup.
- Wave runup could be further reduced by creation of a gradually sloped ecotone between vegetated marsh and uplands, which would also provide valuable transition habitat.
- There may be potential to create suitable habitat to support establishing and expanding populations of native oysters in low tidal and subtidal portions of the site (e.g. along the San Rafael Canal).
- A marsh restoration project would create opportunities to better engage the local Canal community with Tiscornia Marsh through volunteer marsh cleanup days and/or volunteer planting efforts funded under Measure AA (see below).

4.3 Opportunities Beyond the Site

- The diked marsh immediately north of Pickleweed Park is currently at high marsh elevation, making it relatively easy to restore to tidal marsh.
- Raising the Tiscornia Marsh levee could be combined into one construction package with raising (and/or setting back) other portions of the levee on City property, to save the City and MAS in construction costs on future protection of the Canal Community from sea level rise.
- The property directly south of the levee is a City-owned playground, which could be reconfigured and/or replaced to allow that raised levee footprint to encroach on the park.
- Measure AA recently funded volunteer planting efforts by STRAW at several sites, including the western (City-owned) side of Tiscornia Marsh. A partnership project could benefit the new levee and local community.
- The Resilient by Design competition may develop sea level rise adaptation concepts that are compatible with the proposed project, such as redevelopment of Pickleweed Park and the Al Boro Community Center into sea-level rise resilient facilities with a focus on bay resources.

5. CONCEPT ALTERNATIVES DEVELOPMENT

A suite of conceptual alternatives was developed for restoration/enhancement of both the bay edge and the upland edge of Tiscornia Marsh. The alternatives were based on our understanding of existing and projected future conditions, a set of opportunities and constraints for the site, and a set of design criteria aimed at maximizing its potential for restoring habitat and adapting to future sea-level rise. Alternatives for the bay edge and upland edge are intended to be implemented together as one project.

5.1 Project Elements

The project envisions creating and/or enhancing a range of connected natural elements that provide habitat value as well as flood and erosion protection. The overarching design goal is to create a complete wetland system ranging from subtidal to upland elevations. The project elements proposed along the bay edge of the site in the subtidal to mid-intertidal range include a coarse-grained beach at the marsh edge, enhanced/expanded tidal marsh, and a rock jetty along the San Rafael Canal. Design elements along the upland edge of the site in the supratidal to uplands elevations include a transitional ecotone slope and flood protection levee. While the intent is to transition seamlessly between these habitat components, each is discussed separately below.

5.1.1 Coarse Beach

Though the actively eroding scarp at the marsh edge provides favorable cover and foraging habitat for RIRA, this condition is not sustainable. Given current rates of erosion, the northern extent of the marsh is expected to be completely eroded away in roughly 30-50 years, and the southern portion to continue to erode at current or accelerated rates. Therefore, construction of a coarse-grained or “cobble” beach is proposed at the marsh edge to help resist ongoing erosion. Additional measures to preserve and/or replace the eroding scarp elsewhere are discussed below under marsh habitat.

Although this feature would likely include a mixture of sand, gravel, cobbles, and/or oyster shell hash, it is referred to herein as an ‘coarse beach’ or ‘cobble beach’ to distinguish it from a sandy beach suitable for public access. Mixed cobble/gravel/sand beaches throughout the Bay provide multiple benefits, including increasing the stability of eroding shorelines, creating aquatic and wetland habitats, and providing a platform for future adaptation to sea-level rise. Guidance for developing coarse beaches as a protection from marsh erosion has been established by BCDC and ESA PWA (2013), and reference sites will be examined in detail in the next phase of the project.

Coarse-grained beaches within the Bay are typically shallow-sloped shorelines between subtidal and supratidal elevations. At Tiscornia Marsh, the proposed coarse beach feature would extend from the outboard mudflat up to approximately elevation 7-9 feet NAVD88. The actual height of the feature would be established by natural wave action reworking placed materials to the height naturally appropriate to this exact location. Sediment retention groins constructed of wood and/or rock may be incorporated into the beach face to restrict longshore drift and to allow sufficient retention of sand and gravel in the beach profile.

5.1.2 Tidal Marsh Habitat

The project seeks to increase the quantity and quality of vegetated tidal marsh habitat to benefit RIRA, SMHM and other native wildlife. Pickleweed-dominated mid to high marsh is the primary target, both for near term habitat and long term resilience to sea-level rise. In addition, more complex marsh features are proposed to address specific habitat needs of these and other species.

The primary target for marsh habitat restoration would be mid-marsh elevations of 5.5 to 6.1 feet NAVD88 (MHW to MHHW), with areas of high marsh up to roughly elevation 7 feet NAVD88. Other features desirable within the enhanced and/or expanded marsh to improve habitat include:

- An intricate network of tidal channels to provide abundant invertebrate populations for RIRA foraging.
- Channel bank erosional features with overhanging scarps that create cover "tunnels" through the marsh for RIRA and other wildlife.
- High tide refuge habitat with taller marsh vegetation to provide cover and refuge for RIRA and SMHM, located (a) along channel banks, (b) within the marsh as microtopography, and (c) in higher elevation transition zones into terrestrial ecotone and upland habitats. Target vegetation would include gumplant, Pacific cordgrass and bulrush.
- Features to discourage predators, such as strategic gaps that separate high tide refugia in the marsh from the upland perimeter to minimize edge and/or entry points for predators.

Improved marsh habitat could potentially be achieved at the site through four primary means:

- Enhancing the existing marsh through limited intervention (e.g. excavated additional channels and creating high berms along channel banks).
- Passively expanding the existing marsh eastward (bayward), by encouraging accelerated sediment deposition in the outboard mudflats.
- Actively expanding the existing marsh eastward, by placing suitable fill material to raise portions of the outboard mudflat to mid and/or high marsh elevation.
- Expanding the existing marsh westward, by restoring tidal action to the diked marsh (which is already at suitable marsh elevation), contingent upon on City of San Rafael's approval.

The approach for enhancing/creating marsh varies by alternative, as discussed further in Section 5.2 below.

5.1.3 Rock Jetty

Dredging of the San Rafael Canal for navigation, which enlarges it beyond its equilibrium widths and depth, is expected to continue indefinitely. Currently, much of the sediment lost from the Tiscornia Marsh through erosion is likely transported and deposited in the adjacent Canal and possibly nearby marinas and private boat docks (Appendix A). Though installation of a coarse beach would reduce the marsh erosion rate, there would still be a net sediment flux toward the Canal due to the local wave climate (as described in Section 3.5.2). Therefore, a rock jetty element is proposed at the north boundary of Tiscornia Marsh that would extend eastward, parallel to the Canal. The purpose of the rock jetty is to trap and accumulate sediment that would otherwise drift along the beach face and be deposited in the Canal. The rock jetty would reduce erosion of the newly constructed coarse beach, and should reduce the depositional rate in the Canal (possibly reducing the frequency of required dredging).

The rock jetty would be constructed of suitably-sized rock, and would extend vertically from the surface of the mudflats fringing the Canal to approximately 2 feet above MHHW. Given its expected proximity to the Canal, subsequent stages of this design will need to consider its effect on boat navigation. During the future detailed design phase, we will look for opportunities to incorporate features in the lower, subtidal portion of this feature to enhance its potential as oyster reef habitat.

5.1.4 Ecotone Slope

A gradual slope between high marsh and upland areas can create a wide ecotone (transition zone) that combines ecological and flood protection benefits. An expanded ecotone slope could be created at the south and west boundaries of Tiscornia Marsh. The ecotone would be located along the outboard slope of the existing trail and shoreline levee around the site.

The ecotone slope would serve several functions. It would provide high tide refugia for RIRA and SMHM, and create a buffer between the marsh and the Bay Trail on the levee top. The ecotone could also dissipate wave energy by inducing wave breaking over its shallow slope, and by resistance created by vegetation established on the slope. The ecotone would also create transgression space for tidal marsh habitats, whereby upland transitional habitats would gradually convert to tidal marsh as sea level rises.

The actual width of a constructed ecotone slope varies significantly, and depends on functional objectives, available space, ability for long term maintenance, and other factors. For restoration at the relatively expansive South Bay Salt Ponds, the ideal ecotone slope ranges from 20:1 to 100:1 (horizontal foot to vertical foot) (PWA, 2006). For the Oro Loma Ecotone Slope Demonstration Project[6] the ecotone was constructed at a 30:1 slope (ESA, 2018).

[6] The Oro Loma Ecotone Slope Demonstration Project is designed to test various plant palletes and substrates for constructed ecotones. The ecotone is being irrigated with recycled wastewater. A secondary design objective being tested is the ability for the ecotone to achieve recycled wastewater polishing.

At Tiscornia Marsh, space available for an ecotone is limited by existing marsh and developed infrastructure. Given site constraints, we recommend sizing the ecotone (elevation range and slope) at a minimum needed to function as a wind wave dissipation bench. An ecotone sized with this approach can also provide ecological function for habitat and buffering. In general, greater bench widths would be expected to provide greater habitat and wave dissipation benefits. More detailed wind wave analysis will be performed in the future detailed design phase. At this stage, we have developed preliminary dimensions based on similar levee benches designed by ESA.

For example, for the Dutch Slough Tidal Marsh Restoration, ESA performed wind wave analysis and evaluated erosion potential using the wave power concept[7] for the transitional slopes between marsh and levees (ESA PWA, 2015). Results showed that erosion potential was greatest between Mean Tide Level (MTL) and MHW, and diminished significantly with increasing elevation, up to 1.5 feet above MHHW. Based on this analysis, an ecotone was designed to gently slope at 7:1 from the newly-restored low marsh up to 2.5 feet above MHHW. (A flatter slope of 10:1 was used for areas where the levees were fringed by subtidal waters.)

For Tiscornia Marsh, a preliminary design concept for the ecotone would be sloped at 10:1, up to approximately elevation 9 feet NAVD88 (3 feet above MHHW). This would result in an approximately 30-foot wide ecotone based on an existing marsh elevation of approximately 6 feet NAVD88. The slope would be planted with native vegetation adapted to ecotone environmental settings, intermixing high marsh and upland species adapted to infrequent flooding and salinity, and including grasses for nesting materials (e.g. creeping wildrye, *Elymus triticoides*). Plant cover must be entire (or nearly so) throughout the year, and reach elevations which remain emergent (above 1 foot in height) through the highest tides, so that small marsh mammals and secretive marsh birds can find cover from predation.

As a final check, we compared the ecotone width proposed for Tiscornia Marsh to prior designs for the Hamilton Wetlands (PWA, 1998) and Petaluma Marsh Expansion (PWA, 2002) projects. Both of these sites included construction of an earthen “bench” outboard of the new flood control levees to dissipate wave energy and allow for sacrificial erosion. The constructed benches at these sites are 50 to 55 feet wide. However, the levees at both of these sites are exposed to higher wave energy than occurs at Tiscornia Marsh, which is less exposed and has shorter wind fetch. In addition, the levees are fringed by high vegetated marsh at Tiscornia Marsh, as compared to unvegetated mudflat at the other two sites. Given the lower wave energy environment at Tiscornia Marsh, a 30-foot wide ecotone would likely be appropriate for dissipating wave energy, although a greater width (where possible given space constraints) could provide more refugia habitat. The actual design slope and elevations of the ecotone will be determined based on further analysis in the future detailed design phase.

In the project moves forward, we will also examine opportunities for expanding the ecotone along the approximately 800-foot section of western levee between the diked marsh owned by the City

[7] The potential erosion of an earthen levee slope is considered to be proportional to the wave power dissipated on it when averaged over a long time frame. It is noted that wave power, and similar wave energy approaches, are approximate indicators rather than predictors of erosion. The wave power approach considers the frequency of water levels to identify the elevations where the wave power is greatest. The flat, dissipative levee bench is then located vertically within this high-power area.

and the southern portion of the levee within MAS property. Much of this western levee crest is higher than at the southern segment, meaning that there may be opportunities to raise the levee and expand the ecotone without impacting the existing marsh or encroaching on City property in some areas. This could be achieved by increasing the outboard (marsh) ecotone slope above the 10:1 slope proposed for the southern portion or by expanding the ecotone selectively in areas where the levee could be set back slightly without impacting existing City property.

5.1.5 Raised Levee

The existing portion of the levee within MAS's property has a range of crest elevations (all below 12 feet NAVD88) and varies in top width from about 10 to 16 feet. The restored levee would be raised to a consistent height and constructed to a standard width. We have assumed a 16-foot crest width, which would allow 12 feet for the Bay Trail plus a 2-foot shoulder on each side. The actual side slopes and other geotechnical criteria for the raised levee will be addressed in the future design phase. At this stage, we have assumed that the levee would have uniform side slopes of 3:1 (horizontal:vertical) both on the landside, and on the outboard side above the ecotone slope.

The most important design criterion for the levee is the crest height. We selected the levee height for the conceptual design based on three considerations:

- FEMA guidance for accredited flood protection levees
- The existing elevation of the adjacent shoreline levee
- Predicted rates of future sea level rise

We started with FEMA guidance for 100-year flood protection as a design standard, even though the existing levee will likely not be accredited by FEMA due to geotechnical and other factors. FEMA provides the following guidance:

- Riverine levee: Base Flood Elevation (BFE) + 3 feet freeboard
- Coastal levees, the greater of:
  - 100-year stillwater surge level + 1% wave or maximum wave runup (whichever is greater) +1 foot freeboard,[8] OR
  - 100-year stillwater surge level + 2 feet freeboard

The Tiscornia Marsh levee is somewhere between a coastal and riverine levee, with required freeboard of 2 and 3 feet, respectively. Though it may be justifiable to apply the coastal levee criterion, we propose to design a levee to conform with the more conservative criterion for riverine levees. The additional foot of freeboard would provide additional buffer for future sea level rise. Per FEMA, "freeboard is a factor of safety usually expressed in feet above a flood level for purposes of floodplain management." For our purposes, freeboard includes a safety factor to account for (a) future settlement, (b) uncertainty in base flood elevations and (c) future sea-level

[8] Occasionally, exceptions to the minimum coastal levee freeboard requirement described may be approved, based on evaluation of the uncertainty in the estimated base flood loading conditions, with particular emphasis on the effects of wave attack and overtopping on the stability of the levee.

rise. Therefore, the proposed design levee height is 13 feet NAVD88, based on a base flood elevation of 10 feet NAVD88, plus 3 feet of freeboard.

We also compared this design levee height to the adjacent levee, since the raised portion of levee would act as a unit with the entire shoreline levee. As described in Section 3.2.2, most of the existing levee between Pickleweed Park and Spinnaker Lagoon varies in elevation between 11 and 12 feet NAVD88. Therefore, a design elevation of 13 feet NAVD88 for Tiscornia Marsh, which is more protected from wind waves than the east facing shoreline, seems appropriately conservative.

5.2 Alternatives for Marsh Edge Stabilization

We developed four alternative approaches for addressing ongoing erosion along the eastern edge of Tiscornia Marsh. We have three basic restoration alternatives, plus the No Action alternative, for comparison.

We developed the alternatives recognizing that the existing wind climate will persist, and wave power will increase as sea level rises. For this reason, both restoration alternatives include stabilizing the marsh edge with a coarse beach.

- **Alternative 1, No Action.** This alterative anticipates the consequences of not stabilizing the marsh edge
- **Alternative 2, Extended Shoreline Stabilization.** This alternative uses a passive approach of using natural sedimentation to aggrade the existing mudflat, the first approach for expanding the marsh to improve habitat value, as well as attenuating wave erosion.
- **Alternative 3, Restore Eroded Marsh.** This alternative uses a more direct approach of actively rebuilding the marsh using fill placement, the second approach for expanding the marsh to improve habitat value, as well as attenuating wave erosion.
- **Alternative 4, Restore Eroded Marsh and Diked Wetland.** This alternative expands on Alternative 3 to include restoring the diked marsh to the west of Tiscornia Marsh, in the event that City of San Rafael allows restoration actions on their Pickleweed Park property.

Each marsh edge stabilization alternative would include one of the levee raising options described in Section 5.3 below.

5.2.1 Alternative 1 – No Action

Under the No Action Alternative, Tiscornia Marsh would remain in its current condition, and there would be no physical modification to the site (**Figure 14**). We assume that the Canal would continue to be dredged periodically. These assumptions were used to predict the performance of the No Action Alternative in the future. Under the no action scenario, the marsh edge would continue to erode and loss of vegetated marsh would continue. At some future stage when the marsh has completely eroded away, the City would likely need to take action to prevent erosion of the levee surrounding Pickleweed Park.

Figure 14
Alternative 1 – No Action

ESA

5.2.2 Alternative 2 – Extended Shoreline Stabilization

Alternative 2 consists of construction of a coarse beach offset from the marsh, with a rock jetty on its north side. The coarse beach at the marsh edge is designed offset from the existing shoreline both to preserve the existing marsh scarp, and to provide space for the mudflats to aggrade through natural sedimentation. Alternative 2 is shown in plan and section in **Figures 15** and **18**, respectively.

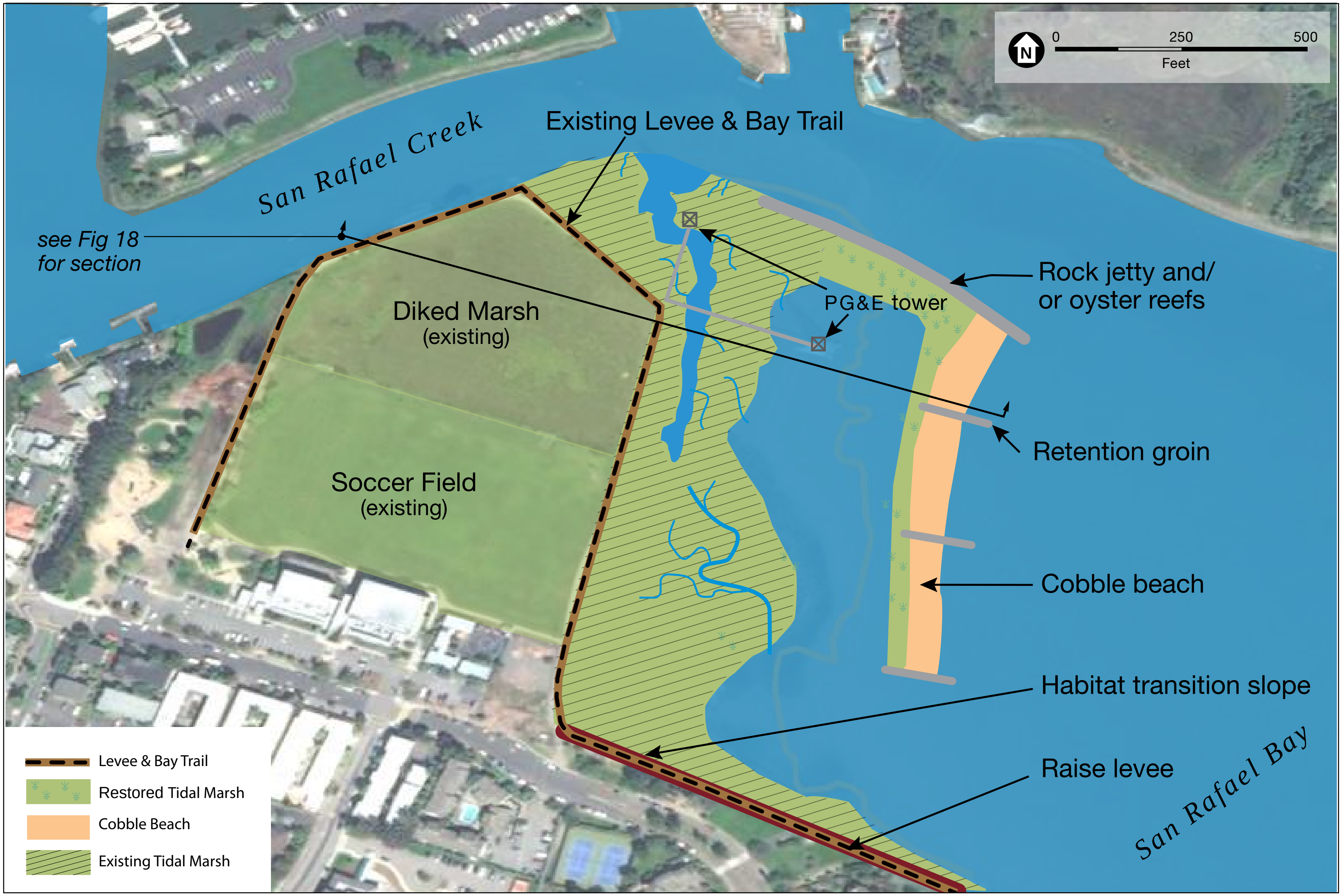
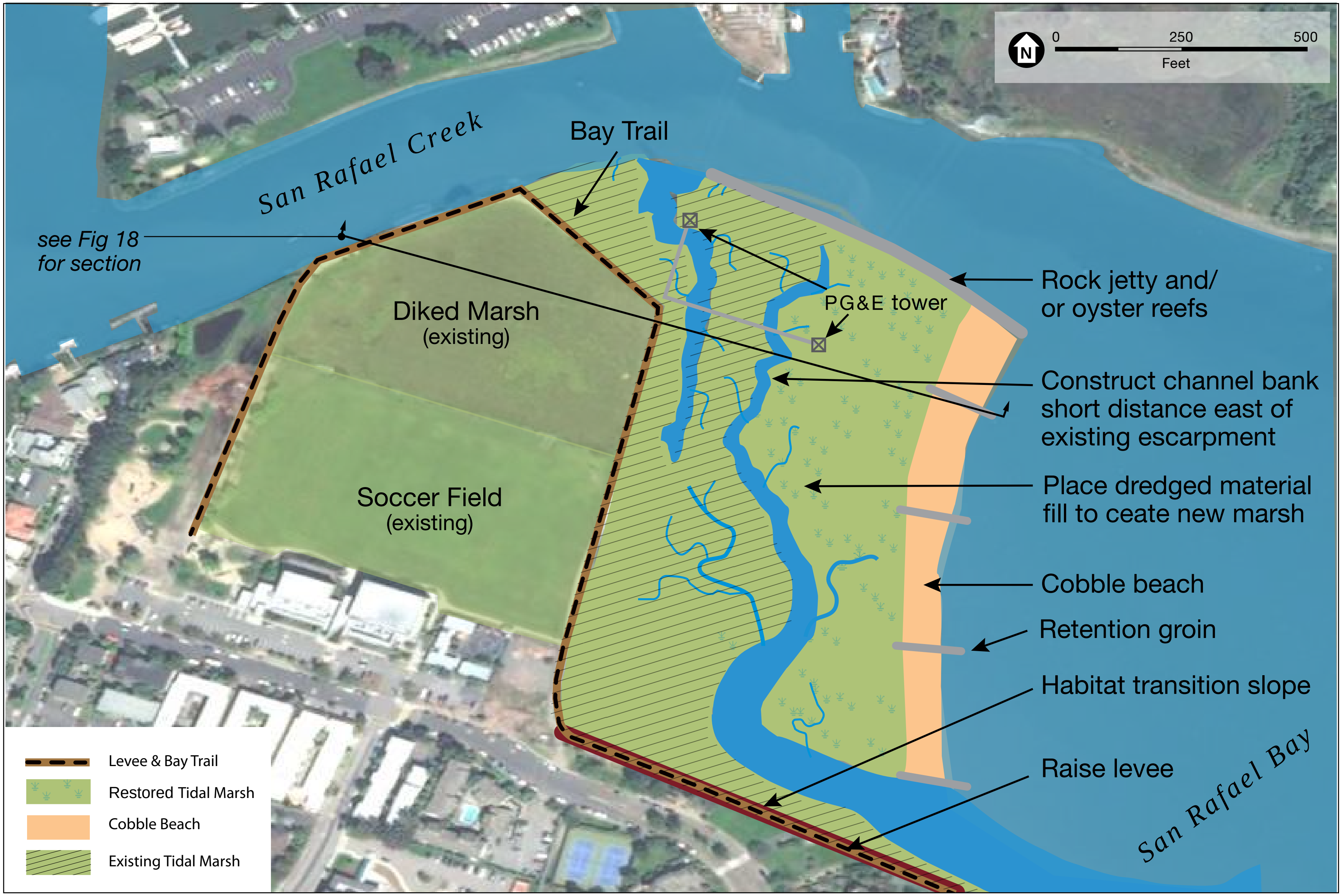


Figure 15

Alternative 2 – Extended Shoreline Stabilization



ESA

Figure 16
Alternative 3 – Restore Eroded Marsh

Tiscornia Marsh Habitat Restoration and Sea Level Rise Adaptation Project

Figure 17

Alternative 4 – Restore Eroded and Diked Marsh

ESA

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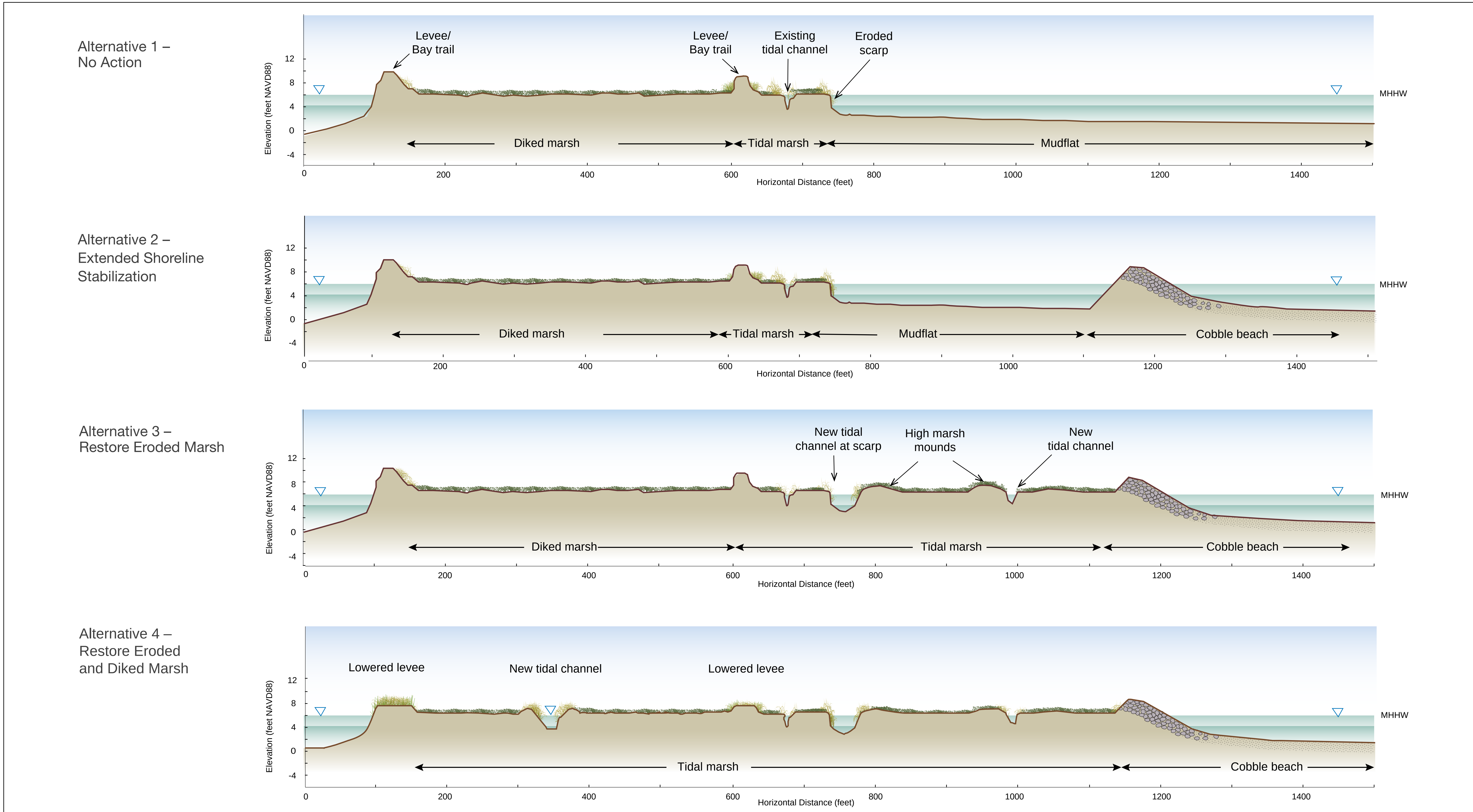

ESA

Tiscornia Marsh Habitat Restoration and Sea Level Rise Adaptation Project

Figure 18
Schematic Sections of Marsh Edge Alternatives

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The coarse beach would likely be placed at least 100 feet bayward of the existing marsh edge and would be designed to encourage sediment trapping and deposition in the mudflat on the lee side of the beach. This alternative would take advantage of the process that transports sediment that tends to accumulate in the southeast corner of Tiscornia Marsh. This alternative would also preserve the overhanging scarp along the existing marsh edge. The area between the existing marsh and the new beach would be expected to experience higher deposition rates than under existing conditions, as discussed in Section 6.1.2. This approach is an alternative to actively filling the mudflats as described under Alternative 3.

The coarse beach would be constructed approximately 100 to 400 feet from the existing marsh edge. The beach would serve to break incoming waves and dissipate wave energy before waves reach the marsh, and should arrest further erosion of the marsh edge. Because the beach would not be supported by the marsh on its lee side, additional micro-groins or other features would likely be needed to provide stability.

A rock jetty would also be constructed on the north side, parallel to the Canal. The jetty would help to trap sediment that would otherwise drift along the new beach face and deposit in the Canal.

With this alternative, there would be opportunity to create a wider ecotone transition on the south side of the marsh as part of the levee raising, as discussed in Section 5.3 below.

5.2.3 Alternative 3 – Restore Eroded Marsh

Alternative 3 includes an expanded marsh, fringed by coarse beach on the east and a rock jetty on its north side. This alternative was developed with the vision of restoring Tiscornia Marsh to its former size. The most direct approach for achieving this goal is to rebuild the marsh by placing fill in the outboard mudflat. Alternative 3 is shown in plan and section in Figures 16 and 18, respectively.

This alternative would expand the existing marsh by approximately 5 to 10 acres. The exact footprint of the new marsh would vary depending on several factors, including property ownership, fill availability, impact avoidance and other factors. The estimated fill volume could range from approximately 40,000 to 100,000 cubic yards.

Bay muds similar to those of the existing marsh would be the most appropriate fill material. Therefore, beneficially reusing dredged material from in or around the Canal or from the Larkspur Ferry Terminal would be the preferred fill method. Availability of local dredge materials is discussed in Appendix A. Dredged material could be placed either hydraulically or mechanically, and would require construction of a containment berm on the new marsh perimeter. The construction approach is discussed in more detail under Section 7.

The new marsh would incorporate desirable habitat features for RIRA and SMHM. The overhanging scarp along the existing marsh edge would be preserved as much as feasible for RIRA habitat. The marsh would include an appropriately-sized tidal channel network that would provide interior mudflats fringed by low marsh for RIRA foraging. High tide refuge habitat with taller marsh vegetation would be located along channel banks and within the marsh as microtopography, and would be disconnected from the upland perimeter to reduce predator access. The mouth of the channel would be placed at the southeast corner of the new marsh, to encourage sediment delivery to the marsh, potentially increasing the vertical accretion of the marsh in the future.

Similar to Alternative 2, a coarse beach would be installed along the eastern edge of the expanded marsh to provide erosion protection and natural beach habitat functions. In addition, a rock jetty will be constructed on the north side of the marsh, parallel to the Canal, to reduce sediment drift into the Canal.

The existing marsh currently has a narrow ecotone band along its west boundary which transitions to the levee/trail around Pickleweed Park and the diked pickleweed marsh to the west. There would be opportunity to create more of an ecotone transition on the south side of the marsh as part of the levee raising. Levee raising and ecotone expansion options are discussed further below.

Opportunities to expand the ecotone along the western edge of the site will also be explored. This levee along the west side of Tiscornia Marsh is on City property, adjacent to the Al Boro Community Center. The existing ecotone slope adjacent to the marsh varies from approximately 10 to 40 feet wide. An undeveloped lot, soccer field, and diked marsh are located on the landward side of the levee (from south to north). Although the existing trail and ecotone slope are relatively narrow, there may be some areas for expansion without encroaching on the marsh, particularly next to the undeveloped lot. In addition, since much of the levee along the soccer field is already at 11 to 12 feet NAVD, it would not require significant additional footprint to raise its crest to 13 feet NAVD and modestly widen the ecotone slope where space allows. Currently, planned work funded by Measure AA and conducted by STRAW is slated to augment the ecotone with native plantings along this western portion of the levee.

5.2.4 Alternative 4 – Restore Eroded and Diked Marsh

The City-owned diked marsh at the north end of Pickleweed Park, to the immediate west of Tiscornia Marsh, provides a low impact opportunity for restoring approximately four acres of pickleweed marsh. This final alternative is a variation of Alternative 3 that could be implemented in the event that the City becomes a project participant. The City has indicated its openness to considering this alternative, but has not committed to it. Alternative 4 is shown in plan and section in Figures 17 and 18, respectively.

This alternative includes all of the elements of Alternative 3, Restore Eroded Marsh, and also includes restoring the diked marsh to tidal marsh habitat. The diked marsh is already at mid-marsh elevation and dominated by pickleweed, but is isolated from tidal action by the perimeter levee/trail. Tidal action would be restored by breaching the perimeter levee. A tidal channel network connected to the levee breach would be excavated. (Because the marsh is covered with erosion-resistant vegetation, tidal channels may not form on their own in the foreseeable future.) Portions of the levee around the diked marsh would be lowered or removed to create disconnected high marsh and upland transitional habitat.

This alternative includes construction of a new setback levee along the north side of the soccer field to maintain or improve existing levels of tidal flood protection for the Al Boro Community Center, Pickleweed Park, and the Canal neighborhood from coastal flooding. The new levee could be designed by a geotechnical engineer to regional flood protection standards (e.g. seepage resistance, seismic performance, etc.). At this conceptual design stage, it is assumed that the levee height would be 13 feet NAVD88, matching MAS's raised levee described below. The existing levee along the east and west sides of the soccer field and community center would also be raised to this same height, providing approximately 2000 feet of uniform flood protection. The new levee would be designed with an ecotone transition to the outboard marsh, similar to MAS's levee as described above.

5.3 Habitat Levee

The levee segment proposed for enhancement as an ecotone slope is located along the south side of Tiscornia Marsh, and borders the existing playground on Spinnaker Point Drive owned by the City. Ideally a wide ecotone (transition zone) that combines ecological and flood protection benefits would be created between the levee crest and the outboard marsh. However, there is limited space for an ecotone along the MAS-owned levee due to the proximity of existing marsh to the north and the City's playground to the south.

We developed three approaches for raising the levee on MAS's property:

- **Option 1: Minimum Footprint.** This option utilizes the smallest levee improvement footprint by not including a gentler ecotone slope on the marsh side and instead utilizing the steepest stable slopes possible.
- **Option 2: Habitat Levee in the Marsh.** This option incorporates an ecotone gentler-sloped levee slope of the marsh side, with the ecotone extending outward atop the existing tidal marsh in order to preserve the footprint of City park.
- **Option 3: Habitat Levee outside of Marsh.** This option incorporates an ecotone gentler-sloped levee slope of the marsh side, with the ecotone extending inward toward the City park.

5.3.1 Option A – Minimum Footprint

Under this option the existing levee would be raised to elevation 13 feet NAVD88 and widened to a uniform crest width of 16 feet. The total footprint of the levee would be the minimum needed to meet these standards, including some allowance for levee settlement. This option would not include an ecotone slope, and therefore would have the minimal encroachment on either the marsh or the City's property.

The outboard toe of the raised levee would start at the marsh edge, slope at 3:1 slope up to the 16-foot wide crest, and slope down at 3:1 to existing grade on the inboard side. Assuming a starting marsh elevation of 6 feet NAVD88, and an initial crest elevation of 14 feet NAVD88 (to allowing for 1-foot of settlement during or soon after construction), the minimum width required for the new levee would be approximately 60 feet. As shown schematically in **Figure 19**, the new levee would encroach into the City's property a few feet in some locations.

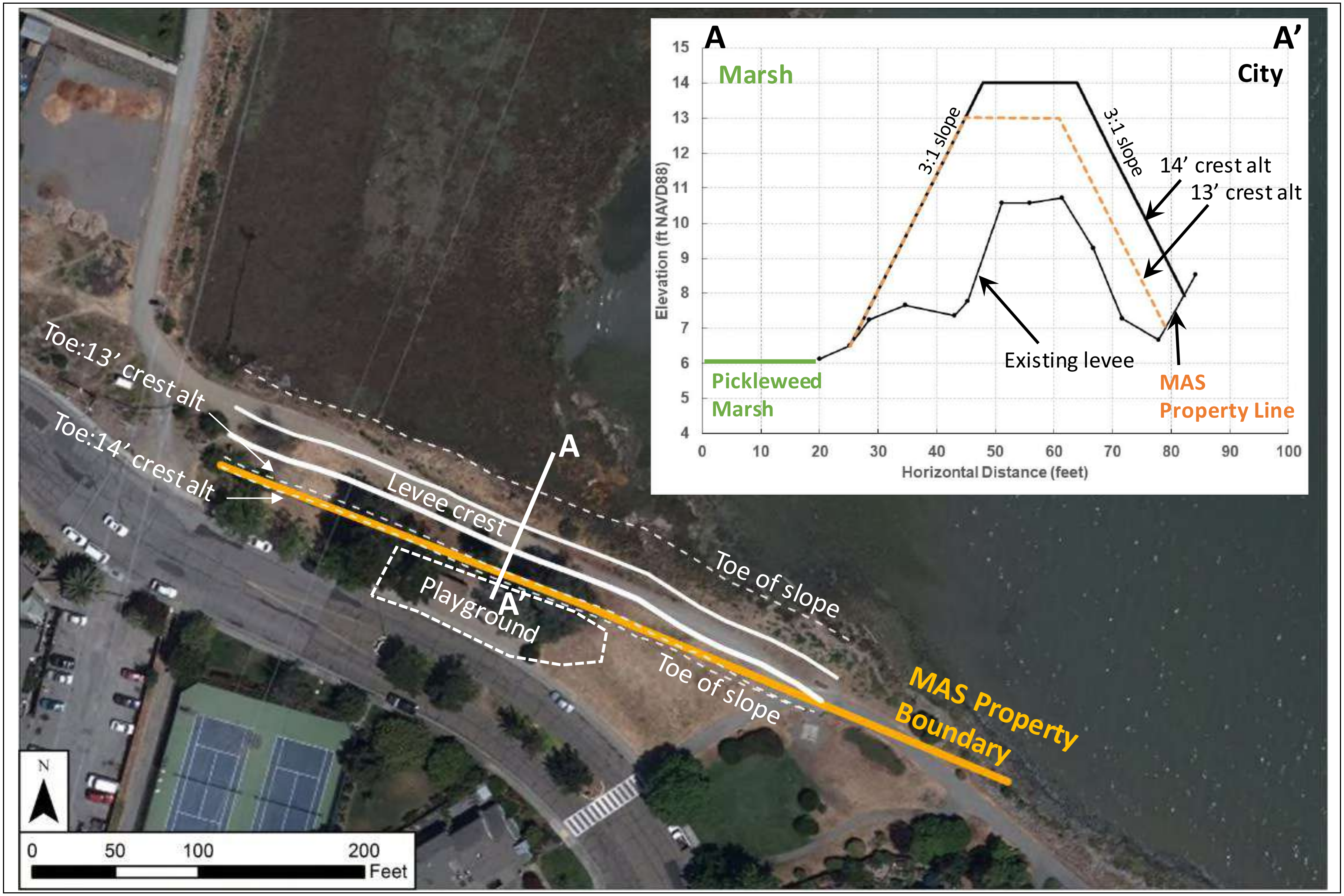

Figure 19

Levee footprint and cross section for Option A.

This option would have minimal impact on adjacent property and improvements. However, there are three trees, one large acacia and two smaller oaks, that could be impacted. In addition, the raised levee might fill the existing drainage swale between the levee and playground, resulting in the inboard levee slope draining directly toward the playground that would have to be addressed to maintain playground functionality. A geotechnical analysis will be performed in the next phase to estimate settlement potential, slope stability, seepage and drainage. Once these details are determined, more detailed layout of the total levee footprint will be performed. At that stage, it may also be possible to modify the levee design in some locations to reduce impacts to trees and other features.

5.3.2 Option B – Habitat Levee in Marsh

This option was developed to examine the potential for creating an ecotone slope with the raised levee, without encroaching on the City's property. The width of the ecotone slope could vary significantly, but for planning purposes is assumed to be 30 feet, as described above in Section 5.1.4. In this option, the earthen fill for levee raising would start at MAS's property boundary. The levee fill would slope up at 3:1 to the 16-foot wide levee crest and down at 3:1 to the top of ecotone (elevation 9 feet NAVD88). The ecotone would slope gradually at 10:1 slope down to existing marsh grade. Again, allowing for 1 foot of settlement, the total fill footprint will be approximately 80 feet wide. As shown in **Figure 20**, the ecotone fill would encroach 10 to 40 feet into the existing marsh. For this option, the habitat tradeoffs between reducing the existing marsh and creating an ecotone need to be carefully considered.

5.3.3 Option C – Habitat Levee Outside of Marsh

This option was developed with the assumption that the City would allow further encroachment onto the existing playground property. In that case, the levee and ecotone would have the same dimensions as in Option B, but would be shifted landward to minimize filling the existing marsh. The total fill footprint would be approximately 80 feet wide. The toe of the ecotone would meet the edge of the existing marsh, which is closest to the levee at the west end and further from the levee at the east end. Therefore, the amount of encroachment on the City's property would vary from 20 to 30 feet, west to east. For this alternative, the new levee crest would be offset from the existing crest, as shown in **Figure 21**. The geotechnical analysis would need to consider the uneven loading of the raised levee and mitigate for potential differential settlement. Under this alternative, the expanded levee would likely require removal of three mature pine trees within the playground. This alternative would also necessitate removing or reconfiguring the playground to accommodate the fill area.

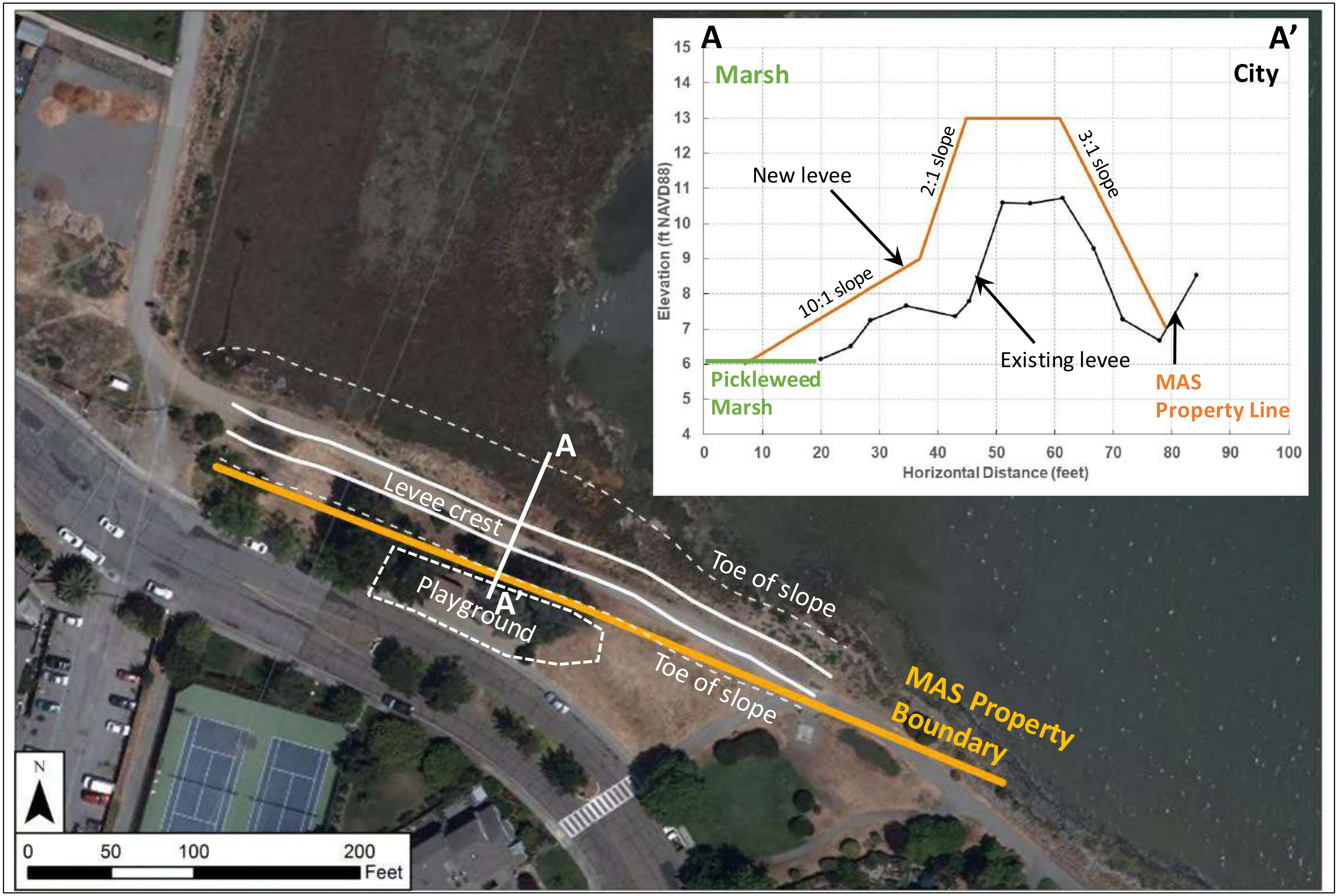

Figure 20

Levee footprint and cross section for Option B.

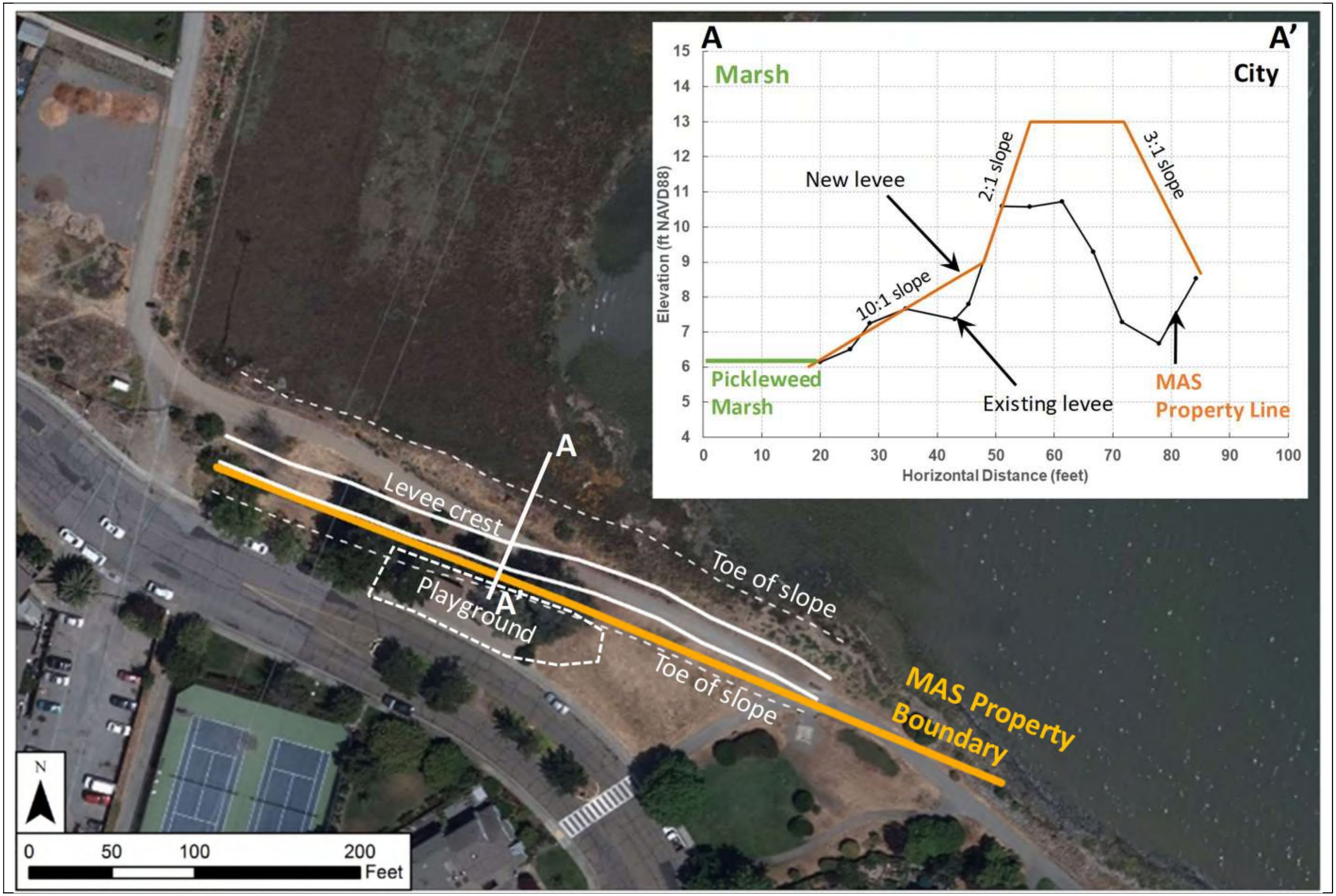

Figure 21

Levee footprint and cross section for Option C.

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6. ALTERNATIVES EVALUATION

The four alternatives for Tiscornia Marsh Edge Stabilization and the three options for the Habitat Levee were evaluated for their relative ability to meet the project goals and objectives described in Section 0. Below we describe the methods used to evaluate the alternatives, such analyses of future marsh erosion and marsh accretion rates. We then present a summary of how the alternatives measured up against the objectives for Tiscornia Marsh Edge Stabilization and the Habitat Levee.

6.1 Evaluation Methods for Marsh Alternatives

Each Marsh Alternative, including the No Action alternative, was evaluated to describe its expected geomorphic evolution over the 50-year planning horizon. We estimated both marsh erosion rates and future marsh accretion, and then predicted future habitat evolution in the face of sea level rise. This analysis relies on a number of simplifying assumptions and is subject to some uncertainty. The future conditions depicted are likely to occur at some point in the future, but the exact timing - whether in 30, 50 or 70 years, for example - is less certain.

6.1.1 Marsh Erosion Rates

Under the No Action alternative, erosion of the existing marsh was projected to continue at rates similar to recent erosion rates, as described in Section 3.1. The northern portion of the marsh has eroded an average of approximately 4 feet/year since 2004 (based on Transects 1 and 2), while the southern portion has eroded at slower rates, an average of 1.5 feet/year (based on Transects 3 and 4). The northern portion of the marsh, which is approximately 150 to 200 feet wide, is anticipated to be completely eroded away over the next 50 years. The southern portion of the marsh is wider than the northern portion, and is also eroding at a slower rate. Approximately 75 feet of landward erosion is expected to occur in the southern marsh over the 50-year planning horizon, based on an average erosion rate of 1.5 feet/year. Overall, the marsh width is expected to decrease to approximately 175 to 300 feet over the 50-years.

The three restoration alternatives described in Section 5 all include construction of a coarse beach outboard of the current marsh edge to reduce exposure to waves and attendant erosion. Therefore, future marsh erosion rates under these alternatives are expected to be negligible.

6.1.2 Marsh Accretion Rates

As discussed in Appendix A, marsh accretion rates are difficult to predict given the variability in inundation, sediment supply, and sediment recruitment by vegetation on the marsh. In general, lower areas tend to have longer quiet-water conditions and are supplied with suspended sediment more frequently than higher areas, leading to greater amounts of deposition and thus faster accretion rates. Local variations in topography that block or limit tidal and wind-wave currents also tend to contribute to higher accretion rates. For example, a design that would separate a mudflat area from the erosive tidal and wind wave currents would be expected to enhance sedimentation, which could lead to deposition rates above 10 cm/year in the early stages of restoration and slowing as marsh elevations rebuild and the deposited surface is submerged for shorter and shorter time periods. Additional factors to consider are the episodic nature of sediment supply, which can be substantial, and the projected long term decline of sediment availability as the Bay deepens with sea level rise (Schoellhamer 2011, Schoellhamer et al. 2018). To examine potential marsh accretion in more detail, we applied the following approach:

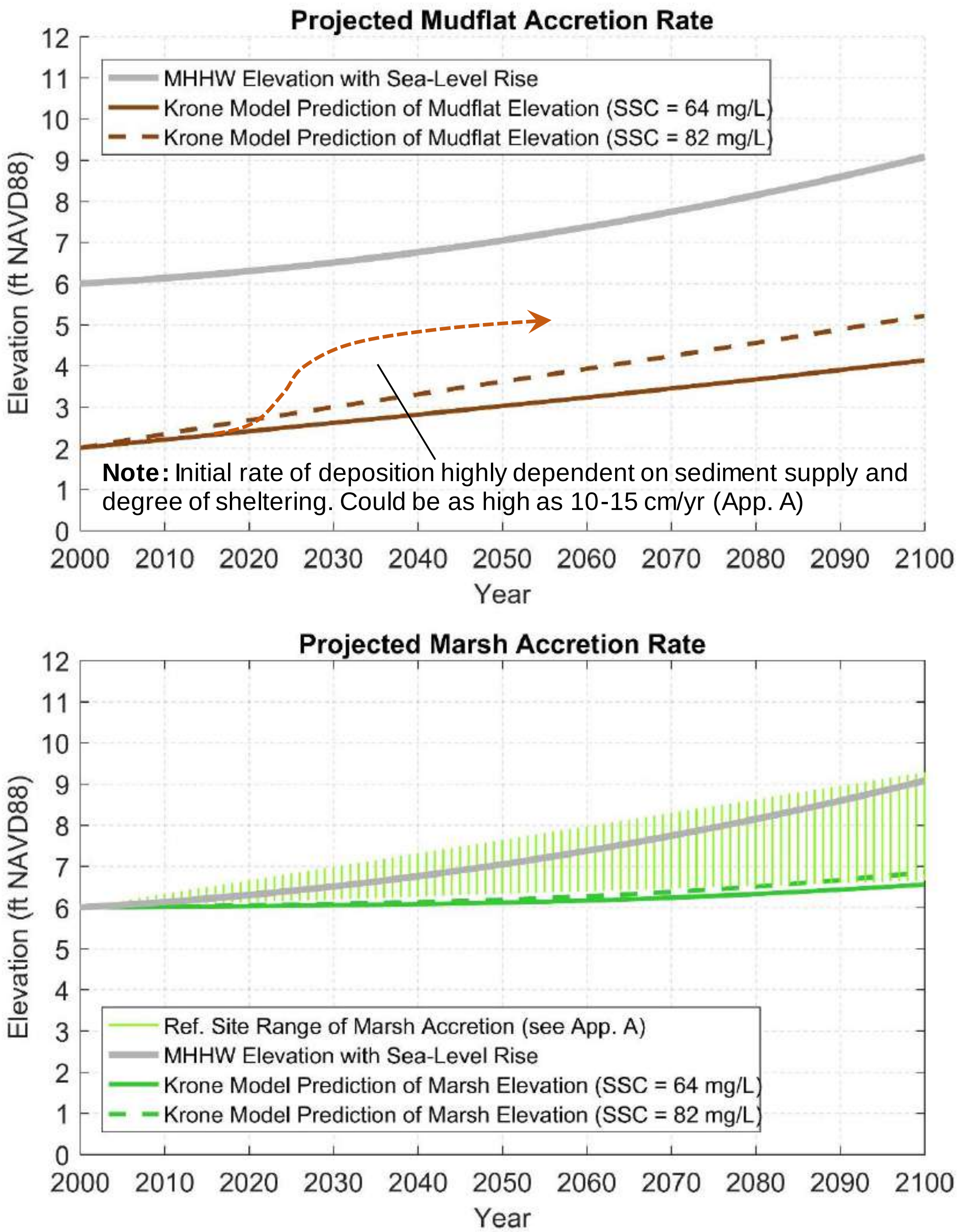
- A Krone (1979) model was applied to predict mudflat and marsh accretion rates into the future, based on the range of expected SSC at the site (Appendix A), and
- The ranges of accretion rates measured at nearby sites, including Corte Madera Marsh, Muzzi Marsh, and China Camp, were projected into the future to provide some additional context, and
- These were compared against the projected sea level rise curve to understand how the inundation regime could change over time (**Table 4** and **Figure 22**)

TABLE 4
ANTICIPATED ACCRETION OF TIDAL MARSH

Tidal Vegetation Zone	Approximate Accretion by 2070 (feet) [1]			Approximate net change relative to MHHW with 1.7 feet of sea level rise by 2070
	Suspended Sediment Concentration 64 mg/L	Suspended Sediment Concentration 82 mg/L	Value Used for Analysis	
Mudflat/Tidal Channel	1.45	2.24	1.8	0.1
Low Marsh	0.87	1.33	1.1	-0.6
Mid Marsh	0.24	0.37	0.3	-1.4
High Marsh	0.04	0.06	0.1	--1.6
Diked Marsh	0	0	0	-1.7

NOTES:
1 Accretion estimated with Krone (1979) model.

Overall, while the reference sites provide a useful comparison, their proximity to less developed watersheds and/or to the more sediment-rich San Pablo Bay environment led to predictions of higher rates of marsh and mudflat accretion than was predicted by the Krone model (Figure 22). The Krone (1979) model suggests that that an increase of 1.7 feet in sea level by 2070 would outpace sedimentation at all marsh zones, meaning that some natural habitat conversion would be expected if sedimentation was not augmented by artificial means. Mudflats were predicted to approximately keep pace with sea-level rise. Natural conversion would consist of some high-marsh areas converting to mid marsh as inundation increases over time, and similar downward transitions for mid and low marsh habitats (mid converting to low marsh and low marsh to subtidal habitats).



SOURCE: ESA Krone (1979) model and estimates of deposition summarized in Appendix A

Figure 22
Projected range of mudflat and marsh accretion rates compared against a medium-emission scenario sea-level rise case.

These results are generally consistent with those of Takekawa et al. (2013), who studied marsh accretion rates in detail throughout San Francisco Bay, and projected future marsh responses to sea-level rise. They used field measurements of inorganic and organic deposition rates to develop a Wetland Accretion Rate Model for Ecosystem Resilience (WARMER) model to project future conditions. Among their study sites, they included Corte Madera Marsh and China Camp, both of which were predicted to convert from primarily mid- and high-marsh to low-marsh and mudflat by 2070.

6.1.3 As-Built and Future Habitat Conditions

For each alternative we predicted habitat conditions immediately following project implementation (as-built conditions), as well as those expected in future conditions. As-built habitat conditions were estimated primarily by translating site grades to habitat types based on the elevation ranges presented in Table 6 and assuming that enough time has lapsed for equilibrium vegetation communities to have become established. As-built habitat conditions for the four marsh alternatives are presented in **Table 5**.

TABLE 5
AS-BUILT HABITAT AREAS FOR MARSH ALTERNATIVES

Tidal Vegetation Zone	Estimated Habitat Area (acres)			
	Alternative 1 No Action	Alternative 2* Intermediate Restoration	Alternative 3 Restore Eroded Marsh	Alternative 4 Restore Eroded Marsh & Diked Wetland
Mudflat/Tidal Channel	10.5	6.9	0.2	0.2
Low Marsh	2.1	2.1	2.1	2.1
Mid Marsh	2.6	5.2	10.7	16.4
High Marsh	3.5	3.3	4.1	4.1
Diked Marsh	5.7	5.7	5.7	0
Coarse Beach	0	1.2	1.6	1.6

* Alternative 2 assumed to create a narrow band of mid-marsh on the landward side of the coarse beach and jetty.

Future habitat evolution of the site is particularly important given the accelerating sea-level rise rate. We predicted future habitat conditions for existing and restored wetlands by applying anticipated marsh accretion and sea-level rise rates (Table 4). There is inherent uncertainty in predicting future conditions, as there are several variable factors anticipated to vary over time, including, but not limited to sea-level rise and local sediment concentrations. For this simplified analysis, we selected a single sea-level rise amount of 1.7 feet by 2017 (see Section 3.4.4) and used the average accretion rate from applying the low and high SSC values. From these two assumptions we extrapolated future habitat conditions. As noted above, the exact timing of when these future conditions would occur is uncertain. Higher sea-level rise rates and/or lower sedimentation rates would make these conditions more likely to occur sooner (i.e. less than 50 years); under lower sea-level rise rates and/or higher sediment concentrations these conditions would be expected farther into the future (i.e. greater than 50 years).

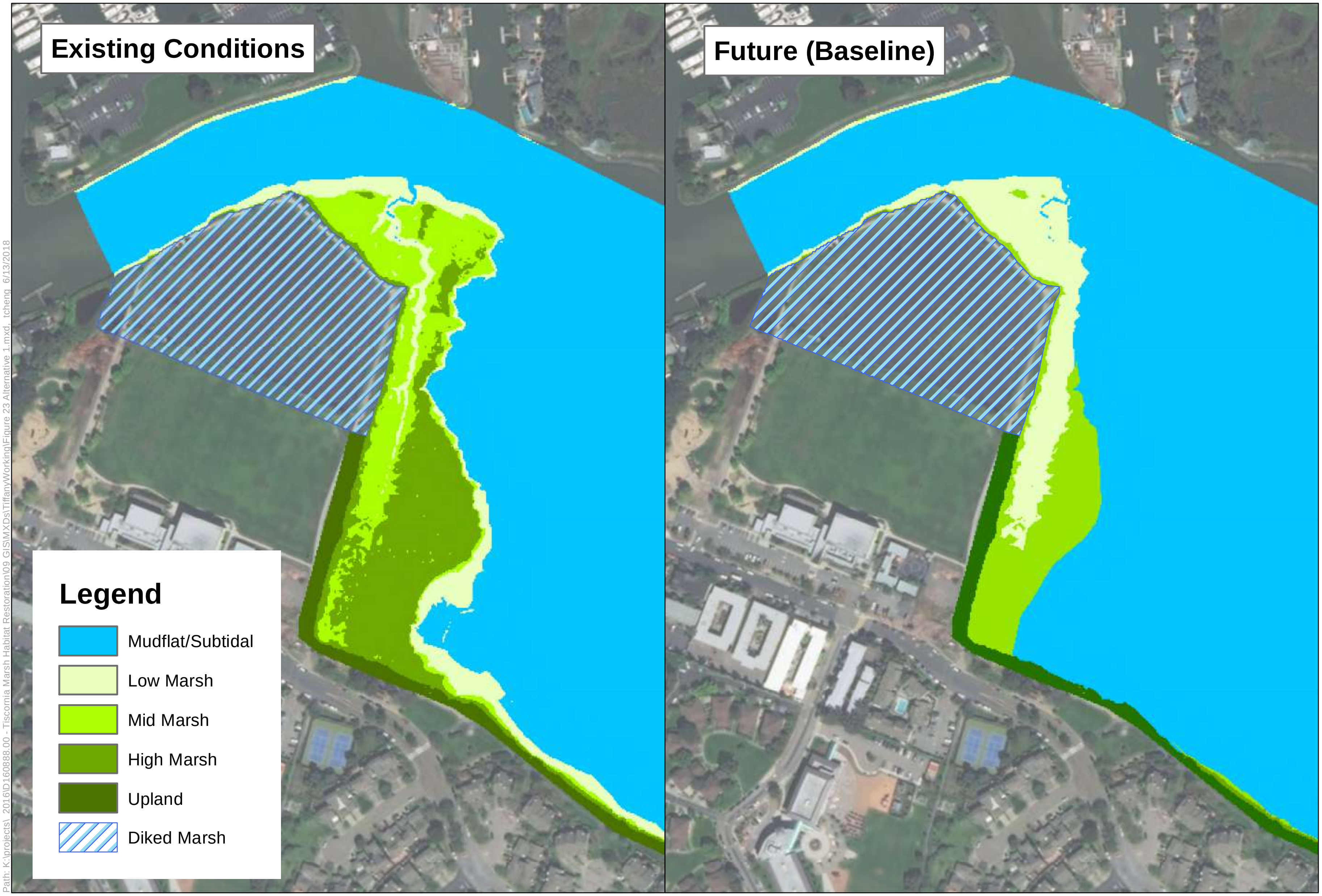
Wetland habitats are anticipated to transgress to higher elevations as estimated in **Table 6** using future tidal datums based on sea-level rise. At the same time, existing wetlands are expected to aggrade at the approximate rates presented in **Table 4**. Future habitat conditions were estimated by comparing future site elevations with future tidal datums. Future habitat conditions for the four marsh alternatives are presented in **Table 7**. **Figures 23 through 26** depict anticipated habitat types under post-project and future conditions for Alternatives 1 through 4, respectively.

TABLE 6
APPROXIMATE ELEVATIONS FOR EXISTING AND FUTURE VEGETATION COMMUNITIES

Tidal Vegetation Zone	Approximate Tidal Range	Existing (Year 2020)	Future (Year 2070)
		Approximate Elevation Range (ft NAVD88)	
Mudflat/Tidal Channel	<MTL	<3.3	<5.0
Low Marsh	MTL to MHW	3.3 – 5.5	5.0 – 7.2
Mid Marsh	MHW to MHHW	5.5 - 6.1	7.2 – 7.8
High Marsh	MHHW to high tide	6.1 – 7.3	7.8 – 9.0

TABLE 7
FUTURE (YEAR 2070) HABITAT AREAS FOR MARSH ALTERNATIVES

Tidal Vegetation Zone	Estimated Future Habitat Area (acres)			
	Alternative 1 No Action	Alternative 2 Intermediate Restoration	Alternative 3 Restore Eroded Marsh	Alternative 4 Restore Eroded Marsh & Diked Wetland
Mudflat/Tidal Channel	14.2	8.0	2.0	2.0
Low Marsh	2.3	5.9	10.4	16.3
Mid Marsh	2.1	3.5	4.6	4.4
High Marsh	0.1	0.1	0.1	0.1
Diked Marsh	5.7	5.7	5.7	0
Coarse Beach	0	1.2	1.6	1.6

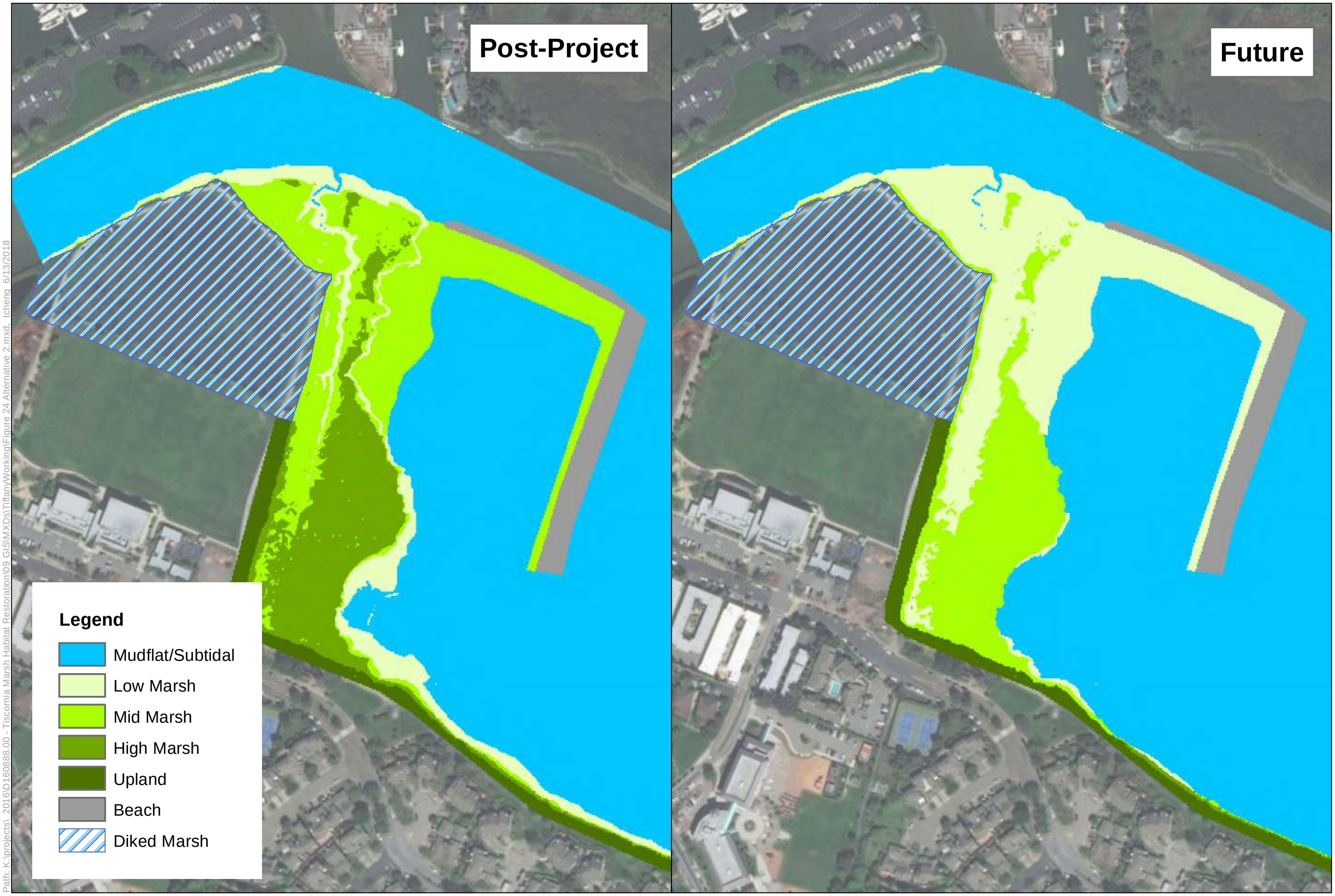


SOURCE: ESRI (Aerial)

D160888.00 Tiscornia Marsh Habitat Restoration and Sea Level Rise Adaptation Project

Figure 23
Alternative 1 - Existing and Future Habitat Conditions

ESA

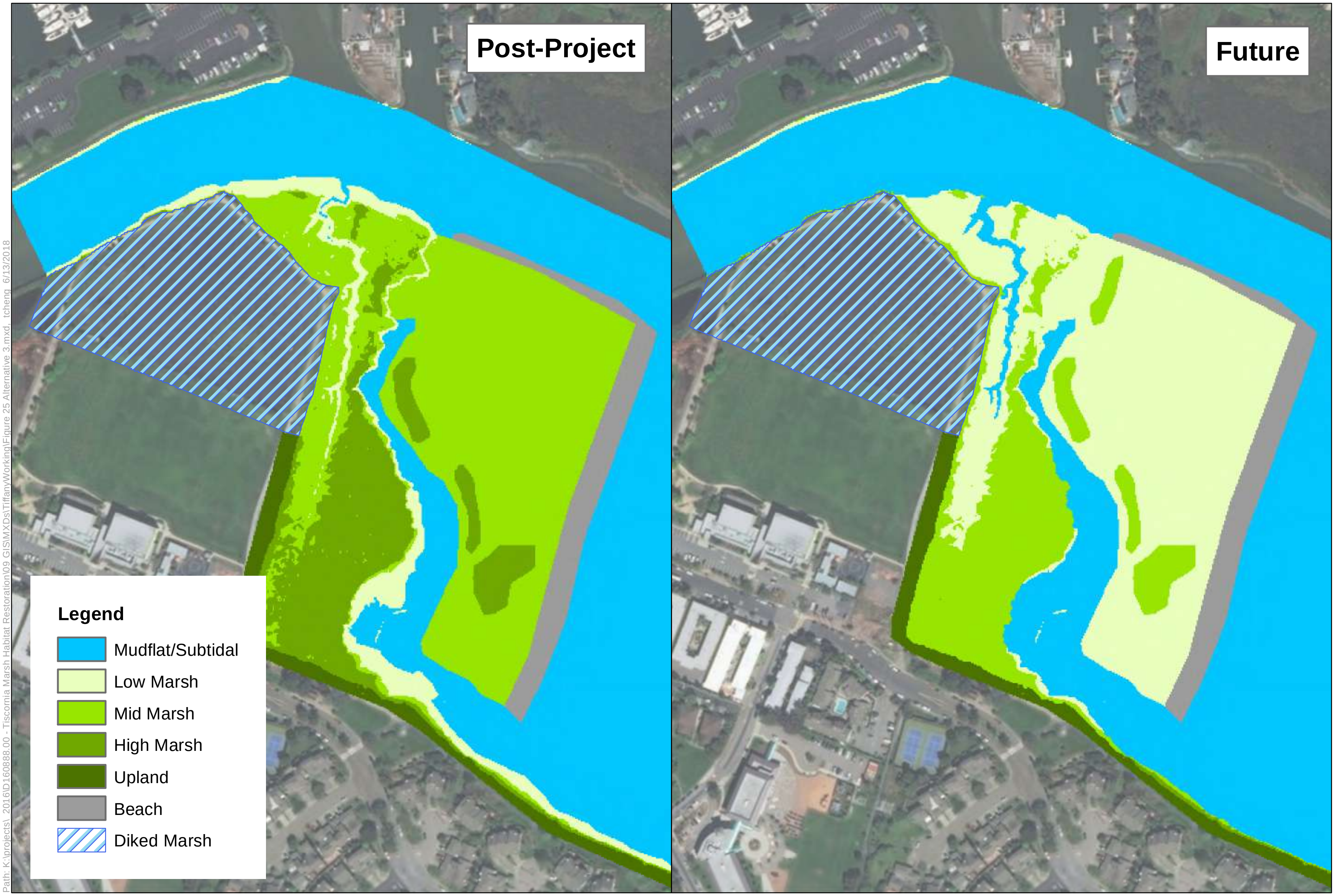


SOURCE: ESRI (Aerial)

D160888.00 Tiscornia Marsh Habitat Restoration and Sea Level Rise Adaptation Project

Figure 24
Alternative 2 - Post-Project and Future Habitat Conditions
Vegetation Map

ESA



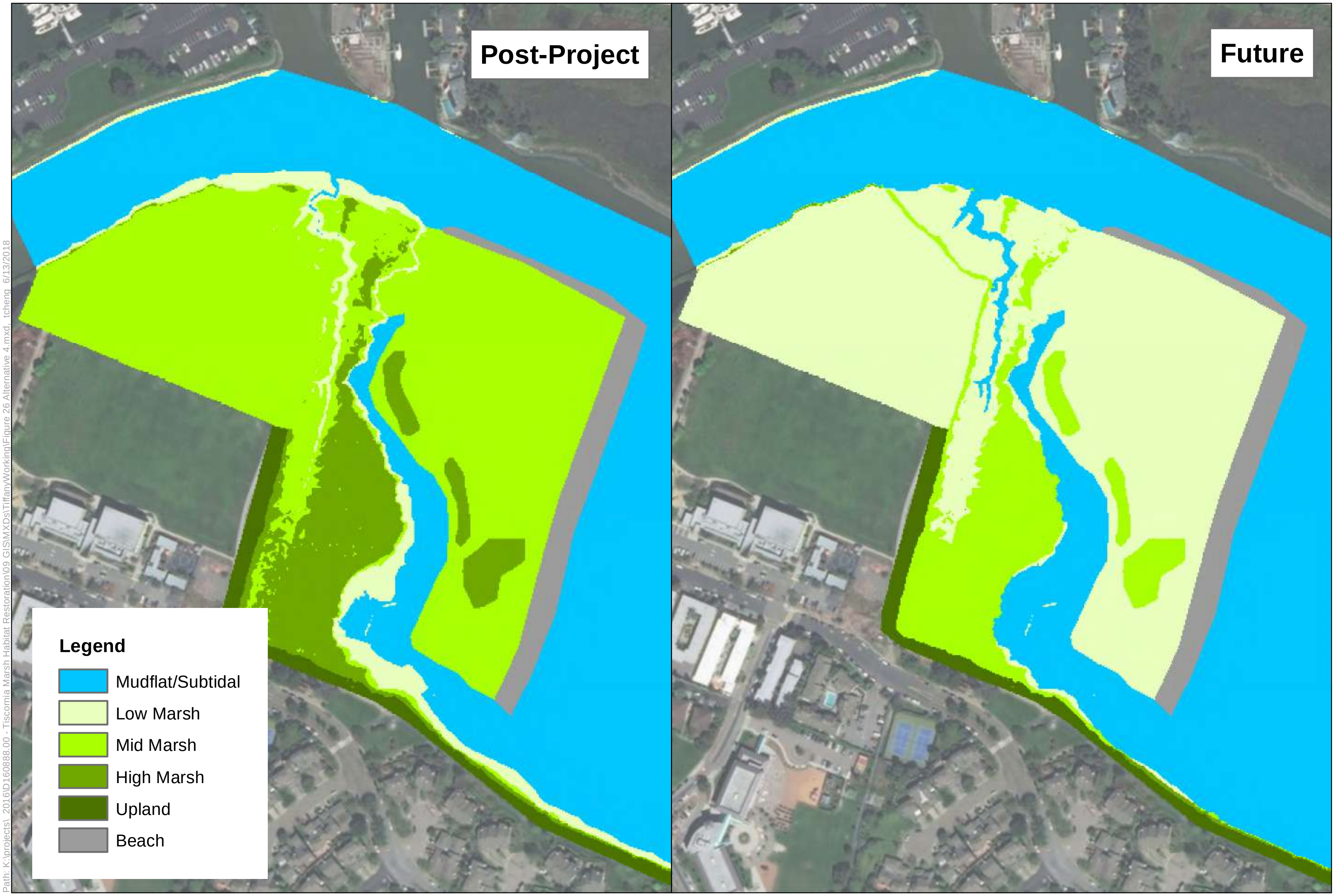
SOURCE: ESRI (Aerial)

D160888.00 Tiscornia Marsh Habitat Restoration and Sea Level Rise Adaptation Project

Figure 25

Alternative 3 - Post-Project and Future Habitat Conditions

ESA



SOURCE: ESRI (Aerial)

D160888.00 Tiscornia Marsh Habitat Restoration and Sea Level Rise Adaptation

Figure 26
Alternative 4 - Post-Project and Future Habitat Conditions

ESA

6.2 Evaluation of Tiscornia Marsh Alternatives

The four alternatives for marsh edge stabilization were evaluated relative to the six objectives listed in Section 0. The results of this evaluation are presented for each alternative below, and summarized in Table 8. After selection of a preferred alternative, this alternative is further evaluated for constructability and other considerations in Section 7.

6.2.1 Alternative 1 – No Action

Though limited in size, Tiscornia Marsh currently provides high marsh habitat for native wildlife, including the endangered RIRA and SMHM. Tiscornia is predominantly pickleweed-dominated high marsh, which is prime habitat for SMHM foraging and breeding. RIRA use a wider range of existing marsh habitats, foraging in tidal channels and mudflats at low tide, and nesting in higher marsh with taller marsh plants (such as gumplant, Pacific cordgrass and bulrush). The overhanging scarp along the marsh edge provides cover for the rail while foraging along the marsh edge in the outboard mudflat. In addition, the vegetated marsh-mudflat edge with gentle slopes at the southeast corner of the marsh is foraging habitat for shorebirds.

Existing habitat conditions at Tiscornia Marsh are not sustainable. Under the No Action scenario, the marsh edge would continue to erode at its current pace or potentially even more rapidly with sea-level rise. As shown in **Figure 14**, the northern portion of the marsh is expected to be completely eroded away in 50 years, and the southern portion will have eroded roughly 150 feet. Further, any remaining pickleweed marsh will be converted to low marsh and/or mudflat because sedimentation/marsh accretion rates are likely not sufficient to keep pace with future sea-level rise.

In future conditions under the No Action alternative, Tiscornia Marsh is expected to provide lower habitat values for SMHM due to conversion of pickleweed-dominated high marsh to cordgrass-dominated low marsh. The future marsh will be significantly reduced in size, and lack the full range of wetland zones used by RIRA for foraging and breeding. The impact to shorebirds is expected to be less, since ongoing erosion would likely cause the marsh-mudflat edge to shift landward, while still providing mudflat foraging habitat.

As the marsh erodes and lowers relative to tide levels in the future, its wave dissipation and flood protection benefits will decrease over time.

6.2.2 Alternative 2 – Extended Shoreline Stabilization

Alternative 2, Extended Shoreline Stabilization, would provide similar marsh habitat and ecological functions as Alternative 1, No Action under current conditions. As noted above, the existing marsh would provide habitat for SMHM and RIRA, with the outboard mudflat providing shorebird foraging habitat. The lower portions of the coarse beach, and the face of the rock jetty along the canal, would provide additional habitat values for native oysters where feasible. Another difference from Alternative 1 is that construction of the coarse beach would reduce the extent of mudflat available for shorebird foraging. We anticipate that this amount would be less than one acre.

The evolution of Alternative 2 would differ from Alternative 1, primarily because the coarse beach would protect the existing marsh from ongoing edge erosion. Under future conditions, the extent of marsh would be similar to current conditions, but its elevation relative to tidal levels would be lower. The marsh vegetation is expected to transition to cordgrass and other low marsh species over time. Therefore, Alternative 2 is expected to provide higher habitat values for both SMHM and RIRA compared to Alternative 1, and lower habitat value for both SMHM and RIRA in the future compared to Alternatives 3 and 4.

The evolution of the overhanging scarp along the marsh edge under this alternative is more uncertain. Most of the wave action that creates the erosional scarp would be dissipated by the coarse beach in the future. Therefore, the marsh edge may become more gently-sloped over time, as marsh edge slumps and sediments deposit. Overall, accelerated sediment deposition in the mudflat between the vegetated marsh and coarse beach is expected. However, as shown in **Figure 15**, this area would be expected to persist as mudflat, because the deposition rate was not predicted to outpace sea-level rise. However, since sites where mudflat areas are sheltered from wind-waves can experience high levels of deposition (see Appendix A), it is possible that modeled conditions are an under-prediction, and that the eventual bed elevation in the new channel feature will be more a function of tidal channel hydraulics (see Williams and Orr 2002).

6.2.3 Alternative 3 – Restore Eroded Marsh

Under Alternative 3, Restore Eroded Marsh, the total marsh area would be roughly double that for Alternatives 1 and 2. This alternative would provide more extensive marsh habitat for SMHM and RIRA. The marsh would be filled in a manner that preserves the overhanging scarp as the west bank of a new tidal channel, to the extent practicable. The expanded marsh would also provide a more extensive tidal channel network for RIRA foraging and movement across the marsh. Similar to Alternative 2, the lower portions of the coarse beach and rock jetty may be designed to enhance habitat for native oysters. It is noted that fill placement for the marsh and coarse beach would reduce the extent of existing mudflat used for shorebird foraging.

Under this alternative, the aerial extent of the expanded marsh is anticipated to persist over time, due to protection provided by the coarse beach on the outboard edge. Under future conditions, the marsh would accrete at a modest rate, but overall would be lower relative to rising tidal levels than under current conditions. High marsh is expected to transition to mid-marsh, and mid-marsh to become low marsh over time.

6.2.4 Alternative 4 – Restore Eroded Marsh and Diked Wetland

Alternative 4 incorporates all of the features of Alternative 3, and in addition, restores tidal action to the 6-acre diked marsh on City lands. This alternative would provide the largest extent of marsh as compared to the other alternatives. This alternative also offers the most opportunity to create and sustain the full range of wetland habitat zones, from mudflat and low marsh along the tidal channels, to high marsh refugia in the newly-created marsh. Therefore, this alternative is considered to have potential for the highest ecological value, particularly for SMHM and RIRA.

The future evolution of this alternative is anticipated to be similar to that projected for Alternative 3. The diked marsh, which is currently mostly at mid-marsh elevations, will evolve to low marsh over time, similar to the newly-created marsh. Again, this alternative is considered to have the highest future ecological value as compared to the other alternatives, based on the extent of vegetated marsh that would be provided.

This alternative also includes replacing the existing levee around the diked marsh with a new setback and/or raised levee. This would result in Alternative 4 also providing the highest level of flood protection compared to the other alternatives, which do not improve the City's levee to the immediate west of Tiscornia Marsh.

6.2.5 Goals and Objectives Evaluation Summary

The Marsh alternatives were evaluated for their relative ability to meet the six project objectives. We summarized this evaluation through a qualitative rating from low (**L**) to high (**H**) as summarized in **Table 8**.

TABLE 8
EVALUATION SUMMARY OF TISCORNIA MARSH ALTERNATIVES

	Qualitative *Relative* Rankings of Each Alternative			
Marsh Objective	**Alternative 1 No Action**	**Alternative 2 Extended Shoreline Stabilization**	**Alternative 3 Restore Eroded Marsh**	**Alternative 4 Restore Eroded Marsh & Diked Wetland**
Reduce current loss of vegetated marsh due to marsh edge erosion.	**LOW**	**HIGH**	**HIGH**	**HIGH**
Reduce future loss of vegetated marsh due to marsh "drowning" through sea level rise.	**LOW**	**LOW**	**MEDIUM**	**MEDIUM**
Enhance habitat for endangered marsh species, including RIRA and SMHM.	**MEDIUM**	**LOW**	**MEDIUM**	**HIGH**
Provide habitat for other wildlife, including shorebirds, ducks and other water birds as well as native fish and oysters.	**MEDIUM**	**MEDIUM**	**LOW**	**LOW**
Preserve and/or enhance flood protection function of the marsh for wave dissipation.	**LOW**	**MEDIUM**	**HIGH**	**HIGH**
Serve as a demonstration project for nature-based sea level rise adaptation strategies for SF Bay.	**LOW**	**MEDIUM**	**HIGH**	**HIGH**

Note that these ratings are both qualitative (estimates from best professional judgment of all the information presented in this report) and relative to each other alternative not to any external absolute raking.

Generally, the extent and resilience of vegetated marsh increases in order from Alternative 1 to Alternative 4. Alternative 1, No Action, provides the smallest extent of marsh, with increasing amounts provided under Alternatives 2 and 3, and Alternative 4, Restore Eroded and Diked Marsh, providing the largest area. The extent and resilience of vegetated marsh translates to improved habitat conditions for endangered marsh species. In addition, the larger the marsh, particularly in the mid to high marsh zones, the higher the wave attenuation function provided.

None of the alternatives can adequately counter eventual marsh “drowning” due to sea-level rise, but presumably the larger amounts of high marsh in Alternatives 3 and 4 would have greater resilience as compared to the more limited areas provided with Alternatives 1 and 2. Alternatives 3 and 4 provide a significant local increase in the near term after project construction, before sea-level rise begins to convert high marsh to mid marsh.

Alternatives 1 and 2 are anticipated to provide better habitat value for shorebirds, owing to the preservation of mudflats outboard of the marsh. While the rock jetty and coarse beach under Alternatives 2 through 4 may provide increased habitat for oysters, at this stage the potential for this benefit is uncertain.

The restoration alternatives incorporate three different nature-based sea-level rise adaptation strategies, coarse beach, beneficial reuse of dredged sediments, and levee ecotone slope. Since Alternatives 3 and 4 incorporate both strategies, they rate higher as suitable for a demonstration project than does Alternative 2, which only includes one such strategy.

6.3 Evaluation of Habitat Levee Options

The three options for the Habitat Levee were qualitatively evaluated against the four objectives of improving ecologic function, increasing flood protection, being compatible with City’s adjacent land use, and accommodating sea-level rise adaptation. The results of this evaluation are presented by objective below, and summarized in **Table 9**.

TABLE 9
EVALUATION SUMMARY OF HABITAT LEVEE OPTIONS

Habitat Levee Objective	Option A Minimum Footprint	Option B Habitat Levee in Marsh	Option C Habitat Levee outside of Marsh
Improve ecological function of the outboard levee slope for the endangered species and other native marsh species.	**LOW**	**MEDIUM**	**HIGH**
Increase level of flood protection for the adjacent Canal District, by raising\reconfiguring the levee to reduce frequency of wave overtopping (same level or better than adjacent levee segments).	**LOW**	**HIGH**	**HIGH**
Be compatible with adjacent public access uses, including the Bay Trail on the levee top and the City park/playground on the landward side of the levee.	**HIGH**	**HIGH**	**MEDIUM**
Allow for future adaptation as sea level rises.	**LOW**	**HIGH**	**HIGH**

Note that these ratings are both qualitative (estimates from best professional judgment of all the information presented in this report) and relative to each other alternative not to any external absolute raking.

The first objective is improving ecologic function. Option A, the minimum footprint option, has relatively low ecological benefit owing to the abrupt transition from the marsh to uplands. Options B and C, which incorporate a 30-foot wide ecotone slope, have similar ecologic value for high tide refugia and provide a buffer between the Bay Trail and the marsh. However, Option B requires filling existing outboard marsh to create the ecotone slope, which reduces the ecological value of the existing high marsh that it fills. Option C is assumed to have the highest ecological value of the three options, as it provides the same benefits as Option B but without impacts to the existing marsh.

In terms of flood management, each levee option will increase flood protection by raising the levee crest elevation to 13 feet NAVD88. In addition, the ecotone slope in Options B and C should also attenuate wave action, which would help to reduce wave runup and potential overtopping of the levee. Given the relatively sheltered wave environment along the south side of Tiscornia Marsh, the ecotone slope is assumed to provides a relatively moderate increased flood benefit, as compared to Option A.

The selected option needs to be compatible with the City's adjacent land use. Options A and B do not encroach upon City-owned property, so are considered most compatible with adjacent land use. Option C entails extending the levee footprint onto the City's property, a portion of which is a children's playground. The City has indicated it is open to considering reconfiguring, or possibly relocating, the playground. Therefore, Option C ranks the lowest in terms of compatibility with adjacent land use.

The final objective is accommodating sea-level rise adaptation. Over time, it will be necessary to raise the levee crest in response to sea-level rise. The expanded levee footprint under Options B and C provides more flexibility for future levee raising, as compared to Option A. In addition, in Option A, the ecotone slope provides a narrow fringe for marsh transgression as sea level rises. Therefore, both Options B and C are rated more highly than Option A for sea-level rise adaptation.

Both Options B and C have similar overall performance, except that Option B is more compatible with adjacent land use, while Option C provides higher habitat value.

Based on this evaluation, and given the emphasis on nature-based solutions in the grant, Option C, Habitat Levee outside the Marsh, is the preferred option.

Implementation of this option relies on the cooperation of the City. It is recognized that the City has its own constraints and priorities, and has not yet approved of this option. If ultimately the City does not agree to this option, then Option A would likely be implemented. It is possible that some of the ecotone slope toward the east end of the site could be constructed as part of the newly created marsh under Alternative 3 or 4.

7. PREFERRED ALTERNATIVE

7.1 Selection of Preferred Alternative

The preferred alternative is a combination of Alternative 4, Restore Eroded Marsh and Diked Wetlands, and Option C, Habitat Levee outside the Marsh. The city has indicated willingness to allow their property to be included in this plan, subject to further discussion. If ultimately the City opts not to move forward with restoration of the diked marsh, then the scope of the marsh stabilization would have to be scaled back to Alternative 3, Restore Eroded Marsh.

Likewise, if the City does not allow the raised levee to encroach into Schoen Park, then the width of the ecotone slope would have to be reduced to minimize filling the existing marsh. In this case, the preferred habitat levee option would be a hybrid between Option A, Minimal Footprint and Option B, Habitat Levee in Marsh, with a gentle ecotone slope (for example 10:1) where space allows.

The following sections describe the conceptual design, permitting considerations and constructability and next steps for the preferred alternative.

7.2 Conceptual Design for Preferred Alternative

Under the preferred alternative, Tiscornia Marsh will be restored to its approximate size in 1987, with a coarse beach and rock jetty on its east and north sides, respectively. In addition, tidal action would be restored to the City-owned diked marsh at the north end of Pickleweed Park. Altogether, the preferred alternative would create approximately 10 to 15 acres of new tidal marsh. Alternative 4 is shown in plan and section in Figures 17 and 18, respectively.

This alternative includes improving approximately 2000 feet of the shoreline levee for flood protection, public access and habitat benefits. The existing levee along the perimeter of the diked wetland at Pickleweed Park would be replaced with a new setback levee along the north side of the soccer field. The rest of the existing levee between Pickleweed Park and MAS's property would be raised and/or widened in place to provide uniform flood protection and public access. The new setback levee and MAS's levee on the south side of Tiscornia Marsh would include a gradually-sloped ecotone transition to the outboard marsh.

7.2.1 Coarse Beach

A coarse beach will be constructed at the marsh edge to help resist ongoing erosion. This coarse-grained feature would emulate naturally-occurring beaches in San Francisco Bay, and would be comprised of a mixture of sand, gravel, cobble, and/or oyster shell hash. The coarse beach would provide multiple benefits, including increasing the stability of eroding shorelines, creating aquatic and wetland habitats, and providing a platform for ecosystem adaptation to sea-level rise.

Coarse beaches within the Bay are typically shallow-sloped shorelines between subtidal and supratidal elevations. At Tiscornia Marsh, the proposed coarse beach feature would extend from the outboard mudflat up to approximately elevation 8 feet NAVD88. Retention groins (or “micro-groins”) constructed of wood and/or rock may be incorporated into the beach to restrict longshore drift and to allow sufficient retention of sand and gravel in the beach profile.

7.2.2 Newly Created Tidal Marsh

The existing mudflat outboard of Tiscornia Marsh would be filled to re-create approximately 8 acres of tidal marsh. Most of the marsh would be at elevation 6 feet NAVD88, with areas of high marsh up to roughly elevation 7 feet NAVD88 along channel banks and other locations. The overhanging scarp along the existing marsh edge would be preserved as much as feasible for RIRA habitat. The marsh would include an appropriately-sized tidal channel network that would provide interior mudflats fringed by low marsh for RIRA foraging.

The exact footprint of the new marsh would vary depending on several factors, including property ownership, fill availability, reducing impacts and other factors. The extent of the marsh as conceptually shown, extends beyond MAS’s property boundary to the north. Adjacent property within the San Rafael Canal is within State Lands Commission’s (SLC) jurisdiction. Further consultation with SLC is needed to approve use of their property for the project. If needed, the marsh footprint could be scaled back to only include MAS’s property.

Bay muds similar to the existing marsh would be the most appropriate fill material. Therefore, beneficially reusing dredged material from in or around the San Rafael Canal is the preferred fill method. At this stage, we have assumed a proposed marsh footprint of 8.5 acres, which is slightly larger than that shown on the 1987 aerial photo footprint. The estimated fill volume for the footprint shown is approximately 60,000 to 100,000 cubic yards.

The exact footprint of the marsh could be somewhat variable between approximately 5 and 10 acres, considering the need for protection against sea-level rise and transition zone habitat, the availability of suitable fill material, cost and other factors.

7.2.3 Restore Diked Wetlands

The diked marsh is already at mid-marsh elevation and dominated by pickleweed, but is isolated from tidal action by the perimeter levee/trail. Tidal action would be restored by breaching the perimeter levee. A tidal channel network connected to the levee breach would be excavated. Also portions of the levee around the diked marsh would be lowered or removed to create disconnected high marsh and upland transitional habitat.

7.2.4 Rock Jetty

A rock jetty would be constructed at the north boundary of Tiscornia Marsh that extends eastward, parallel to the Canal. The purpose of the rock jetty is to trap and accumulate sediment that would otherwise drift along the beach face and deposit in the Canal. The jetty will reduce erosion of the newly constructed beach, and should reduce the depositional rate of the Canal. The jetty would likely be a flexible structure constructed of suitably-sized rock. The jetty would extend from the Canal bottom up to approximately 2 feet above MHHW, (approximately elevation 7 to 9 ft NAVD88). During the future detailed design phase, we will look for opportunities to incorporate features in the lower, subtidal portion of this feature to enhance its potential as oyster reef habitat.

7.2.5 Ecotone Slope

A gradual slope between high marsh and upland areas would create a wide ecotone (transition zone) that combines ecological and flood protection benefits. The ecotone would be located along the outboard slope of the existing shoreline levee and trail. The actual width of a constructed ecotone slope varies significantly, and depends on functional objectives, available space, and other factors. Given site constraints, we recommend sizing the ecotone (elevation range and slope) at a minimum to function as a wind wave dissipation bench. An ecotone sized with this approach can also provide ecological function for habitat and buffering. More detailed wind wave analysis will be performed in the future detailed design phase. At this stage, we have developed preliminary dimensions based on similar levee benches designed by ESA.

As described above, we have developed preliminary dimensions for the ecotone slope for Tiscornia Marsh based on our experience with similar projects. At this stage, the ecotone would be approximately 30 feet wide, assuming a 10:1 slope between elevations 6 and 9 feet NAVD88. The actual slope and elevations of the ecotone will be determined based on further analysis in the future detailed design phase.

The slope will be planted with native vegetation adapted to historic ecotones, intermixing high marsh and upland species adapted to infrequent flooding and salinity, and including grasses for nesting materials (e.g. creeping wildrye, *Elymus triticoides*). Plant cover must be entire (or nearly so) throughout the year, and reach elevations which remain emergent (above 1 foot in height) through the highest tides, so that small marsh mammals and secretive marsh birds can find cover from predation.

7.2.6 Raised Levee

The portion of the existing levee on MAS's property will be raised to a consistent height and constructed to a standard width. We have assumed a crest elevation of 13 feet NAVD88 and a 16-foot crest width, to accommodate the Bay Trail. At this stage, we have assumed that the levee will have uniform side slopes of 3:1 (horizontal:vertical) on the landside, and on the outboard side above the ecotone slope. The actual side slopes and other geotechnical criteria for the raised levee will be addressed in the future design phase. The new levee would be designed by a geotechnical engineer to regional flood protection standards (e.g. seepage resistance, seismic performance, etc.)

Under the preferred Option C, the new levee footprint would encroach into the City-owned Schoen Park. The total fill footprint will be approximately 80 feet wide. The toe of the ecotone will be at the edge of the existing marsh, which is closer to the levee at the west end, and further at the east end. Therefore, the amount of encroachment on the City's property will vary from 20 to 30 feet, west to east. For this alternative, the new levee crest will be offset from the existing crest, as shown in Figure 21. The geotechnical analysis will need to consider the uneven loading of the raised levee and mitigate for potential differential settlement. Under this alternative, the expanded levee would likely require removal of existing trees. This alternative would also necessitate reconfiguring the existing playground, so that it is moved landward of the new levee or relocated nearby.

7.3 Construction Approach

Given that much of the work needs to occur in the open Bay waters, the construction approach is a significant consideration for cost, permitting and feasibility. Potential construction methods for the conceptual design are described below. This section has been prepared with input from B.K. Cooper, a marine contractor who has constructed many marsh restorations and other marine improvements in the Bay Area. The construction approach is subject to refinement in future phases based on more detailed studies, input from regulatory agencies, information on potential dredged material and other fill sources and further discussion with local contractors.

7.3.1 Fill Placement Options

The project entails significant fill placement for several elements including: raising and/or building the flood protection levee; rebuilding the marsh; and constructing the beach and rock jetty. Potential fill sources can generally be divided into two categories: fill excavated from uplands, and material dredged from open waters. Uplands fill is transported to the site using trucks and placed using land-based construction equipment (excavator, bulldozers, etc.). Importing significant volumes of upland fill requires multiple truck trips, which could become problematic for residents due to traffic congestion and noise.

The second source is dredged material, which is typically excavated by hydraulic dredging (e.g. using a suction dredge), or mechanically (e.g. using a crane). The dredging method determines the composition of dredged material (e.g. water content) and delivery method to the site. For hydraulic dredging, excavated sediment is mixed with water to form a slurry that can be pumped to a discharge location. Slurries are generally 15-20% sediment and 80-85% water. As an alternative, dredging can be performed mechanically using a crane outfitted with a clamshell bucket, dragline or similar. Mechanically dredged material is wet - but with much lower water content than slurried material - and is usually loaded into a barge for transport to the disposal location.

At this stage, we have made preliminary assumptions regarding fill sources and placement methods for the major design elements. We assume that uplands fill will be used to improve the existing levee and construct the ecotone slope, since there is relatively good road access to the levee locations, and the required fill volumes are not excessive (roughly 10,000 to 13,000 cubic yards).

For marsh construction, we assume that it would be most feasible to hydraulically-place the fill material. Placing fill mechanically (either upland soils or dredged spoils) would require staging a crane or excavator in the mudflat to place and spread material. We anticipate significant challenges with constructing access roads or crane pads in the existing mudflat given the soft, saturated sediments. Significant volume of imported rock material and geotextiles would likely be required, and would create mud waves until the road/pad were stabilized. Therefore, hydraulically placing fill material as a slurry appears to be a more feasible method for obtaining uniform fill placement throughout the marsh.

For the beach and jetty construction, fill materials (rock, sand, gravel and/or shell hash) would likely be imported from commercial suppliers within the Bay (e.g. Hanson Products, Dutra or Syar quarry, and/or Jericho Products) and transported by barge to the project site. Beach materials would be offloaded and placed along the constructed marsh edge using a floating crane. The placement of beach materials would be coordinated with construction of a containment cell and placement of marsh fill, with the exact sequence to be determined.

The assumed fill sources and placement methods for the various design elements, as well as alternatives for further consideration, are summarized in **Table 10** below.

TABLE 10
ASSUMED FILL SOURCES AND PLACEMENT METHOD

Design Element	Fill Source	Transport & Placement Method	Alternative Types of Fill & Placement Methods to be Considered
Levee & Ecotone Slope	Upland soils (meeting levee core criteria)	Trucked to site and mechanically placed and compacted	Potential to use dried and conditioned dredged sediments, if needed
Marsh Reconstruction	Dredged sediments (see Appendix B for potential sources)	Barge transport & hydraulic placement	Consider mechanical placement of fill material.
Beach and Jetty Construction	Imported rock, sand, gravel and/or shell hash	Barge transport & mechanical placement, in conjunction with marsh reconstruction	To be evaluated as design develops

7.3.2 Dredged Material Sources

As part of this project, Stuart Siegel of Siegel Environmental examined potential sources of dredged sediment for beneficial reuse at Tiscornia Marsh (see April 11, 2018 memorandum included in Appendix A). This memorandum identifies several maintenance dredging projects along San Rafael Creek and other nearby locations that could feasibly provide dredged sediment for Tiscornia Marsh. **Table 11** lists all the dredging along San Rafael Creek since 2010, which includes dredging the Canal, as well as marinas and private boat docks.

TABLE 11
DREDGING RECORDS ALONG SAN RAFAEL CREEK SINCE 2010

Location	Year	Approximate Volume (cubic yards)
Marin Yacht Club 2016 7,106 SF-10	2016	7,106
Larkspur Ferry Terminal	2015	378,654
Aqua Vista Drive #16, 20, 24 (private docks)	2015	1,241
Loch Lomond Marina	2015	66,068
Lowrie Yacht Harbor 2015	2015	1,306
Marin Yacht Club	2015	24,820
Pt San Pedro Road #100-110 (private docks)	2015	1,794
Mooring Road HOA (private docks)	2013	4,403
Aqua Vista homeowners (private docks)	2012	1,538
Lowrie Yacht Harbor 2012 26,376 SF-10	2012	26,376
Porto Bello HOA (private docks) 2012 6,073 SF-10	2012	6,073
Royal Court homeowners (private docks)	2012	1,815
Marin Yacht Club	2011	21,206
San Rafael Yacht Harbor	2011	4,400
San Rafael Channel (USACE)	2011	48,600
Larkspur Ferry Terminal	2010	310,449
San Rafael Yacht Harbor	2010	900

SOURCE: Dredged Material Management Office annual reports (DMMO 2011 to 2017), as reported in Appendix A.

Unfortunately, the timing of future dredging of the San Rafael navigation canal is uncertain, as it is a low priority for the U.S. Army Corps of Engineers (USACE). However, the volumes of sediment from dredging marinas and private dock range from as anywhere between 1,000 and 66,000 cubic yards. It is possible that two or more local dredging projects could provide suitable fill volume required for the project. In addition, Larkspur Ferry Terminal is dredged by Golden Gate Bridge, Highway and Transportation District every four to five years. One dredge cycle for the ferry terminal generates more than enough material needed for Tiscornia Marsh. More detail on the proposed fill sources is provided in Appendix A.

Depending on the source, dredged material will either be hydraulically or mechanically dredged. If the dredge material comes directly from a site that has been hydraulically dredged, it may be possible to discharge the material directly into the mudflat, provided it is fully contained. If the dredge material comes by barge from a mechanically dredged site, it would best be transferred to an offshore unloader, slurried and pumped into the contained mudflat.

7.3.3 Dredge Material Placement

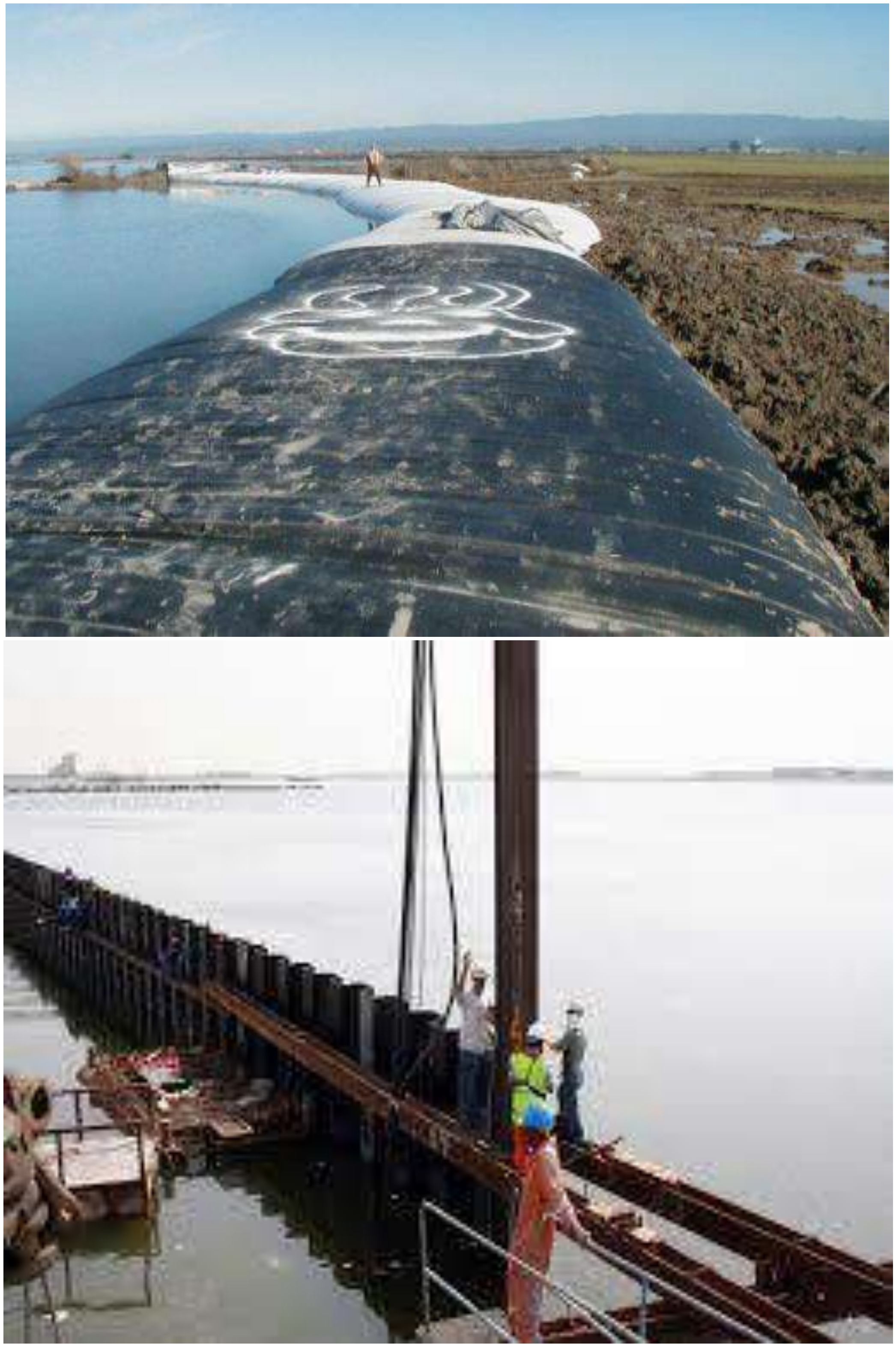
As noted above, we currently assume that hydraulic-placement of dredged material is most feasible. Prior to fill placement, a containment cell needs to be constructed around the entire area. The containment cell is needed to contain sediments over several months of draining and consolidation, while protecting adjacent waters and wildlife. Since we are applying a hydraulic slurry to build the marsh, the containment method needs to be close to watertight to hold decant water until it meets water quality discharge requirements. Ideally the containment cell would extend 5 to 7 feet above finished marsh elevation (i.e. up to elevation 11 to 13 feet NAVD88).

B.K. Cooper considered numerous types of containment, and concluded that steel sheet piling and water dams were the two most feasible options. Steel sheet piling, while relatively costly, are predictable and efficient. A steel sheet piling wall can accommodate water control structures such as flap gates, slide gates, weirs or pumping systems, and/or can be used to support a working platform. Sheet piling are relatively water tight, although a sealant applied to the connecting joints, before installation, provides a water tight barrier. Sheet pilings, while expensive, retain a high resale value. Installation of steel sheet piling in this mud flat environment is typically performed by a barge crane with a shallow draft, using a vibratory hammer.

Portable water (or bladder) dams may be a reasonable alternative to steel sheet piling and they are less expensive to purchase. Water dams are flexible tubes that can be placed from the water using marine floating gear (e.g. small barge-mounted crane), then filled with water using portable pumps. For Tiscornia Marsh, a series of 16-foot tall, 32-foot wide water bags would likely provide sufficient containment; additional smaller tubes may be needed for stability. If the water dams were used, water control structures would need to be installed separately. Some disadvantages of water dams are that they can deteriorate over time and do not usually have reuse value. One viable containment option may be to install a water dam along the existing marsh edge to protect the overhanging escarpment in-place, and install a sheet pile wall along the new outboard marsh edge.

Water removal and management are key considerations for hydraulically-placed material. Since placed material is 80% or more water, water needs to be constantly decanted and removed to allow drying and consolidation of sediments. Removed water can either be discharged directly to the Bay, or be recycled in a closed-loop system, where decant water is pumped to the dredge pump and used as slurry makeup water. If discharging directly to Bay, a decant weir can be built into the sheet pile wall. For a closed loop system, a standpipe or similar would be installed within the fill placement area, and the removed decant water would be pumped to back to the dredge pump. We assume a closed system would be somewhat more costly, but would be more acceptable to regulatory agencies, and could possibly accelerate dewatering (since water quality standards for removing water would be lower than discharging directly to Bay).

Onsite conditioning of the dredge materials will be important to shape the new marsh. Initially the dredge discharge pipes will be maneuvered using low ground pressure dozers and/or amphibious excavators to distribute the slurry throughout the new marsh. As material is dewatered, it can be further dried and conditioned using low ground pressure dozer pulling a disk. It is likely that dredged material may need to be placed in at least two phases. The majority of dredged sediments would be placed in an initial phase, and allowed to dewater, consolidate and settle over several months. A second phase of material placement may be needed to raise the site to final grades. Interior berms may be constructed to focus subsequent phases of dredged fill placement. It is anticipated that dredged fill placement and consolidation will occur over three to five years.



SOURCE: B.K.Cooper

Tiscornia Marsh Habitat Restoration Arial **.D160888.0**

Figure 27

Containment options: examples of bladder dam (top) and sheetpile wall (bottom).

7.3.4 Permitting Considerations

Potential jurisdictional wetlands and other waters are considered sensitive biological resources under the California Environmental Quality Act (CEQA), and are regulated by the USACE, RWQCB, BCDC, and CDFW. Wetlands and waters in the Study Area consist of mudflats, tidal channels, low marsh, mid-marsh, and high marsh/transition zone biological communities. Mudflats and tidal channels are considered potential jurisdictional waters, and the remainder of these communities is considered wetlands. In addition, the site does or has the potential to support special status plant and wildlife species as listed in Section 3.3.4 and as regulated by the USFWS, NMFS, and CDFW; impacts to these wildlife resources may also require permits or authorizations.

Those permits or approvals expected to be required are listed below, by agency. In particular, we anticipate that significant effort may be required to obtain permits from the USACE, RWQCB, BCDC, and the DMMO as restoration activities will involve:

- Significant in-water work
- Placement of significant volumes of dredged and/or fill material in the Bay and adjacent marsh habitats
- Potential for construction-related turbidity, noise, and vibration; and
- Potential for associated disturbances to protected habitats and/or sensitive species which utilize the site.

U.S. Army Corps of Engineers

The discharge of dredged and/or fill material within the San Francisco Bay requires a Section 404 CWA permit from the USACE. In addition, the placement of structures or conducting work in navigable waters requires a Section 10 Rivers & Harbors Act permit from the USACE. A jurisdictional delineation would need to be performed under the next phase of the project to support permitting. However, at this stage it is assumed that most of the site is jurisdictional wetlands or waters. It is also assumed that none of the site's existing levees are built or maintained by the USACE, and therefore, no Section 408 approval from the USACE would be required for levee alteration.

USACE Section 404 CWA authorization can be obtained by complying with specific Nationwide Permit conditions that are applicable to a proposed action. If there are no applicable Nationwide Permits that fit a project, the applicant must apply for an Individual Permit, which can be rigorous to prepare, requires an associated NEPA analysis (typically prepared by the USACE, but with significant applicant support) as well as an alternatives analysis to demonstrate project compliance with the EPA/USACE's 404(b)(1) Guidelines, and can take much longer for the USACE to review.

As a result, the simplest and most efficient way to obtain a USACE permit is to meet the requirements of a Nationwide Permit, and obtain USACE's written verification of compliance. It appears that some, if not all, components of the proposed project could meet the requirements of

USACE' Nationwide Permit #27-Aquatic Habitat Restoration, Enhancement, and Establishment Activities, provided the project can demonstrate a net increase in aquatic resources functions and services. The Tiscornia Marsh should qualify, since it results in a net increase in tidal wetland and tidal channel acreage, improves habitat value for endangered marsh species, as well as providing sea-level rise resilience. If the entire project is determined to be suitable for authorization under NWP 27, then the USACE does not typically require compensatory mitigation (say, for project activities that may result in small wetland acreage losses that are necessary to achieve significant aquatic resource gains in functions and services).

However, some project components such as the rock jetty, and possibly also the raised levee may not be viewed as fitting the intent of NWP 27. Instead these components would need to be authorized under an additional NWP, such as NWP 13 – Bank Stabilization, which could then have associated compensatory mitigation requirements for net permanent losses of waters or wetlands. Such 'stacking' of more than one NWPs is permitted under many circumstances. However, if all project components cannot fit into one or stacked NWPs, due for example to exceedances of certain NWP thresholds for acreage or linear foot limits, an Individual Permit may be required. Because the appropriate permit approach for the USACE is not obvious at this time, the potential permitting approach(es) should be discussed with the USACE before applying for project permits.

Dredged Material Management Office

With respect to the disposal of dredged material in Bay waters, the USACE hosts and participates in the inter-agency Dredged Material Management Office (DMMO), which reviews all proposals for dredging and dredge disposal in the Bay. The DMMO also includes participation by the BCDC, RWQCB, SLC, CDFW, NMFS, and EPA. As the proposed project anticipates to beneficially re-use some dredged material for tidal marsh creation, it will be subject to review and suitability determination(s) by the DMMO.

Regional Water Quality Control Board (RWQCB)

The RWQCB, which administers both federal and state water quality laws, must provide its approval of all permits issued by the USACE in the form of a Clean Water Act Section 401 Water Quality Certification and/or Waste Discharge Requirements (WDRs) under the state's Porter-Cologne Water Quality Control Act. Often, the RWQCB issues a combined 401 Certification/WDR for a project. Certifications and/or WDRs issued by the RWQCB can be assumed to include water quality standards for the discharge of dredged material decant water to the Bay, as well as best management practices and avoidance and/or minimization measures aimed at minimizing turbidity and other construction-related impacts that could adversely affect water quality.

It should be noted that the State Water Resources Control Board (SWRCB) is currently proposing the "State Wetland Definition and Procedures for Discharges of Dredged or Fill Material to Waters of the State" for inclusion in the forthcoming "Water Quality Control Plan for Inland Surface Waters and Enclosed Bays and Estuaries and Ocean Waters of California." If adopted as currently drafted, it is expected to include clarifications on the definition of a wetland under both federal and state regulations administered by the RWQCB, wetland delineation procedures, and permitting process changes, all of which could have implications, though not anticipated to be major, for the project's RWQCB permitting process.

In addition, under its current interpretation of the state's No Net Loss policy for wetlands (Executive Order W-59-93), the project can be expected to require compensatory mitigation for net permanent increases in Bay fill. However, it should also be noted that, as with several other regulatory agencies around the Bay, RWQCB may be currently attempting to revise its regulations and/or implementation guidance, to better enable the beneficial reuse of dredged and/or fill material in the Bay for habitat creation, restoration, and enhancement and especially for such actions that also promote sea-level rise resiliency and adaptability. In fact, based on ESA's similar recent project experience, it may be possible to deduct those project areas that are temporarily converted to uplands, but will become wetlands under projected sea-level rise, from the overall accounting of project 'net loss' and the subsequent requirement for compensatory mitigation.

U.S. Fish and Wildlife Service (USFWS)

The USFWS must issue their approval of any projects that require federal approval (e.g., a USACE permit) and that have a potential to adversely affect federal-listed species regulated by the USFWS. Two federally-listed species regulated by the USFWS, RIRA and SMHM, have the potential to occur within the project site and have been documented as present at the site in the past (Section 3.3.4).

As a result, the USACE (as the assumed federal lead agency for the project) will initiate consultation with the USFWS pursuant to Section 7 of the Endangered Species Act, during processing of the Nationwide Permit or Individual Permit application. Assuming the project results in some adverse effects to USFWS-listed species during construction (despite proposed avoidance and minimization measures), a focused Biological Assessment report would be required. Field survey data collection is likely needed to prepare a Section 7 Biological Assessment report.

Focused species surveys have not been performed recently to assess presence or absence of SMHM at the project site. Wildlife resource agencies would likely assume presence of the SMHM for the purposes of project environmental compliance and permitting. While the presence of RIRA has been recently documented (OEI 2018), it is possible that focused surveys would be requested by the USFWS during the consultation process. Generally, wildlife resource agencies do not accept either general habitat assessments or focused species surveys that are older than 3 years.

National Marine Fisheries Service (NMFS)

Similar to the USFWS, NMFS must issue their approval of any projects that require federal approval (e.g., a USACE permit) and that have a potential to adversely affect federally-listed species regulated by NMFS, such as federally-listed fish including green sturgeon and several species of salmonids), under Section 7 of the Endangered Species Act. In addition, NMFS regulates potential impacts to non-listed marine mammals such as seals, sea lions, and porpoises under the Marine Mammal Protection Act (MMPA). Finally, NMFS regulates activities that may affect Essential Fish Habitat (EFH) under the Magnuson-Stevens Fishery Management and Conservation Act (MSFCMA); EFH is essentially ubiquitous throughout the San Francisco Bay and can therefore be assumed present in the waters surrounding the project site. As a result, the USACE will request Section 7 consultation with NMFS during processing of the USACE's Nationwide Permit or Individual Permit application.

Assuming the project can effectively minimize potential construction-related effects to listed fish, marine mammals, and EFH through measures it may be possible to avoid adverse effects and the need for formal take authorization. Protective measures would likely include using a containment cell for the controlled placement of dredged material, and observing in-water work windows to protect listed fish and EFH (typically June 1 – November 30), and use of vibratory pile driver (instead of impact hammer) for sheetpile installation. If this is the case, NMFS can concur with a Not Likely to Adversely Affect determination, via the informal Section 7 consultation process.

If, instead, it is determined that the project will result in some unavoidable adverse effects, a formal Section 7 consultation process may be required. Regardless of the nature of the anticipated effects to NMFS-listed species and the form of consultation determined suitable, field survey data collection will likely be needed to prepare an assessment of effects to NMFS-protected biological resources.

Bay Conservation and Development Commission

BCDC asserts jurisdiction over the tidal waters of the San Francisco Bay, certain tributaries to the Bay, adjacent tidal marsh areas up to the elevation of 5 feet above the Mean Tide Line, plus a 100-foot 'shoreline band' as measured from the edge of areas subject to tidal action. As we currently understand, the extent of BCDC jurisdiction at the site may end at the powerlines traversing the San Rafael Canal at Tiscornia Marsh (Brenda Goeden, pers. Comm. February 9, 2018). The remainder of the site east of the existing power lines is assumed to be within BCDC's jurisdiction, as are the waters surrounding the site.

A Regionwide, Administrative, or Major Permit Application would be prepared for BCDC, with the specific permit type to be based on the nature of the proposed activities, prior BCDC permits issued for the site, and direction provided by BCDC staff. The permit application would incorporate much of the information contained in the USACE and RWQCB permit applications, including a focus on the proposed placement of in-water fill, plus additional detail on public access, improved shoreline appearance and/or public amenities.

It should be noted that the BCDC, similar to the RWQCB, can be expected to require compensatory mitigation for net permanent increases in Bay fill, which is likely to include some or all in-water fill to create new tidal marsh, the rock jetty and coarse beach. However, it should also be noted that, as with RWQCB and other regulatory agencies around the Bay, BCDC is currently attempting to revise their regulations and/or implementation guidance, to 1) better enable the beneficial reuse of dredged and/or fill material in the Bay for habitat creation, restoration, and enhancement, especially for such actions that also promote sea-level rise resiliency and adaptability, and 2) to acknowledge certain site and project limitations on provision of public access or amenities, in light of potentially conflicting objectives such as wildlife conservation.

California Department of Fish & Wildlife (CDFW)

The CDFW regulates activities that occur in streams, lake beds, and some tidal tributaries to the Bay that support wildlife and their habitats, and therefore may require a Section 1602 Lake and Streambed Alteration Agreement (LSAA) for the project based on its location in and around San Rafael Creek. While some information required in the CDFW LSAA notification is similar to that required by the USACE and RWQCB, as well as an assessment of potential impacts to water quality and quantity, trees and vegetation, and wildlife movement or other life stage functions.

The CDFW also regulates activities that may affect state-listed species and their habitat protected under the California Endangered Species Act (CESA). If the project would adversely affect state-listed species, need for a Section 2080.1 Consistency Determination or a separate Section 2081 Incidental Take Permit (ITP), may be required under the California Endangered Species Act.

State Lands Commission (SLC)

The California SLC (Commission) has jurisdiction and management control over sovereign lands of the State that were received by the State from the United States. Sovereign lands, or lands underlying the State’s navigable and tidal waterways, as well as the state’s tide and submerged lands along the State’s coastline.

The SLC holds its sovereign lands for the benefit of all the people of the State, subject to the Public Trust for water related commerce, navigation, fisheries, recreation, open space and other recognized Public Trust uses. The Commission maintains a multiple use management policy to assure the greatest possible public benefit is derived from these lands. The Commission will consider numerous factors in determining whether a proposed use of the State's land is appropriate, including, but not limited to, consistency with the Public Trust under which the Commission holds the State's sovereign lands. Proposed projects on land with SLC jurisdiction must typically apply either for a lease from the SLC for their proposed structures and/or uses of the land, or, if a lease already exists, a lease amendment.

As we currently understand, some adjacent property within the San Rafael Canal is within SLC’s jurisdiction. Therefore, further consultation with SLC is needed to confirm the extent of their jurisdiction and approve use of their property for the project, which may include obtaining a lease or lease amendment.

Cultural Resources Assessment

As stated above, the project will require the issuance of a USACE Section 404 permit. Section 404 permit issuance by the USACE will require meeting the requirements of Section 106 of the National Historic Preservation Act (NHPA) of 1966 (as amended), which address cultural resources, through interagency coordination between the USACE and the State Historic Preservation Office (SHPO). It is anticipated that the Section 106 coordination requirements will include the preparation of a combination *Historic Properties Survey Report/Finding of Effect* report (*HPSR/FOE*) that can also be used to meet the cultural resources requirements of CEQA

7.3.5 Next Steps for Implementation

This phase of the project concludes with conceptual design for the preferred alternative for the marsh edge and the habitat levee. The overall goal is to move the project forward to implementation. Below is a summary of some of the major next steps.

Obtain additional grant funding for next phase. As a non-profit organization, MAS relies on grant funding to accomplish marsh restoration and sea-level rise adaptation demonstration projects. Potential funding sources include local, state and federal grant programs focused multi-benefit ecosystem restoration projects, particularly those with an emphasis on sea-level rise adaptation.

Partner with the City. Continue to coordinate with the City to better define conditions for City participation in the project. This may require adjusting the design as needed to address the City's concerns regarding flooding, recreational use and other considerations.

Perform additional technical studies including:

- Topographic Mapping: use licensed surveyor to identify property boundaries, perform utilities survey and perform more detailed mapping of park, diked marsh and other features.
- Geotechnical Investigation: Hire geotechnical engineer to perform subsurface investigation and provide geotechnical design recommendations for raising the existing levee, constructing the new setback levee and installing the temporary containment cell.
- Wave analysis: perform more detailed wave analysis to inform the design dimensions and elevations of the beach and the ecotone slope.
- Ecological/Biological Surveys: Perform jurisdictional wetland delineation and biological surveys needed to inform the design, perform CEQA and initiate permitting.

Continue to perform outreach with the public, regulatory agencies and potential fill sources.

- Public Outreach: to build on the momentum already started, keep the community informed and better understand public concerns to be considered in CEQA documentation and project design.
- Initiate outreach to the regulatory agencies (including the SLC, who have jurisdiction over the property immediately adjacent to Tiscornia Marsh to the north) to obtain early input on potential concerns, required studies, and permitting restrictions.
- Perform outreach to identify potential sources of fill material, including prospective sediment and soil generators, BCDC and the DMMO, and the San Francisco Bay Joint Venture's SediMatch program (developed for this purpose).

Develop the preliminary design for preferred project. Advance the design based on results of technical studies, and input from the City, regulators and the public. Preliminary design will completely define the scope of the project, including portions requiring City participation, and will provide an initial estimate of construction costs.

Perform CEQA Analysis. Once the project is better defined, we recommend initiating the CEQA process to further advance the project toward implementation. The initial approach would be to pursue an Initial Study/Mitigated Negative Declaration, assuming that all potential impacts can be limited to less than significant by implementing suitable mitigation measures.

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APPENDIX A: MEMORANDA FROM SIEGEL ENVIRONMENTAL

This appendix includes the following memoranda provided by Siegel Environmental:

- A February 22nd 2018 memorandum: 'Dredged Sediment and Upland Soils Reuse Potential for Tiscornia Marsh'
- A March 9th 2018 memorandum: 'Tiscornia Marsh Sediment Supply Conditions and Potential Marsh Accretion Rates'

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Memorandum #2.1 (Final)

Dredged Sediment and Upland Soils Reuse Potential
Tiscornia Marsh

By: **Stuart Siegel**
Date: **February 22, 2018**

This final memo incorporates feedback on the December 27, 2017 draft memorandum from Barbara Salzman (January 3, 2018 email) and Ed Nute (January 8, 2018 email), a field visit with Brenda Goeden of BCDC on February 9, 2018, and community efforts as described in a Marin Independent Journal story that ran on December 31, 2017 and an associated Editorial that ran on January 6, 2018.

This memorandum addresses one element of Task 2: the potential for dredged sediment to be available for reuse to rebuild the eroded eastern bayward edge of Tiscornia Marsh. Based on MAS review of the draft memorandum, consideration of upland soils reuse has been added to this final memorandum.

Stuart Siegel spoke with the City of San Rafael (Kevin McGowan) and Loch Lomond Marina (Pat Lopez, Harbormaster). He left a message for but has not spoken with Salt River Construction, the primary dredging contractor that works along San Rafael Creek. Based on those two conversations, dredging along San Rafael Creek can be divided into two categories each discussed below: (1) dredging along San Rafael Creek, and (2) dredging from other nearby locations.

1 Coordinating Prospective Sediment and Upland Soil Sources

There are three general methods for coordinating with prospective dredge or upland soils generators: direct outreach and communication with prospective sediment and soil generators, close coordination with BCDC and the Dredged Material Management Office, and engagement with the San Francisco Bay Joint Venture's SediMatch effort established for this specific purpose. As Tiscornia Marsh proceeds to the next phase of work after completing the Conceptual Plans and funding is secured for the next phase of project planning, pursuing these outreach efforts in the context of the final Conceptual Plan would be appropriate.

2 Dredging Methods, Uplands Soils, and Placement Considerations

Dredging Methods

Dredging is typically conducted in one of two general manners relative to how material could arrive at Tiscornia Marsh.

- **Hydraulic dredging:** sediment is mixed with water to form a slurry and pumped in a pipeline directly to a placement or discharge area. Slurries are generally 15-20% sediment and 80-85% water. Placement generally requires containment cells and discharge of slurry water after all the sediment settles out into the containment cell. Routing of dredge pipelines across the San Rafael Creek federal navigation channel may increase technical or regulatory challenges and potentially cost. Researching those issues is beyond the scope of this memorandum.
- **Clamshell or other excavation methods:** sediment is excavated from the dredge area and placed onto barges or trucks for transport to the reuse or disposal area. These sediments are generally mostly (wet) sediment with a minor amount of additional water, and the sediment cohesiveness and thus ease of handling is a direct function of sediment type and percent moisture. Barge transport is standard for dredging along San Rafael Creek where most sediment is currently disposed of in-bay at the approved SF-10 aquatic disposal site in San Pablo Bay. The cost difference to transport and bottom-dump barges at SF-10 versus transport a short distance and unload at Tiscornia or alternatively load sediment into trucks and drive around to Tiscornia is beyond the scope of this analysis to assess. Were there any cost increases, most likely they would need to be borne by the Tiscornia project.

If a source dredging project generates more sediment in its dredging cycle than Tiscornia will need, it is most likely that a single dredging method would be employed, so as to avoid additional equipment mobilization and demobilization costs. For all the dredged sediment sources reviewed below, clamshell dredging with barge transport is how they currently conduct their dredging. If it is to the advantage of the Tiscornia project to receive dredge material as a pumped slurry and if there are additional costs to the dredger, then the Tiscornia project would most likely need to provide the funding differential.

<u>Upland Soils Reuse</u>

Another approach for Tiscornia Marsh is reuse of upland soils in addition to or in place of using dredge material. The most notable example of this approach is Bair Island in Redwood City, which used substantial quantities of uplands soils. Upland soils most typically originate from a construction project that generates soil cut and is in need of identifying economical soil disposal locations. Upland project sponsors have two over-riding cost considerations in selecting disposal locations: trucking distances and tipping fees. Two assumptions and one statement of fact must be made for the analysis: (1) assume Tiscornia would not charge a tipping fee, (2) assume additional costs to the upland project sponsor, if any, would be borne by the Tiscornia Project, and (3) soil quality would have to meet regulatory standards for wetlands reuse. Consequently, feasibility for an upland soils generator relates to meeting or reducing their costs relative to other disposal options, which will relate to trucking distances and soil testing costs. Bair Island developed a comprehensive Quality Assurance Project Plan with the Regional Water Quality Control Board that served as the framework for assessing soil quality and soil physical characteristics. The other feasibility consideration for any soil generator is timing. Flexibility in timing may exist for some upland construction projects but not for all, so arranging timing alignment with Tiscornia could have challenges depending on the project details of the upland soils source.

Upland soils availability is generally known over fairly short time horizons before the upland construction begins (on the order of months) and less often with longer notice (many months to a year or more). From the perspective of constructing Tiscornia Marsh improvements including accounting for seasonal construction constraints likely to be required from the Resource agencies and construction costs, lining up all the necessary soils in advance for delivery within the target construction window would be beneficial, probably necessary, and can be challenging because of probable need to receive soils from multiple construction projects. Perhaps it might work to be an “open” upland soils placement area for an extended period of time, if a holding location can be identified and incorporated feasibly into the Conceptual Design that can make it through CEQA analysis. To obtain the to-be-determined soil volumes, MAS or its consultants would need to be in ongoing communication with construction firms and upland project sponsors working in Marin and local jurisdictions permitting construction projects.

Volumes Needed for Tiscornia

As part of Conceptual Design, ESA will make estimates of placement volumes desired for any of the design approaches identified and elected by MAS to be incorporated. Once those volume numbers are estimated, any future discussions with prospective dredge material or upland soils sources would include the volumes needed, that the Tiscornia Project would not be able accept additional material (unless the project includes a long term holding facility component), and that the project seeks the maximum amount of material consistent with the economics of dredge reuse of any dredge project.

Placement Considerations

The ability of the Tiscornia Marsh project to receive sediment from either or both of these dredging methods or uplands soils reuse will have to be incorporated into the Conceptual Designs being prepared by ESA and included to the extent appropriate for the project. Sediment reuse would conceivably be incorporated into restoring eroded marsh on the east side of Tiscornia Marsh, the wetland-upland transition, and perhaps thin layer deposition atop the remnant marsh. The Conceptual Design will also need to consider whether it is accepting the volume of dredge sediment needed for initial marsh restoration and enhancement work, or possibly additional sediment that is stockpiled somewhere for later addition as consolidation and sea level rise needs arise. This latter element is purely elective for MAS to pursue, and until the restoration project has well established goals and objectives it is difficult to determine whether stockpiling for future use would be an important part of the project.

Engineering considerations for receiving dredge material include but are not limited to: (1) geotechnical, construction, regulatory, and cost feasibility of any necessary containment features built on mudflats, marsh edge, or upland; (2) feasibility of managing decant water if hydraulic dredging is utilized; (3) geotechnical, construction, regulatory, and cost feasibility of features to ensure the placed sediment is retained and not scoured away and transported into the San Rafael Creek navigation channel.

3 Dredging Sources from San Rafael Creek (the “Canal”)

Dredging along San Rafael Creek falls into three distinct dredge areas: federal channel maintenance dredging (San Rafael Creek is a federal authorized navigation channel), marina maintenance dredging, and private boat dock maintenance dredging. It is common that dredging across these three areas is done concurrently, in order to gain efficiencies with mobilization and demobilization costs in particular as well as with the dredging work itself. This is especially the case with the private dock dredging as homeowners seek the most economical path for their dredging. Table 1 lists all the dredging that has taken place along San Rafael Creek since 2010 across all three of these categories.

Table 1. Dredging Records along San Rafael Creek Since 2010

Location	Year	Volume	Disposal
Marin Yacht Club	2016	7,106	SF-10
Larkspur Ferry Terminal	2015	148,425	SF-10
		157,153	Ocean
		73,076	Montezuma
Aqua Vista Drive #16, 20, 24 (private docks)	2015	1,241	SF-10
Loch Lomond Marina	2015	66,068	SF-10
Lowrie Yacht Harbor	2015	1,306	SF-10
Marin Yacht Club	2015	24,820	SF-10
Pt San Pedro Road #100-110 (private docks)	2015	1,794	SF-10
Mooring Road HOA (private docks)	2013	4,403	SF-10
Aqua Vista homeowners (private docks)	2012	1,538	SF-10
Lowrie Yacht Harbor	2012	26,376	SF-10
Porto Bello HOA (private docks)	2012	6,073	SF-10
Royal Court homeowners (private docks)	2012	1,815	SF-10
Marin Yacht Club	2011	21,206	SF-10
San Rafael Yacht Harbor	2011	4,400	SF-10
San Rafael Channel (USACE)	2011	48,600	SF-10
Larkspur Ferry Terminal	2010	57,774	SF-10
		166,800	SF-11
		85,875	Ocean
San Rafael Yacht Harbor	2010	900	SF-10

Source: Dredged Material Management Office annual reports (DMMO 2011 to 2017)
Disposal Sites:

- *SF-10 = San Pablo Bay in-bay aquatic disposal site*
- *SF-11 = Alcatraz Island in-bay aquatic disposal site*
- *Ocean = Deep Ocean Disposal Site*
- *Montezuma = Montezuma Wetlands Restoration Project*

3.1 Federal Channel Maintenance Dredging

Federal channel maintenance took place in 2001 along the entirety of San Rafael Creek and in 2011 along the creek up to the point where contaminated sediments are known to be present, roughly in the vicinity of the San Rafael Yacht Club. Almost 49,000 cubic yards were dredged in 2011 and disposed in-bay at SF-10 (DMMO 2012). The U.S. Army Corps of Engineers is responsible for federal channel maintenance, and San Rafael Creek is not currently identified as a priority project. San Rafael is working with the local dredge sponsors for the Petaluma and Napa rivers to pursue a "combined" dredging project with the intent that its larger scope raises its priority with Corps of Engineers. As reported in the Marin IJ on December 31, 2017, this effort is being conceived as a Public-Private Partnership, which the federal Administration has recently required development of new procedures by the Corps of Engineers for this approach to be pursued. The effort also has the attention of the San Rafael City Council, Marin County Board of Supervisors, and Congressman Huffman.

Based on these findings, the timing of any federal channel maintenance dredging is difficult to estimate and thus may or may not align with the unknown future timing of Tiscornia. As Tiscornia advances towards implementation planning, close coordination with these efforts should be pursued if deemed beneficial to Tiscornia Marsh.

3.2 Marina Maintenance Dredging

San Rafael has five marinas: Loch Lomond Yacht Harbor, Marin Yacht Club, Lowrie Yacht Harbor, the San Rafael Yacht Harbor, and the Municipal Yacht Harbor (Figure 1). Loch Lomond is located east across the open bay about ¾ mile from Tiscornia Marsh. Marin Yacht Club is located northwest across San Rafael Creek about ¼ mile from Tiscornia Marsh. The remaining marinas are all located upstream along San Rafael Creek to the west of Tiscornia Marsh.

Figure 1. Marina Locations Relative to Tiscornia Marsh

Stuart Siegel spoke with Pat Lopez, the Loch Lomond Harbormaster. Loch Lomond is the largest marina and dredges on a variable three-to-five year cycle, with the most recent being in 2015. Each cycle generates up to 90,000 cubic yards of dredged sediment, with 68,000 being dredged in 2015 (Table 1). Sediment quality is consistently not an issue with the exception in some dredging cycles of sediment from the immediate vicinity of the fueling dock and other localized areas. Salt River Construction most typically conducts this dredging, as it has the smallest equipment for accessing dredging areas. Currently, dredge disposal is in-bay at SF-10. Loch Lomond expressed interest in providing dredged sediment for Tiscornia Marsh, especially if it reduces their disposal costs. Conceivably, dredging could be conducted via hydraulic dredge and pumping through a temporary pipeline to Tiscornia Marsh or via clamshell dredge and barge transfer. Given the dredging cycle for Loch Lomond and its proximity, with advance planning and coordination it could well be possible to reuse dredge sediment for Tiscornia Marsh. The volume dredged is likely greater than Tiscornia Marsh will need, so this source could meet the entire needs for Tiscornia. That volume difference suggests that Loch Lomond would not split its dredging into clamshell and hydraulic at its own cost, so Tiscornia would likely have to pick up any added costs if hydraulic dredging and pumping were deemed preferable.

Similarly, Marin Yacht Club, the second largest marina, is also close by and with advance planning and coordination, it could also be a source of dredge sediment for marsh restoration reuse via hydraulic or clamshell dredging. Recent dredging includes 2016 with a volume of 7,100 cubic yards, 2015 with a volume of 25,000 cubic yards, and 2011 with a volume of 21,000 cubic yards, all with disposal at in-bay site SF-10 San Pablo Bay (Table 1). It could deliver sediment by pipeline across the navigation channel or by barge. The other three marinas are smaller in size and further away upstream of Tiscornia Marsh. They may all be viable options. Lowrie Marina, for example, had its last major dredging in 2012 with volume of 26,000 cubic yards disposed at SF-10 (Table 1). Information on sediment quality from these other marinas was not readily available so is not compiled or assessed here.

3.3 Private Dock Maintenance Dredging

San Rafael Creek is lined with private boat docks, directly along the creek and along a number of side channels. According to Pat Lopez from Loch Lomond, many private dock owners align their maintenance dredging needs with Salt River Construction dredging of one of more of the marinas, for cost effectiveness. Mr. Lopez suggested to work directly with Salt River if the need arises to consider dredged sediment from the private boat docks.

4 Dredging Sources from Other Nearby Areas

Two other nearby areas are dredged with varying degrees of frequency and conceivably are located close enough to Tiscornia Marsh that material transport costs to Tiscornia may be feasible: Gallinas Creek and Larkspur Ferry Terminal (Figure 2).

Figure 2. Nearby Dredging Projects in Relation to Tiscornia Marsh

4.1 Gallinas Creek Dredging

The South Fork of Gallinas Creek is a navigation channel serving residents in the Santa Margarita and Santa Venetia neighborhoods of North San Rafael. Marin County Service Area Number 6 – Gallinas Creek (CSA 6), which is staffed by the Marin County Department of Public Works, carries out this dredging. The last dredging of this channel was in 1992/1994 (Marin County 2015). CSD #6 is currently planning a "geomorphic dredge" of this channel. The "geomorphic dredge" concept reduces the total dredging volume, compared to historical dredging, by focusing on channel geometries that can be maintained more effectively by natural tidal and watershed runoff flows thus reducing future dredging needs. The current dredging plan is to place all the dredged sediment into the McGinnis Marsh Restoration Project nearby to the dredging area. Unless that plan breaks down, this sediment source is not available for Tiscornia.

4.2 Larkspur Ferry Dredging

The Golden Gate Bridge District dredges the Larkspur Ferry Terminal and navigation channel approximately every four to five years with about 300,000 to 400,000 cubic yards dredged each cycle[1]. The last dredging took place in 2015, with disposal split between the Deep Ocean Disposal Site (DODS) about 50 miles offshore (157,000 cubic yards), reuse at Montezuma Wetlands (73,000 cubic yards), and in-bay aquatic disposal at SF-10 (148,000 cubic yard) (Table 1). The previous dredging was in 2010, with 85,000 cubic yards to DODS, 225,000 cubic yards to in-bay (SF-10 and SF-11) (Table 1). Though data has

[1] Brenda Goeden, BCDC, personal communication, February 9, 2018.

not been obtained on sediment quality, BCDC confirmed[2] it is reasonable to assume that there is enough suitable material in each Larkspur Ferry Terminal dredging cycle for Tiscornia Marsh.

It is conceivable that reuse at Tiscornia Marsh is viable with Larkspur Ferry dredged sediment. Given the relatively high costs the District currently pays for transit to and tipping fees at Montezuma and transit to DODS, Tiscornia has strong potential to be an economical disposal alternative for the District.

Outreach to the Bridge District following completion of the Concept Designs for Tiscornia Marsh and with projections of implementation timing would be the appropriate strategy to initiate the discussion with the Bridge District.

5 Conclusions

It appears reasonable to consider dredge sediment reuse for Tiscornia Marsh. The time it will take for Tiscornia to be ready to accept dredge material, probably 3-5 years from now maybe sooner and possibly later, works to the advantage of dredged sediment reuse.

There are multiple viable sources of dredged material, listed in order of estimated overall feasibility:

1. **Larkspur Ferry Terminal dredging may be the most feasible** overall for two reasons. First, reuse at Tiscornia is probably less costly than Montezuma or DODS, which translates into a benefit to the Bridge District and no need for Tiscornia to raise supplemental funds to make reuse feasible for the dredger. Second, the reliability of periodic dredging reduces uncertainty of sediment availability, leaving timing of the dredging cycle as the primary uncertainty. This material would be delivered by barge.
2. **Marina and private dock dredging along San Rafael Creek has a reasonable chance of being feasible**. Being privately funded dredging translates to reliability of implementation. The uncertainty of feasibility of these sediment sources is cost. As these projects normally use low-cost in-bay aquatic disposal, it is possible that reuse costs could be higher necessitating the Tiscornia project raise funds to cover the differential. This conclusion is tentative at best as no cost analysis has been done. Barge delivery is the default method, hydraulic pumping and perhaps truck delivery may be possible.
3. **San Rafael Creek navigation channel dredging is the most uncertain.** Navigation channel dredging is a federal action. The currently relatively low priority by the Corps of Engineers and the history of long time periods between dredging cycles introduces comparatively high uncertainty of sediment availability and ability to plan around its availability. This situation may change with active efforts by the City of San Rafael, Marin County, and Congressman Huffman. Cost differentials may exist as for the marina and private dock dredging but again that conclusion is tentative until a cost analysis is performed. Barge delivery is the default method, hydraulic pumping and perhaps truck delivery may be possible.

[2] Brenda Goeden, BCDC, personal communication, February 22, 2018.

4. **Gallinas Creek dredging is already designated for reuse at the McGinnis marsh restoration project.** Unless the situation changes with that intended reuse, these sediments are not available for reuse at Tiscornia. If McGinnis falls through, then feasibility shifts to the uncertainty of when dredging might take place and the probable higher costs of reuse at Tiscornia relative to either in-bay aquatic disposal or the previously considered reuse at the San Rafael Airport property.

From an engineering perspective, dredged sediment reuse will most likely require construction of containment cells and a barrier to transport of any mobilized sediment into the San Rafael Creek navigation channel. The manner in which the dredge sediment is delivered, hydraulic or clamshell, dictates the specifics needed to meet containment requirements. The geotechnical, construction methods, environmental, and cost considerations of these containment features atop soft bay muds and the regulatory considerations of in-bay placement will play importantly into the overall feasibility of using dredged sediments.

Upland soil reuse is a reasonable possibility. Its upside is likely no cost to receive the soils and perhaps less complicated placement containment. The primary drawbacks are difficulty of long-range advance planning to meet the volume needs at Tiscornia combined with the possibility that such volumes may require multiple upland soil sources, and compatibility considerations of soil physical characteristics as marsh substrate.

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Memorandum #2.2 (Draft #2)

Tiscornia Marsh Sediment Supply Conditions and Potential Marsh Accretion Rates

This memorandum addresses two elements of Task 2: review existing data to (1) characterize current and future sediment supply that may be available for natural deposition and (2) potential marsh accretion rates. This Draft #2 incorporates comments received from Ed Nute (February 21), Dane Behrens (February 21), and Ann Borgonovo (March 5).

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637 Lindaro Street, Suite 201, San Rafael, CA 94901
415.299.8746 • www.siegelenvironmental.com

Figures and Tables

1 Tiscornia Marsh Setting

There are several setting factors for Tiscornia Marsh that influence the sediment concentrations it may experience for accretion.

1.1 Landscape Setting

Figure 1 shows its local bathymetric setting. Tiscornia Marsh sits at the confluence of San Rafael Creek with San Rafael Bay. The western edge of San Rafael Bay is very shallow intertidal (green in Figure 1). San Rafael Bay itself consists of a broad expanse of very shallow subtidal mudflats (blue in Figure 1). San Rafael Bay borders the deep San Pablo Straits channel (white in Figure 1). Cutting across San Rafael Bay is the dredged navigation channel for San Rafael Creek (straight black dashed line in Figure 1). These broad mudflats are a likely source of wind-wave sediment resuspension that can be transported toward Tiscornia Marsh on flood tides. San Rafael Creek itself may carry suspended sediment mainly during storms though such conditions are not monitored. When storm flows of San Rafael Creek meet flood tides of San Rafael Bay, the opposing-direction flows can result in increased deposition potential. The relatively regular frequency of dredging the lower reaches of San Rafael Creek and the nearby marinas suggest moderately high deposition potential where water velocities are low enough to allow settling and sediment concentrations are high enough to support actionable deposition.

Figure 2 shows the Tiscornia Marsh setting in relation to the shallow San Rafael and Corte Madera bays to the south and the deeper waters of Central Bay to the east. In addition to sediment resuspension potential of San Rafael Bay described above, similar resuspension can occur on Corte Madera Bay with flood tide transport north toward Tiscornia Marsh. Sediment carried in the deeper Central Bay waters from upstream and downstream sources have the potential to be transported west to San Rafael Bay and Tiscornia Marsh by wind and tidal currents.

Figure 3 shows the setting of Tiscornia Marsh in the broader extent of San Pablo Bay to the north. The broad, shallow expanse of San Pablo Bay is a significant source of wind and wave sediment resuspension (Ganju et al. 2004) that drive locally high deposition rates (see Section 2 below). Currents can carry these sediments great distances each tidal cycle. The extent to which Tiscornia Marsh can be on the receiving end of this sediment transport process may be limited by the relatively close proximity of Pt. San Pedro to San Pablo Straits. Transport to Tiscornia Marsh would more likely occur on ebb tide and suspended sediment would have some potential to be captured by the high flows in San Pablo Straits. To reach Tiscornia Marsh, sediment would then have to exit the high flows of San Pablo Straits and move west up San Rafael Bay. Wind direction and secondary currents during ebb tides would likely exert an influence on the extent to which this transport mechanism would occur.

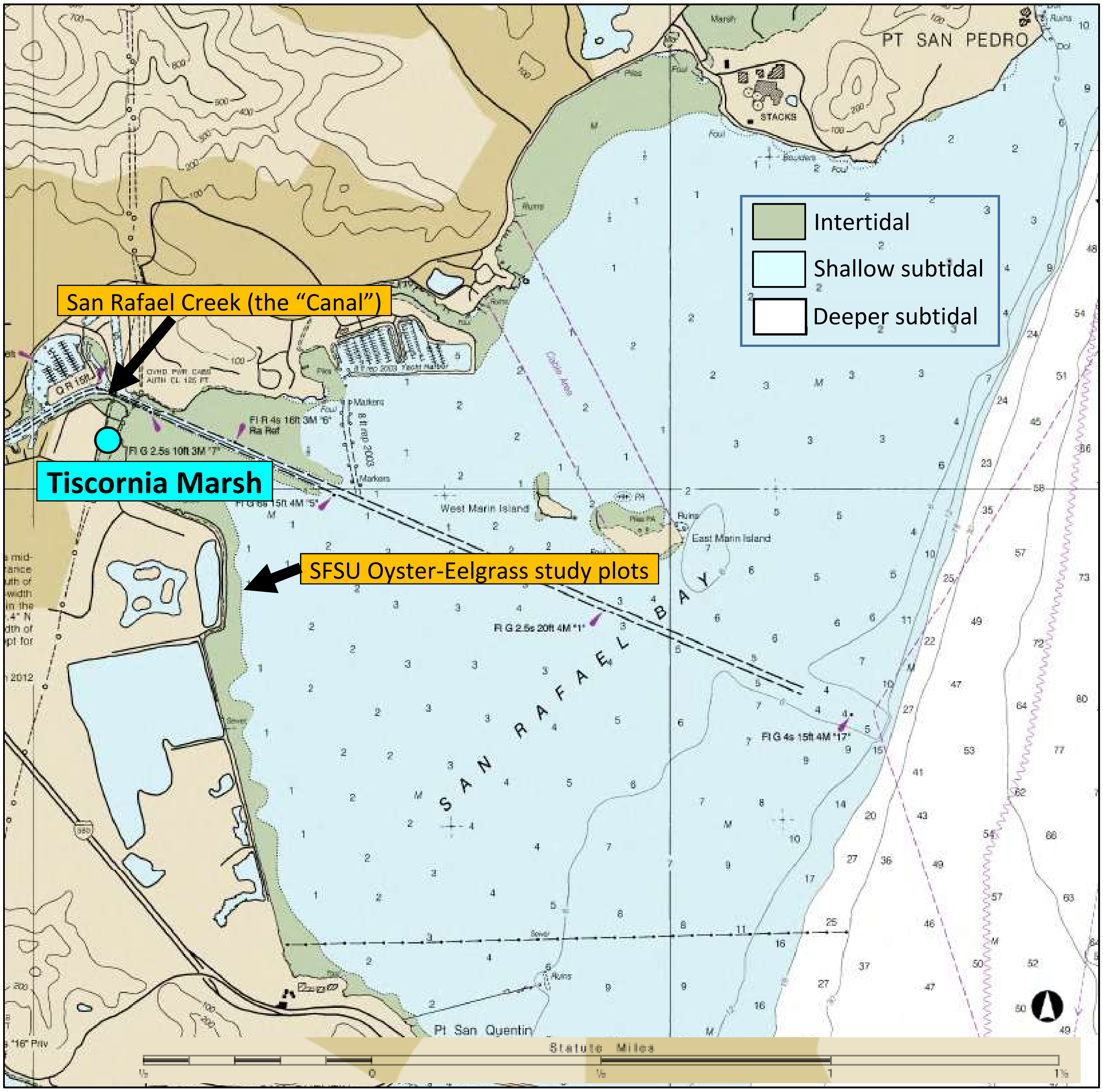


Figure 1. Local Bathymetric Setting of Tiscornia Marsh

Base Map Source: NOAA Chart 18653. All soundings in feet below mean lower low water.

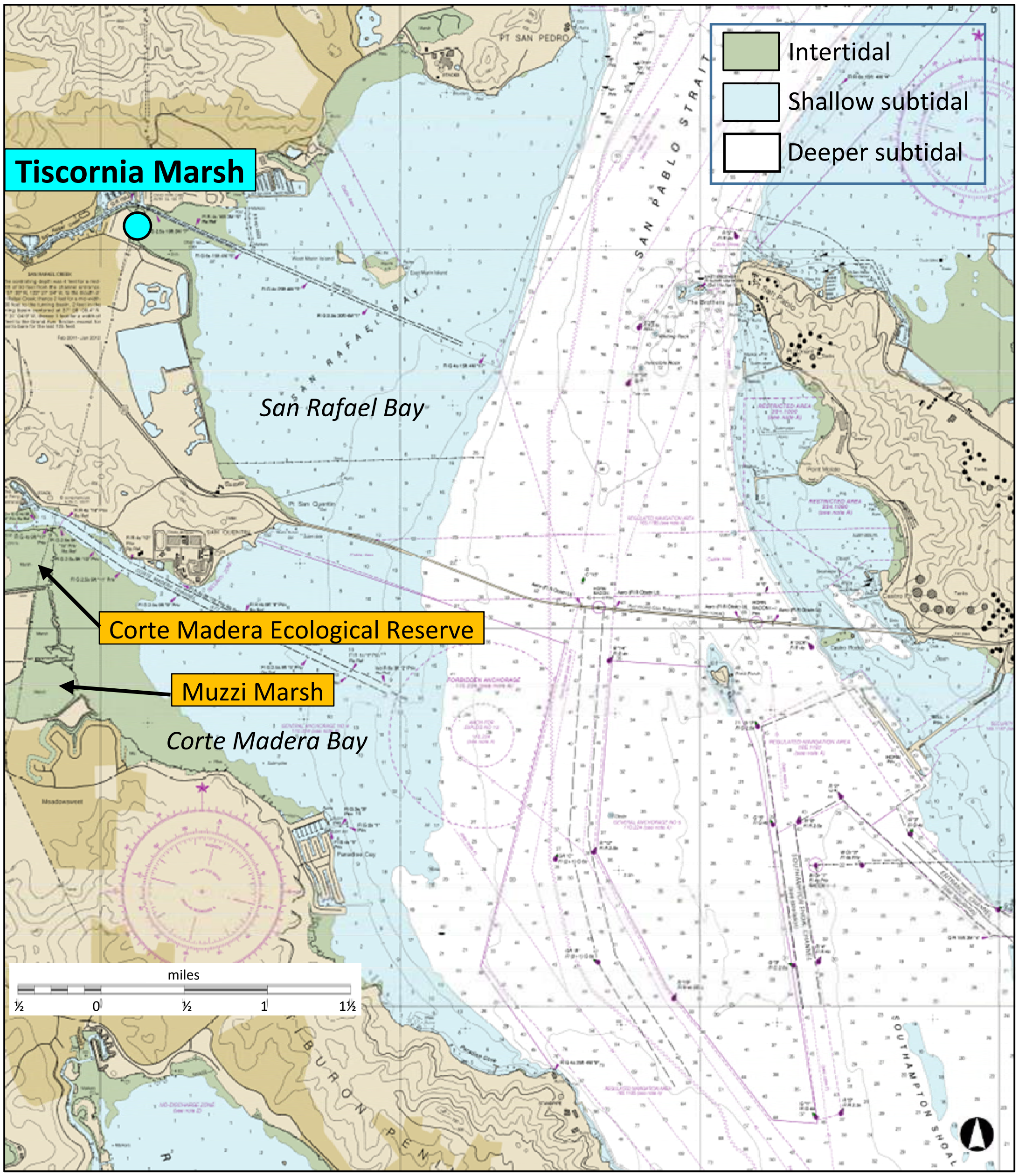


Figure 2. Setting in Relation to San Rafael and Corte Madera Bays and the Deeper Central Bay

Base Map Source: NOAA Chart 18653. All soundings in feet below mean lower low water.

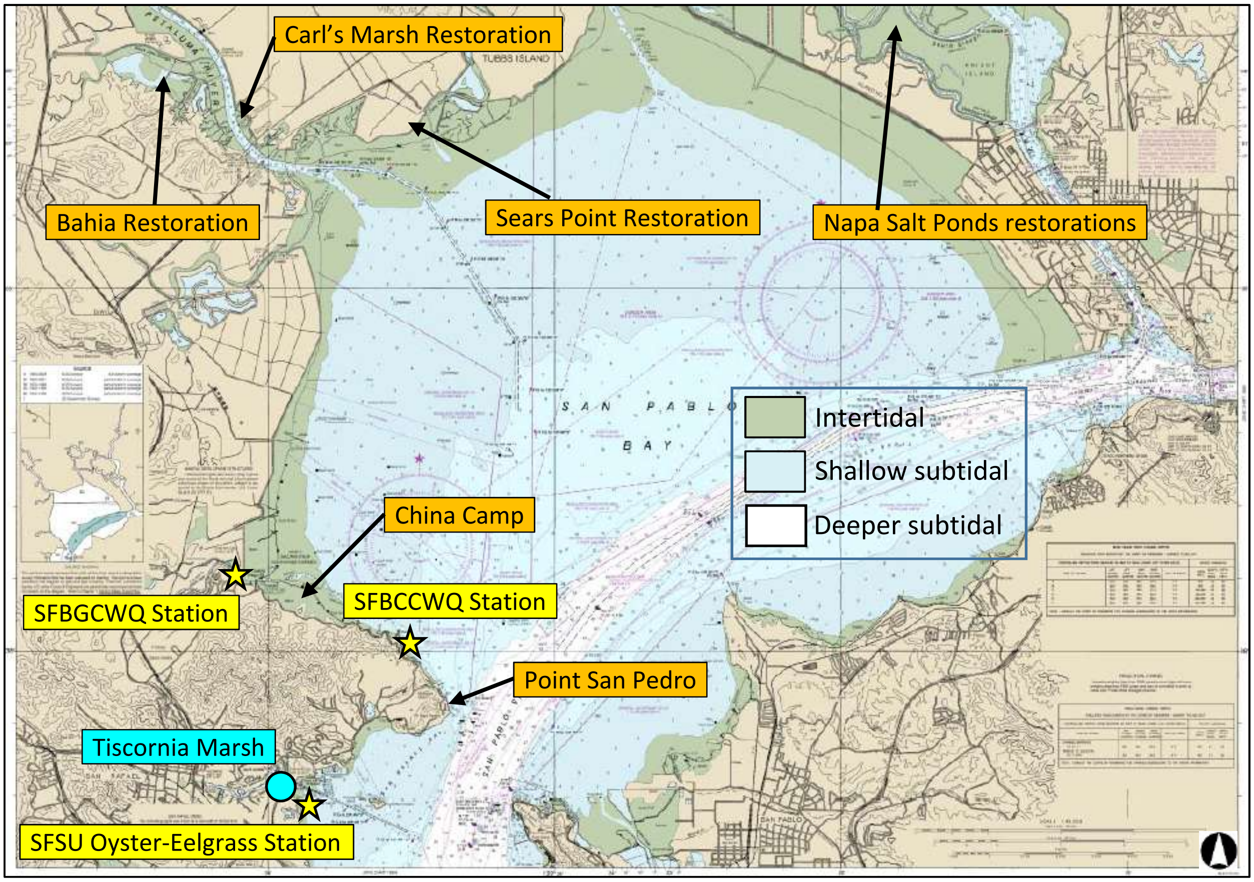


Figure 3. Water Quality Monitoring Stations Relatively Close to Tiscornia Marsh
Base Map Source: NOAA Navigation Chart 18654. All soundings in feet below mean lower low water.

1.2 Local Weather Station Wind Data

Given that sediment deposition and resuspension is affected by wind-wave resuspension, gaining some understanding of dominant wind directions helps to inform the setting.

Weather Underground compiles weather data from numerous privately-operated weather stations around the country and internationally. The closest station to Tiscornia Marsh is a short distance northeast across San Rafael Creek. Wind speed and direction data are available at this station beginning in January 2016 (Figure 4). These data indicate wind directions that are predominant from the southern direction west to east, with winds from the northern direction west to east being uncommon. This data period is relatively short and thus may not represent longer term wind conditions.

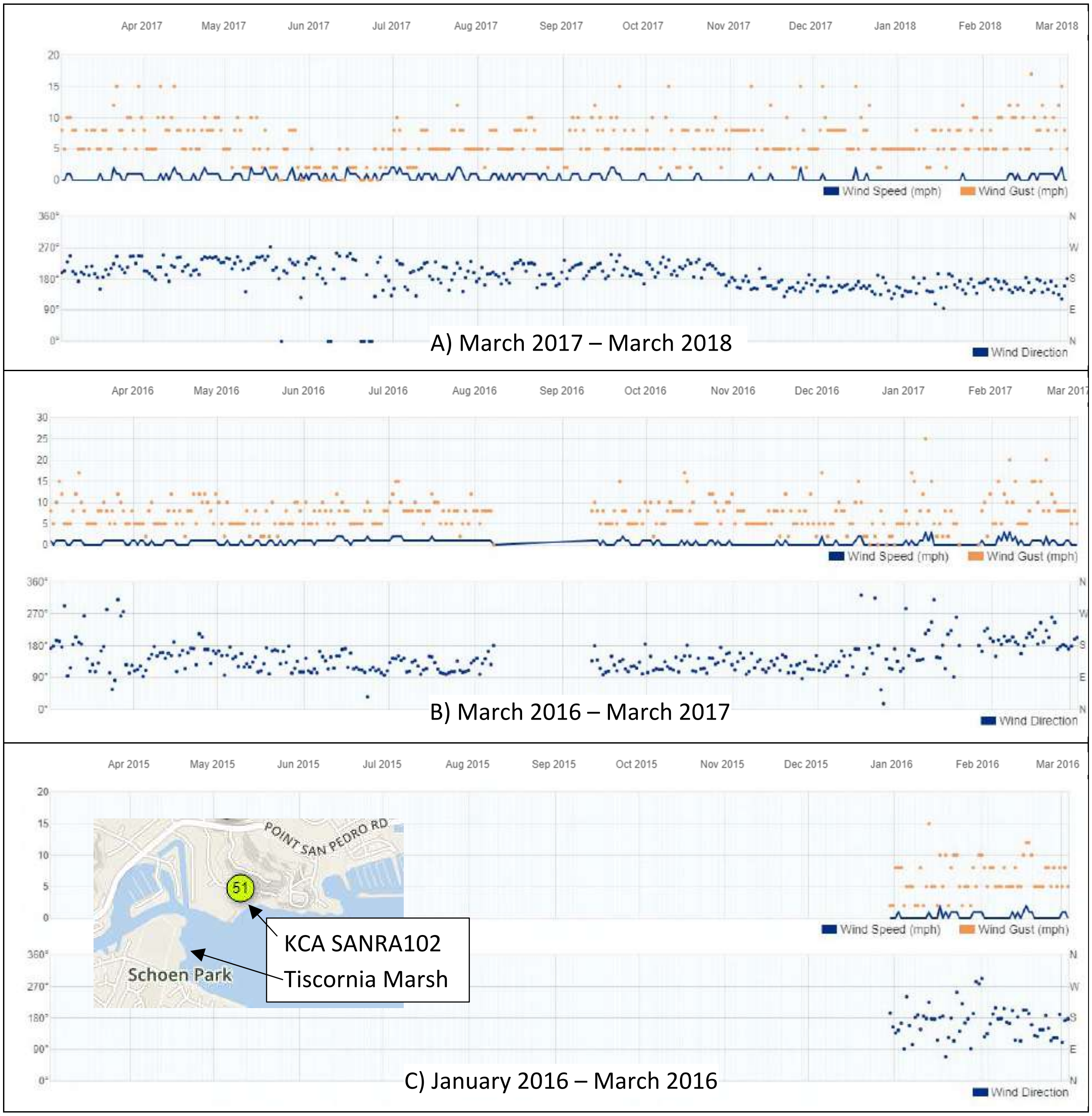


Figure 4. Wind Speed and Direction Data for KCA SANRA102, January 2016-March 2018
Source: Weather Underground, www.wunderground.com

2 Sediment Supply

Estimating sediment supply that may be available for accretion at Tiscornia Marsh is an imprecise exercise in the absence of long-term on-site measurements. Sediment supply perhaps can be roughly estimated utilizing available data from nearby locations, which requires interpreting the representativeness of these available data to conditions at Tiscornia Marsh and recognizing the inherent complexity of suspended sediment characteristics in the San Francisco Estuary. The main factors that affect how representative any given existing data source are include distance from Tiscornia, station depth, station location relative to surrounding mudflats that can generate suspended sediment, station location relative to prevailing winds and currents that influence sediment suspension and transport processes, station location relative to watershed flows, and station location relative to the main channel of San Pablo Bay that carry sediment from the Delta and from upstream local tributaries.

2.1 Prospective Sediment Concentration Data Sources

There are three relatively nearby water quality monitoring stations that measure turbidity levels over long time periods at nearshore locations and that perhaps may reasonably represent conditions at Tiscornia, and a fourth data set that has both sediment concentration and accretion rate data (Figure 3):

1) **San Francisco State University study plot for oyster and eelgrass recruitment** located about 0.7 mile to the southeast (Figure 1). Water quality data (turbidity) were collected by ESA (2018) on behalf of SFSU at this station from May 2013 to October 2017 with some extended data gaps. Attributes of this station that support its applicability to Tiscornia Marsh are its close proximity, its location along the margins of San Rafael Bay near to the confluence of San Rafael Creek where Tiscornia Marsh is located, and its location on shallow subtidal mudflats that may help elucidate sediment resuspension. Its primary drawback is the relatively short period of data and its data collection largely during the prolonged California drought though data do cover much of the wet 2017 winter. Turbidity data may not be well representative of longer term and more varied conditions but do provide reasonable insight.
2) **SF Bay NERR water quality monitoring station at the China Camp Village pier**, located about 4¾ water miles to the northeast (Station "SFBCCWQ" on Figure 3). Turbidity data have been collected at this station since March 2005. Attributes of this station that support its applicability to Tiscornia Marsh are its location along the southwest margin of San Pablo Bay where it experiences sediment concentrations reflecting local resuspension, transport of sediment from more distant mudflats to the north, transport of sediment along the main San Pablo Bay channel, and its long data period. Its primary drawbacks are its greater distance, its location on the north side of Point San Pedro putting it into a somewhat different sediment regime (see discussion above). Its proximity to the tidal marshes at China Camp State Park that have been monitored for accretion allow it to contribute to the accretion assessment in Section 2 below.
3) **SF Bay NERR water quality monitoring station at the mouth of Gallinas Creek**, located about 7½ water miles to the north (Station "SFBGCWQ" on Figure 3). Turbidity data have been collected at this station since May 2008. Attributes of this station that support its applicability to Tiscornia Marsh are its location at the mouth of a local stream at the Bay where it experiences a mix of watershed discharges. It is approximately similar to the China Camp Village pier station both in its exposure to Bay sediments and its proximity to the China Camp tidal marshes.
4) **Carl's Marsh sediment accretion study.** Carl's Marsh, a tidal marsh restoration project opened in 1994, is located at the confluence of the Petaluma River with San Pablo Bay, on the east side of the river. Stuart Siegel studied accretion at this site for his dissertation research at UC Berkeley (Siegel 2002) and collected turbidity data and calibrated it to suspended sediment

concentration. He also collected accretion rate data. Carl's Marsh is located directly across the river from the Marin Audubon Society Bahia Tidal Marsh Restoration Project. Carl's Marsh will have higher sediment concentrations than Tiscornia Marsh, so its paired sediment concentration-accretion rate data and the comparison of accretion rates to Bahia provide insight into prospective conditions at Tiscornia Marsh.

5) **Integrated Regional Wetland Monitoring Pilot Project.** This CALFED-funded intensive field study took place at six tidal marshes in the North Bay and upper estuary: Carl's Marsh at the Petaluma River mouth, Pond 2A, Coon Island and Bull Island in the Napa-Sonoma marsh complex, and Browns Island and Sherman Lake at the Delta's confluence with Suisun Marsh (WWR 2007). This study collected turbidity data and calibrated it to suspended sediment concentration. Carl's Marsh is the closest site and thus may have higher data applicability. The Napa sites have similarities that supports data applicability. The Suisun/West Delta sites are the most different and would have lesser data applicability.

2.2 The Difficulty of Calibrating Turbidity to Suspended Sediment Concentration

The primary challenge in using the three nearby turbidity data sets is the reliability of converting turbidity to suspended sediment concentration in absence of associated calibration data. Turbidity is a measure of light scattering in the water column and has high utility in studying aquatic productivity related to incident sunlight (e.g., phytoplankton and submerged aquatic vegetation such as eelgrass). Turbidity is relatively easily measured with optical backscatter sensors commercially available (such as YSI water quality sondes widely used including at China Camp and Spinnaker Point). In contrast, suspended sediment concentration (SSC) is a measure of sediment mass per unit volume in the water column and has high utility in studying sediment dynamics processes such as marsh accretion. SSC is measured by laboratory analysis of water samples. Much of the tidal marsh restoration literature and assessments of marsh resiliency with sea level rise utilize SSC (e.g., Williams and Orr 2002, PWA and Faber 2004, Schile et al. 2014).

Turbidity data can be converted to SSC data via sensor calibration, a process that involves approaches relating independent measures of water column SSC to concurrent turbidity sensor readings. There are many factors that affect this relationship, including sediment concentrations, sensor ranges, sediment grain size, mineralogical composition, organics, cation exchange capacity, and fluid properties including salinity, pH and temperature (Mehta 1986, Guillen et al. 2000). Given the relatively high level of effort to calibrate turbidity to SSC, oftentimes it is omitted and data are reported as turbidity and without SSC. Such is the case for the three nearby data sources (Matt Ferner, SF Bay NERR, pers. comm. March 2018 and Damien Kunz, ESA, pers. comm. March 2018).

These many controlling factors on the turbidity-SSC conversion mean that converting data after-the-fact reliably depends on the specific conditions at the study site. Consequently for the purposes of the analysis presented in this memorandum, the conversion values to be applied will be approximate, the estimate will be conservative so that potential accretion rates are not overly optimistic, and necessarily result in the findings requiring an error estimate that is made qualitatively. Table 1 below lists some San Francisco Estuary data with included conversion equations.

Based on the data in Table 1, this assessment will use the following conversion for the NERR China Camp and SFSU-ESA Spinnaker Point turbidity data sets:

$$SSC\ (mgL^{-1}) = 1.0 * NTU/FTU \pm \text{at least } 20\% \qquad \text{(Eq. 1)}$$

Table 1. Turbidity to Suspended Sediment Concentration Conversion Equations

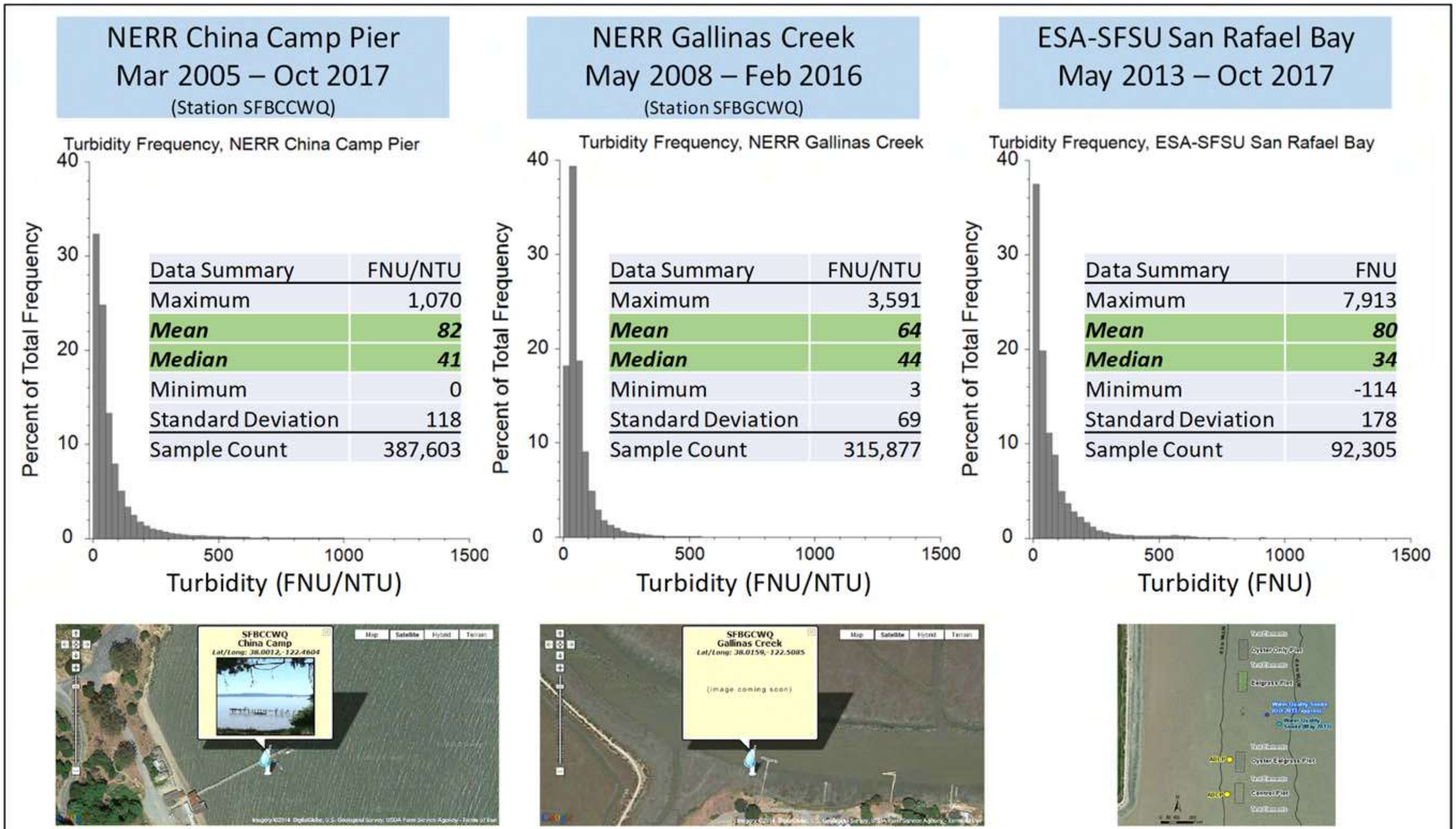
Data Source	Conversion Equation	Site Location	Comments
IRWM (WWR 2007)			
Carl's Marsh	0.89*NTU	San Pablo Bay at Petaluma River	Brackish/saline
Pond 2A	1.01*NTU	Napa-Sonoma Marsh Complex interior	Brackish/saline
Coon Island	0.90*NTU	Napa-Sonoma Marsh Complex Napa River	Brackish/saline
Bull Island	1.02*NTU	Napa River	Brackish/saline
Browns Island	0.47*NTU	Suisun/West Delta confluence	Brackish/fresh
Other Sources			
NERR – Rush Ranch	1.26*NTU	Suisun Marsh	Brackish (M. Ferner pers. comm.)
West Mediterranean	1.74*FTU	Europe	For context (Guellin et al. 2000)
Eastern Australia	4.85*NTU	Australia subtropical estuary	For context (Chanson et al. 2008)

Another source for calibration data is the long-term USGS sediment monitoring in the San Francisco Estuary (e.g., Buchanan and Morgan 2010, Buchanan and Rule 2000). However, USGS uses different instrumentation that yields voltage outputs rather than turbidity. For the purposes of this analysis, sorting out how these data might be applied has not been undertaken.

2.3 Suspended Sediment Concentration Data Converted from Turbidity without Calibration Data

Figure 5 presents histogram plots and summary statistics of all the turbidity data from the two China Camp NERR stations and the Spinnaker Point SFSU-ESA station described above. Histogram plots illustrate the frequency of sediment concentration data on the y-axis (measured at these stations as turbidity) against turbidity values on the x-axis. The summary statistics provide the maximum, mean, median, and minimum values recorded during the monitoring period of each data set. All data are reported as turbidity, in units of Nephelometric Turbidity Units (NTU) or Formazin Nephelometric Units (FNU), which measure light scattering by particles in the water column. Both these units are equivalent and reflect sensor type employed[1].

[1] https://www.iso.org/standard/62801.html



Data Summary	FNU/NTU
Maximum	1,070
Mean	***82***
Median	***41***
Minimum	0
Standard Deviation	118
Sample Count	387,603

Data Summary	FNU/NTU
Maximum	3,591
Mean	***64***
Median	***44***
Minimum	3
Standard Deviation	69
Sample Count	315,877

Data Summary	FNU
Maximum	7,913
Mean	***80***
Median	***34***
Minimum	-114
Standard Deviation	178
Sample Count	92,305

These data represent 15-minute sampling interval mostly continuously over the stated time periods, from YSI or similar water quality sondes. NERR data are post quality assurance and quality control downloaded from national SWMP database (http://cdmo.baruch.sc.edu/). ESA-SFSU data collected and provided by ESA.

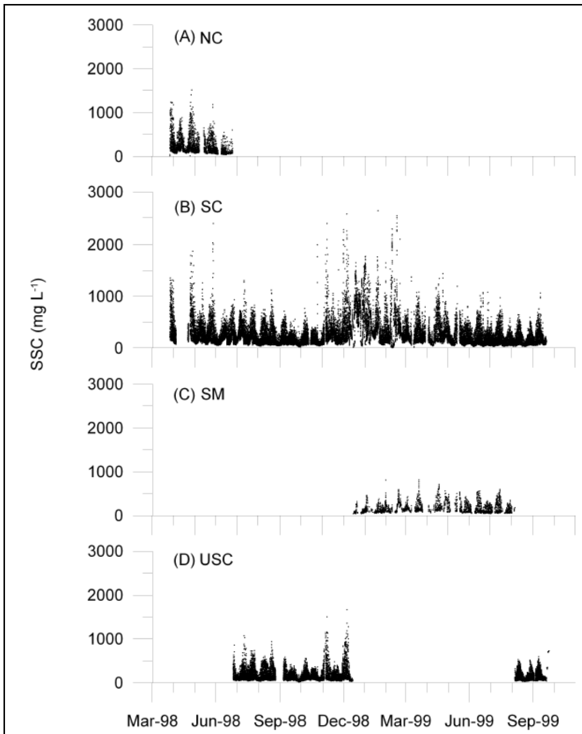
Figure 5. Histograms of Turbidity Data, China Camp, Gallinas Creek and San Rafael Bay, Variable Dates 2005-2017

NTU = Nephelometric Turbidity Units / FNU = Formazin Nephelometric Unit

2.4 Suspended Sediment Concentration Data Calibrated from Turbidity

Carl's Marsh 1998-1999

The fourth data set, from Carl's Marsh for the period February 1998 to September 1999 (Siegel 2002), shows average SSC values ranging from 182 to 284 mg/L, with the most representative sampling station (sediment entering the subsided restoration site) being at the upper end of the range (Figure 6). Carl's Marsh was breached in 1994 and the site had subsided to about local mean lower low water elevation. This data period covers an active depositional period starting four years after levee breach in a location with known high sediment rates (as evidenced by the now-vacant Port Sonoma Marina).



Statistic	SSC (mg/L) by Station			
	NC	SC	SM	USC
Minimum	7	20	40	19
Mean	228	284	227	182
Median	159	208	183	131
Maximum	1,514	2,633	932	1,665
Count	3,349	40,151	3,611	11,959

Sample locations:

- SC = southern main channel, near bed (most representative of sediment influx)
- USC = southern main channel, mid water column
- NC = interior (northern) end of southern channel
- SM= southern mudflat adjacent to SC station

Figure 6. Suspended Sediment Concentration Data for Carl's Marsh, February 1998 to September 1999
Source: Siegel (2002)

Integrated Regional Wetland Monitoring Pilot Project 2003-2005

The final data set considered in this analysis is from six North Bay to West Delta study sites studied from December 2003 to September 2005 by the CALFED Science Program-funded *Integrated Regional Wetland Monitoring Pilot Project*. These data do not have accompanying accretion rate data and thus are provided for their context of sediment concentrations in restored tidal marshlands.

Table 2. Suspended Sediment Data from the IRWM Study Sites, Dec 2003 – Sep 2005

		SSC in milligrams per liter			
Site	**Count**	**Minimum**	**Maximum**	**Mean**	**Median**
Carl's Marsh	29191	0.0	2034.1	94.6	70.5
P2A	44431	0.0	2028.2	42.8	31.3
Coon	25063	0.0	797.0	38.5	30.6
Bul	27772	0.0	1686.4	27.9	16.5
Bri	45279	0.0	854.8	12.5	8.3
Sherman Lake	---	---	---	---	---

Notes:
1. Suspended sediment data converted from NTU data recorded at CTDS station mooring located in inlet channel
2. Carl's Marsh and Coon Island instruments exposed during some low tides. Exposed values excluded.

Source: WWR (2007)

2.5 Findings Regarding Sediment Supply Data from China Camp and Spinnaker Point

The key findings of these data relative to understanding available sediment supply and assessing the potential for tidal marsh accretion are:

- **Data applicability is high for Spinnaker Point and China Camp.** The close proximity of these stations to Tiscornia Marsh and their relatively similar turbidity measurements support these data being reasonably applicable for Tiscornia Marsh. Mean and median values range from 64 to 82 and from 34 to 44 FNU-NTU, respectively. This relative similarity suggests that these data can be applied with an acceptable level of confidence as representing conditions that Tiscornia Marsh experiences over the long term.
- **Sediment concentration is on the lower end meaning slower accretion rates.** The turbidity/SSC values are within the range of estimates considered in Williams and Orr (2002) relating SSC to accretion rates, and these lower values would land on the less rapid accretion spectrum (see discussion below in Section 3). These data are also skewed to lower concentrations as reflected in the much lower median versus mean values. Thus, concentrations toward the lower values are the "norm."
- **Maximum sediment concentrations were very high.** All three stations had very high maximum values which, though experienced over short time periods, can support major sedimentation events such as occurs during major wet winters. Siegel (2002), for example, found accretion of about 0.5 foot over three months in early 1998 during that El Niño winter at Carl's Marsh at the mouth of the Petaluma River. Similar rapid rates were observed during the very wet winter 2017 at Sears Point Restoration on the northwest shore of San Pablo Bay (SLT and SF Bay NERR 2017). Predictability of extreme event occurrence is low, so counting on bursts of high sediment loads can be risky as a means to achieve restoration goals.

2.6 San Rafael Creek as Possible Fluvial Sediment Supply

There is no monitoring of flows or sediment concentrations for San Rafael Creek nor any analysis of watershed erosion conditions. Thus, the analysis presented here is general in nature and draws from regional understandings of local watersheds combined with a description of this watershed. Two useful sources of information are McKee et al. (2013) which utilized a mixture of USGS measurement stations and modeling to estimate sediment yields from 39 Bay Area watersheds in contrast to sediment delivery from the Central Valley. San Rafael Creek was not one of the assessed watersheds but other Marin watersheds were. The second is the Marin County (2010) Stormwater Plan which provides comparative information on Marin Watersheds helpful to apply the McKee et al. (2013) data. The key findings of the McKee et al. (2013) analysis is that local watersheds have the potential to generate considerable sediment loads episodically, their sediment loads are highly variable and dependent on rainfall, local geology, and land use, and that they should be considered when planning wetland restoration efforts. In addition, the Marin County Watersheds Program provides overview information of all of Marin's watersheds including San Rafael Creek[2].

The San Rafael Creek watershed comprises 11 square miles (Figure 7) and is densely developed from its hills to filled wetlands. The creek originates in the hills above Tamalpais Cemetery and flows through residential and industrialized areas before forming the San Rafael Canal in the vicinity of Highway 101. The upper stream corridor consists of short stretches of open stream channel, underground culverts, and trapezoidal open channels. Much of the watershed consists of impervious surfaces (Figure 8). This map shows that the lower watershed is developed and thus quickly converts rainfall to runoff, and that the upper watershed is largely undeveloped and thus absorbs more rainfall and is also where much of the available sediment can be derived via erosion and transport.

For comparison, the Corte Madera Creek Watershed, which was examined in the McKee et al. (2013) study, is 28 square miles and has a much larger percent of open lands with less than 10% impervious surfaces[2]. This means it has a much greater potential to generate and deliver sediment via hillslope erosion processes and stormwater runoff than does San Rafael Creek. McKee et al. (2013) reported that Corte Madera Creek delivered 10,500 metrics tonnes of sediment annually on average, with a range of sediment yield by area of 217 to 246 metric tonnes of sediment per square kilometer per year. If we assume San Rafael Creek with its much more developed watershed delivers half this annual sediment supply per unit area and is 40% the size of Corte Madera Creek watershed, then it might yield about 2,100 metric tonnes of sediment annually on average. Converting this average sediment yield to cubic yards requires estimating bulk density. If one assumes a bulk density of 1 g/cm^3, which is very roughly reasonable, then 2,100 metric tonnes per year equates to roughly 2,750 cubic yards of sediment volume delivered per year from the watershed. Between 2010 and 2016, about 218,000 cubic yards of sediment were dredged from the marinas, private boat docks, and federal navigation channel of San Rafael Creek, or about 31,000 cubic yards per year on average. The watershed contribution to this dredging volume

[2] http://www.marinwatersheds.org/creeks-watersheds/san-rafael-creek

thus is about 9%. Recognizing the several assumptions employed to arrive at this value, it must be considered approximate and it could have a range of ±25-50%.

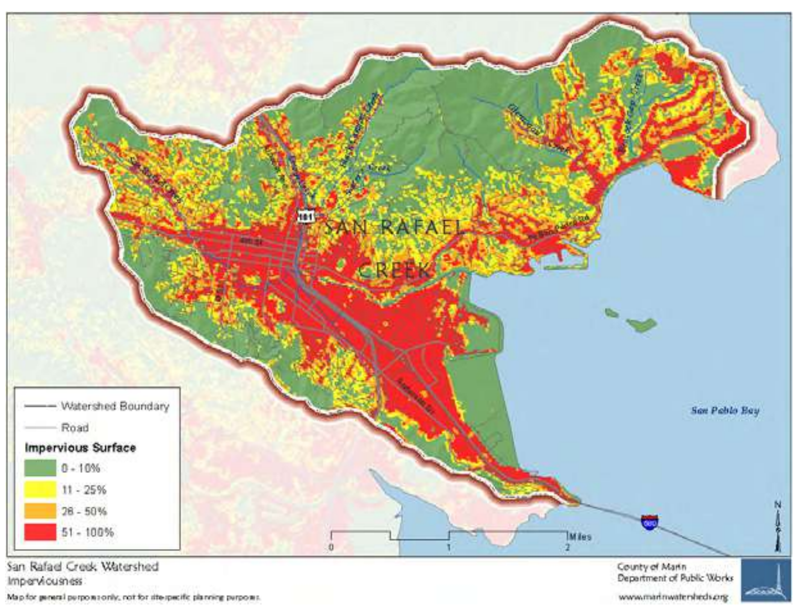
Erosion within the watershed falls into two categories. First is low-level routine erosion in small volumes from rainstorms that has a moderate chance to reach San Rafael Creek over shorter time scales. This material may originate as coarser grained bedload material that initially deposits in the lower ends of tributary channels before it reaches San Rafael Creek and that is winnowed down in grain size and transported further downstream over time. Second is locally-high erosion from landslides. Landslide sediment would work its way through drainages down to San Rafael Creek over time as well as deposit higher in the watershed initially. These episodic and unpredictable sediment deliveries could be larger in volume per event but it is difficult to estimate on long-term average whether they deliver more or less sediment than routine low-level watershed erosion and transport processes.

The fate of watershed sediment once it reaches San Rafael Creek depends on its grain size, flow rates to transport the sediment, and ebb vs. flood tide conditions in the creek at the time of the storm flows. Base watershed flow in San Rafael Creek is not monitored and is likely to be very low in the summer and fall and fairly small in the winter and spring. Because the watershed is fairly urbanized, it presumably has a very flashy discharge curve, spiking during and shortly following storms and dropping to base flow relatively quickly (probably on the order of days, depending on storm size). In addition, the City of San Rafael operates several stormwater pumps that discharge into San Rafael Creek. These operate only during storms and can add considerable downstream flows and yield some sediment, as well as potentially trapping some sediment in pump basins.

Since most fluvial sediment is transported only during storm events, tide direction exerts a very important influence. If storm flows with their fluvial loads occur on ebb tide, then a greater proportion of the sediment would likely be transported out into the bay where it either deposits on local mudflats or is carried out to the deeper San Pablo Bay straits channel. Mudflat deposited sediment then could be tidally resuspended later and transported on flood tides back into San Rafael Creek. If storm flows occur on a flood tide, then there is greater potential for reduced flow velocities and thus deposition within San Rafael Creek and the adjacent marinas and side channels.

Figure 7. Marin County Bay-Side Watersheds Map
Source: MCSTOPPP 2010.

Figure 8. Impervious Surfaces of San Rafael Creek Watershed
Source: Marinwatersheds.org



2.7 Projections of Future Sediment Supply

"Past performance does not indicate future conditions." This famous stock market adage applies well to future sediment supply projections for the San Francisco Estuary. Schoellhamer (2011) published the seminal paper describing the shift in the San Francisco Estuary to a sediment supply-limited system from a sediment transport-limited system, resulting in the increased role of within-embayment sediment dynamics becoming more important drivers of suspended sediment concentrations. This work has formed informed regional understanding that the future suspended sediment concentrations are likely to be lower than those observed over the past several decades of active tidal marsh restoration. Ganju and Schoellhamer (2010) also report a 57% decline in sediment supply from the Sacramento River watershed between 1957 and 2004, forming the prelude the Schoellhamer (2011) paper. Also, the wind-wave resuspension processes that mobilize mudflat sediment will decline in magnitude as sea level rise puts the bay bottom deeper and thus less accessible to the wind wave forces. These projected changes are well summarized in the recent Baylands Ecosystem Habitat Goals Update (Goals Project 2015).

3 Potential Marsh Accretion Rates

3.1 Factors that Influence Accretion Rates

As with suspended sediment data, estimating marsh accretion rates requires consideration of many factors, including water velocity, roughness of the bed surface including vegetation, wind and wave regime, and sediment grain size characteristics (commonly silts and clays are in suspension and can flocculate in salt water). The three dominant controls on marsh accretion rates are sediment concentrations (see discussion above), elevation of depositional area as it relates to time submerged for deposition to occur (the lower the elevation the longer amount of time submerged for deposition to occur), and flow velocities as it relates to allowing sediment to settle out from the water column and exposure to or shelter from resuspension forces.

3.2 Accretion Rates from Nearby Locations

Marsh accretion can be measured in several ways, from use of stable isotopes in sediment cores to reconstruct longer duration accretion to deployed field techniques such as sediment elevation tables (SETs) with marker horizons which are very involved to install and read yet very accurate, to sediment plates or sediment pins and similar methods, and to topographic surveys (field or aerial based) repeated over time.

To keep the analysis as local and thus applicable as possible, several North Bay studies are reported here, and the data presented in Table 3:

- **Corte Madera Bay data.** Callaway et al. (2012) employed four field strategies (sediment pads, feldspar markers, SETs, and sediment cores) across low, middle and high marsh at the remnant historical tidal marshes at the Corte Madera Ecological Reserve and at the nearby tidally restored Muzzi Marsh (Figure 2). No SSC or turbidity data were collected.

- **China Camp data.** Philip Williams and Associates reported sedimentation data at China Camp for 1991 to 2000 from sediment plate installations. No SSC data were collected at comparable times, but extensive turbidity data are available from 2005 onward.
- **Napa Pond 3.** Brand et al. (2012) reported data for some of the restored Napa salt ponds (Figure 3). No SSC or turbidity data were collected.
- **Carl's Marsh.** Siegel (2002) reported data from DEM comparisons and sedimentation pins at Carl's Marsh (Figure 3). Net accretion rates are presented, and considerable sediment consolidation of the rapidly accreting sediment was reported prior to vegetation colonization, due to daytime desiccation during summer low tides and regular winds. This location, at the mouth of the Petaluma River, is understood to have routinely high sediment concentrations (Ganju et al. 2003). Siegel collected SSC data from February 1998 to September 1999 which encompassed a major El Niño event. The IRWM project collected SSC data there from December 2003 to September 2005 which represented a drier period. SSC values differed by about three times between the earlier and later data periods.
- **Sears Point.** SLT and SF Bay NERR (2017) reported data from one DEM comparison at Sears Point (Figure 3). Net accretion rates are presented. Data applicability is limited due to insufficient baseline topographic data for the comparative topographic analysis. No SSC or turbidity data were collected.
- **Bahia Marsh.** WWR (2013) reported topographic transect results at numerous cross sections at Bahia (Figure 3). The data exhibited a wide range from significant scour to significant deposition on the restoring marsh plain. No SSC or turbidity data were collected.

Table 3. Marsh Accretion Rates, North Bay Tidal Marshes

Location	Data Period	Accretion Rates (cm/yr)	Method(s)	References
Napa Pond 3	2005 vs. 2009	2.8-8.2	DEM comparisons	Brand et al. 2012 [1]
CMER, low marsh	Long term	0.38-0.6	Isotopes (^{137}Cs and ^{210}Pb	Callaway et al. 2012 [2]
CMER, mid marsh		0.3-0.49		
CMER, high marsh		0.3-0.39		
CMER, low marsh	Apr 2011 – Jul 2012	0.34±0.04	SETs and feldspar markers	
CMER, mid marsh		0.26±0.07		
CMER, high marsh		0.2±0.02		
Muzzi, low marsh		0.94±0.04		
Muzzi, mid marsh		1.0±0.05		
Muzzi, high marsh		0.46±0.08		
China Camp	1991-2000	0.25-1.0	Topographic surveys, sediment plates	PWA and Faber 2004[3]
Carl's Marsh (early stage mudflat)	Aug 1994 – Aug 1999	30-60	Sediment pins	Siegel 2002

Location	Data Period	Accretion Rates (cm/yr)	Method(s)	References
Carl's Marsh (early stage mudflat)	Mar 1997 – Aug 1999	-39 to +68	DEM comparisons	
Bahia Marsh (early stage mudflat)	Jul 2009 – Apr 2012	-16 to +35	Topographic surveys	WWR 2013
Sears Point (early stage mudflat	Oct 2015 – Jun 2017	0-32	DEM comparisons from airborne LiDAR 2017 and truck LiDAR 2015 baseline	SF Bay NERR and SLT in preparation

Notes:

1. *Data reported in manuscript sedimentation results text.*
2. *Isotope data reported in Table 3, SET and feldspar data reported in Figures 5 and 6. These data were incorporated into the BCDC Corte Madera Bay Adaptation Strategy Report of 2013.*
3. *Data reported in Appendix B, Table 10.*
4. *Net accretion rates: sediment pin data reported in Figure 5-5, DEM comparison data reported in Figure 5-4.*

3.3 Sedimentation Estimates for Lower Elevation (Mudflat) East Side without Constructed Subsidence Reversal

What can influence sedimentation in lower elevation mudflat areas, including areas that may be considered for sediment or soil placement, is to shelter these areas from higher velocities driven by winds and currents. High velocities slow down or preclude deposition and promote resuspension. With sheltered conditions, sedimentation rates will be driven by available sediment supply and by the time of submergence which is a function of elevation. Based on the sedimentation rate data shown in Table 3 and assuming lower intertidal mudflats are the current condition, Table 4 presents estimates of initial sediment rates based on observed data from Bahia, Carl's Marsh and Sears Point and adjustments based on the SSC data sets shown in Table 2 and Figure 5 and Figure 6.

Suggested mudflat accretion rates: up to 10-15 cm/yr.

Table 4. Estimates of Sedimentation Rates at Lower Elevation Mudflat Sheltered Areas

Reference Location	Source Data	Initial Adjustment	Subsequent Adjustment
Carl's Marsh	30-60 cm/yr	Scale down by Siegel (2002) vs. IRWM (WWR 2007) SSC: 95 mgL^{-1}/284 mgL^{-1} = 0.33 ratio → 10-20 cm/yr	Scale down by IRWM vs. Spinnaker (ESA 2018): 80 mgL^{-1} /95 mgL^{-1} = 0.84 → **8.5-17 cm/yr**
Bahia	-16 to 35 cm/yr	Same basis as for Carl's Marsh → -5 to 12 cm/yr	Same basis as for Carl's Marsh → **-4 to 10 cm/yr**
Sears Point	0-32 cm/yr	Same basis as for Carl's Marsh → 0 to 11 cm/yr	Same basis as for Carl's Marsh → **0 to 9 cm/yr**

3.4 Sedimentation Estimates for Existing Tidal Marsh Platform and Constructed Higher Elevation Areas

Sedimentation on the high marsh platform is a function of sediment supply, duration of submergence, and sediment trapping capacity of vegetation and other surface roughness features. Table 5 summarizes the nearby high marsh accretion data and recommended adjustments based on landscape settings and possible differences in sediment supply. For the purposes of this analysis, no adjustments are suggested to these data.

Suggested high marsh accretion rates: 0.2 to 1 cm/yr.

Table 5. Estimates of Sedimentation Rates at Higher Elevation Areas

Reference Location	Source Data[1]	Initial Adjustment
CMER high marsh	0.2-0.4 cm/yr	Accept estimate without adjustment
Muzzi, high marsh	0.4-0.6 cm/yr	Accept estimate without adjustment
China Camp, high marsh	0.25-1 cm/yr	Accept estimate without adjustment

Notes:

1) *Sediment rates rounded from Table 3 to align with principle of estimating rates for Tiscornia*

3.5 Estimating Accretionary Time Periods Based on Estimated Suspended Sediment Concentration Data

There are empirical models used to estimate accretion rates based on a range of site factors including suspended sediment concentration data (see for example, Fagherazzi et al. 2012, Schile et al. 2014). Utilizing either any of these models is beyond the scope of this analysis. Instead, this analysis draws upon Williams and Orr (2002) to illustrate the comparative accretionary time frames based on sediment concentrations summarized above. Based on the simpler Williams and Orr (2002) model, sedimentation rates at Tiscornia Marsh appear to be on the lower end requiring longer time periods for accretion and risk of not maintaining elevations with sea level rise over time.

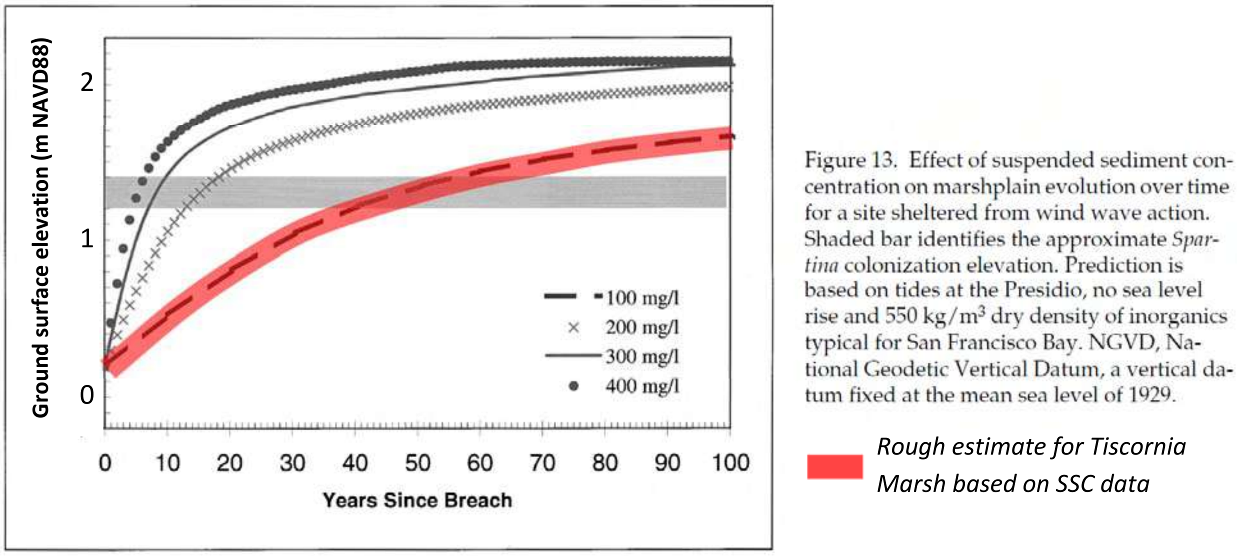


Figure 9. Effect of Suspended Sediment Concentration on Marshplain Evolution Over Time for a Site Sheltered from Wind Wave Action

Source: Williams and Orr (2002), Figure 13

Notes:

1) *Y-axis converted to meters NAVD88 from the original meters NGVD29*
2) *Red line provides very approximate estimation of accretion time periods, based on the Spinnaker Point and China Camp NERR data, assuming that the 1:1 conversion from turbidity to SSC applies to the available data sets, and with line thickness reflecting qualitative indication of uncertainty in the SSC concentrations.*

4 Conclusions: Relating Sediment Concentration and Accretion Data to Tiscornia Marsh Design Considerations

The data presented in the above two sections provides a number of insights about the potential for marsh accretion and associated design considerations at Tiscornia Marsh in the near and long term:

1) Local waters appear to have low to moderate sediment concentrations at present, supportive of lower rates of natural sedimentation under the right hydrodynamic conditions conducive to deposition.
2) Marsh accretion rates are strongly a function of marsh elevation as well as sediment supply and hydrodynamic conditions. Accretion rates for lower elevation mudflat areas are estimated to be up to 10-15 cm/yr. Accretion rates for high marsh are estimated to be up to 1 cm/yr. Given the importance of reducing flow velocities to promote settlement of sediment from the water column, incorporating design features at Tiscornia Marsh to create sheltered areas, consistent with protection of existing natural resource functions, would be expected to maximize accretion potential.
3) Long term projected declines in available regional suspended sediment supply are expected to reduce marsh accretion potential in general. The proximity of Tiscornia Marsh to the shallow San Rafael Bay may provide a moderate source of suspended sediment for years to come.

Inherently, long term sedimentation rate declines projected regionally are likely to apply also to Tiscornia Marsh, though perhaps they may be more delayed due to the nearby mudflat sediment sources.

4) Long term projected declines also suggest the value of starting restoration actions sooner than later to take advantage of available suspended sediments before the projected supply declines start to be observed.
5) Future Tiscornia Marsh design efforts may want to include geomorphic modeling to apply the currently documented sediment concentrations alongside future projections of supply decline to compare restoration design configurations and strategies, including differences between restoring marsh lost to previous erosion versus maintaining relative elevations of the remaining tidal marsh.
6) If more precise estimates of sediment accretion are desired for Tiscornia Marsh, then a combination of stable isotope sampling of cores taken from Tiscornia Marsh combined with additional water column suspended sediment concentration monitoring (inclusive of effort to calibrate turbidity sensor measurements to SSC) would be appropriate to consider.

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APPENDIX B: DATA COLLECTION

This appendix provides a brief overview of data collected at Tiscornia Marsh in September and October 2017. Section B1 describes water level data collected at the site, and Section B2 describes a topographic survey of the marsh, adjacent mudflats, and the levee backing the site.

B1. Water Level Data

ESA installed a Solinst pressure transducer and barometric pressure logger ('barologger') at Tiscornia Marsh on September 19th, 2017. Figure B1 shows the location of the logger, near the northern extent of the marsh. The pressure transducer was located near the mudflat surface, which was surveyed at about 2 feet NAVD88. The pressure logger was housed in a perforated pipe, to create still water conditions above the sensor while allowing tidal variations. Due to its position on the mudflat, the logger did not collect data during low tides (i.e. when the mudflats were exposed). The barologger collected continuous barometric pressure measurements. Both loggers were in place from September 19th to October 27th, 2017.

Pressure measurements were converted to depths by subtracting the barometric pressure at each time step, and using the hydrostatic assumption to convert pressure to depth in the pipe. Depths were then converted to elevations relative to the NAVD88 datum by surveying the sensor. Water surface elevations were also surveyed at the beginning and end of the deployment to check the sensor readings.

Figure B2 compares time series of water surface elevations at the site against water levels reported at the NOAA Richmond gauge. Water level data are described in more detail in Section 3 of the main report.

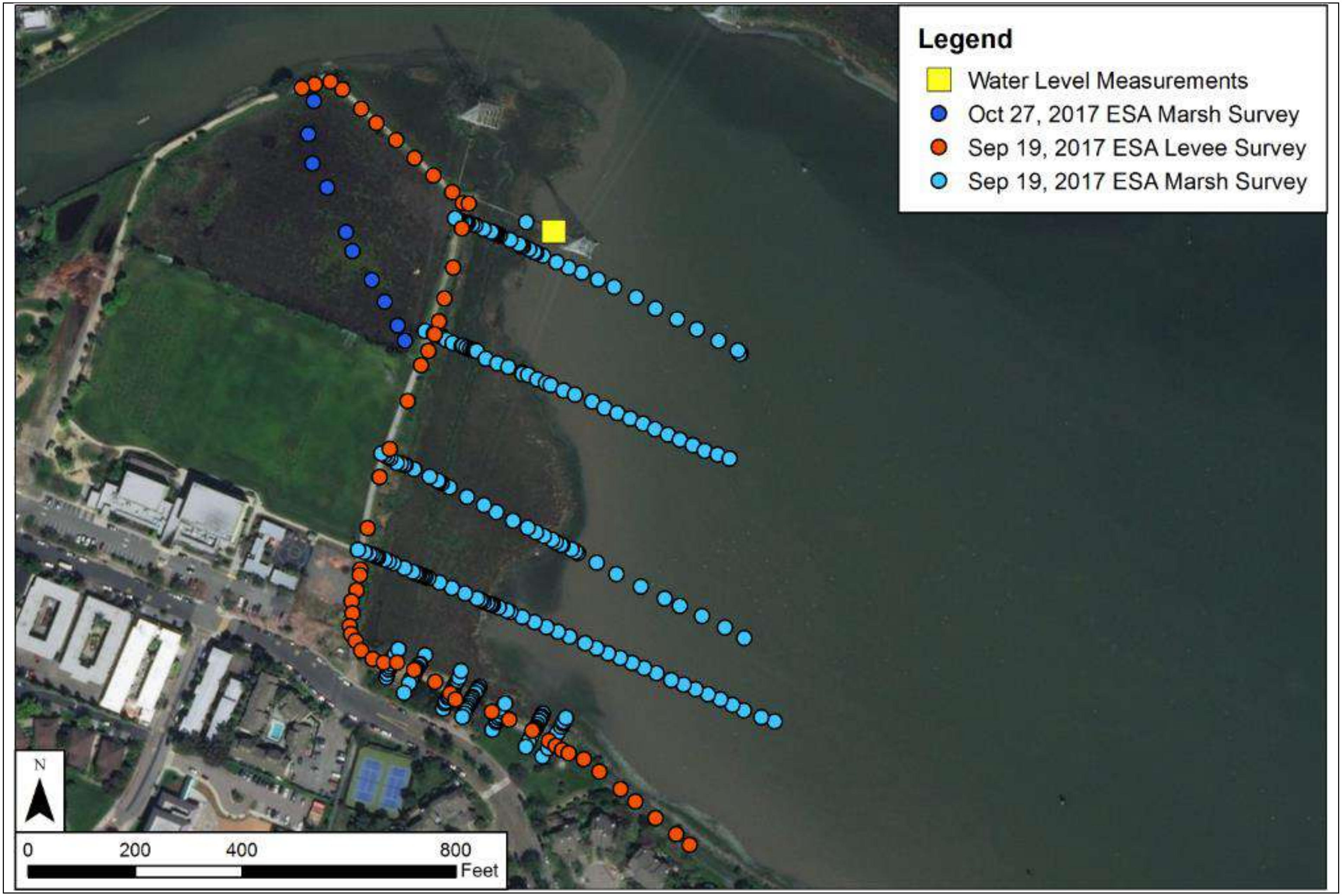
B2. Topographic Survey

ESA performed a topographic survey of the site on September 19th and October 27th 2017. During the first survey, 4 marsh and mudflat transects were collected in addition to 7 cross sections of the levee at the southern edge of the site (Figure B1). A levee profile was also collected (see Figure 8 in main report). On October 27th, and additional survey was performed to characterize elevations of the diked marsh immediately west of Tiscornia Marsh and north of the soccer field at Pickleweed Park. Both surveys were performed with RTK-GPS equipment, and were referenced to the NAVD88 vertical datum and NAD83 horizontal datum. Both surveys were completed relative to NGS control point PID = HT3837. The benchmark sheet for the control point can be accessed at the following site: https://www.ngs.noaa.gov/cgi-bin/ds_mark.prl?PidBox=HT3837

An addition to topographic data, the surveys also noted transitions between different bands of vegetation, and transitions between geomorphic features (e.g. location of marsh edge scarp). These were used in the main report to help delineate marsh areas for the assessment of alternatives.

Survey data on the marsh surface at Tiscornia Marsh and at the diked marsh to the west indicated a vertical bias due to marsh vegetation in the available LiDAR of the site. This was on the order of 0.25 to 0.5 feet in the diked marsh and in the upland transition area at Tiscornia Marsh.

Figures B3 and B4 provide illustrations of the marsh transects. Figure B5 illustrates the cross sections of the southern portion of the levee.

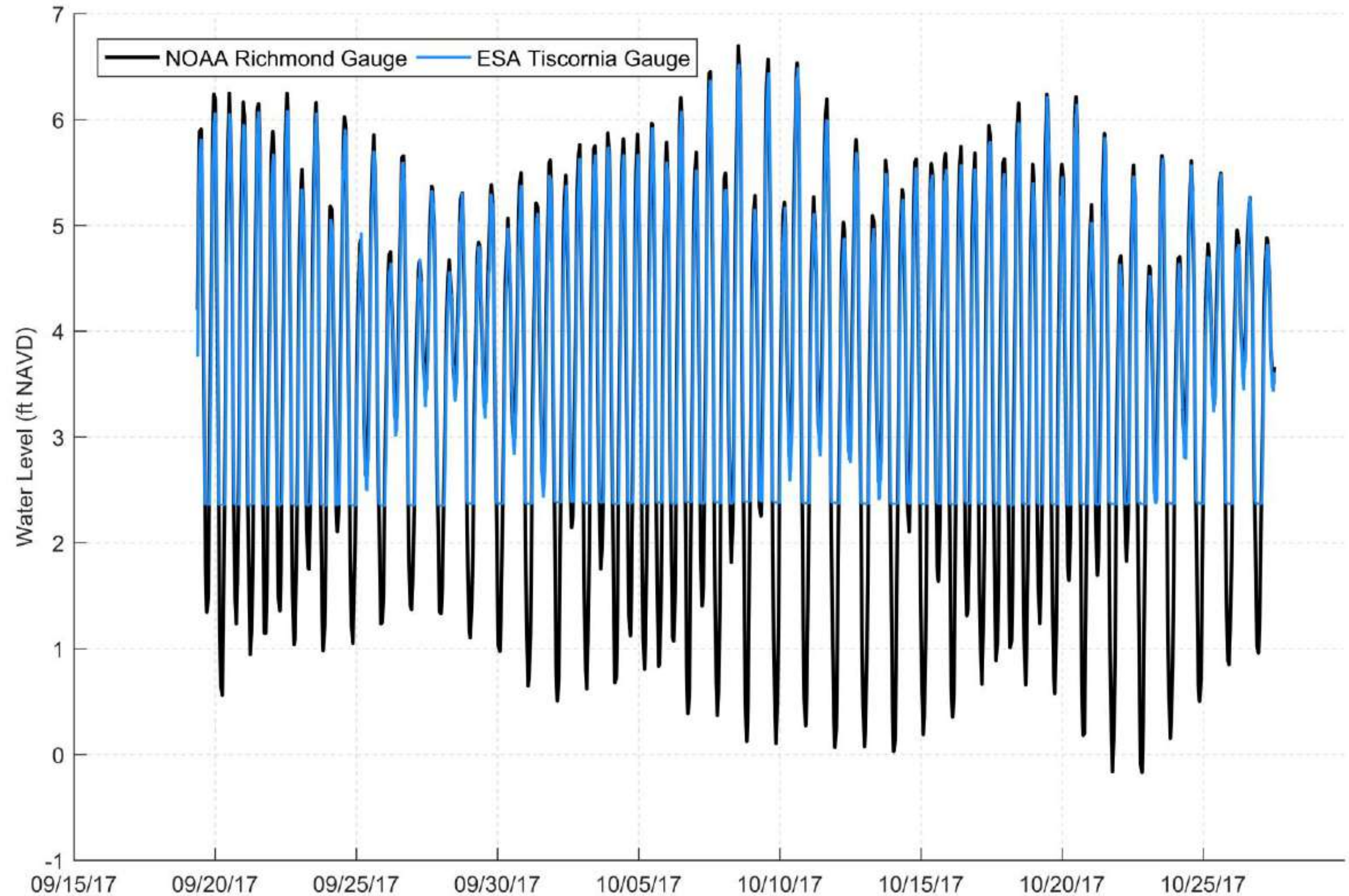


SOURCE: Background Image from Google Earth

Tiscornia Marsh Habitat Restoration . D160888.0

Figure B1

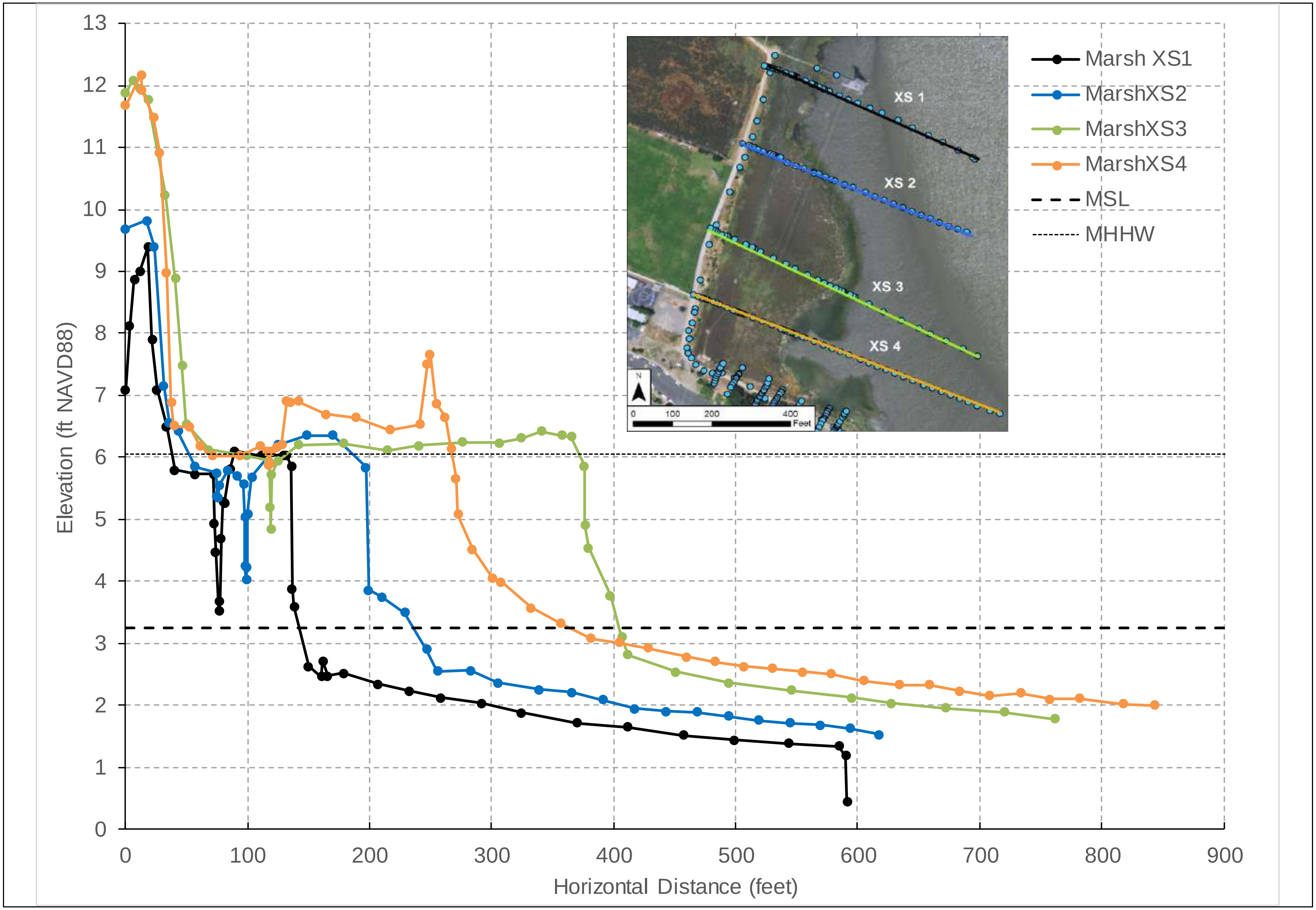
ESA survey points and water level gauge location



SOURCE: NOAA Richmond gauge and ESA temporary WL gauge at Tiscornia Marsh

Figure B2

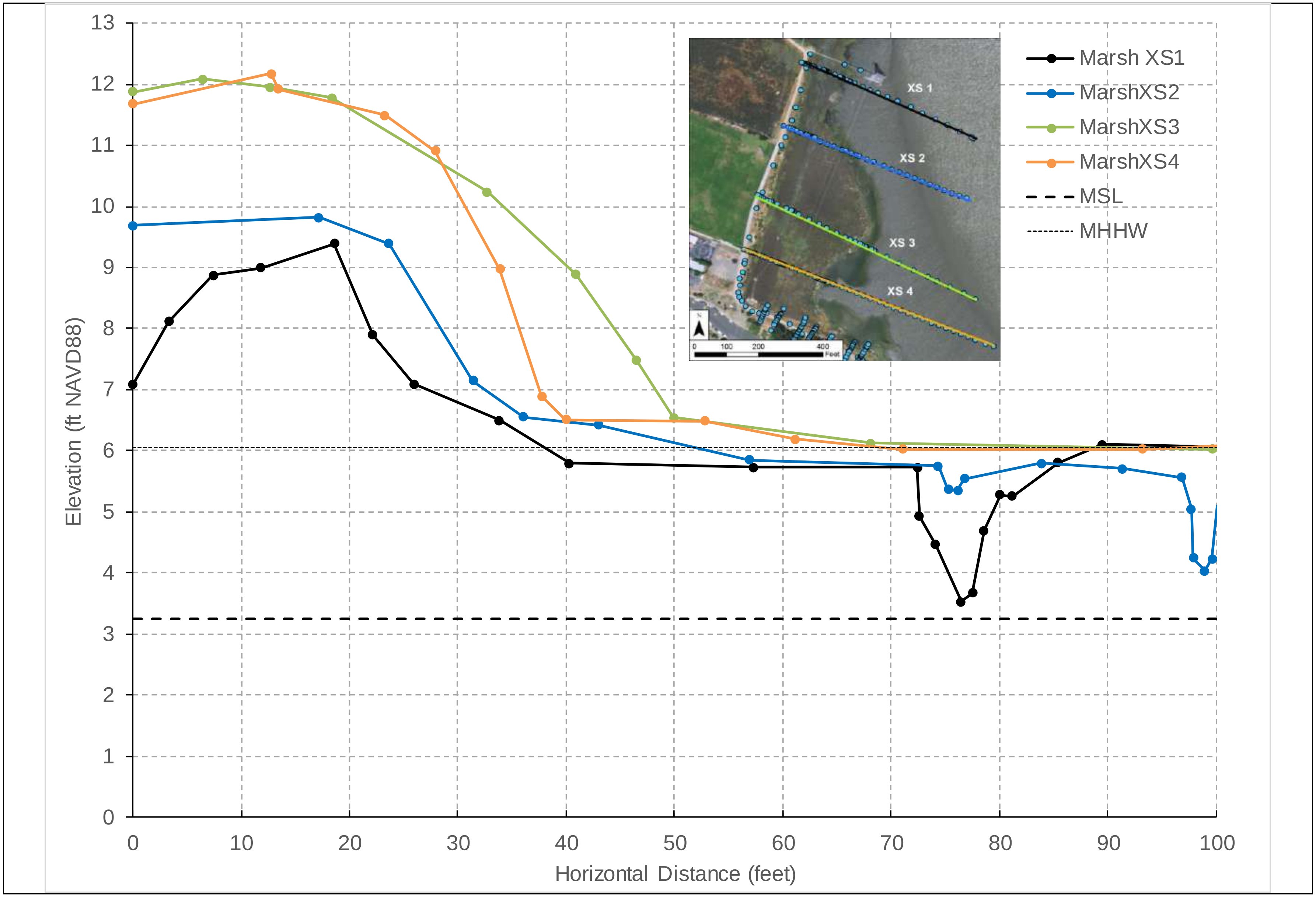
Time series of water levels in Richmond and at Tiscornia Marsh.



SOURCE: Tidal datums obtained from NOAA Richmond (Chevron Pier) Gauge

Figure B3

Tiscornia Marsh transects surveyed on September 19th, 2017.

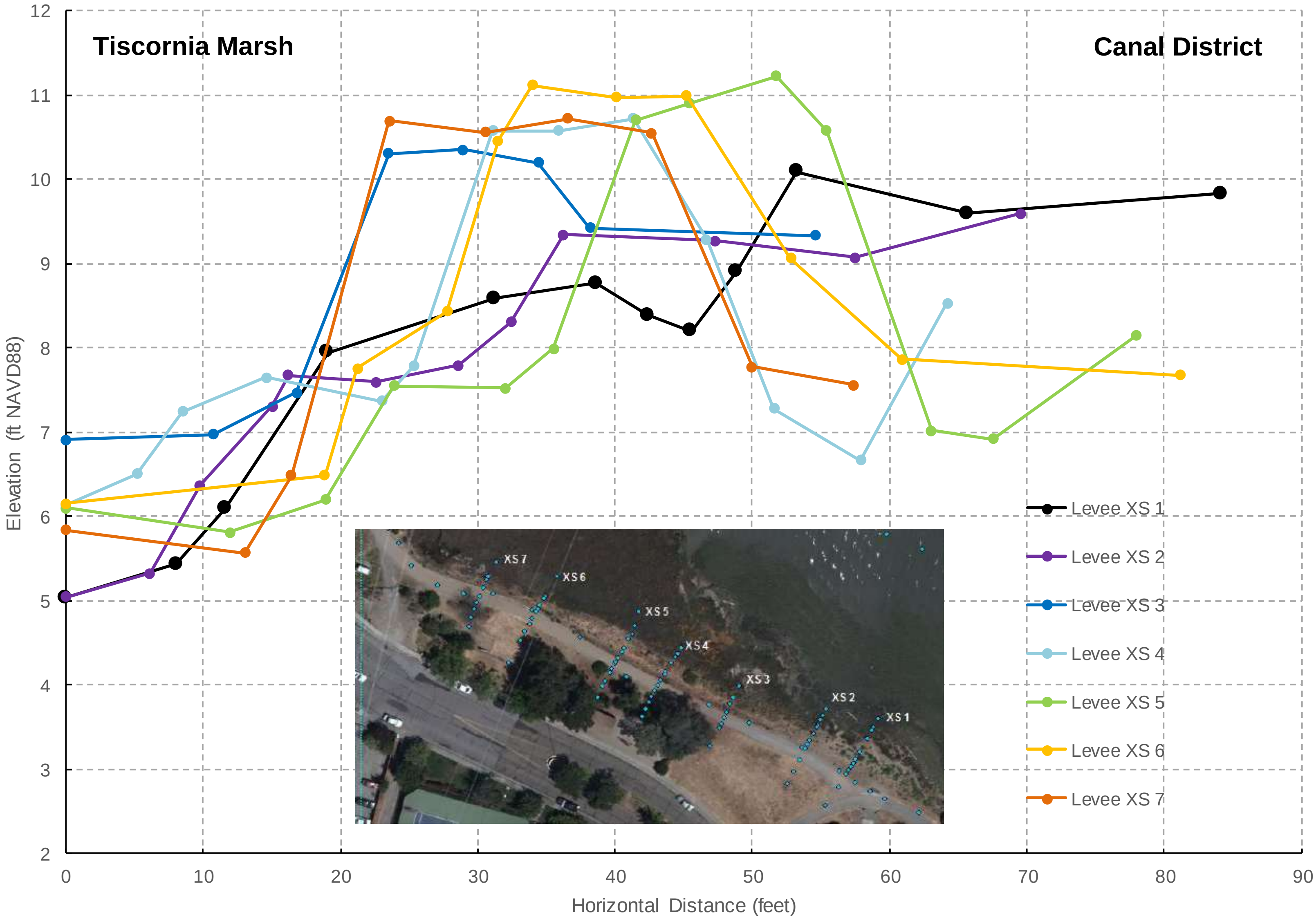


SOURCE: Background Image from Google Earth

Tiscornia Marsh Habitat Restoration . D160888.0

Figure B4

Close-up of September 19th topographic survey focusing on the upland transition between the levee and Tiscornia Marsh.



SOURCE: Background Image from Google Earth

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Figure B5

Levee cross sections collected on September 19th, 2017